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Running title: Bird diversity in planted forests

**Impact of four silvicultural systems on birds in the
Belgian Ardenne: implications for biodiversity in
plantation forests**

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1 **Abstract**

2 Uneven-aged management of conifer plantations is proposed as a way to
3 increase the value of these forests for the conservation of bird diversity. To
4 test this assumption, we compared the impact of 4 common silvicultural
5 systems on bird communities, defined by cutblock size (large in even-aged
6 silvicultural systems/smaller in uneven-aged silvicultural systems) and tree
7 species composition (spruce/beece) in the Belgian Ardenne where beech
8 forests have been replaced by spruce plantations. The abundances of bird
9 species were surveyed in young, medium-aged and mature stands in three to
10 five forests per silvicultural system (66 plots in all). The effect of silvicultural
11 systems on bird species richness, abundance and composition were analysed
12 both at the plot and at the silvicultural system levels. In plots of a given age,
13 beech stands were richer in species. The composition of bird species at the
14 plot level was explained by stand age and tree composition, but weakly so by
15 stand evenness. For the silvicultural systems, bird species richness was
16 significantly higher in even-aged and in beech forests, and bird species
17 composition depended on the silvicultural system. This study emphasises the
18 importance of maintaining native beech stands for birds and suggests that
19 uneven-aged management of conifer plantations does not provide a valuable
20 improvement of bird diversity comparatively with even-aged systems.

21 **Keywords:** Silvicultural system / Biodiversity / Bird communities /
22 Silvicultural cycle / Coniferous plantation.

1 **Introduction**

2 The replacement of native broadleaf stands by uniform conifer plantations is a
3 matter of concern for biodiversity conservation (Lack, 1933; Lack, 1939;
4 Ledant *et al.*, 1983; Laiolo *et al.*, 2004) and this question needs detailed
5 analysis. Bird species composition is affected by tree species composition
6 (e.g. Moss, 1978; Müller, 1987; Bersier & Meyer, 1994; Bersier & Meyer,
7 1995; Hansen, 1995) with few species associated with conifers while some
8 are more associated with broadleaf species. Bird species composition is also
9 influenced by vertical and horizontal vegetation structure that is determined
10 by tree growth in the stand (Wigley & Roberts, 1997; Lertzmann & Fall,
11 1998) and the silviculture (Bellamy *et al.*, 1996; Jokimäki & Huhta, 1996;
12 Drapeau *et al.*, 2000). The size of the disturbance created by harvesting
13 operations (cutblock size) defines different silvicultural systems and is known
14 to influence biodiversity (Attiwill, 1994; Chesson & Pantastico-Caldas, 1994;
15 Schnitzer & Carson, 2001). In most of the cases, planted conifers are
16 managed with large cutblocks (>2ha) that are considered as unfavorable for
17 bird diversity conservation (Ledant *et al.*, 1983).

18 To improve the value of planted conifer forests for bird diversity, alternative
19 silvicultural systems based on varying the areas where mature trees are
20 harvested have been proposed (Kerr, 1999). To test this idea, the differences
21 in bird diversity between cutblock sizes in planted conifer forests have to be
22 compared to similar differences in the original broadleaf forests. The Belgian
23 Ardenne has the particularity of containing within a restricted region, four
24 main silvicultural systems, including conifer plantations and broadleaf forest,
25 and both forests managed by small and large cutblocks. In the forest

1 manager's terminology, the large cutblock sizes are typical of the "even-
2 aged" silvicultural system, while smaller cutblock sizes are typical of the
3 "uneven-aged" silvicultural system used in this part of Europe (Kerr, 1999).

4 Silvicultural systems have to be characterised by considering the whole
5 silvicultural cycle. Moreover, as biodiversity can be influenced considerably
6 by stand age, the effect of silvicultural systems can only be understood by
7 considering the whole cycle (du Bus de Warnaffe, 2002). Yet the age of the
8 stand should be seen as a stage rather than an absolute age, since the effect of
9 the absolute age on birds depends on the composition of the stand. Three
10 stages can be identified in managed forests: a short one just after logging
11 when low vegetation is dominant, a medium-aged stage when trees grow
12 rapidly and induce a closed canopy, a long mature stage when trees have
13 commercial dimensions and induce a high canopy with an overstorey (du Bus
14 de Warnaffe & Lebrun, 2004). An over-mature stage with collapsing and
15 senescent trees can be identified in forests where harvesting does not occur
16 (Fuller & Moreton, 1987). Different silvicultural systems can be compared
17 for each stage, or by gathering the stages over space, using a space-for-time
18 substitution. Two spatial levels must therefore be considered: the plot, which
19 only considers one stage, and a larger spatial and temporal scale integrating
20 the complete silvicultural cycle of a silvicultural system (Huston, 1999).

21 The hypothesis tested in this paper is that uneven-aged conifer planted forests
22 have a higher value for bird conservation than even-aged conifer planted
23 forests. This difference was tested with a sampling design including several
24 stages of forest development and was compared with the same design in
25 natural beech forests. These comparisons help to identify the impacts on

1 biodiversity of the silvicultural systems applied to a large part of the forests in
2 Europe and may provide guidance to mitigate their consequences on
3 biodiversity conservation.

