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Correspondence of Satellite Measured Phenology to European Farmland Bird Distribution Patterns

IVITS Eva; **CHERLET** Michael; **BUCHANAN** Graeme; **MEHL** Wolfgang

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Land Management and Natural Hazards Unit
Institute for Environment and Sustainability
Joint Research Centre, Ispra (Italy)

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Contact information
Address: Via Enrico Fermi, 2749 (T.P.280), I-21027 Ispra(VA). Italy
E-mail: Eva.ivits-wasser@jrc.ec.europa.eu
Michael.cherlet@jrc.ec.europa.eu .
Tel.: +39-0332-789982
Fax: +39-0332-786394

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1. Introduction

The quantification of phenological processes is very important for understanding ecosystems and ecological development. Phenological processes are determined by the length of the growing season, frost damage, timing and duration of pests and diseases, water fluxes, nutrient budgets, carbon sequestration and food availability. All these factors together determine population growth and influence species-species interactions (competition, predation, reproduction) and species distribution. The timing and progression of plant development may also provide information to help making inferences about the condition of plants and their environment.

NDVI (Normalised Difference Vegetation Index) extracted from remote sensing images has been related to Net Primary Productivity (NPP) at broad spatial scales (e.g. Prince et al., 1991). Goward et al. (1987) for instance demonstrated that the time integral (area under the curve) of the Normalised Difference Vegetation Index (NDVI) over an annual period produced a measure related to net primary productivity values of different biomes. The relationship between biological diversity and Net Primary Productivity (NPP) has been the subject of a long-standing debate in ecology. Energy availability is one of the factors most often discussed as determinant of regional variability in species richness. Energy explains most of the observed variance in regional species richness patterns (median R^2 value of 70% based in 41 studies; Kerr and Packer, 1996). The productivity hypothesis predicts that when resources are abundant and reliable, species become more specialized allowing more species per unit area. Above the point of central tendency, species richness decreases as productivity increases while below this point species richness increases as productivity increases. The heterogeneity hypothesis states that diverse ecosystems support richer assemblages of species when compared with simple ecosystems. The within region variability of NDVI and other vegetation indices, which can be defined as the standard deviation of the maximum NDVI, should relate to the heterogeneity of habitats and consequently should have a positive relationship with species richness of mammals and plants (Oindo and Skidmore, 2002). Because most management decisions concerning the conservation of species are made at the landscape scale it is essential to identify indicators that determine species at the same scale. The relationship from NPP to NDVI and NPP to species richness justifies the present research in establishing linkages between remotely sensed information of vegetation cover and biological diversity.

There are promising results concerning the linkage of net primary productivity to species richness. In Kenya, higher yearly average NDVI was correlated with lower species richness of mammals and plants, whereas standard deviation and coefficient of variation was correlated positively with species richness (Oindo and Skidmore, 2002). As nutrients increase, light availability becomes a problem for competing plants (Newman, 1973) and this way higher productivity is associated with increasingly intense competition for light. According to Rosenzweig and Abramsky (1993), beyond the certain point in the productivity gradient the habitat heterogeneity that supports mammalian diversity declines. This leads to increased production of woody species, which in turn reduces the primary production of grass resources due to shading by trees. The positive correlation found between species richness and indices of habitat heterogeneity (standard deviation of maximum NDVI and coefficient of variation) confirms that highly variable areas are endowed with more species. Bailey at el. (2004) found positive relationship between maximum NDVI and number of functional guilds of birds, species richness of neotropical migrant birds and species richness of butterflies. By contrast, heterogeneity of NDVI was negatively associated with the number of functional guilds of birds and species richness of resident birds but no association was found with species richness of butterflies. Phillips et al. (2008) correlated the NDVI, NPP and GPP measures with native landbird species richness derived from the North American Breeding Bird survey and found that the productivity measures explained substantially more variation then the NDVI.

Birds have long been used to provide early warning of environmental problems. They are the best known and documented major taxonomic group, especially in terms of the sizes and trends of populations and distributions, and the number of species (c.10.000) is manageable, thereby permitting comprehensive and rigorous analyses (BirdLife International, 2008). An assessment in 1994 estimated that 25% of all European bird species were undergoing substantial population declines (Murphy, 2003). Especially farmland species are endangered. Chamberlain et al. (2000) showed the evidence of cause effect links between farmland bird abundance and agriculture by illustrating how both have changed through time. Gates and Donald (2000) addressed the long-term risks of local extinction among farmland species and showed how losses have been more likely in less suitable habitats, and least likely in traditional lowland arable locations. The Pan-European Common Bird Monitoring Scheme (PECBM) has been launched by the BirdLife Partnership in Europe and the European Bird Census Council (EBCC). Birds data was collected from 20 independent breeding bird survey programs across Europe over the last 25 years. The study confirmed that common farmland birds are in decline throughout Europe, with the cumulative populations of all 33 species of farmland birds suffering a decline of 44 per cent between 1980 and 2005 (BirdLife International, 2007). The 'farmland bird index' has been formally adopted by the European Union as a Structural Indicator, as a Sustainable Development Indicator, and as a baseline indicator under the Rural Development Regulation (Council Regulation (EC) No 1698/2005).

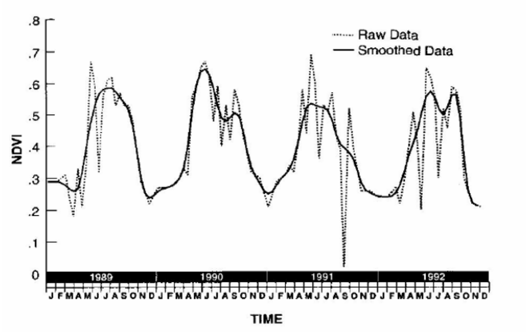
A Pan European initiative, SEBI2010 (Streamlining European 2010 Biodiversity Indicators), was launched in 2004. Its aim is to develop a European set of biodiversity indicators to assess and inform about progress towards the European 2010 targets. The work is performed in collaboration between EEA (the European Environment Agency), DG Environment of the European Commission, ECNC (the European Centre for Nature Conservation), UNEP/PEBLDS Secretariat with the lead of Czech Republic and UNEP-WCMC (the World Conservation Monitoring Centre). Work is lead by a Coordination Team. In 2005 the Coordination Team and Expert groups involving more than 100 experts nominated by European countries as well as non Governmental Organisations started working for the compilation of a First European Set of Biodiversity Indicators for assessing the 2010 target.

According to the SEBI 2010 assessment, the initial steep decline of farmland birds was associated with increasing agricultural specialisation and intensity in some areas, and large-scale marginalisation and land abandonment in others. The falling trend has levelled off since the late 1990s, partly because of stabilising inputs of nutrients and pesticides and the introduction of set-aside in the EU15. Moreover, the drastically lower nutrient inputs in the EU10 as a result of political reforms and the resulting economic crisis in the agricultural sector have also contributed to the stabilization of farmland birds population. However, the assessment report warned that increased agricultural production in the East linked to higher inputs of nutrients and pesticides, combined with further land abandonment in some parts of Europe and the proposed abolition of set-aside, may lead to a new decline. Conservation measures adopted under the EU Birds Directive have proven effective in the recovery of rare bird populations (Donald *et al.* 2007), but not in the case of widespread birds, where different recovery mechanisms are now required. Well-designed agri-environment measures have been shown to reverse bird declines at local levels. The challenge now is to deploy them or other measures widely enough to help populations recover at national and European scales.

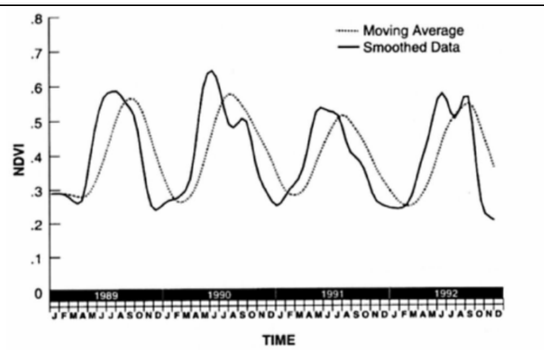
2. Methods

2.1 Image processing

After the method of Reed et al. (1994) phenological indices were calculated from the time series of the SPOT Vegetation images (1989-2005). The satellite data were measured in dekads format using the 10 days maximum NDVI image (36 images a year, 252 images for the whole time series). The metrics derived here may not necessarily correspond directly to conventional ground-based phenological events but provide indicators of ecosystem dynamics and a measurable change in ecosystem characteristics.



Running median smoothing of the time-series data (after Reed et. Al, 1987)



Forward lag created by a moving average algorithm: crossing of the original and the lagged data define the start of the growing season

Figure 2.1.1: Running median smoothing and the moving average lag of the time-series data

The SPOT Vegetation time series data was smoothed using a 5 interval running median filter (Figure 2.1.1) followed by the calculation of two forward and backward lagging curves, by means of a moving average algorithm. Moving averages are used to smooth out short-term fluctuations, thus highlighting longer-term trends or cycles. The threshold between short-term and long-term depends on the application, and the parameters of the moving average have to be set accordingly. A **simple moving average** (SMA) is the unweighted mean of the previous *n* data points. For example, a 10-day simple moving average of phenological values is the mean of the previous 10 days' phenological values. If those values are p, p_{-1}... p_{-9} then the formula is

$$SMA = \frac{p + p_{-1} + \ldots + p_{-9}}{10}$$

When calculating successive values, a new value comes into the sum and an old value drops out, meaning a full summation each time is unnecessary:

$$SMA_{today} = SMA_{yesterday} - \frac{p_{-n+1}}{n} + \frac{p_{+1}}{n}$$

In all cases a moving average (MA, Figure 2.1.2) lags behind the latest data point, simply from the nature of its smoothing. The period of the lag selected depends on the kind of movement one is concentrating on, such as short, intermediate, or long term.

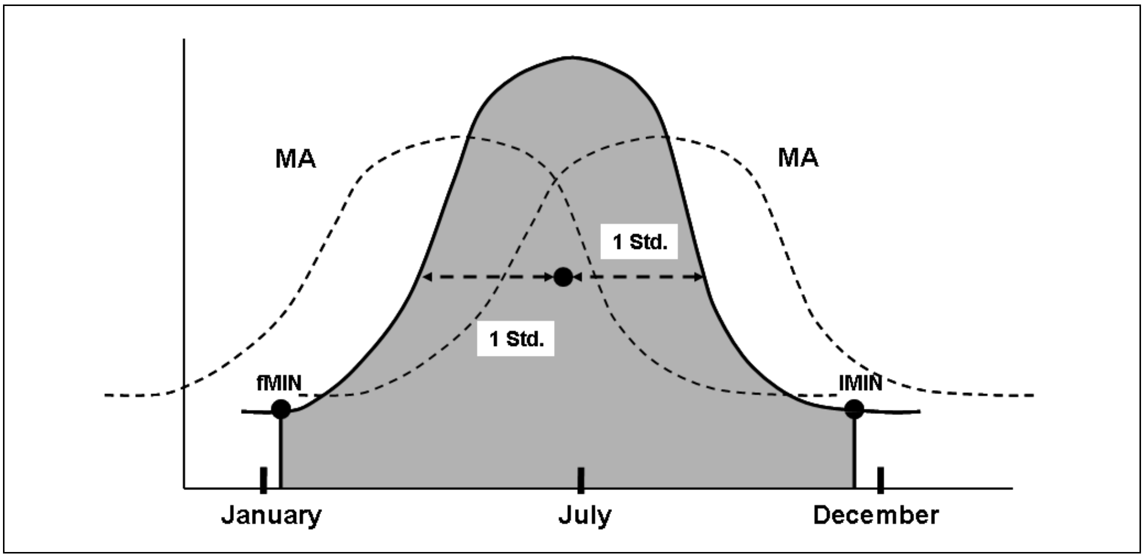


Figure 2.1.2: Definition of the moving average lag of the time-series data

According to the recommendations of Reed et al. (1994) the period should correspond approximately to the length of the non-growing season for the environment in question. For the present study and for the follow up European wide and global application however this method seemed too arbitrary and therefore another solution was searched for, that defines the lag from the data itself and not in a subjective manner. After several test runs, the method applying 1 standard deviation (in days) from the bary centre of the integral surface under the curve seemed the most appropriate. The surface of the curve was defined between the first and last absolute minimas (fMIN and lMIN, see Figure 2.1.2). The 1 standard deviation (SD, in days) was used as the lag distance to shift the original curve forward and backward. The application of the moving average forwards (in the chronological order of the observation dates) creates a new curve lagging behind the original curve whereas if the algorithm runs in the reverse order the new curve will lag before the original curve.

The Total Biomass (TB), the vegetation present above the ground throughout a year, was calculated as the integral surface under the curve defined by the two absolute Minimas (the grey area in Figure 2.1.2). The start and the end of the seasons (SOS and EOS, respectively) are defined as the points where the lagged mowing average curves cut the original time series curve (Figure 2.1.3). The corresponding indices are the dates of the SOS and EOS and the values on the vegetation curve. Similarly, the dates (fMINd and lMINd, respectively) and the values (fMINv and lMINv, respectively) of the first and last absolute yearly minima were defined on the vegetation curve. After the definition of the SOS and EOS points and the two absolute minima a number of phenological indices were derived from each year's vegetation curves (Figure 2.1.3). Total Permanent Fraction is the area under the curve defined by the first and last absolute MINIMA (fMIN and lMIN) and the X axis whereas the Seasonal Permanent Fraction will be defined by the SOS and EOS points. The Seasonal Cyclic Fraction is the area under the curve above the Seasonal Permanent Fraction while the Total Cyclic Fraction is the area above the Total Permanent Fraction (see Figure 2.1.3). The season exceeding integral is the area under the curve before and after the SOS and EOS points, respectively when subtracting the Seasonal Permanent Fraction (see Figure 21.5).

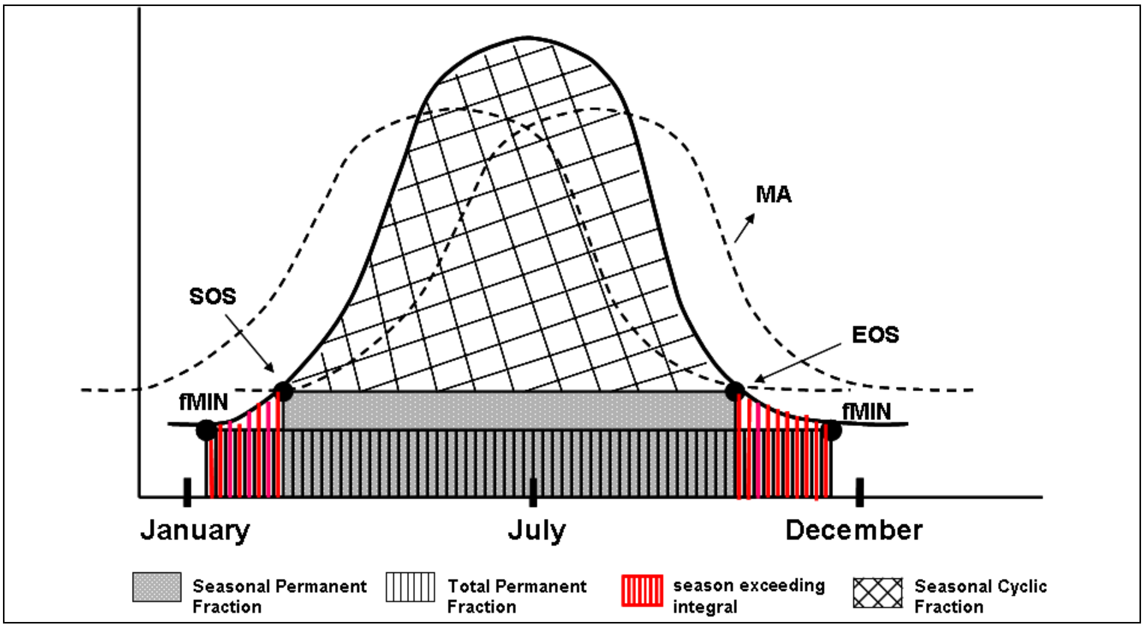


Figure 2.1.3: SOS, EOS, absolute MINIMA (MIN), permanent fractions, and cyclic fractions.