4 **Materials and methods**

5 **Study region**

6 The study was conducted in the Belgian Ardenne, between Namur and
7 Luxembourg (Figure 1). The historical land-use types in this region are
8 pastures and broadleaf woodlands, which now account for 20% and 40% of
9 the region (Paquet *et al.*, 2006). They have been partly transformed into
10 commercial conifer plantations (30% of the area) over the last 150 years
11 (Devillez & Delhaise, 1991). The elevation of our study plots ranged from
12 320 to 560 m, mean annual rainfall from 1050 to 1200 mm.yr⁻¹ and mean
13 annual temperatures from 7.3 to 7.8 °C (Weissen *et al.*, 1994). All study plots
14 comprised plantations established on *Luzulo-Fagetum* or *Luzulo-Quercetum*
15 vegetation types, according to Noirfalise (1984) and Rameau *et al.* (2000)
16 phytosociological systems, on flat or very gently sloping ground with acid
17 and moderately dry soils (*Dystric cambisol*) (FAO, 1990). The main tree
18 species are native, mostly Norway spruce (*Picea abies* (L.) Karst), beech
19 (*Fagus sylvatica* L.) and oaks (*Quercus petraea* (Mattme.) Liebl. and
20 *Quercus robur* L.), with few introduced species, mostly Douglas fir
21 (*Pseudotsuga menziesii* (Mirb.) Franco). Rotation length is typically 60 to 80
22 years for spruce, which is usually planted, and 120 to 150 years for beech,
23 which is usually natural. Logging is done by clearcut on cutblocks with sizes
24 ranging from 0.1 ha to more than 2 ha.

1 In even-aged systems, all the tree of a stand ($>1\text{ha}$) are of the same age at a
2 given time, in this system, logging is applied on large areas (cutblocks) by
3 clearcutting. Even-aged systems result from planted forests for conifer tree
4 and for beech tree from naturally regenerated forests managed to produce
5 timber wood. In uneven-aged systems, the trees of different ages are mixed
6 on smaller areas ($<0.5\text{ha}$), logging is done by cutting mature trees on small
7 cutblocks, as younger trees remain we do not be considered it as a clearcut.
8 Uneven-aged conifer silvicultural system has developed from even-aged
9 planted forests where small logging areas have been used rather than the large
10 typical clearcuts. Forest managers consider it as a way to improve the
11 sustainability of planted conifer forests.

12

13 **Sampling design**

14 The study compared four important silvicultural systems in the Belgian
15 Ardenne :

16 1) even-aged conifer (EC): planted forests with greater than 80% cover of
17 Norway spruce logged by clearcut on large cutblocks ($> 2\text{ ha}$);

18 2) even-aged Beech (EB): naturally regenerated forests with greater than 80%
19 cover of Beech logged by clearcut on large cutblocks ($> 2\text{ ha}$);

20 3) uneven-aged conifer (UC): planted forests with greater than 80% cover of
21 Norway spruce logged on small cutblocks ($< 0.5\text{ ha}$) producing a mix of trees
22 of different ages;

23 4) uneven-aged Beech (UB): naturally regenerated forests with greater than
24 80% of Beech logged by small cutblocks ($< 0.5\text{ ha}$).

1 We selected three to six forests per silvicultural system, these forests
2 comprised at least 15 ha corresponding to the silvicultural system as defined
3 above and managed for at least two rotations with the same system (Du Bus
4 de Warnaffe & Dufrêne, 2004). The size of the cutblocks and the composition
5 of each forest were determined by GIS analysis of 1/10.000 aerial
6 photographs, and checked on site.

7 Plots were selected in three non-overlapping stages covering the silvicultural
8 cycles of each silvicultural system (Fuller & Moreton, 1987; Hansen, 1995;
9 Lertzmann & Fall, 1998): regeneration stage (stage 1: trees 3–10 years old),
10 medium-aged stage (stage 2: 20–40 years old for conifer, 30–60 years old for
11 beech), and mature stage (stage 3: 50–80 years old for conifer, 80–140 years
12 old for beech). The stage in uneven-aged systems was defined according to
13 the time since the last logging, it is similar to the age of the oldest trees at a
14 given time. The plots were separated by at least 200 m. A set of three plots
15 belonging to these three stages in the same forest and the same silvicultural
16 system defined a silvicultural cycle since it included the tree stages (Figure 2).
17 The sampling was thus characterised by 54 plots belonging to 18 silvicultural
18 systems (Table 1 & 2).

19 **Bird data**

20 The bird survey method was based on point counts (Bibby *et al.*, 1985;
21 Frochet & Roché, 1990; Petty & Avery, 1990) within a maximum 25 m fixed
22 radius visually estimated. Singing birds were surveyed by trained observers
23 over 20 minute periods in each plot, twice during the breeding season (April
24 and early June 2000), to record both sedentary and migrant species, and to

1 reduce the bias associated with differences in detectability. The data were
2 collected in the first four hours after dawn, avoiding rainy and windy days.
3 According to the territorial behavior of most of the bird species in spring, the
4 fixed radius of the plots and the experience of the surveyors, we assumed to
5 have comparable lists, but not necessarily exhaustive, of the bird species
6 living in the plots (Buckland *et al.*, 2001; Kery & Schmid, 2004). All
7 recorded species were used for the analyses, except over-flying birds, such as
8 raptors and corvids, which were discarded. The abundance was estimated as
9 two individuals (a pair) for each bird heard singing and one individual for
10 each bird that was only seen or heard calling (not singing). The highest
11 abundance recorded on the two dates was used as abundance index (Frochot
12 & Roché, 1990). For silvicultural systems, abundance of each species was the
13 sum of the abundance index in the three plots (stages 1, 2 and 3).

14 **Data analysis**

15 ANOVA was used to test for differences in species richness and abundance
16 between the datasets defined by the silvicultural systems and the stages:
17 three-way ANOVA for the plot analysis (cutblock size, tree species
18 composition, growth stage) and two-way ANOVA for the analysis of
19 silvicultural systems (cutblock size, tree species composition) (Sokal &
20 Rohlf, 2000). Interactions between factors were included in the model and
21 post-hoc tests, after Bonferonni correction, were used to identify significant
22 differences between the means.

23 We used a linear ordination (Correspondence Analysis (Hill, 1974)) to reduce
24 the bird community data (in presence-absence) to a smaller set of dimensions,

1 allowing us “to describe the strongest patterns in species composition”
2 (McCune & Grace, 2002). The result is an ordination of the species and the
3 samples along axes computed as the solution of linear equations linking (1)
4 the species space, where each sample is a coordinate, and (2) the sample
5 space, where each species is a coordinate. Correspondence analysis can be
6 interpreted as a summary of the departure of the observed contingency table
7 (species by sample) from a null hypothesis of independence between species
8 and samples, estimated by the Chi^2 distance (Couteron *et al.*, 2003). Several
9 orthogonal axes can be computed and can be interpreted as follow: the closer
10 the species on the axes, the more similar their distributions in samples; the
11 closer the samples, the more similar their bird species composition. The
12 higher values along the axes indicate samples or species with composition or
13 distribution respectively, more different from the mean composition or
14 distribution of the whole sample (Balent & Courtiade, 1992). Samples and
15 species ordinations can be displayed on the same plan: the closer a species
16 and a sample, the higher the probability, estimated from Chi^2 distance, to
17 have this species observed in this sample (Pelissier *et al.*, 2003). This
18 ordination of the samples, based on the covariations and associations among
19 the species, was constrained by the silvicultural system classes to measure
20 their influence on the bird species communities. This so called “between-
21 group analysis” can be seen as a discriminant analysis adapted to species
22 survey data and is a special case of the Canonical Correspondence Analysis
23 (CCA) with only one explaining qualitative factor. It allows us to test the
24 influence of qualitative variables on the structure of a species community
25 (McCune & Grace, 2002). The results are displayed as factorial plans where

1 the separation of the sample classes is maximised according to their species
2 composition (Thioulouse *et al.*, 1997). A permutation test measured the
3 departure of the observed structure from a random distribution of the species
4 and gave a significance level of the difference between groups. All
5 calculations were performed with R software (R development core team,
6 2006) and with ade4 package (Chessel *et al.*, 2004).

7 **Results**

8 A total of 44 species were found but 10 were recorded only once. The most
9 abundant species were Chaffinch (*Fringilla coelebs*), Robin (*Erithacus*
10 *rubecula*), Wren (*Troglodytes troglodytes*), and Wood pigeon (*Columba*
11 *palumbus*) (Table 3).

12 **Species richness and abundance**

13 *Plot analysis (each stage)*

14 We found 3 to 20 species per plot. Tree species composition was the only
15 factor with a significant effect on bird species richness ($F=10.8353$; $df=1$;
16 $p=0.0020$). The mean species richness in beech plots (14.12 ± 4.38 ; $n=24$) was
17 higher than in conifer plots (10.50 ± 3.59 ; $n=30$). The variability of the species
18 richness was higher in beech plots than in conifer plots (Figure 3). In beech
19 plots, the mean species richness of small cutblocks size (uneven-aged system)
20 was not significantly different from the richness in the larger cutblocks, but in
21 both cases, intermediate stages 2 had a lower species richness that masked the
22 higher differences observed with stages 1 and 3 (Figure 3). When considering
23 only these two stages, uneven-aged plots had higher bird species richness
24 than in even-aged plots, the few cases with extremely low values may explain

1 why these differences were not significant. In conifer plots, no particular
2 differences were identified between species richness according to cutblock
3 size and stage.

4 Total bird abundance was highly correlated to species richness ($r^2=0.86$,
5 $p<0.001$). As for bird species richness, tree species composition was the only
6 factor explaining a significant part of bird abundance variability ($F=7.4354$
7 $df=1$; $p=0.0092$); the highest mean abundance was in beech plots
8 (21.46 ± 7.75 ; $n=24$), the lowest in conifer plots (16.03 ± 6.31 ; $n=30$) (Figure 3).
9 In conifer plots, no clear pattern was observed for abundance, nor for species
10 richness. In beech plots, on the other hand, the pattern was different. In even-
11 aged plots, mature stands had clearly a higher abundance (but few samples
12 with extremely low values) than younger stages. Conversely, the highest
13 value was for first stage in uneven-aged plots, but with lower differences with
14 the other stages comparatively with even-aged plots.

15 *Silvicultural system analysis (stages 1+2+3 pooled together)*

16 We found 12 to 27 species in the silvicultural systems. Cutblock size
17 ($F=6.8983$; $df=1$; $p=0.0176$) and tree composition ($F=4.7767$; $df=1$;
18 $p=0.0431$) significantly explained bird species richness variability, with the
19 highest bird species richness in even-aged beech forests (24.67 ± 2.08 ; $n=3$)
20 and the lowest in uneven-aged conifer forests (16.33 ± 4.88 ; $n=6$) (Figure 4).
21 The difference of bird species richness between beech and conifer was higher
22 in uneven-aged forests than in even-aged ones. No factor explained a
23 significant part of bird species abundance, however, it can be noticed that in
24 beech forests, the abundance was higher in uneven-aged forests than in even-
25 aged, while the differences were less visible in conifer forests (Figure 4).

1 **Species composition**

2 *Plot analysis*

3 The first stages of the even-aged silvicultural systems were significantly
4 ($p < 0.001$) separated from the others groups along the first axis of the between
5 group analysis (Figure 5). The beech plots and the conifer plots of the older
6 stages were separated along the second axis, but the even-aged and uneven-
7 aged plots in these groups were not separated. *Sylvia communis*, *Emberiza*
8 *citrinella* and *Carduelis cannabina* were positively associated with even-aged
9 first stage plots, while *Regulus* species and *Nucifraga caryocatactes* were
10 positively associated with coniferous plots. No particular species seemed to
11 be associated with the beech plots, since most of the species close to the
12 position of these plots were close to the origin of the factorial plan and thus
13 were common in most of the samples (Figure 5).

14 *Silvicultural systems analysis*

15 Conifer plots were separated ($p < 0.001$) from the other ones on the first axis of
16 the between group analysis (Figure 6). Even-aged beech forests were
17 separated from the other groups on the second axis, with a lower variability of
18 their composition (distribution along axes). Cutblock size showed a
19 significant effect ($p < 0.001$) in beech forests. *Regulus* species, *Nucifraga*
20 *caryocactactes*, *Sylvia communis* and *Carduelis carduelis* were associated
21 with the coniferous forests; *Dendrocopos minor*, *Saxicola torquata* and *Picus*
22 *canus* were associated with the even-aged beech, *Dendrocopos medius* was
23 associated with uneven-aged beech forests.