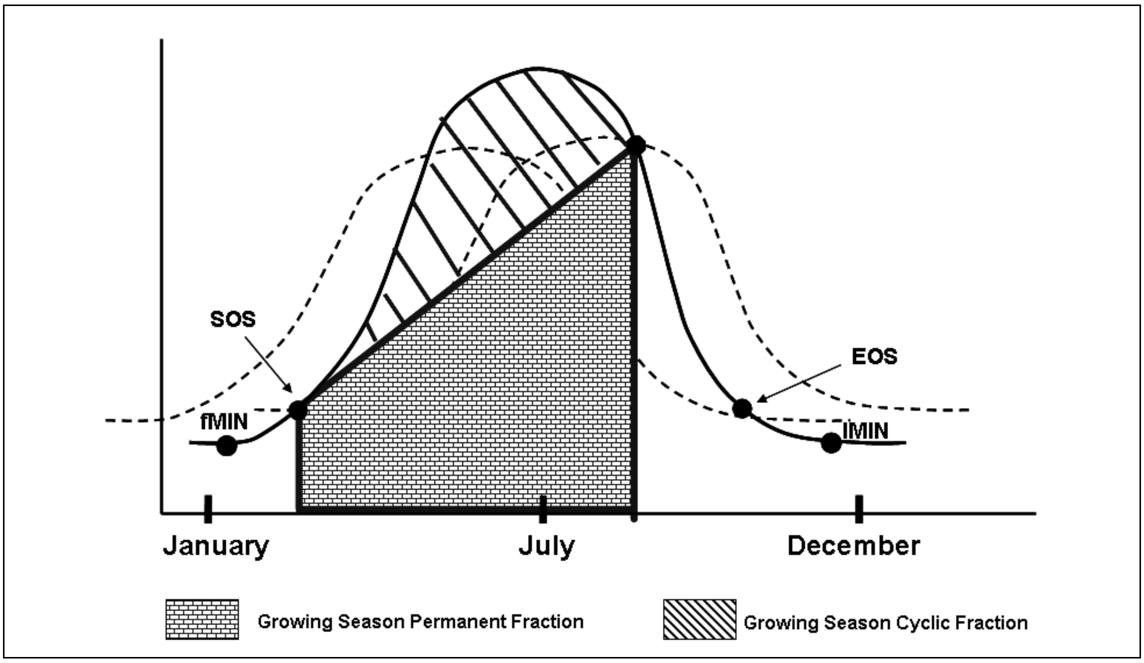


Figure 2.1.4: Growing season, growing season permanent fraction, growing season cyclic fraction.

The forward lagging curve after cutting the original curve will meet the same curve again before the EOS point. This point was defined as the end of the growing season (EGS), named such way as this could mostly differ between agricultural seasons (Figure 2.1.4). The start of the growing season equals the SOS point. Growing Season Permanent Fraction was defined as the area under the curve defined by the growing season points whereas the Growing Season Cyclic Fraction is the area under the curve above the permanent part. Growing season exceeding integral was defined as the area under the curve between the EGS and the second absolute minima points (Figure 2.1.5).

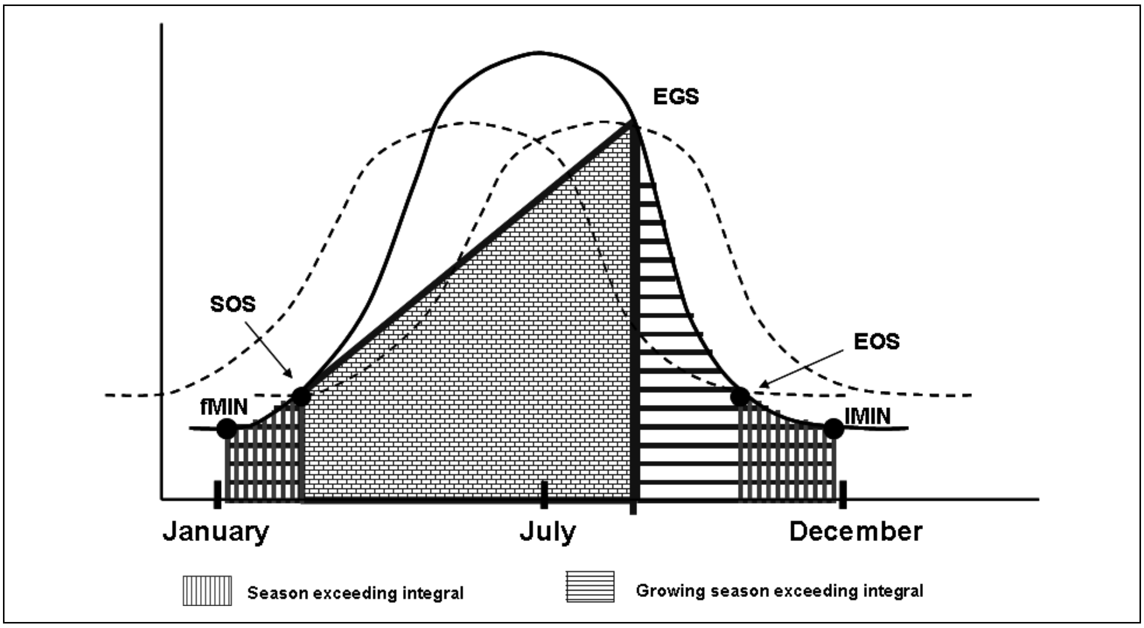


Figure 2.1.5: Growing season exceeding integral

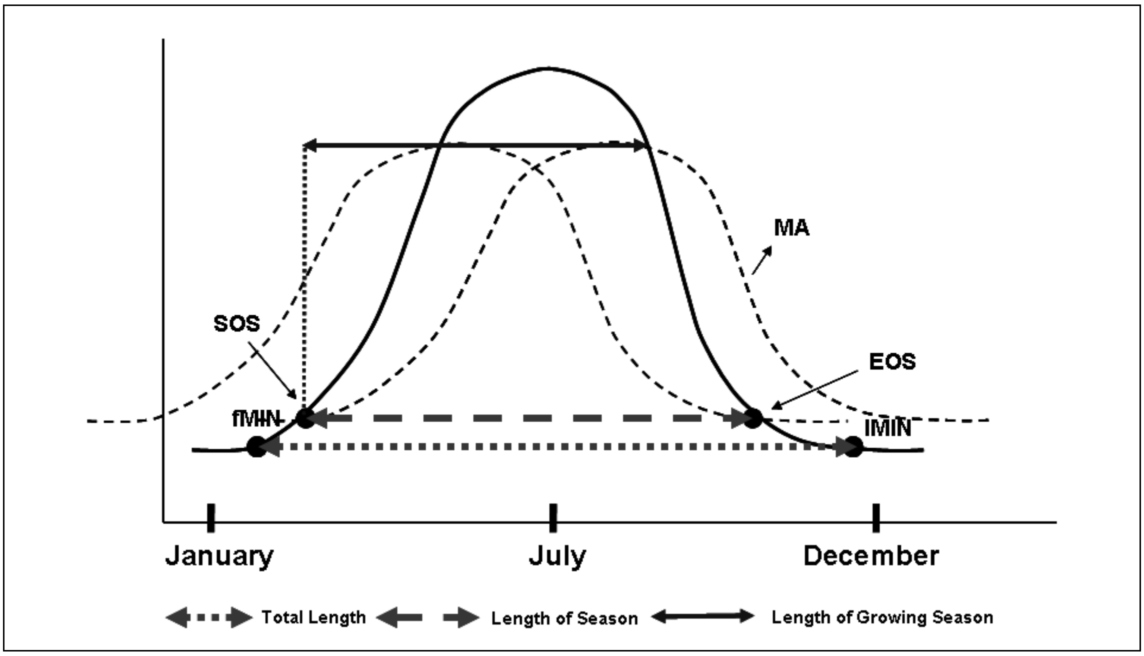


Figure 2.1.6: Season length and total length

The lengths of the growing season (between the SOS and the EGS points), of the vegetation season and the total length were also calculated and were used for the normalization of the integrals. Thus the normalised Total Cyclic Fraction (nTCF) is the Total Cyclic fraction under the NDVI curve divided by the total length between the two minimas whereas the normalised Seasonal Cyclic Fraction was calculated by dividing the Cyclic Fraction with the season length. Similarly, the normalised Growing Season Cyclic Fraction was obtained by a division with the Growing Season's length (Figure 2.1.6).

2.2 Data and spatial processing of indicators

Remote Sensing and spatial data

Eight values were calculated for each phenological metrics representing the eight years vegetation development. In order to ease the further statistical analysis these yearly values were summarized in two statistical measures, which are called time series or series statistics thereafter and are:

1. the mean of the 8 years values,
2. the standard deviation of the 8 years values,

As an example Figure 2.2.1 displays the mean and standard deviation of the eight years Total Biomass index, an approximation of the Net Primary Production, for each pixel over Europe. The mean clearly indicates areas with high yearly biomass and also those areas where the dry climate (the Mediterranean and mostly Andalusia) or the mountain environment like the Swiss Alps and the Northern European regions allows the development of less vegetation. The Standard Deviation index on the other hand indicates where the yearly vegetation cover is the most stable, i.e. the Balkans, most part of the Carpathians and also the mountainous area of the Swiss Alps and the Pyrenees. The between years vegetation cover changes the most in the Mediterranean and the Atlantic regions of France and the UK.

These series statistics were aggregated within the second hierarchical level of the Environmental Classification of Europe (Metzger et al, 2005, Figure 2.2.2) by means of a zonal statistics method. Within one environmental Strata the mean and the standard deviation of the pixel values were reported, which are called spatial statistics thereafter. This classification contains 84 Strata therefore the spatial and series statistics of each phenological indices contained 84 observations (Figure 2.2.2).

Furthermore, the climatic variables reported in the Strata of the Environmental Classification were used in the analysis. These variables were:

- Mean and standard deviation of minimum monthly temperature
- Mean and standard deviation of maximum monthly temperature
- Mean and standard deviation of monthly precipitation

The reported variables were abbreviated in the shortest possible but meaningful manner. First the spatial statistics is reported followed by the summary statistic of the time series and finally the name of the index is accounted for. The name ZMTVfMINd for example stands for the Zonal Mean (ZM, mean summary statistic of all pixels within the Environmental Strata) of the series standard deviation (TV, temporal standard deviation of the 8 years observations) of the first MINIMUM day. The climatic variables were reported as one value within the zones, therefore only the series mean and standard deviation values but not the spatial statistics are indicated in the abbreviated names.

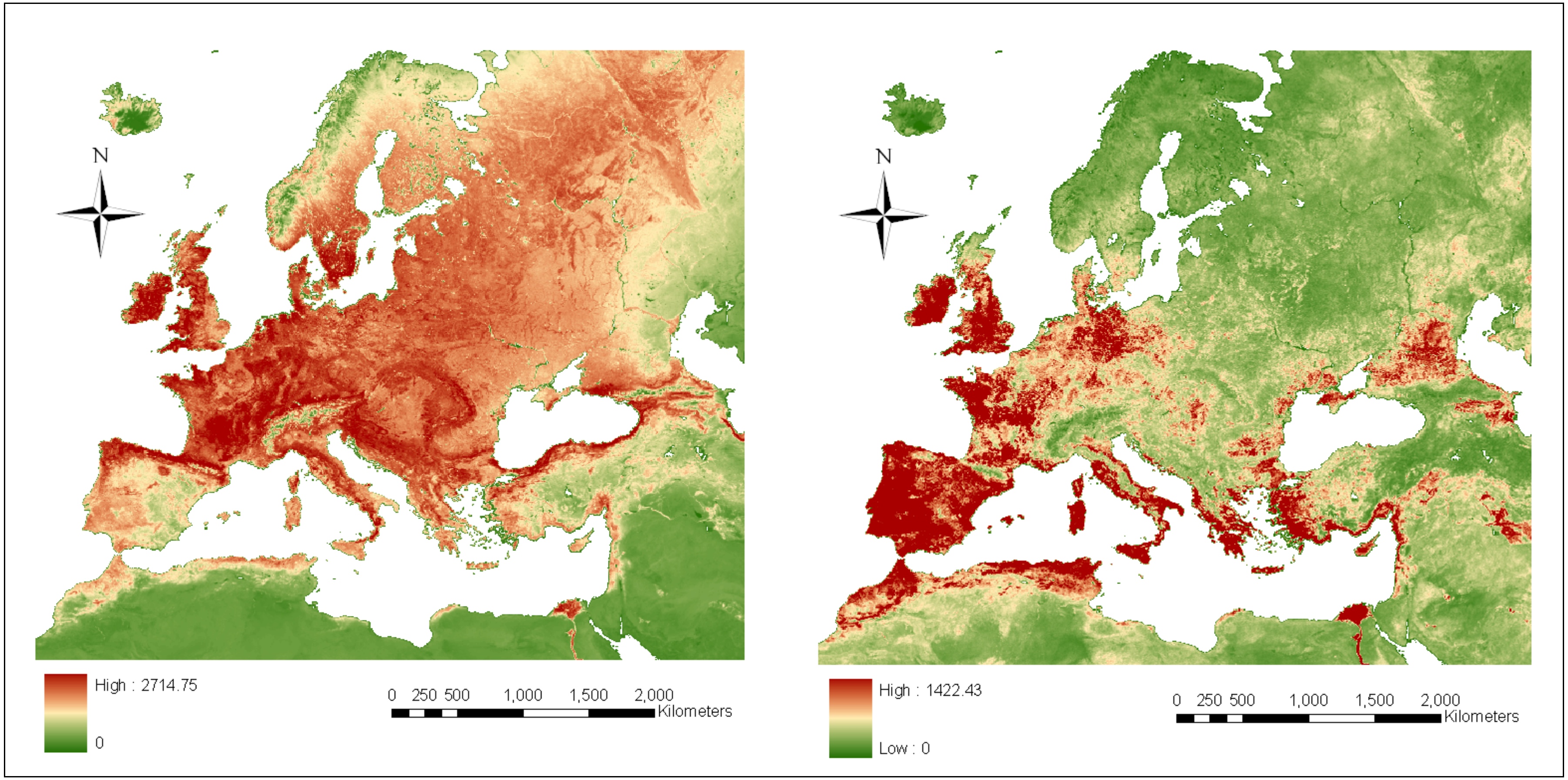


Figure 2.2.1: Mean (left) and standard deviation (right) of the eight years (1998-2005) Total Integral index.