1 **Discussion**

2 **Stand composition: conifer vs beech**

3 Although some studies have identified little impact of tree species
4 composition on bird communities (Müller, 1987; Patterson *et al.*, 1995;
5 Donald *et al.*, 1998), most authors have found, as we have, a greater diversity
6 in broadleaf forests compared with coniferous forests of similar stages, at plot
7 level (Moss, 1978; James & Warmer, 1982; Bibby *et al.*, 1985; Lebreton *et*
8 *al.*, 1987; Lebreton & Choisy, 1991; Baguette *et al.*, 1994; Solonen, 1996;
9 Gjerde & Saetersdal, 1997) as well at larger levels including the whole
10 silvicultural cycle (Jokimäki & Huhta, 1996; Drapeau *et al.*, 2000). Conifer
11 forests seem to attract only few bird species, as suggested by Drapeau *et al.*
12 (2000). In the Ardenne region, the total bird species richness in mature
13 conifer plantation is estimated to be 43 species with a mean richness per plot
14 of 13 species, while the estimations for beech forests are 44 species for the
15 total richness and 16 species for the mean richness per plot (Paquet *et al.*,
16 2006). However, historical factors may play an important role in that pattern
17 because Norway spruce stands have been planted for about only 150 years in
18 Belgium and thus bird communities may have not adapted yet to this new
19 habitat.

20 **Stand structure: even-aged vs uneven-aged silvicultural systems**

21 Bird community was more related to the dominant tree species (beech vs
22 conifer) than to cutblock size (Baguette *et al.*, 1994; Jokimäki & Huhta, 1996;
23 Kirk & Hobson, 2001). The only differences identified were related to the
24 first stages, especially with bird composition: the between group analysis at
25 plot level clearly showed that the bird composition of the first stage of even-

1 aged systems, whatever the tree composition, was different from the other
2 stages (Figure 5). The species more associated to first stages of even-aged
3 forests were mainly species known to be able to live in open habitats, having
4 adapted to the practice of large clear-cuts (Paquet *et al.*, 2006), while smaller
5 logged areas in uneven-aged forests seem to have fewer associated species.
6 Paquet *et al.* (2006) demonstrated that the species associated to the open areas
7 in forest are not intermediate between the typical bird communities from
8 agricultural habitat and forests, but were “specific” and contributed to 38.6%
9 to the conservation value in large open areas.

10 These results do not confirm the main hypothesis of the paper, that uneven-
11 aged management of planted conifer forests improves their bird conservation
12 value. However, this conclusion should be moderated by the spatial
13 dimension of even-aged and uneven-aged silvicultural systems, which has not
14 been taken into account in this study (Pickett *et al.*, 1989; Kotliar & Wiens,
15 1990). Even-aged system produces a coarser grain spatial pattern of
16 heterogeneity than uneven-aged systems, with larger patches of even-aged
17 trees. This induces edge-effects that may also have an influence on bird
18 species distribution (Deconchat & Balent, 2001).

19 **Stand age: Bird diversity according to silvicultural stages**

20 Bird species composition in even-aged stage 1, i.e. large cutblocks, had a
21 sharp contrast with stage 2 and 3. It was characterised by species known to be
22 associated with open habitat conditions (Haila *et al.*, 1980; Fuller & Moreton,
23 1987; Baguette *et al.*, 1994; Jacob, 1996). Though Bibby *et al.* (1985)
24 suggested that very few species require large clear-cuts, a number of species
25 preferred even-aged stage 1 as it has been already noticed by Paquet *et al.*

1 (2006). We were surprised not to obtain a higher species richness in stage 1
2 than in stages 2 and 3, as did a number of authors (Müller, 1987; Bersier &
3 Meyer, 1994, Patterson *et al.*, 1995; Jokimäki & Huhta, 1996; Fuller &
4 Green, 1998). Indeed, species richness can greatly vary in young stands in
5 plantations (Frochot, 1971; Bibby *et al.*, 1985), as well as in natural forest,
6 even under strong disturbances such as coppice clear-cuts (Deconchat &
7 Balent, 2001).

8 Some authors have identified differences in bird communities between
9 medium-aged and mature stands (Fuller & Moreton, 1987; Lebreton & Pont,
10 1987) with some bird species associated with old and senescent trees. We did
11 not identify such a pattern, probably because of the intensive silviculture
12 practised in the Ardenne, based on short rotations, high densities and
13 systematic removal of diseased and dead trees. At stage 3 in our study area,
14 trees were not very large (Table 2), and hollow or dead trees were rare, which
15 makes a difference with the same stage observed in less intensive contexts.

16 **Conclusion**

17 The results confirm the strong impact of tree species composition on bird
18 species richness, abundance and composition. In the Belgian Ardenne, the
19 massive introduction of spruce plantations has allowed some new species to
20 breed (e.g. *Nucifraga caryocatactes*) but their bird diversity is clearly of
21 lower conservation value than in the beech forests they have supplanted
22 (Ledant *et al.*, 1983). The conversion of even-aged conifer plantations to
23 uneven-aged management (Schütz, 2001), which has been proposed as a way
24 to improve biodiversity in conifer forests, does not seem to improve their
25 ability to shelter richer or more diverse bird community than in even-aged

1 plantations. Even-aged management in beech forest was suspected to have
2 negative impacts on biodiversity (Paquet *et al.*, 2006). This opinion is not
3 supported by the results of our study. We observed that the first stage after
4 clear-felling on large zones seemed to offer temporary habitats for species
5 also inhabiting fallow areas and extensive meadows (Delvaux, 1998; Paquet
6 *et al.*, 2006), and species richness and composition do not differ much in
7 simple (even-aged) and more complex (uneven-aged) canopies of the same
8 age (stage 2 or 3).