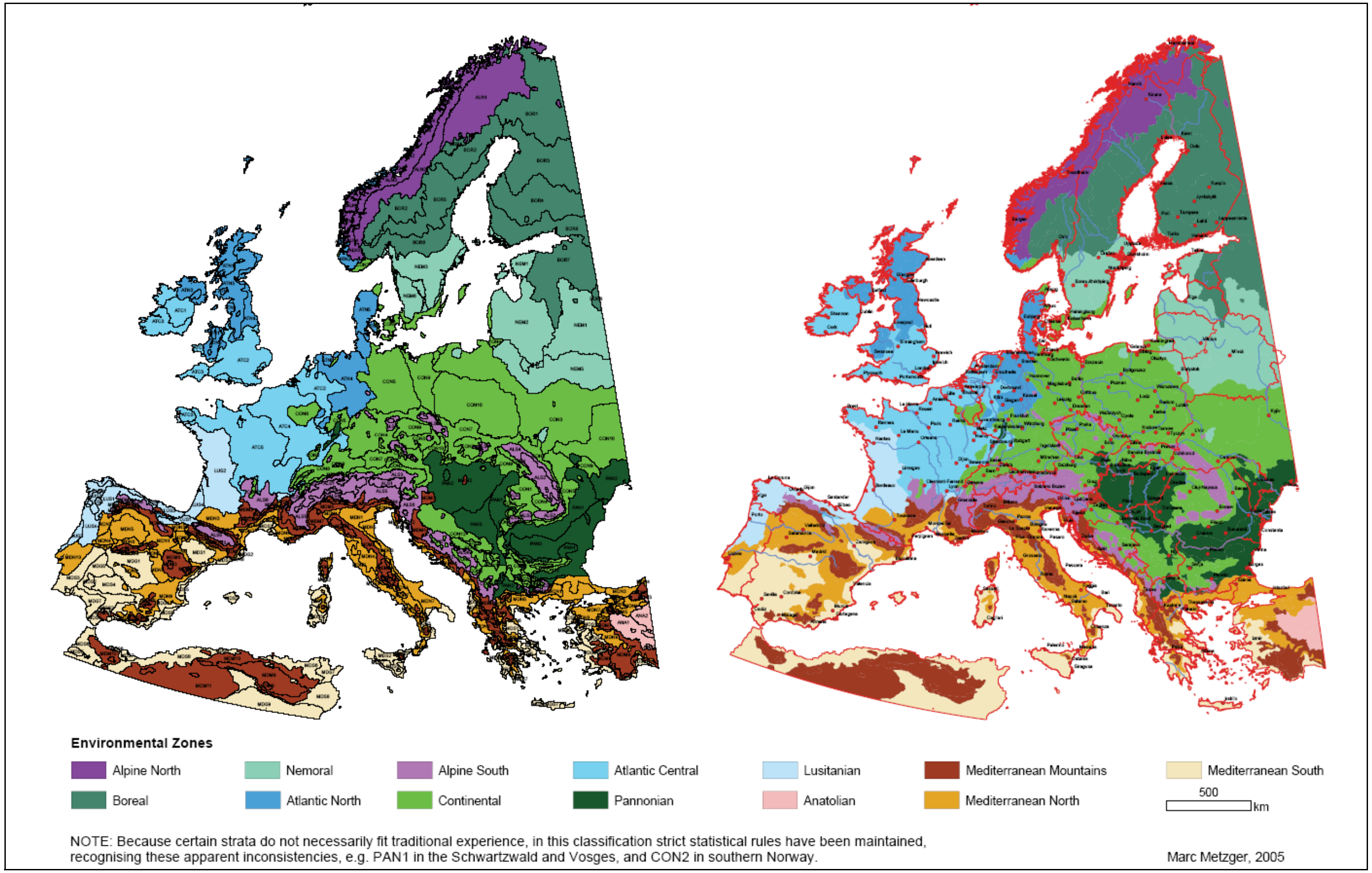


Figure 2.2.2: The environmental stratification of Europe (after Metzger, 2005).

Biological data

In 1997 the European Bird Census Counsel (EBCC) Atlas of European breeding birds, also referred to as European Ornithological Atlas or 'EOA', was published. For all the bird species present in a 50 by 50 km square in the breeding period, an indication of the breeding certainty was given. Next to information on breeding certainty, a number of countries or regions provided also estimates on the numbers of breeding pairs per square. These estimates are given in the 6 classes with exponentially increasing ranges (table 2.2.1).

Table 2.2.1: Estimate classes of the number of pair per square.

'

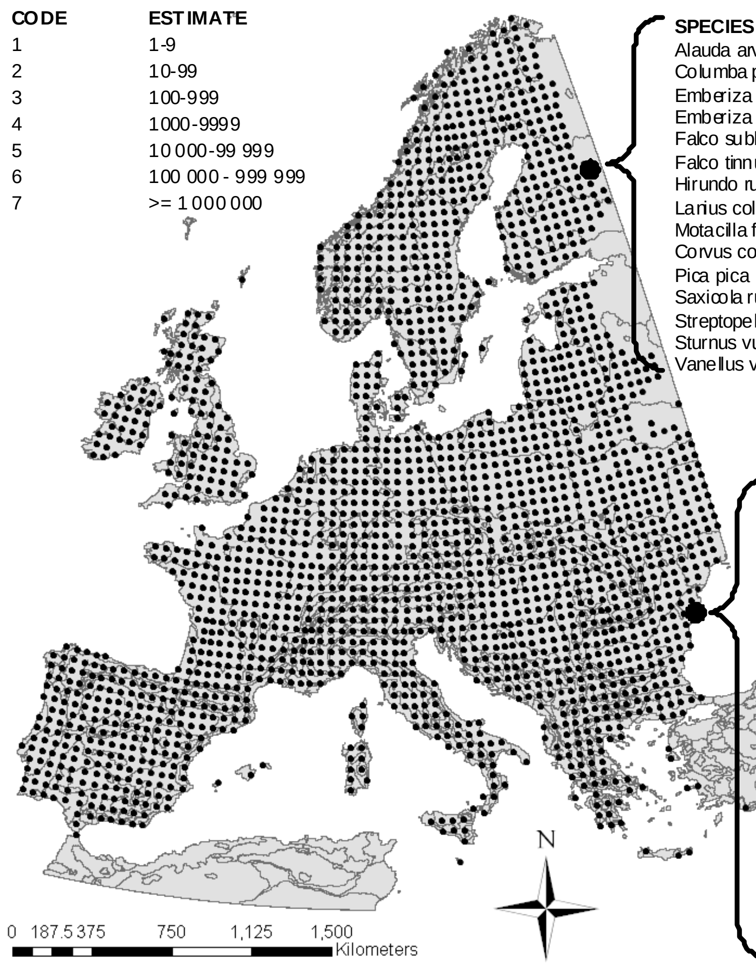
code	estimate	geomean
1	1-9	3.0
2	10-99	31.5
3	100-999	316.1
4	1000-9999	3162.1
5	10 000-99 999	31622.6
6	100 000 – 999 999	316227.6
7	>= 1 000 000	1500000.0

For the present study farmland bird species were selected from the Atlas based on the study of Gregory et al (2005). In their study expert ornithologists classified and selected 24 breeding bird species typical of agricultural habitats in Europe. The selected species had large European ranges and were abundant enough to be monitored accurately in the majority of countries by common bird monitoring schemes. Furthermore, they are well monitored by standard field methods and were considered to some degree dependent on the habitat for nesting or feeding. All these 24 species but Carduelis chloris (greenfinch) were present in the EBCC database therefore 23 farmland bird species entered the final analysis (Table 2.2.2). Figure 2.2.3 presents the distribution of the sampling grid in the study area.

For the statistical analysis the estimate classes code was used for each reported farmland bird species and was considered as count data. In order to adjust to the spatial extent of the climatic variables and phenological indices, the estimate classes of each species was summarised within each of the Environmental Classification Strata resulting in a data table with 84 rows for the Strata and 23 columns for each species. Figure 2.2.4 displays the estimate classes summed up over all 23 species within the Environmental Strata in the analysis. This figure illustrates the total picture with very few farmland species over the Mediterranean and the Alpine North regions (Norway) and large numbers over the Atlantic central, Continental and Pannonic regions (see also Appendix 1 for the abbreviations of the Strata).

Table 2.2.2: Farmland bird species

abbreviation	species name	common name
AlaArv	Alauda arvensis	Skylark
AthNoc	Athene noctua	Little Owl
CarCan	Carduelis cannabina	Linnet
CarCar	Carduelis carduelis	Goldfinch
ColPal	Columba palumbus	Woodpigeon
CorCor	Corvus corone spp	Carrion Crow
CorMon	Corvus monedula	Jackdaw
CotCot	Coturnix coturnix	Quail
EmbCit	Emberiza citrinella	Yellow Hammer
EmbSch	Emberiza schoeniclus	Reed Bunting
FalSub	Falco subbuteo	Hobbz
FalTin	Falco tinnunculus	Common Kestrel
HirRus	Hirundo rustica	Swallow
LanCol	Lanius collurio	Red-backed Shrike
MilCal	Miliaria calandra	Corn Bunting
MotFla	Motacilla flava	Yellow Wagtail
PasMon	Passer montanus	Tree Sparrow
PicPic	Pica pica	Magpie
SaxRub	Saxicola rubetra	Stonechat
StrTur	Streptopelia turtur	Turtle Dove
StuVul	Sturnus vulgaris	Starling
SylCom	Sylvia communis	Whitethroat
VanVan	Vanellus vanellus	Lapwing



SPECIES	ESTIMATE	LAT	LON	Env. Zone
Alauda arvensis	2	64.228314	30.477329	BOR3
Columba palumbus	3	64.228314	30.477329	BOR3
Emberiza citrinella	4	64.228314	30.477329	BOR3
Emberiza schoeniclus	3	64.228314	30.477329	BOR3
Falco subbuteo	2	64.228314	30.477329	BOR3
Falco tinnunculus	2	64.228314	30.477329	BOR3
Hirundo rustica	3	64.228314	30.477329	BOR3
Larius collurio	3	64.228314	30.477329	BOR3
Motacilla flava ssp	4	64.228314	30.477329	BOR3
Corvus corone ssp	3	64.228314	30.477329	BOR3
Pica pica	3	64.228314	30.477329	BOR3
Saxicola rubetra	4	64.228314	30.477329	BOR3
Streptopelia turtur	0	64.228314	30.477329	BOR3
Sturnus vulgaris	2	64.228314	30.477329	BOR3
Vanellus vanellus	2	64.228314	30.477329	BOR3

SPECIES	ESTIMATE	LAT	LON	Env. Zone
Alauda arvensis	4	44.9065459	29.21817389	PAN3
Athene noctua	2	44.9065459	29.21817389	PAN3
Carduelis cannabina	2	44.9065459	29.21817389	PAN3
Carduelis carduelis	0	44.9065459	29.21817389	PAN3
Corvus monedula	3	44.9065459	29.21817389	PAN3
Coturnix coturnix	2	44.9065459	29.21817389	PAN3
Emberiza citrinella	2	44.9065459	29.21817389	PAN3
Emberiza schoeniclus	6	44.9065459	29.21817389	PAN3
Falco subbuteo	3	44.9065459	29.21817389	PAN3
Falco tinnunculus	1	44.9065459	29.21817389	PAN3
Hirundo rustica	4	44.9065459	29.21817389	PAN3
Lanius collurio	3	44.9065459	29.21817389	PAN3
Miliaria calandra	2	44.9065459	29.21817389	PAN3
Motacilla flava ssp	3	44.9065459	29.21817389	PAN3
Corvus corone ssp	4	44.9065459	29.21817389	PAN3
Passer montanus	4	44.9065459	29.21817389	PAN3
Pica pica	4	44.9065459	29.21817389	PAN3
Streptopelia turtur	2	44.9065459	29.21817389	PAN3
Sturnus vulgaris	4	44.9065459	29.21817389	PAN3
Sylvia communis	0	44.9065459	29.21817389	PAN3
Vanellus vanellus	3	44.9065459	29.21817389	PAN3

Figure 2.2.3: Distribution of the EBCC sampling grid.

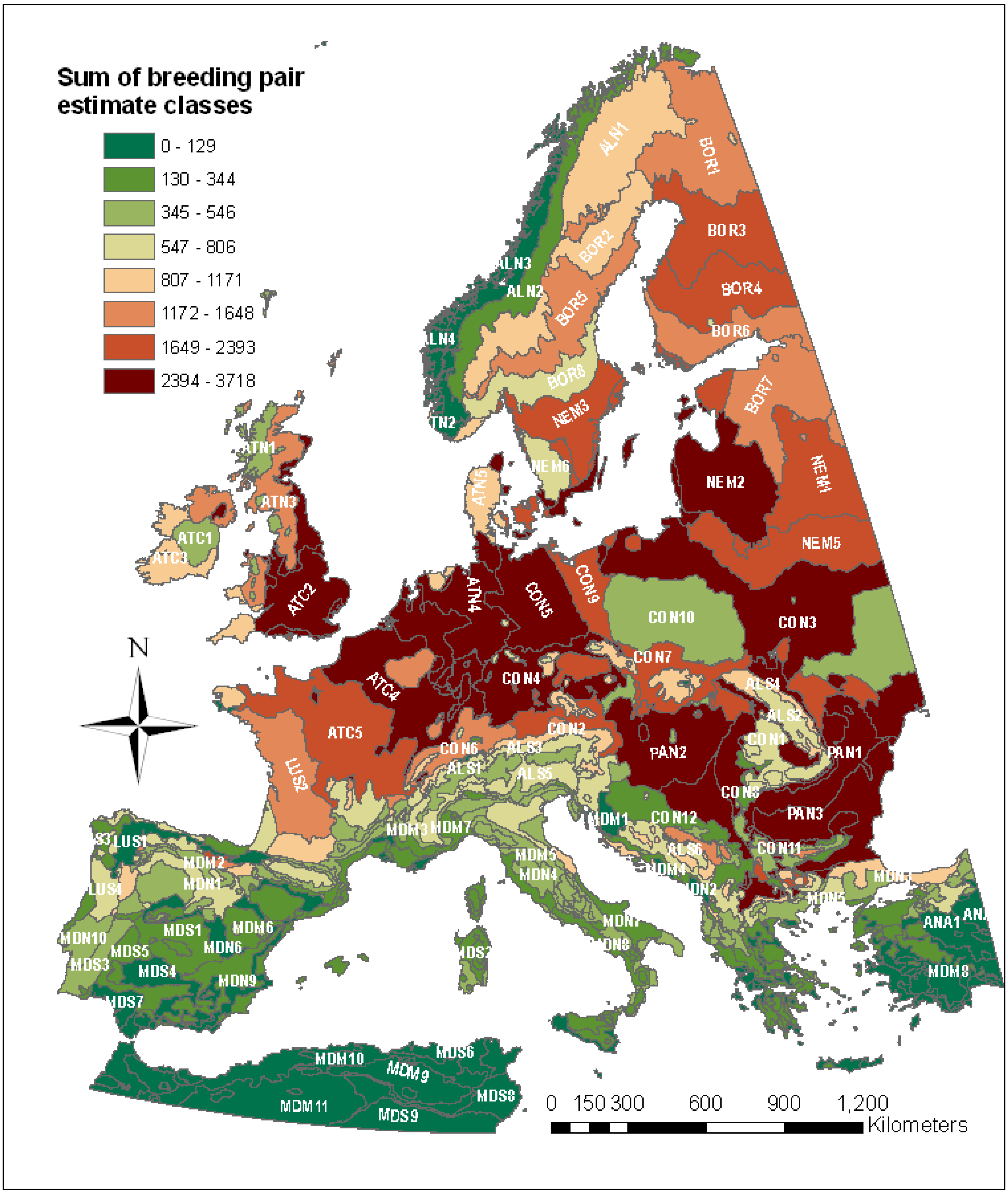


Figure 2.2.4: Farmland bird breeding pair classes aggregated in the Environmental Strata (see Appendix 1 for the abbreviations of the Strata).

2.3 Statistical analysis

Ordination analysis

In quantitative community ecology scientists typically need to analyse the effects of multiple environmental factors on many species simultaneously. Ordination is a term for multivariate statistical techniques that orders species and/or sampling units along a measured environmental gradient. The results of ordination in two dimensions is a diagram in which sites are represented by points arranged such that points that are close together correspond to sites that are similar in species composition and points that are far apart correspond to sites that are dissimilar in species composition. In indirect gradient analysis environmental information is missing and therefore the species composition of the sites is analysed. This, in some cases, might be a more informative indicator on the environment as environmental indicators are more difficult to measure. In direct gradient analysis measured environmental variables are available and one is interested in the pattern of relations between these variables and the species.

Ordination methods are essentially operations on a community data matrix or a species by sample matrix. The elements of such a matrix are the abundances of the species, referring to density, biomass, cover or presence/absence of the species. Most techniques are grouped into a linear response model, in which the abundance of the species either increases or decreases with the value of the latent (indirect ordination) or measured (direct ordination) environmental variable. In the other group methods with an unimodal response model are grouped where species occur in a limited range of values of each of the latent or measured environmental variables. Most ordination methods use an eigenanalysis technique which is performed on a square, symmetric matrix derived from the data matrix. Each ordination axis is an eigenvector associated with an eigenvalue, which will rank the ordination axes. Thus, the first axis has the highest eigenvalue, the second axis has the second highest eigenvalue, etc. In linear ordination methods eigenvalues are ‘variance extracted’ whereas in unimodal methods eigenvalues are ‘inertia extracted’, or equivalently, correlation coefficients. Species and samples are ordinated simultaneously, and can hence both be represented on the same ordination diagram (termed a *biplot*).

Detrended Correspondence Analysis (DCA) was run on the farmland bird data to discover the underlying environmental gradient that governs the species distribution. Furthermore, this analysis helps to discover weather the species respond in an unimodal or linear manner to the environmental gradient. The length of the gradient was far less then 4 indicating a linear response to the gradient (ter Braak and Prentice 1988). The species data was therefore further analysed with a Principal Component Analysis (PCA) in order to examine the environmental gradient, i.e if this gradient was explained by the Environmental Strata of Europe. In case the underlying gradient responded to the Strata the eigenvalue of the first PCA axes is expected to be over 0.5 and the percentage variance of species data explained by the axes is expected to be reasonably high.

Redundancy Analysis (RDA, Ter Braak 1994) modells a linear response of the species to the underlying environmental gradient when considering the effect of the explanatory variables in the model. This method, as implemented in CANOCO (ter Braak 1991), was used to reveal the species-environment relationships. The species data was log transformed and centered before the analysis but not standardised as abundances of the recorded species were in the same units (Lepš and Šmilauer, 2003). First, two partial RDAs were run with the log area of the Environmental Zones as covariables and with the phenological respectively the climatic variables as explanatories. The best 20 variables were selected from both RDA runs based on their F-value and significance. The significance and F-value of each variable in structuring the bird community data was determined with the Monte-Carlo test (999 permutations).

Subsequently, a hierarchical cluster analysis was performed on both sets of selected environmental variables using the squared Euclidean distance as proximity measure. Results were observed in a dendrogram and variable groups within the rescaled distance of 5 were identified. In case variables that were reported significant ($p < 0.05$) from the RDA fell in the same cluster group and their Person’s correlation coefficient was larger the 0.8 the one with the higher F-value was chosen. This way one initial set of phenological and one initial set climatic variables were chosen. Subsequently, another partial RDA was run on the initial set of variables with the log area as covariables and with forward selection of the environmental variables (999 permutations). The collinearity of the environmental variables was inspected by the variance inflation factor of the RDA models and it was kept as low as possible but below the upper limit of 20. This way one final set of phenological and one set of climatic variables were selected that significantly explained farmland birds assemblages.

Generalized Additive Models (GAM) represent an advance in regression analysis appropriate for studies of species distributions (Austin 2002; Guisan et. al. 2002). Species response curves to the phenological and climatic variables were calculated by means of a GAM using the Poisson distribution and two degrees of freedom to predict the number of breeding birds per environmental zone. Only statistically significant results ($p<0.05$) were included in the plot. The significance and F-value of the species-explanatory variables relationship were reported in a table.

The first two RDA axes were investigated focusing on their eigenvalues and on the cumulative percentage of variance they explained in the species data. These results were visualised in form of a biplot displaying the species and the Environmental Strata as well as in a triplot displaying the phenological or climatic variables respectively with the species and the Environmnetal Strata. For the triplots the sample scores, that are linear combinations of the environmental values (SamE in Canoco), were used. Biplots were created with the sample scores that are linear combinations of species in the samples (Samp in Canoco). This choice was made to better display the variability in species composition. Additionally, the correlation of the selected environmental variables with the two RDA axes (intra-set correlations) was reported together with their conditional effect and their p-values.

3. Environmental gradient explaining the distribution of farmland birds.

3.1 Unrestricted ordination of farmland birds: DCA and PCA

DCA was run on the EBCC farmland birds data in order to check whether the species respond in a multinomial or linear manner to the environmental gradient. The length of the first DCA axis was less then 4 (1.798, Table 3.1) suggesting a linear response of the species to the environmental gradient.

Table 3.1: DCA analysis of EBCC farmland birds data

Axes		1	2	3	4	Total inertia
Eigenvalues	:	0.061	0.006	0.003	0.002	0.107
Lengths of gradient	:	1.798	0.695	1.183	0.881	
Cumulative percentage variance of species data	:	57.4	63.1	65.7	67.6	
Sum of all eigenvalues						0.107

[Fri Mar 28 18:56:25 2008] CANOCO call succeeded

Because of the linearity of the gradient the analysis was repeated with a PCA. The first two PCA axes explained 87 % of the variation in the birds data (Table 3.2). There was a strong first axis gradient explaining 66% of the variation whereas the second PCA axis explained 20%. The other PCA axes had far less explanatory power suggesting two environmental gradients influencing the distribution of the species. The Environmental Strata and the species were visualised in the so-called biplot (Figure 3.1). The first axis was dominated by a gradient from the Continental regions through the Pannonic and Atlantic areas to the Mediterranean while along the second axis the Boreal, Nemoral, and Alpine regions were important following a South-North gradient (Figure 3.1, see Appendix 1 for the abbreviation of the Strata). This indicates that the environmental classification zones of Europe supplies two environmental gradients that describe the European farmland bird distribution pattern (see also Appendix 2, species scores of the PCA).

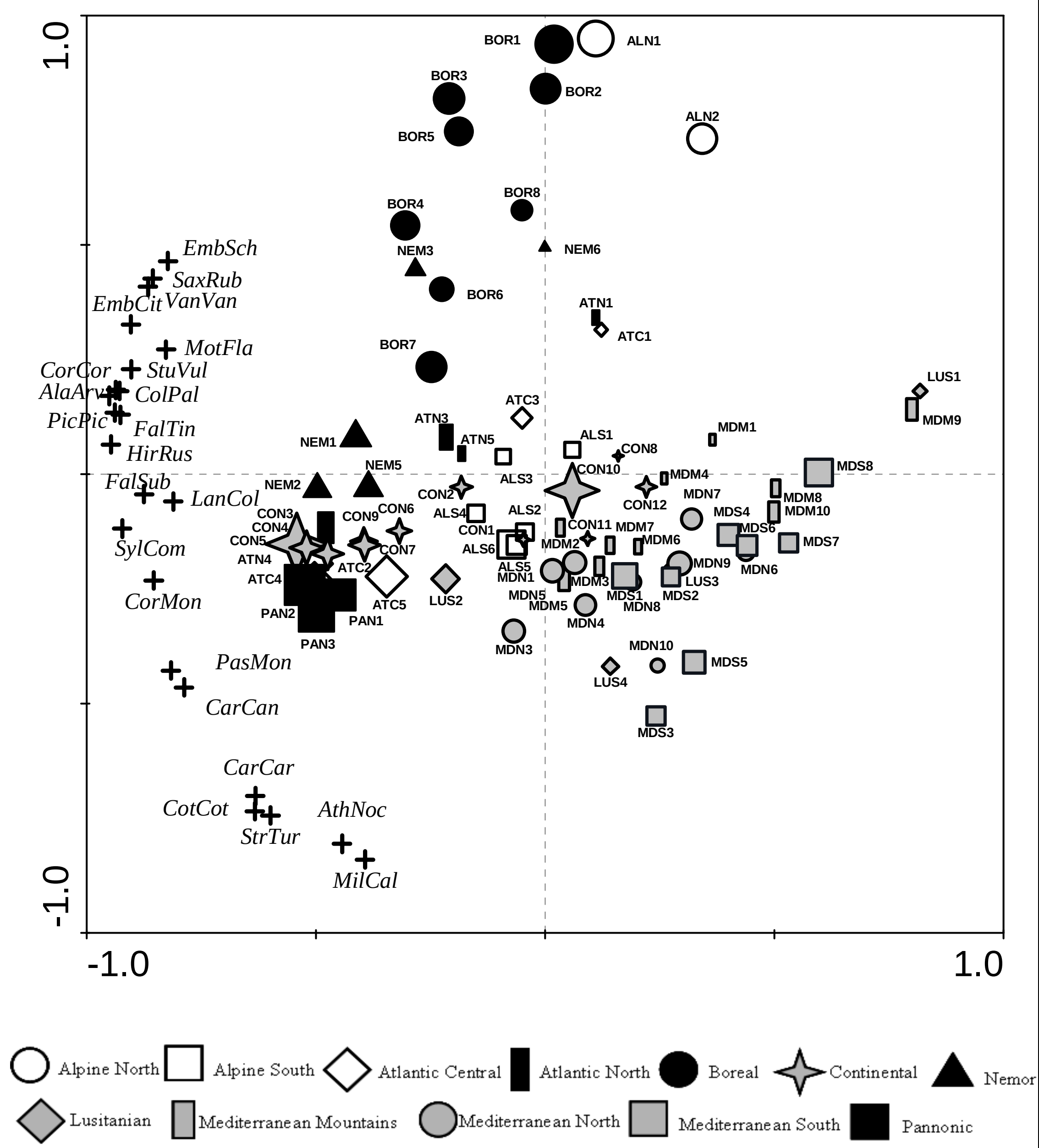
Most of the Continental regions of the UK, France, the Benelux states, Germany and the new member states had a high negative sample score on the first axis together with the Nemoral regions of Lithuania, Latvia and Belarus (see Appendix 3, sample scores of the PCA). The Continental regions of Poland and Ukraine were exceptions with close to zero sample scores. The Boreal, Atlantic, Northern and Southern Alpine, and Northern and mountainous Mediterranean regions were in the middle of the first axis gradient. The Southern and Northern Mediterranean regions of the Iberian Peninsula, Italy and Greece and the Lusitanian regions of Portugal occupied the farther end of the environmental gradient. The second PCA axis expressed a strong Northern-Southern gradient (Figure 3.1). The Boreal, Northern Alpine and Nemoral regions of Sweden and Finland expressed high and positive second axis sample scores while the Southern Mediterranean and Lusitanian regions of Portugal and the middle and lower Danube plain of Hungary and Romania expressed very high negative scores. The other regions were in the middle of the second axis gradient.

Table 3.2: PCA analysis of EBCC farmland bird data

Axes		1	2	3	4	Total variance
Eigenvalues	:	0.664	0.202	0.033	0.026	1.000
Cumulative percentage variance of species data	:	66.4	86.6	89.9	92.4	
Sum of all eigenvalues						1.000

All the farmland bird species had a high and negative score on the first axis but were well distributed along the second axis (Figure 3.1). Environmental zones which also expressed high and negative scores on the first axis had high number of breeding pairs. Highest values occurred in the Continental regions of the Check republic and Poland (CON3), followed by the middle and lower Danube plains of Hungary, Slovakia, Austria, Serbia, Romania and Bulgaria (PAN2 and PAN3). High number of breeding pairs occurred also in the Continental regions (CON5) of Germany (Brandenburg, Sachsen, Pfalz) and Romanian Moldova. The Atlantic central regions of South Eastern England, the Benelux states, Northland Westfalend in Germany (ATC2), the North-Eastern part of France (ATC4) and the Nemoral regions of Latvia and Lithuania (NEM2) also expressed high negative sample scores and high total number of estimated breeding pairs. Very few breeding pairs were found in the Coastal plains of the Adria (MDN2, Croatia, Bosnia-Herzegovina, Montenegro, Albania), on the South-West Norvegian cost (ATN2) and Northern alpine regions of the Norwegian fjords (ALN2 and ALN4). These zones had high positive sample scores and were plotted on the right hand side of the biplot with no species around. Few breeding pairs were indicated in the Foothills of the Cantabrian Mountains and West Pyrenees (LUS1, Spain), the whole Southern Iberian Penninsula and the Sothern, Northern and mountainous Mediterranean areas. These zones were also plotted further from the species in the biplot. As on overview, Figure 3.2 displays the percentage of species in the 12 Environmental Zones, the higher hierarchy of the Environmental Classification.

All these findings strongly correspond with Figure 3.3 presenting the estimated number of breeding pairs in the Environmental Strata summed over all species extracted from the collected EBCC data. This indicates that there is an underlying environmental gradient that structures the distribution of the species within the Environmental Strata. The question is weather this gradient can be best described buy the phenological indices or by the climatic variables.



AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 3.1: PCA biplot with species and environmental zones; the size of the symbols corresponds to the total number of estimated breeding pairs for all species in the samples. For easier interpretation species are displayed with symbols instead of arrows.

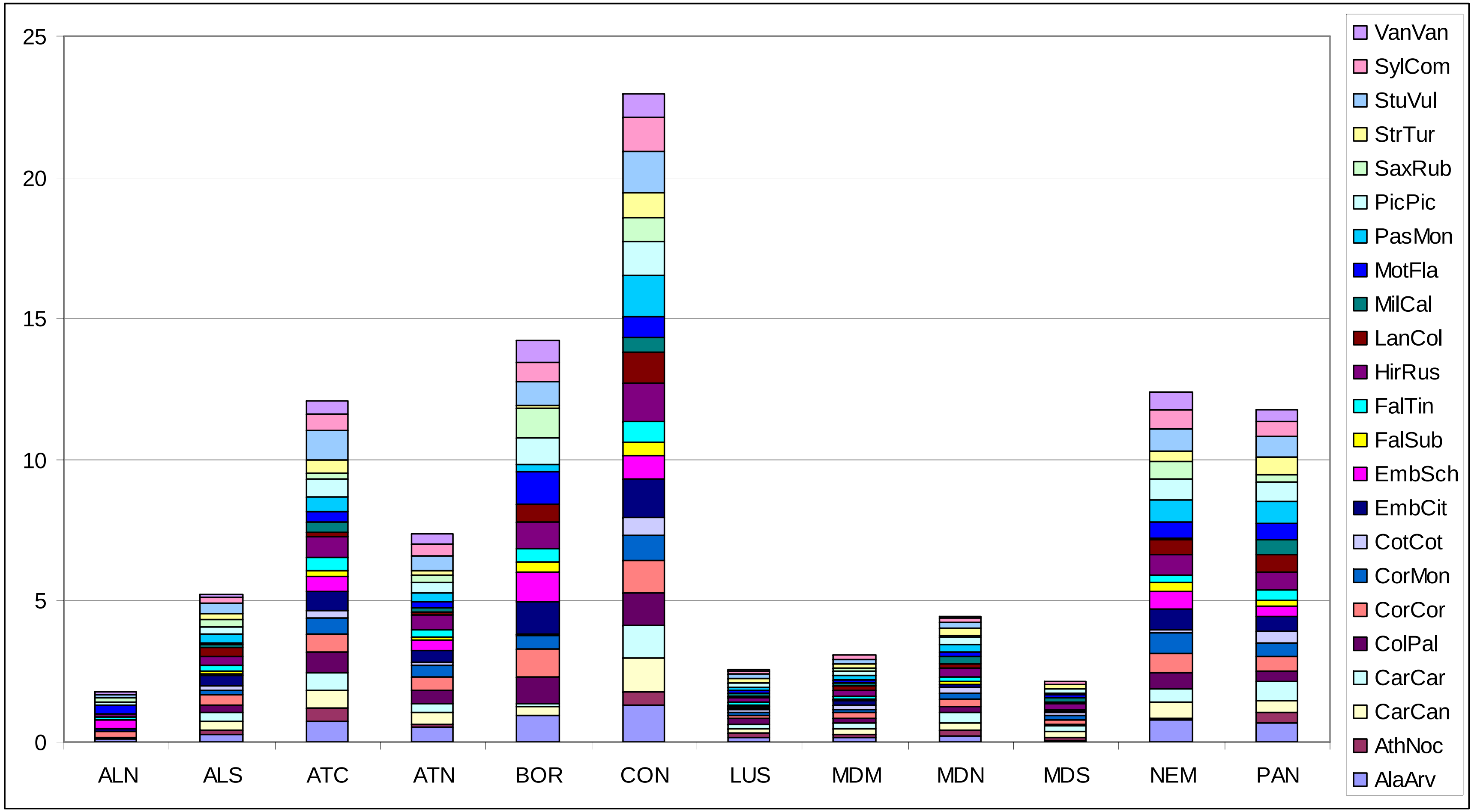


Figure 3.2: Percentage of species in the Environmental Strata. The study area i.e. the Environmental Stratification for Europe was considered 100%.