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1 **Du Bus de Warnaffe, G. - Table 1**

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Silvicultural system	EC	EB	UC	UB	Total
Number of plots: in stage 1	4	3	6	5	18
in stage 2	4	3	6	5	18
in stage 3	4	3	6	5	18
Total number of plots	12	9	18	15	54

6

7 Table 1. Number of plots. Silvicultural systems are defined by cutblock
8 size and tree species composition of the forest: EC = Even-aged Conifer;
9 EB = Even-aged Beech; UC = Uneven-aged Conifer; UB = Uneven-aged
10 Beech. Each silvicultural system contains 3 stages. See text and Figure 2
11 for details.

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Du Bus de Warnaffe, G. – Table 2

Silvicultural system	Stage	Tree species	Altitude (m)	Mean dbh (cm)	Basal area (m²/ha)	Cutblock size (ha)
EC	1	PA	380-520	2-7	1-7	4-12
	2	PA, PM	320-490	20-27	34-41	-
	3	PA, PM	320-520	43-50	47-53	-
EB	1	FS	410-540	2-6	1-5	3-6
	2	FS	380-540	28-44	21-31	-
	3	FS	380-460	43-59	22-28	-
UC	1	PA, PM	420-580	2-8	18-27	0.02-0.45
	2	PA, PM	420-580	22-36	32-40	-
	3	PA, PM	420-580	41-52	31-42	-
UB	1	FS (+ QP, QR)	410-500	1-8	11-20	0.03-0.25
	2	FS	350-500	23-33	17-28	-
	3	FS (+ QP, QR)	350-500	34-52	21-29	-

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Table 2. Major characteristics of plots in each class (see Table 1 for codes). All plots were situated on flat or very slightly sloping ground, on acid brown and moderately dry soils. Dbh (diameter at breast height) and basal area were measured on 0.20 ha. Cutblock size was measured for stage 1. Tree species : PA = *Picea abies*; PM = *Pseudotsuga menziesii*; FS = *Fagus sylvatica*; QP = *Quercus petraea*; QR = *Quercus robur*.

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Du Bus de Warnaffe, G. – Table 3

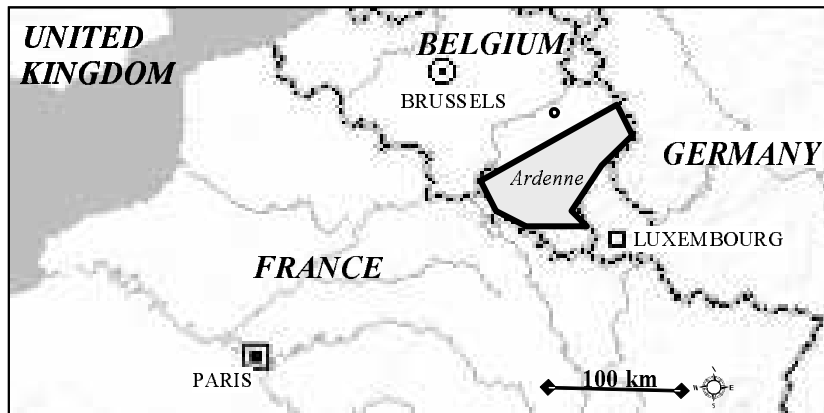
Code	Scientific name	Beech				Conifer		Total
		Beech Even-aged	Beech Uneven-aged		Conifer Even-aged	Conifer Uneven-aged		
ACAU	<i>Carduelis cannabina</i>	0	0	0	0	1	1	1
ATRI	<i>Anthus trivialis</i>	3	1	4	2	0	2	6
CBRA	<i>Certhia brachydactyla</i>	1	4	5	0	1	1	6
CCAN	<i>Cuculus canorus</i>	2	1	3	4	0	4	7
CCAR	<i>Carduelis carduelis</i>	0	0	0	1	1	2	2
CCOC	<i>Coccothraustes coccothraustes</i>	1	4	5	2	0	2	7
CFAM	<i>Certhia familiaris</i>	0	2	2	0	4	4	6
CPAL	<i>Columba palumbus</i>	3	4	7	3	4	7	14
CSPI	<i>Carduelis spinus</i>	0	0	0	0	0	0	0
DMAJ	<i>Dendrocopos major</i>	3	5	8	0	4	4	12
DMAR	<i>Dryocopus martius</i>	3	3	6	0	1	1	7
DMED	<i>Dendrocopos medius</i>	0	3	3	0	0	0	3
DMIN	<i>Dendrocopos minor</i>	1	0	1	0	0	0	1
ECIT	<i>Emberiza citrinella</i>	1	0	1	1	0	1	2
ERUB	<i>Erithacus rubecula</i>	3	5	8	4	6	10	18
FCOE	<i>Fringilla coelebs</i>	3	5	8	4	6	10	18
GGLA	<i>Garrulus glandarius</i>	2	5	7	2	5	7	14
LCUR	<i>Loxia curvirostra</i>	1	0	1	1	1	2	3
NCAR	<i>Nucifraga caryocatactes</i>	0	0	0	1	0	1	1
PATE	<i>Parus ater</i>	3	2	5	4	5	9	14
PCAE	<i>Parus caeruleus</i>	1	5	6	0	2	2	8
PCAN	<i>Picus canus</i>	1	0	1	0	0	0	1
PCOL	<i>Phylloscopus collybita</i>	3	3	6	3	4	7	13
PCRI	<i>Parus cristatus</i>	0	2	2	3	2	5	7
PMAJ	<i>Parus major</i>	3	5	8	3	1	4	12
PMOD	<i>Prunella modularis</i>	3	1	4	4	4	8	12
PMON	<i>Parus montanus</i>	0	3	3	0	0	0	3
PPAL	<i>Parus palustris</i>	3	4	7	1	3	4	11
PPYR	<i>Pyrrhula pyrrhula</i>	1	1	2	0	1	1	3
PSIB	<i>Phylloscopus sibilatrix</i>	3	4	7	0	2	2	9
PTRO	<i>Phylloscopus trochilus</i>	3	1	4	4	1	5	9
RIGN	<i>Regulus ignicapillus</i>	0	0	0	3	3	6	6
RREG	<i>Regulus regulus</i>	1	3	4	4	6	10	14
SATE	<i>Sylvia atricapilla</i>	3	4	7	4	6	10	17
SBOR	<i>Sylvia borin</i>	1	0	1	1	1	2	3
SCOM	<i>Sylvia communis</i>	0	0	0	1	0	1	1
SEUR	<i>Sitta europaea</i>	3	5	8	0	2	2	10
STOR	<i>Saxicola torquata</i>	1	0	1	0	0	0	1
SVUL	<i>Sturnus vulgaris</i>	1	0	1	0	0	0	1
TMER	<i>Turdus merula</i>	3	5	8	4	6	10	18
TPHI	<i>Turdus philomelos</i>	3	5	8	4	5	9	17
TPIL	<i>Turdus pilaris</i>	0	1	1	1	0	1	2
TTRO	<i>Troglodytes troglodytes</i>	3	4	7	4	6	10	17
TVIS	<i>Turdus viscivorus</i>	3	4	7	4	4	8	15