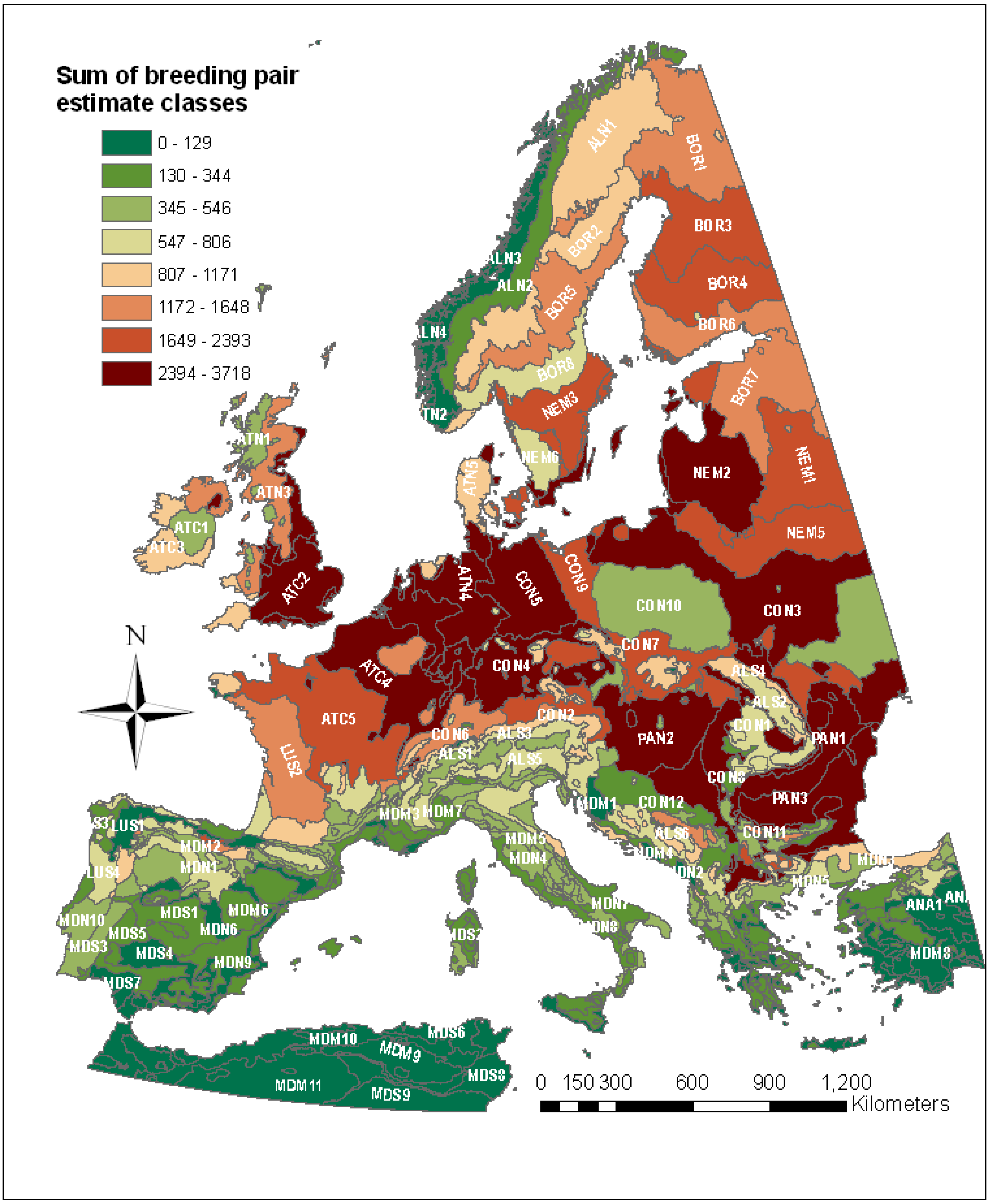


Figure 3.3: Farmland bird breeding pair classes aggregated in the Environmental Strata (see Appendix 1 for the abbreviations of the Strata)

4. Statistical linkage between farmland birds, phenological indices and the climatic variables.

4.1 Phenological indices

Redundancy Analysis with phenology as explanatory and the area of the Strata as covariables

Partial RDA was run with the farmland birds as response variables, the phenological indices as explanatories, and the areas of the Strata as covariates. The model was requested to select the 20 best uncorrelated variables with high F-values by means of the Monte Carlo permutation test. The 20 best variables were investigated in a hierarchical cluster analysis. The dendrogram together with the F-tests of the variables identified nine independent indices (see Appendix 4 for the dendrogram). These variables entered another partial RDA, this time with forward selection of the explanatory variables and with the log area of the Strata as covariables. The forward selection with the Monte Carlo permutation test resulted in six phenological indices with a variance inflation factor below 20. The selected indices are presented in Table 4.1.1 together with the conditional effect (λ), F value and significance of the variables. These indices were as follows: (1) the series mean first MIN day varying within the Strata; (2) the series mean normalized Total Cyclic Fraction averaged within the Strata; (3) the temporal variation of the portion of Total Cyclic Fraction from the Total Biomass averaged within the Strata; (4) the temporal variation of the normalized Seasonal Cyclic Fraction averaged within the Strata; (5) the series mean of the Start of Season day averaged within the Strata. The variables are listed in the order of their importance (F-value), i.e. the first MINIMUM day was the most important explanatory variable.

Table 4.1.1: Phenological variables selected by the RDA of farmland birds with the area of the Strata as covariables.

Variables names and code	Λ	F-ratio	P
Spatial variation and series mean of the first MIN day (ZVSMfMINd)	0.26	35.9	0.001
Zonal and series mean of the normalized Total Cyclic Fraction (ZMSMnTCF)	0.11	18.1	0.001
Zonal mean and series variation of Total Cyclic Fraction and Total Biomass ratio (ZMSVTCF/TB)	0.04	7.9	0.001
Zonal mean and series variation of the normalized Seasonal Cyclic Fraction (ZMSVnSCF)	0.04	8.2	0.003
Zonal and series mean of Start of Season day (ZMSMSOS)	0.02	4.5	0.013

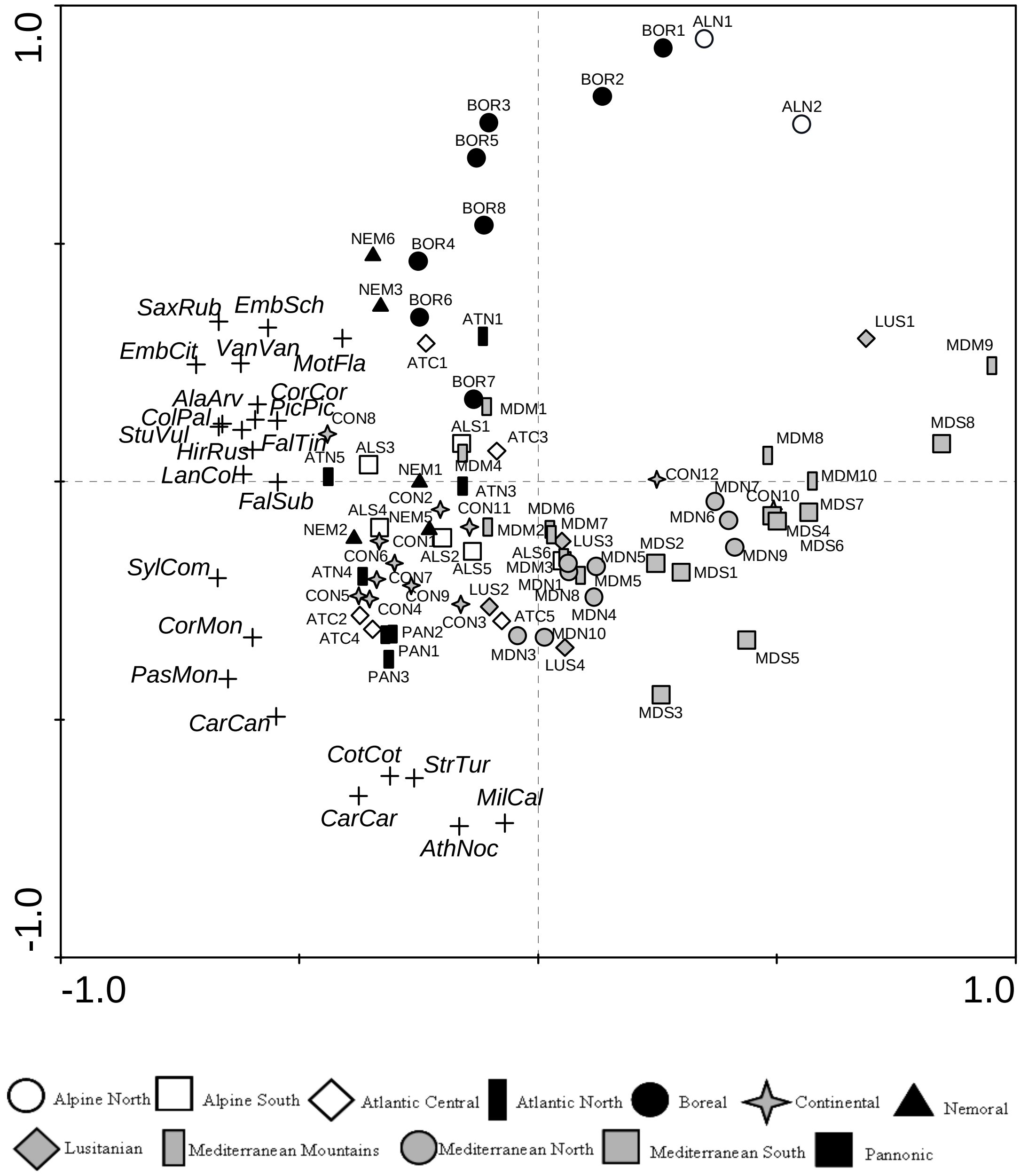
The Monte Carlo permutation test showed that both the first axis and the overall model were statistically significant ($p < 0.001$, Table 4.1.2). The selected phenological indices explained 47 % of variation in European farmland birds assemblages (sum of all canonical eigenvalues). The variability explained by the area of the Environmental Strata was only 21 % (Total variance – sum of all eigenvalues). The eigenvalues of the first four axes were 0.297, 0.150, 0.013 and 0.008, respectively showing that the first two axes captured the majority of the variation in the species-environment relationship. Accordingly, the first two canonical axes explained 95% variance in the fitted responses (cumulative percentage variance of species-environment relation), i.e. from all the variation phenology can explain the first two axes accounted for the major part. This is another indication for the relative importance of the first two axes and the ignorable role of the remaining axes. Furthermore, respecting the variation in the species data the first two canonical axes accounted for 57%, supporting the importance of two environmental gradients. All the RDA axes had high species-environment correlation indicating strong relation between farmland bird species and phenology.

Table 4.1.2: Summary of the RDA of farmland birds with phenology as explanatory and area of the Strata as covariables.

```
 **** Summary ****

 Axes                               1       2       3       4  Total variance

 Eigenvalues                :   0.297   0.150   0.013   0.008          1.000
 Species-environment correlations :   0.806   0.868   0.707   0.615
 Cumulative percentage variance
    of species data         :    37.5    56.6    58.2    59.3
    of species-environment relation:    63.1    95.1    97.8    99.6

 Sum of all              eigenvalues                                    0.790
 Sum of all canonical    eigenvalues                                    0.470


 The sum of all eigenvalues is after fitting covariables
 Percentages are taken with respect to residual variances
                 i.e. variances after fitting covariables

 *** MESSAGE ***
 The fit for species is additional to the fit due to covariables.
 With covariables, CANOCO cannot calculate residuals for samples.

1
 *** Unrestricted permutation ***


 Seeds:  25045 16631



 **** Summary of Monte Carlo test ****

 Test of significance of first canonical axis: eigenvalue =    0.297
                                               F-ratio    =   41.483
                                               P-value    =    0.0010

 Test of significance of all canonical axes  : Trace      =    0.470
                                               F-ratio    =   20.298
                                               P-value    =    0.0010
```

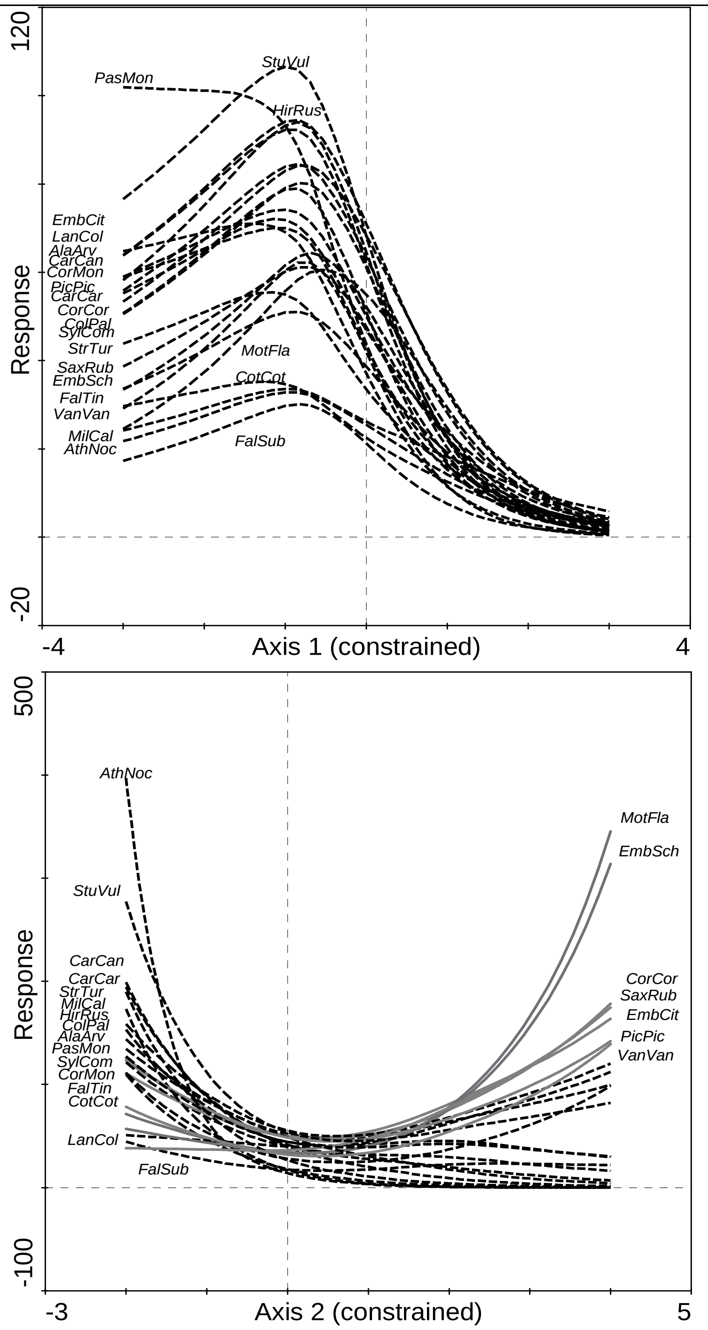
The first RDA axis clearly structured the Environmental Strata of southern Europe (Figure 4.1.1). The axis positively correlated to the southern, northern, and mountainous Mediterranean and the Lusitanian regions and negatively with the Continental, Alpine South, Atlantic Central and Pannonic regions (correlation visualized by the position of the Strata along the positive and negative end of the axis). The second RDA axis revealed a Nothern-Southern gradient from the Alpine North, Boreal and Nemoral regions through the Continental areas to the Pannonic lower Danube Plains of the former Yugoslavia, Bulgaria and Romania.

All the species exhibited a negative association to the first RDA axis (similarly to the PCA results) and were plotted on the left hand side of the biplot (Figures 4.1.1 and 4.1.2). Most of these associations were significant on the $p<0.001$ level, Motacilla flava and Athene noctua expressed a significant relation to the first axis on the $p<0.01$ level while the association of Miliaria calandra was rather week ($p<0.5$). The second RDA axis clearly separated farmland bird species expressing negative and positive association to the axis (Figures 4.1.1 and 4.1.2). Eleven species showed significant association ($p < 0.5$) to the second constrained axis (Table in Figure 4.1.2). Carduelis carduelis, Coturnix coturnix, Streptopelia turtur formed one group while Athene noctua and Miliaria calandra another one on the lower end of the RDA biplot (Figure 4.1.1). These species mostly breed in hedgerows, orchards and scrubs. Species in the former group migrate to Africa or to the Mediterranean while Athene noctua and Miliaria calandra are residents. Passer montanus, Carduelis cannabina and Corvus monedula formed another group of species of sedentary birds although some individuals of the latter migrate from more northerly breeding areas. Falco subbuteo, Lanius collurio, Corvus monedula and Sylvia communis are species nesting in trees, edges of woods or heathland and woodland margins and migrate to Africa in the winter. These species were plotted in the middle of the gradient formed by the second RDA axis. Finally, in the upper part of the RDA biplot species with grassland, pastures, moorlands, and parks and gardens as breeding habitats were plotted.



AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 4.1.1: RDA biplot of species and the Strata of the Environmental Zones. Species are plotted with symbols (cross) for easier interpretation of the diagram.



	AXIS1
AlaArv	27.9; ***
AthNoc	5.5; ***
CarCan	18.6; ***
CarCar	14.8; ***
ColPal	22.8; ***
CorCor	18.8; ***
CorMon	23.1; ***
CotCot	8.5; ***
EmbCit	25.9; ***
EmbSch	9.4; ***
FalSub	18.6; ***
FalTin	15.1; ***
HirRus	22.5; ***
LanCol	24.7; ***
MilCal	3.4; *
MotFla	6.6; **
PasMon	26.3; ***
PicPic	19.5; ***
SaxRub	13.1; ***
StrTur	11.1; ***
StuVul	25.4; ***
SylCom	25.7; ***
VanVan	19.2; ***

	AXIS2
AlaArv	4.1; *
AthNoc	23.9; ***
CarCan	9.8; ***
CarCar	14.4; ***
ColPal	7.6; **
CorCor	6.6; **
CorMon	3.5; *
CotCot	15.1; ***
EmbCit	5.7; **
EmbSch	10.1; ***
FalSub	2.9; *
FalTin	7.9; ***
HirRus	5.3; **
LanCol	0.6; /
MilCal	17.1; ***
MotFla	9.5; ***
PasMon	5.3; **
PicPic	4.8; *
SaxRub	7.1; **
StrTur	12.3; ***
StuVul	6.4; **
SylCom	3.1; *
VanVan	5.2; **

AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 4.1.2: Species response curves modeled by a GAM to the first and second RDA axes. The tables show the F-value and the significance of the relationships. (***: p < 0.001; **: p<0.01; *: p<0.5; /: not significant).

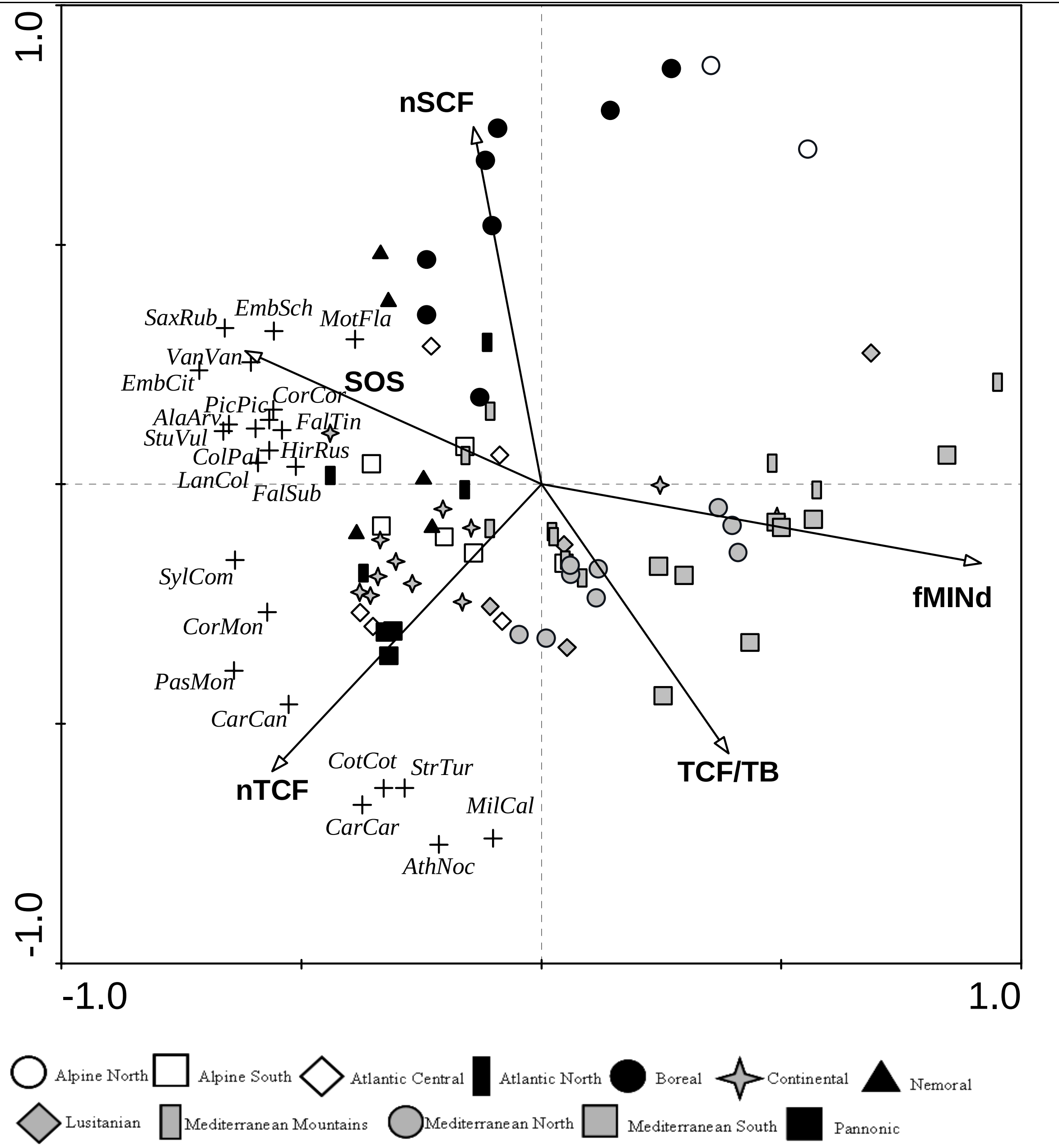


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Figure 4.1.3: RDA triplot of species, sites and Phenological variables. Species are plotted with symbols (cross) for easier interpretation of the diagram. Phenological variables are plotted with arrows.

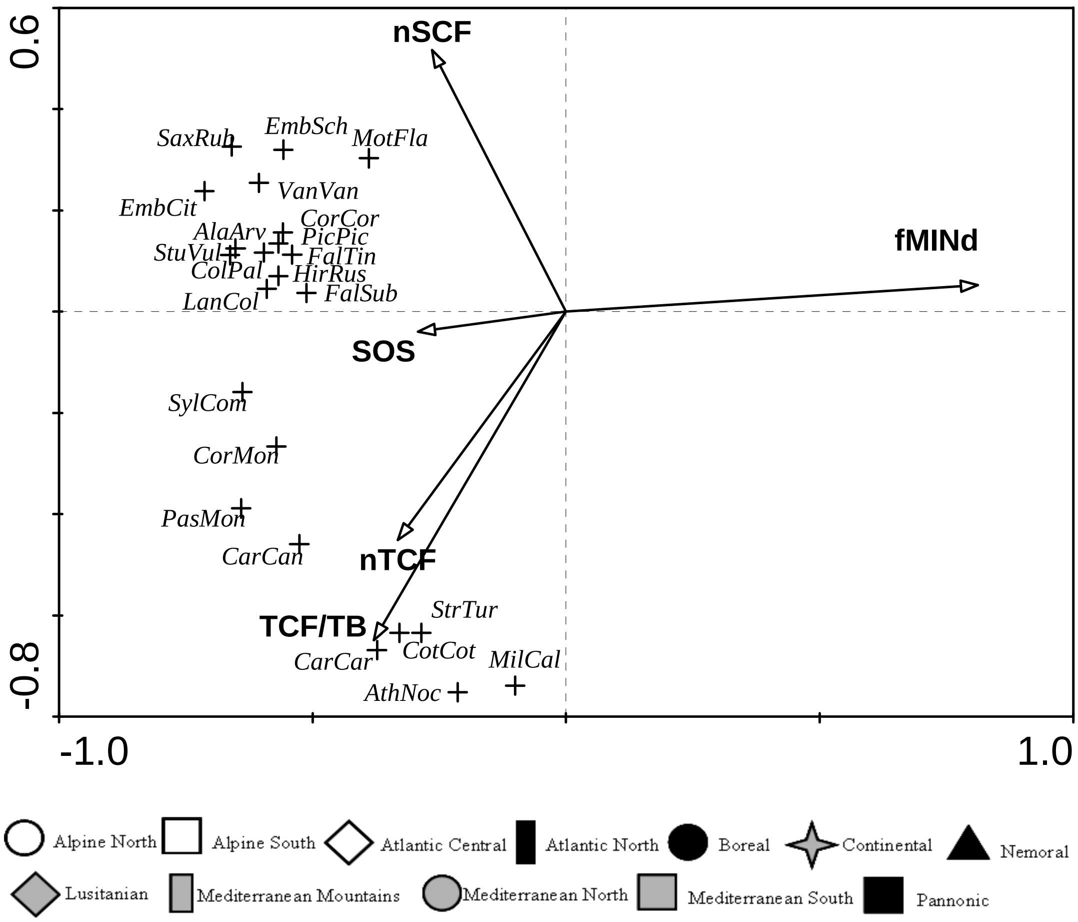

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Figure 4.1.4: RDA regression biplot of species, sites and Phenological variables. Species are plotted with symbols (cross) for easier interpretation of the diagram. Phenological variables are plotted with arrows.

The zonal variation of the series mean first MIN day (fMINd) was the strongest phenological predictor selected by the RDA model (F=35.4, p<0.001, Table 4.1.1 and Figure 4.1.3) with a negative but very significant link to all the species (Table 4.1.3). This negative link means that farmland bird species tend to concentrate on areas were the first appearance of some green vegetation starts on earlier dates, and where these dates are stable throughout the time period observed. This negative link is well represented when comparing the aggregated distribution of farmland birds breeding pairs (Figure 2.2.3.) and the index aggregated in the Environmental Strata shown in Figure 4.1.5. Most farmland bird species were observed in the Continenta, Pannonic and Atlantic regions where the date of the first MINIMUM is the earliest. The start day of the growing season (SOS) is similar in principal to the first MINIMUM day, however the former was selected over its spatial average while the latter over its spatial variation (Figure 4.1.9). Furthermore, rather then indicating the first appearance of green vegetation the SOS indicates the growing season where according to the Moving Average method the surface vegetation cover is significantly higher then the cover in any previous dates of the year. The two index has a strong and negative correlation and accordingly all of the observed species expressed a positive link to the Start of Season day (Figure 4.1.3). Species observed in the Continental and Pannonic regions (i.e. Athene noctua, Miliaria calandra, Carduelis carduelis, Streptopelia Turtur) expressed a weaker association to this index.

The series and spatial mean of the normalized Total Cyclic Fraction (nTCF) was another strong indicator of the farmland birds distribution pattern ($F=18.2$, $p<0.001$, Table 4.1.1 and Figure 4.1.3). However, only eleven species that breed in hedgerows, orchards and scrubs expressed a strong and significant positive link to this indicator (Table 4.1.3 and Figure 4.1.3, these species are plotted along the arrow of the indicator). This phenological index had highest values in the Lusitanian regions of Northern Portugal and South West France, in the Atlantic Central regions of the UK and in the Continental regions of the Black Forest (Germany) (Figure 4.1.6). In these Environmental Strata mostly the above mentioned species are present thus the positive link between the indicator and the species is convincing. The importance of the normalized Total Cyclic vegetation Fraction, i.e. the total amount of vegetation that follows a cyclic pattern throughout a year and is expressed in terms of the season length, is plausible over these areas.

Somewhat similar to this index is the temporal variation of the Total Cyclic Fraction divided by the Total Biomass (TCF/TB), which expresses the portion of yearly changing vegetation from the total vegetation observed in a year. The indicator had highest values in the Mediterranean, including the Southern and Northern regions of Spain, Italy and Greece and in the mountainous regions of Turkey (Figure 4.1.7). This index had a very strong and significant link to all the species observed (Table 4.1.3 and Figure 4.1.3). Species plotted on the lower side of the diagram nest in hedgerows, orchards and scrubs and expressed a positive association with this index (the arrow of the indicator points to the same direction). Species plotted on the upper side of the diagram expressed a negative association with this index (the arrow points into the opposite direction). These nest in trees, edges of woods or heathland and woodland margins and migrate to Africa in the winter or breed in grassland, pastures, moorlands, and parks and gardens. The reason for this differentiation lies most probably in the temporal variation this index expresses: the Mediterranean is more exposed to variation in weather conditions therefore the temporally varying portion of Total Biomass will be more associated to these regions and also to species present here.

The temporal variation of the normalized Seasonal Cyclic Fraction (nSCF) expresses the fraction of vegetation that varies in the growing season depending on the length of the season. This index had highest values in the Boreal and Alpine North regions of Sweden, Norway and in the Boreal regions of Finland (Figure 4.1.8). Species plotted on the upper part of the diagram expressed a strong and significant positive link to this phenological index (Figure 4.1.3, i.e.