2 Table 3: List of bird species observed in Belgian Ardenne. Total is the total number
3 of forests (at silvicultural system level) where a given species was observed; Beech
4 and Conifer are respectively the number of beech or conifer forests where a given

- 1 species was observed (beech+conifer=Total); the same for even-aged and uneven-
- 2 aged columns, splited according to tree species composition of the forests.

1 **Du Bus de Warnaffe, G. - Figure 1**

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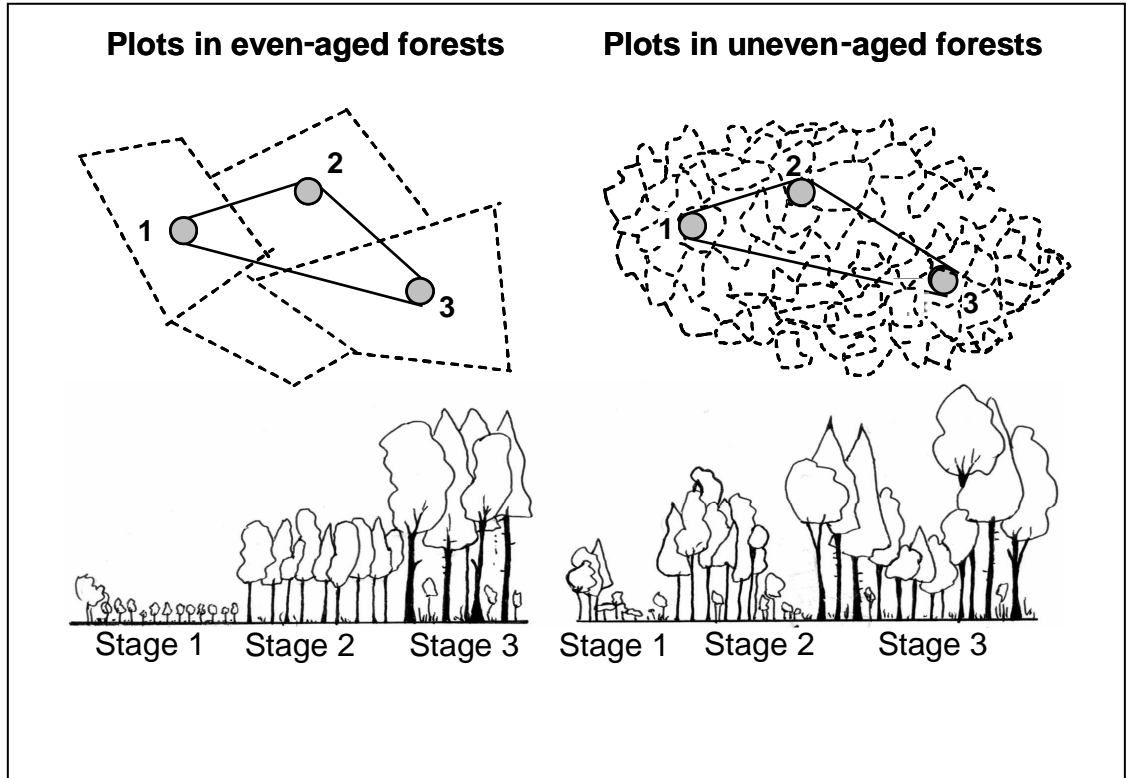


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10 Figure 1. Study area: Ecological limits of the Belgian Ardenne (grey area with
11 solid lines).

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Du Bus de Warnaffe, G. - Figure 2