Motacilla Flava, Emberisa Schoeniculus, Emberise Citrinella, Saxicola Rubetra, Vanellus Vanellus). These species breed over grasslands, pastures, moorlands, parks and gardens and are found in the Boreal and Nemoral regions, thus the species-indicator link is plausible. Species observed in the more Continental and Pannonic regions, where this index has rather low values (Figure 4.1.8) expressed a strong and significant negative link to this index (i.e. Athene noctua, Miliaria calandra, Carduelis carduelis, Streptopelia Turtur). The importance of this index lies most probably in the fact that the cyclic vegetation fraction restricted by the length of the season is one of the biggest constrain in the Northern European regions.

Table 4.1.3: Significant positive (+) and negative (-) relationships between species and phenological indices. Significance was assessed based on Generalised Additive Modell. The table shows the F-value and the significance of the relationships. (***: p < 0.001; **: p<0.01; *: p<0.5; /: not significant).

	fMINd	nTCF	TCF/TB	nSCF	SOS
AlaArv	32.2; ***	1.8; /	9.4; ***	5.1; **	19.4; ***
AthNoc	4.3; *	11.1; ***	8.1; ***	7.7; ***	4.4; *
CarCan	13.8; ***	9.7; ***	7.1; **	6.8; **	9.1; ***
CarCar	10.7; ***	13.5; ***	11.8; ***	13.6; ***	8.1; ***
ColPal	25.1; ***	1.1; /	7.5; **	4.3; *	14.9; ***
CorCor	22.8; ***	0.7; /	9.1; ***	6.8; **	12.7; ***
CorMon	22.1; ***	6.3; **	6.4; **	5.1; **	17.5; ***
CotCot	6.9; **	12.8; ***	11.9; ***	10.8; **	5.5; **
EmbCit	39.1; ***	0.9; /	12.1; ***	8.1; ***	18.3; ***
EmbSch	15.3; ***	1.4; /	14.2; ***	11.9; ***	10.2; ***
FalSub	28.4; ***	2.7; /	6.6; **	4.1; *	15.6; ***
FalTin	16.6; ***	1.1; /	6.3; **	4.1; *	10.3; ***
HirRus	22.5; ***	1.8; /	5.6; **	5.2; **	12.3; ***
LanCol	37.6; ***	5.3; **	7.2; **	6.9; **	14.8; ***
MilCal	2.6; *	9.6; ***	7.5; **	8.4; ***	4.1; *
MotFla	10.9; ***	3.6; *	13.3; ***	12.1; ***	7.7; ***
PasMon	22.9; ***	14.3; ***	12.6; ***	9.3; ***	12.4; ***
PicPic	26.1; ***	1.1; /	8.4; ***	5.4; **	14.7; ***
SaxRub	23.8; ***	2.6; /	12.9; ***	16.4; ***	12.7; ***
StrTur	10.5; ***	13.8; ***	10.6; ***	10.3; ***	7.9; ***
StuVul	30.4; ***	2.9; /	9.5; ***	3.2; *	18.9; ***
SylCom	31.1; ***	4.1; *	7.6; ***	4.4; *	19.9; ***
VanVan	29.2; ***	0.7; /	8.9; ***	8.8; ***	15.6; ***

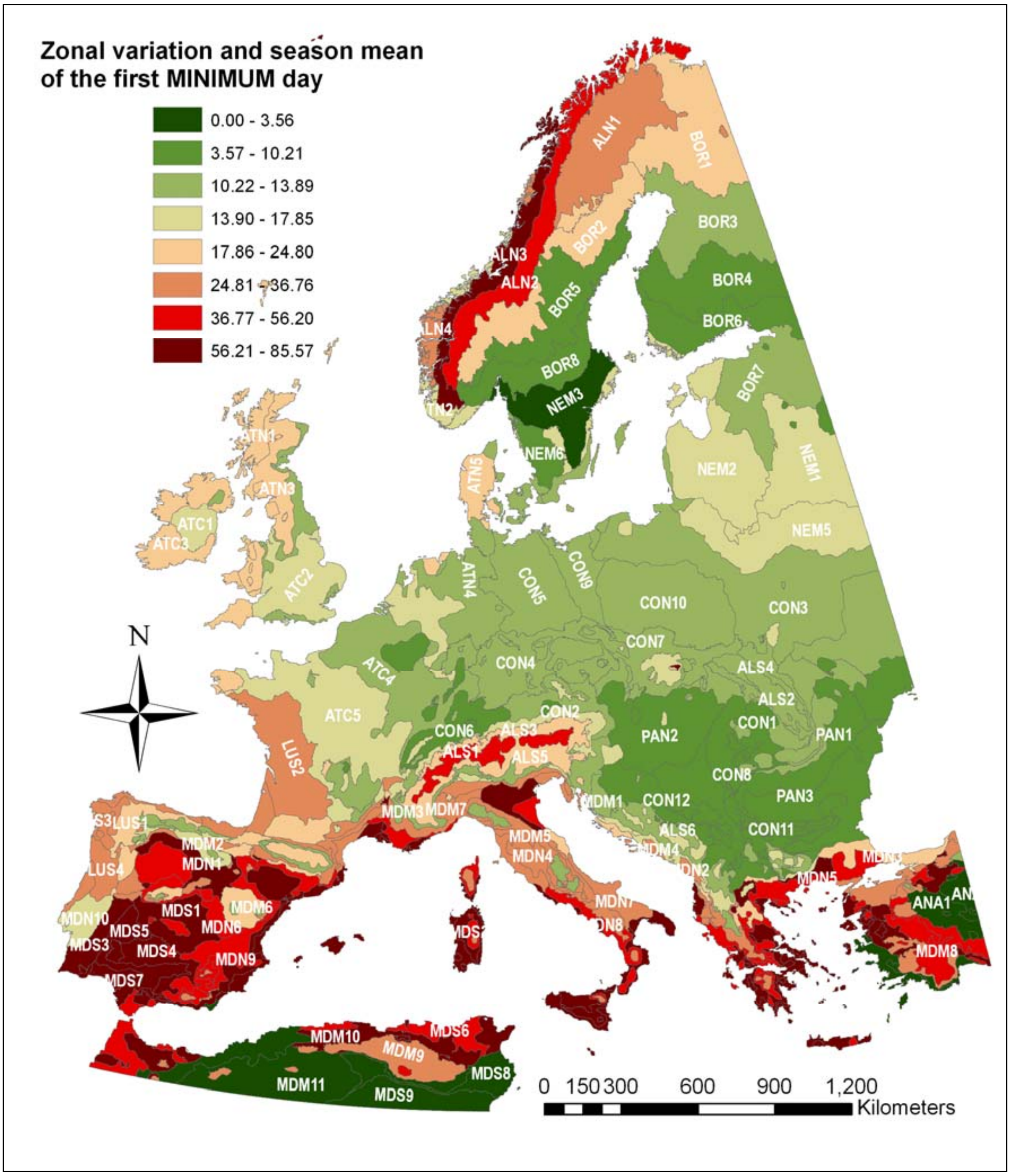


Figure 4.1.5: Zonal variation (within the Strata) and series mean of the first MINIMUM day.

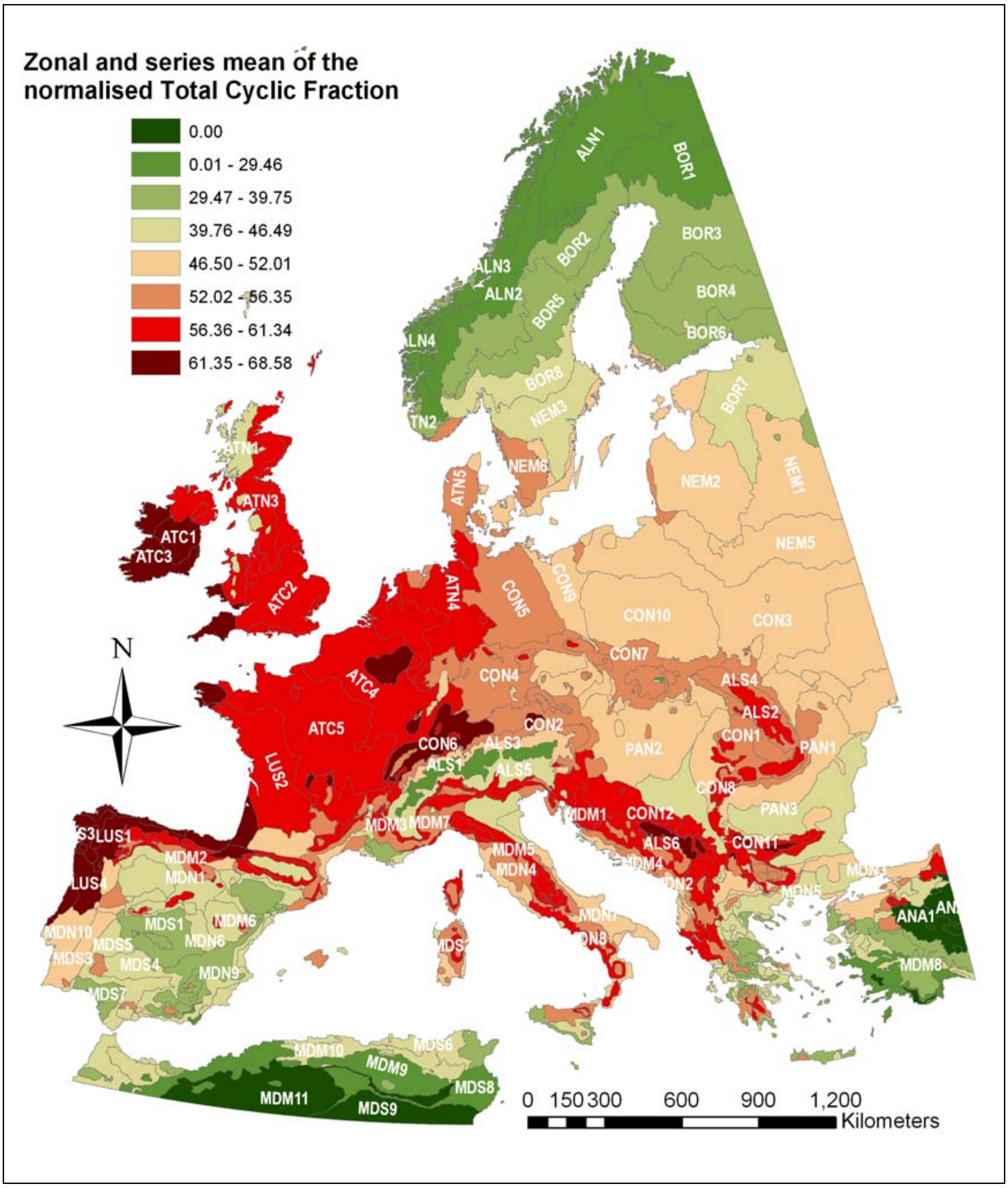


Figure 4.1.6: Zonal and series mean (within the Strata) of the normalized Total Cyclic Fraction.

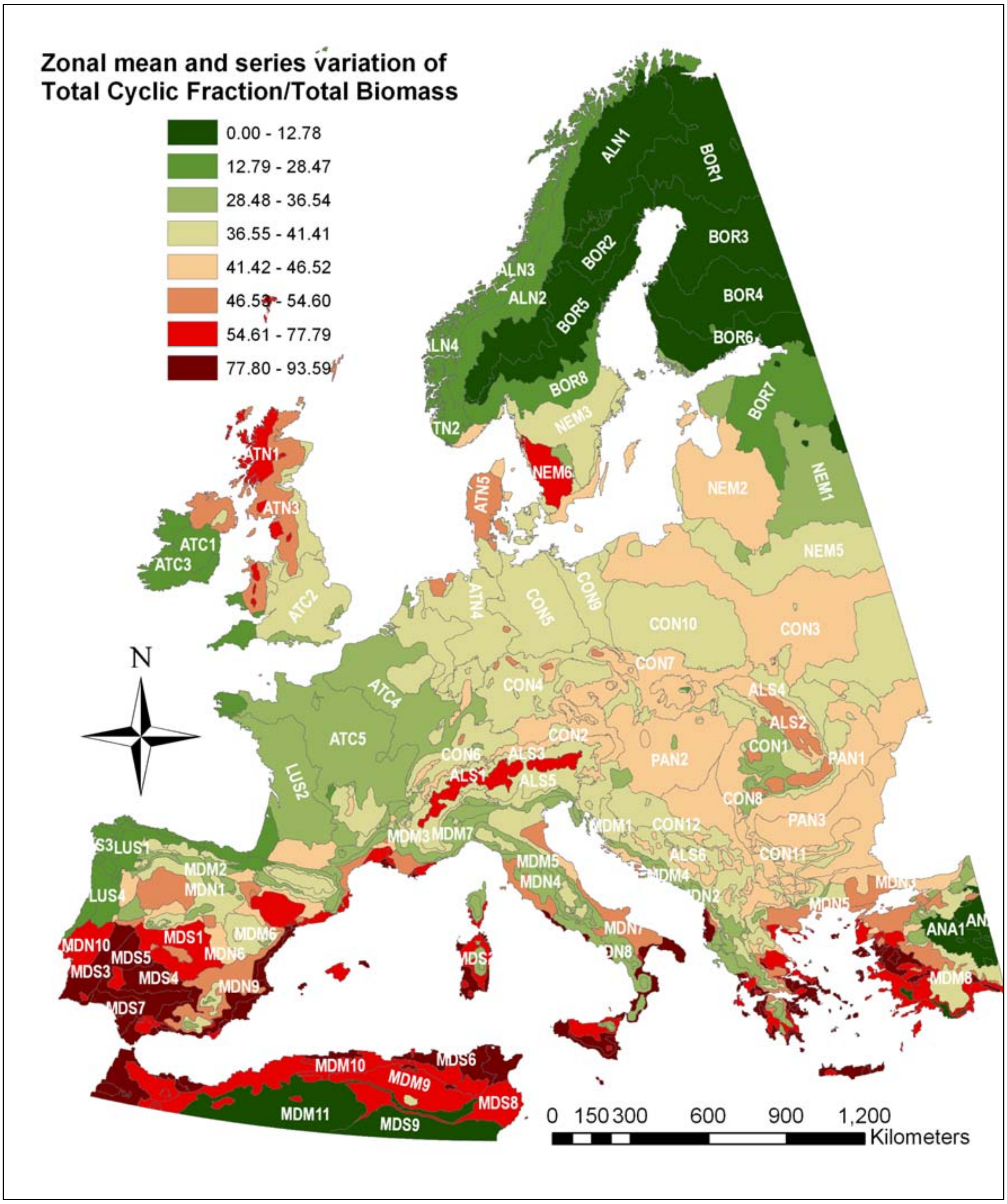


Figure 4.1.7: Zonal mean (within the Strata) and series variation of the portion of Total Cyclic Fraction from the Total Biomass.