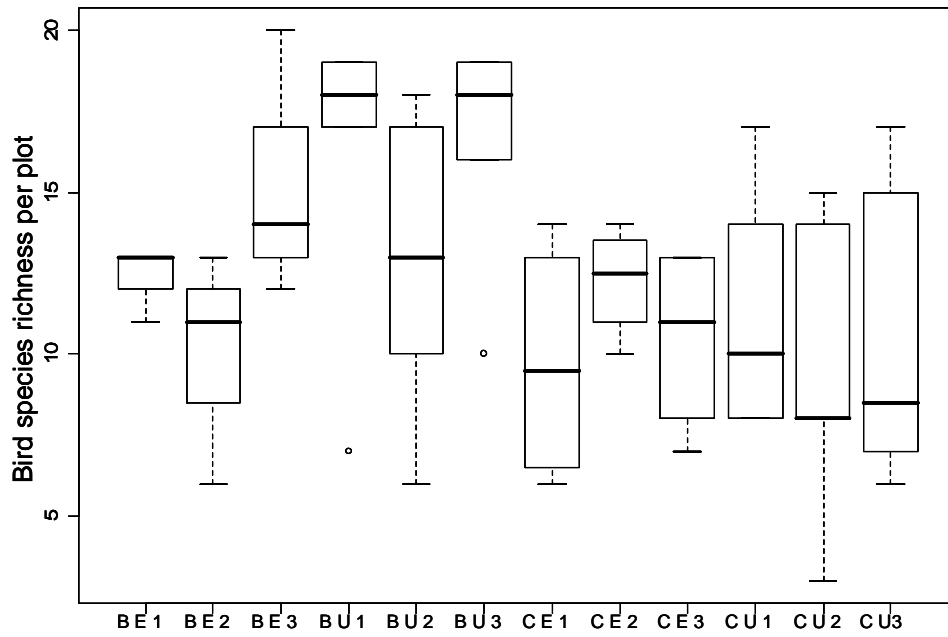


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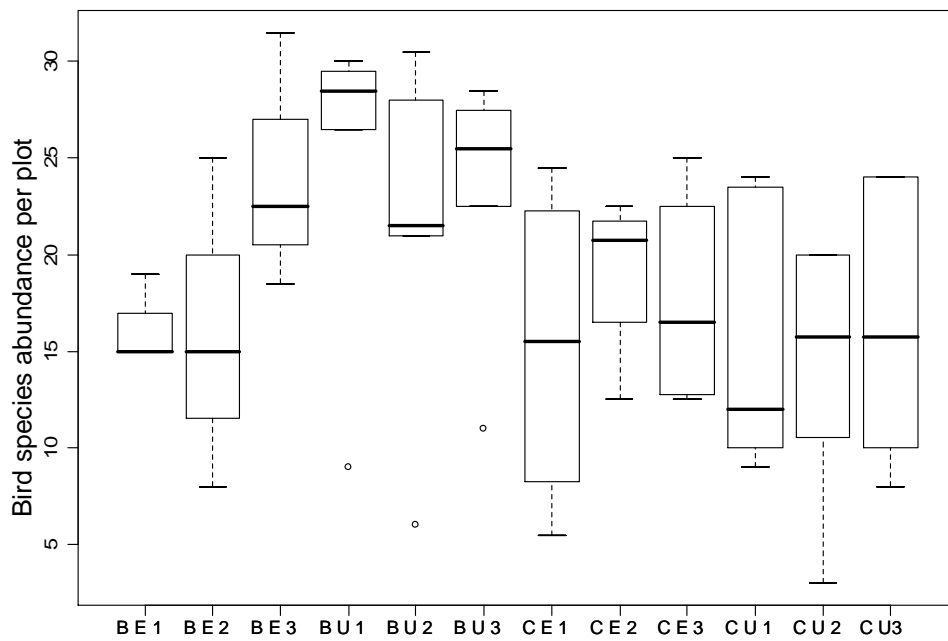
Figure 2. Scheme of the location of the plots in even-aged and uneven-aged forest areas, in aerial and field views. Broken lines define stands of different ages and/or tree composition, circles represent bird counting zones in plots (25 m circle) and solid line convex hulls define the silvicultural system (about 15 ha).

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Du Bus de Warnaffe, G. - Figure 3



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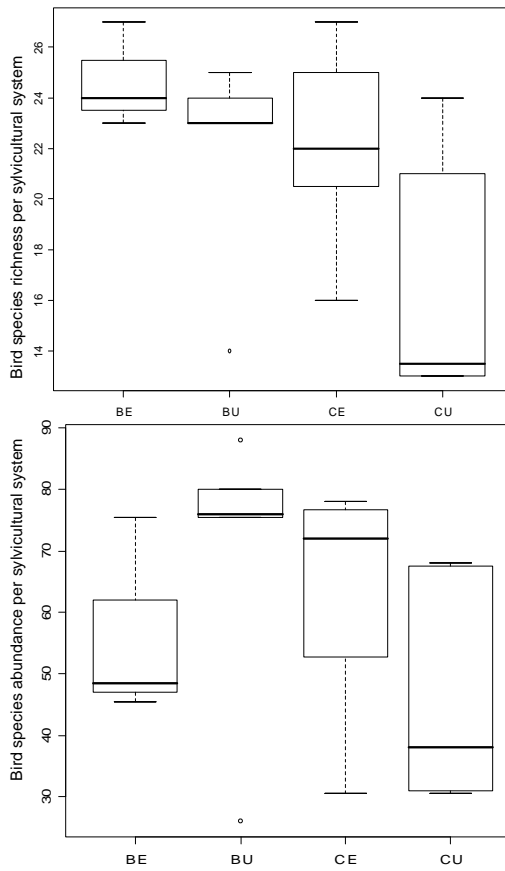
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Figure 3. Box plots of the bird species richness (top) and abundance (bottom) in sample plots according to tree species composition (B: beech or C: conifer), cutblock size (E: even-aged or U: uneven-aged) and stages (1, 2 or 3).

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Du Bus de Warnaffe, G. - Figure 4

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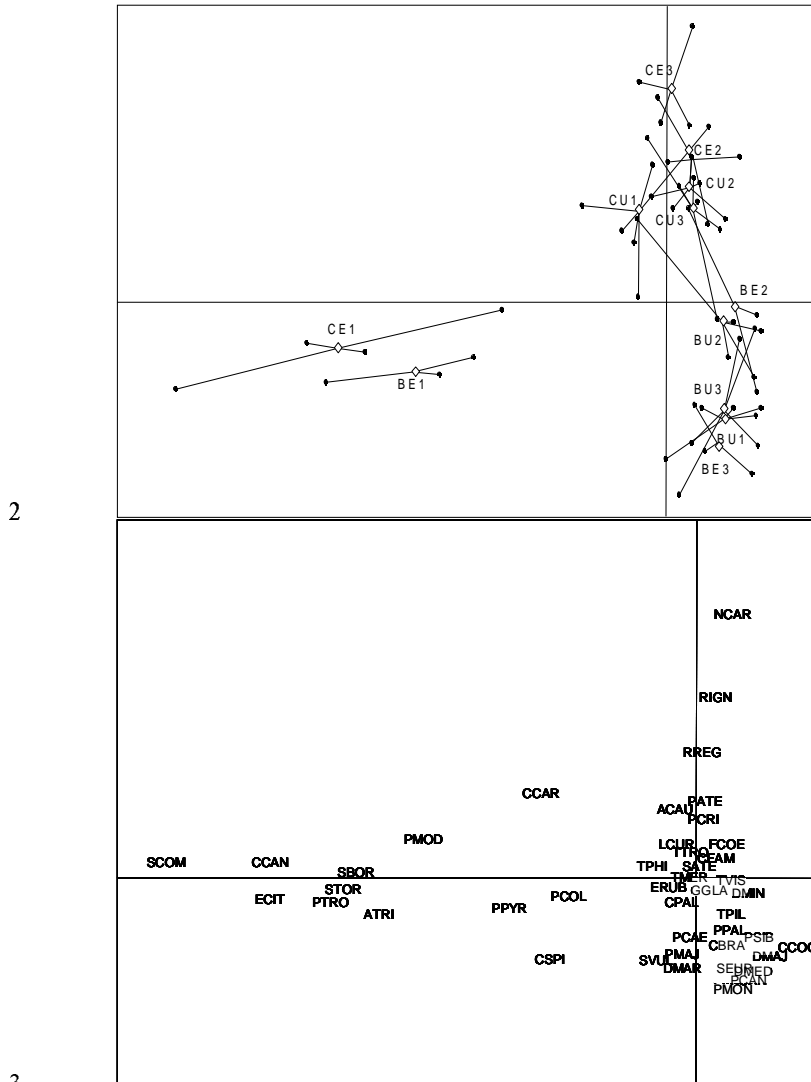


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7 Figure 4. Box plots of the bird species richness (top) and abundance
8 (bottom) in silvicultural systems according to tree species composition (B:
9 beech or C: conifer) and cutblock size (E: even-aged or U: uneven-aged).

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1 **Du Bus de Warnaffe, G. - Figure 5**

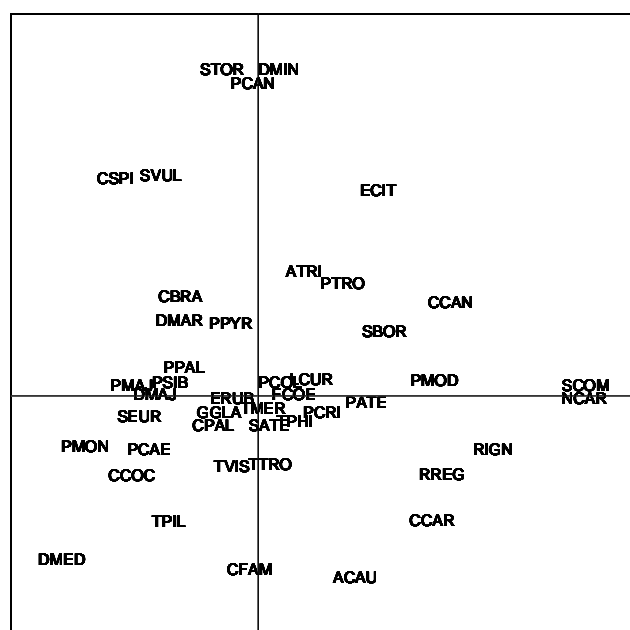
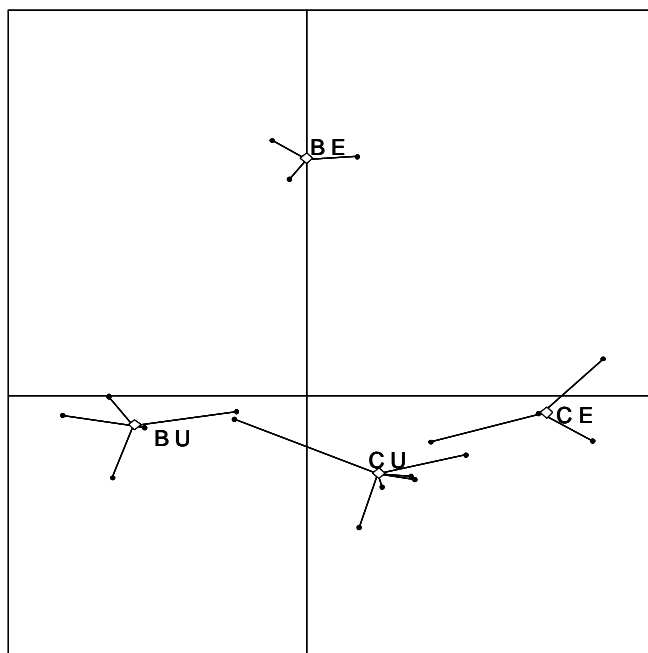


4 Figure 5 : Scatterplot of the between group analysis of the bird community data at
 5 the sample plot level. Top plot: sample plots (black dots) are linked to the mean
 6 position (diamond) of their silvicultural system and stage identified by the
 7 following code: EC = Even-aged Conifer; EB = Even-aged Beech; UC = Uneven-
 8 aged Conifer; UB = Uneven-aged Beech, the final number indicating the stage
 9 (see text and Figure 2). Bottom plot: Ordination of the bird species on the same
 10 axes. The code of the species is based on the first genus letter and the three letters
 11 of the scientific name (Table 3). Their positions have been slightly modified for a

1 better readability.

1 **Du Bus de Warnaffe, G. - Figure 6**

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4 Figure 6 : Scatterplot of the between group analysis of the bird community data at
 5 the silvicultural system level. Top plot: forest (black dots) are linked to the mean
 6 position (diamond) of their silvicultural system identified by the following code:
 7 EC = Even-aged Conifer; EB = Even-aged Beech; UC = Uneven-aged Conifer;
 8 UB = Uneven-aged Beech (see text and Figure 2). Bottom plot: Ordination of the

1 bird species along the same axes. The code of the species is based on the first
2 genus letter and the three letters of the scientific name (Table 3). Their positions
3 have been slightly modified for a better readability.