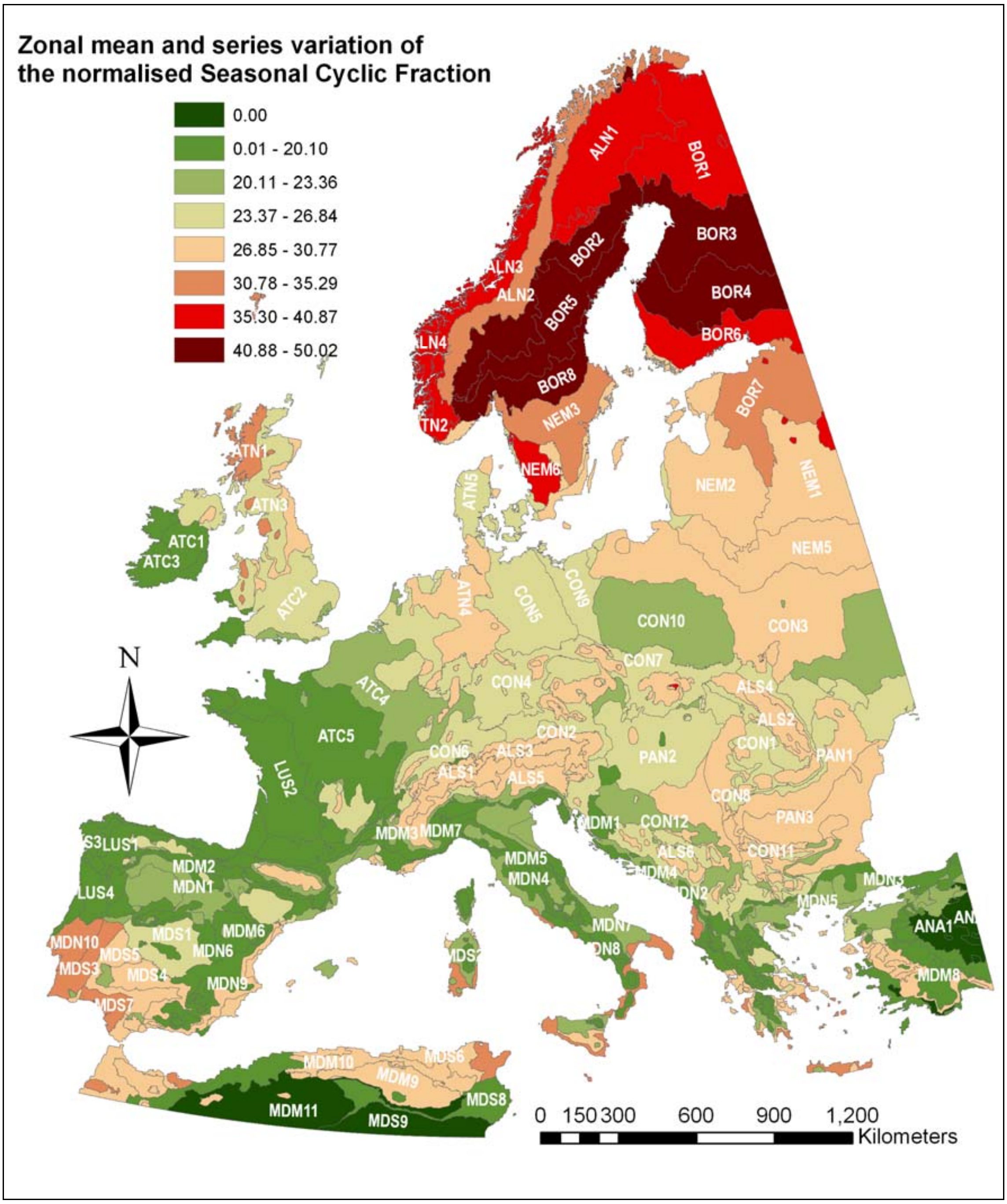


Figure 4.1.8: Zonal mean (within the Strata) and series variation of the normalised Seasonal Cyclic Fraction.

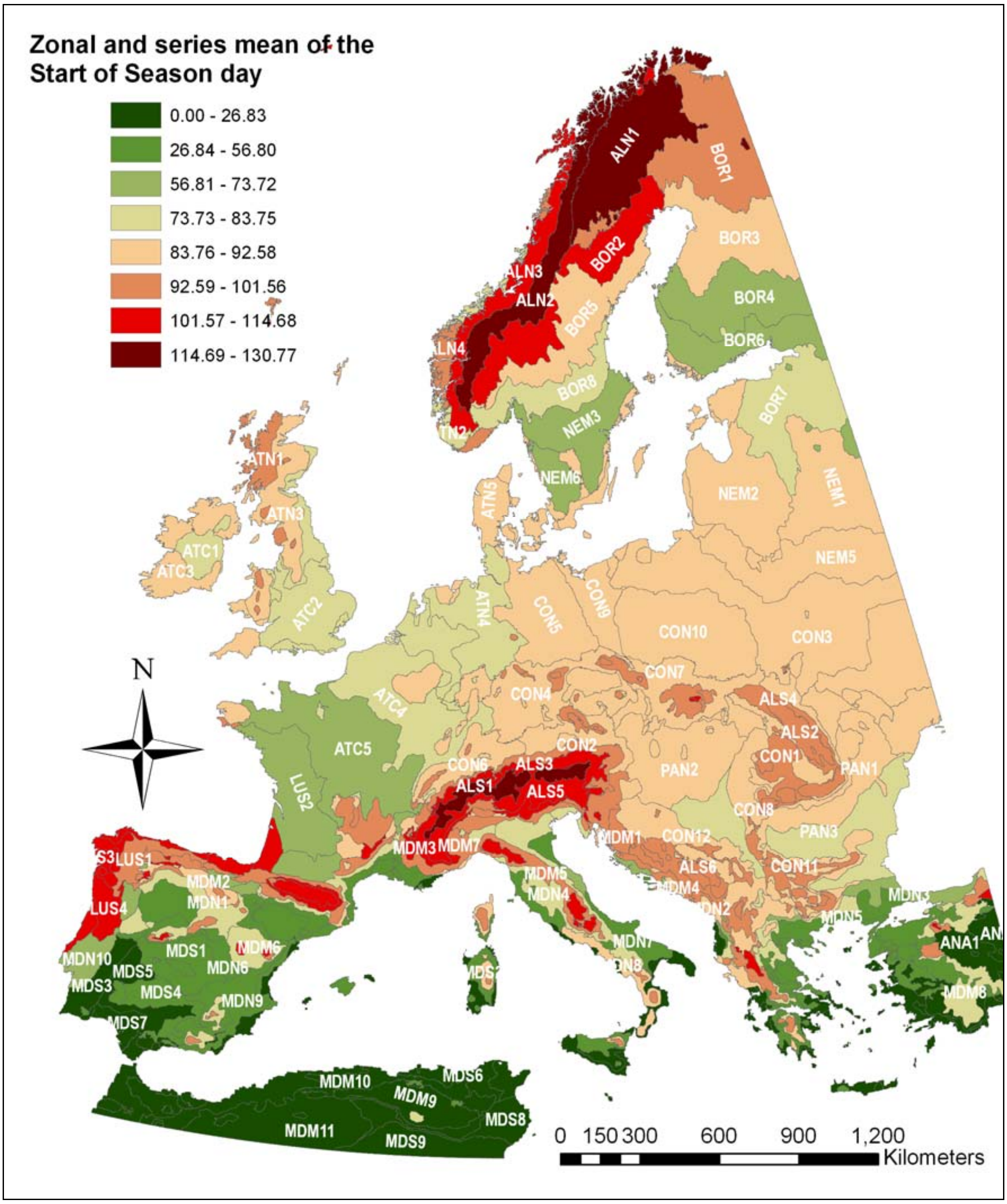


Figure 4.1.9: Zonal mean (within the Strata) and series mean of the Start of Season day.

4.2 RDA with climate variables as explanatories and the area of the Strata as covariables

Redundancy Analysis with climatic variables as explanatory and the area of the Strata as covariables.

Partial RDA was run with the farmland birds as response variables, the climate variables as explanatories, and the areas of the Strata as covariates. The model was requested to select the 20 best uncorrelated variables with high F-values by means of the Monte Carlo permutation tests. These 20 variables were further investigated in a hierarchical cluster analysis. The dendrogram together with the F-tests of the variables identified 5 independent indices. These variables entered a second partial Redundancy Analysis (RDA) with forward selection of the variables and with the log area of the Strata as covariables. The RDA with the Monte Carlo permutation test resulted in all the five environmental variables with a variance inflation factor below 20. The selected variables are presented in Table 4.2.1 together with the conditional effect, F value and significance of the variables. Most important biophysical variables were the Strata's mean July precipitation and minimum November temperature and the spatial variation of the January precipitation. Spatial variation of the June precipitation and the spatial mean of the September precipitation were other significant but rather week predictors. All the variables were very significant on the $p<0.001$ level.

Table 4.2.1: Environmental variables selected by the RDA of farmland birds with the area of the Strata as covariables.

Variable names and codes	Λ	F-ratio	P
Spatial mean of July precipitation (JulP)	0.21	25.6	0.001
Spatial mean of the minimum November temperature (NovminT)	0.12	20.1	0.001
Spatial variation of the January precipitation (JanP)	0.10	20.1	0.001
Spatial variation of the June precipitation (JunP)	0.03	6.0	0.001
Spatial mean of the September precipitation (SepP)	0.03	6.2	0.001
Explained variance; model significance; F-ratio		48.9; 0.001; 22.5	

Monte Carlo permutation test showed that both the first axis and the overall model were statistically very significant ($p < 0.001$, Table 4.2.2). The selected environmental variables explained 49% of variation in European farmland birds assemblages (sum of all canonical eigenvalues), comparable to the phenological indices. The variability explained by the area of the Environmental Strata was 21 % (Total variance – sum of all eigenvalues). The eigenvalues of the first four canonical axes were 0.296, 0.169, 0.016 and 0.006 respectively showing that the first two canonical axes captured the majority of the variation in the species-environment relationship. The first two canonical axes explained 93% variance in the fitted responses (cumulative percentage variance of species-environment relation), i.e. from all the variation climate can explain the first two axes accounted for the major part. This is another indication for the relative importance of the first two axes and the ignorable role of the remaining axes. Furthermore, respecting the variation in the species data the first two canonical axes accounted for 59%, which is again comparable to the phenological indices. The first two canonical axes had strong species-environment correlation indicating a strong relation between farmland bird species and the climatic variables.

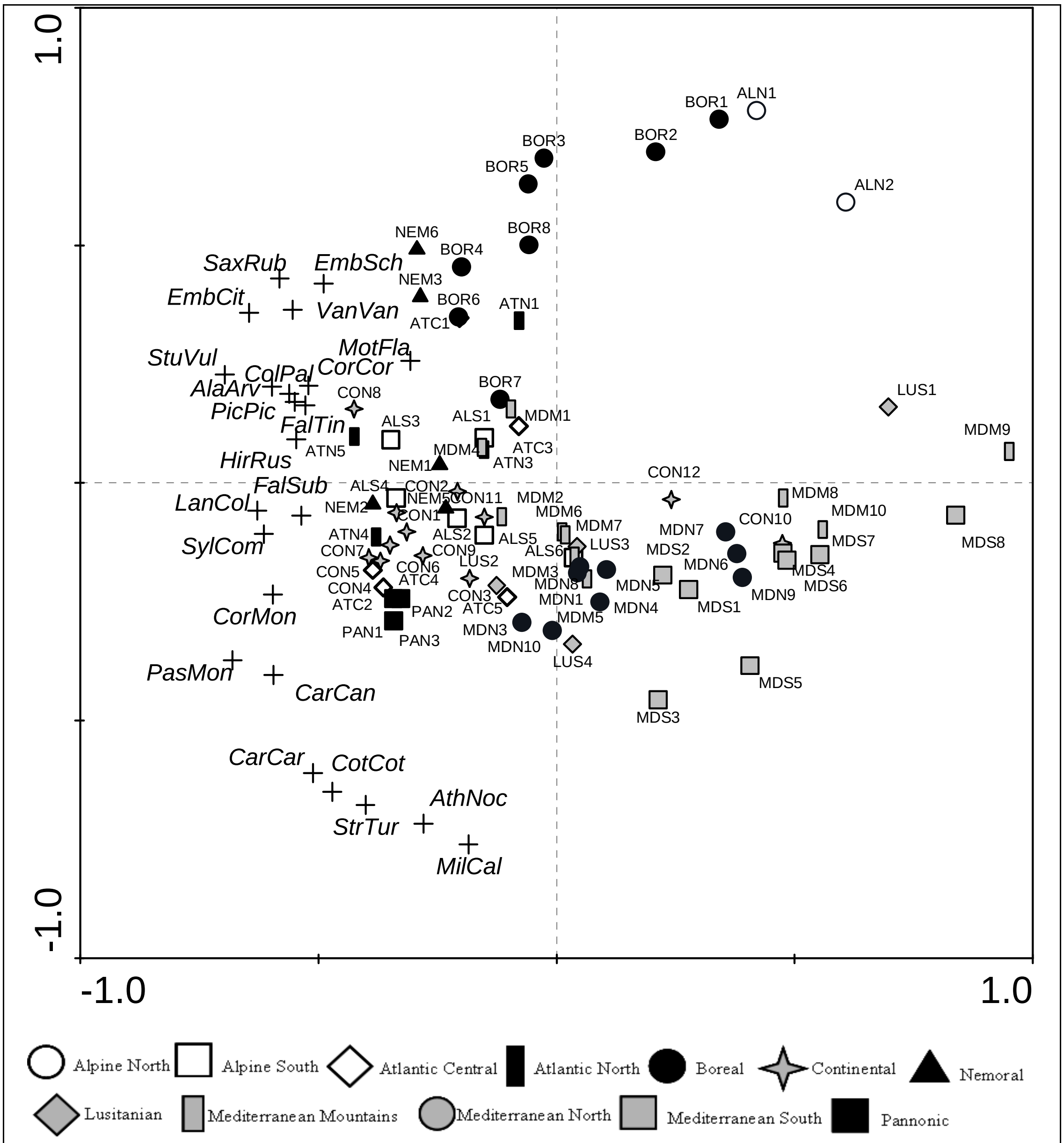
Table 4.2.2: Summary of the RDA of farmland birds with climatic variables as explanatory and area of the Strata as covariables.

```
              Tminnovm        precjans        precjuns        precjulm        precsepm

   N    name       (weighted) mean         stand. dev.  inflation factor

   1    SPEC AX1               0.0000          1.2482
   2    SPEC AX2               0.0000          1.0785
   3    SPEC AX3               0.0000          1.2116
   4    SPEC AX4               0.0000          1.7000
   5    ENVI AX1               0.0000          1.0000
   6    ENVI AX2               0.0000          1.0000
   7    ENVI AX3               0.0000          1.0000
   8    ENVI AX4               0.0000          1.0000
  29    Tminnovm               1.6151          4.7420          2.7399
  58    precjans              15.5322         10.5444          2.0651
  68    precjuns              11.6818          6.1077          1.7666
  69    precjulm              60.0039         33.7853          5.8426
  73    precsepm              66.5233         28.8196          5.1404

**** Summary ****

Axes                                  1       2       3       4  Total variance

Eigenvalues                     :     0.296   0.169   0.016   0.006         1.000
Species-environment correlations  :   0.801   0.927   0.825   0.588
Cumulative percentage variance
   of species data              :      37.5    58.9    60.9    61.7
   of species-environment relation:    60.5    95.0    98.3    99.6

Sum of all              eigenvalues                                           0.790
Sum of all canonical     eigenvalues                                           0.489

The sum of all eigenvalues is after fitting covariables
Percentages are taken with respect to residual variances
                i.e. variances after fitting covariables

*** MESSAGE ***
The fit for species is additional to the fit due to covariables.
With covariables, CANOCO cannot calculate residuals for samples.
1
*** Unrestricted permutation ***

Seeds:  22145  5505

**** Summary of Monte Carlo test ****

Test of significance of first canonical axis: eigenvalue =    0.296
                                              F-ratio    =   41.319
                                              P-value    =    0.0010

Test of significance of all canonical axes  : Trace      =    0.489
                                              F-ratio    =   22.461
                                              P-value    =    0.0010
```

The species-samples biplot of the RDA presents a very similar arrangement to the results obtained by the phenological indices. As in the previous analysis, the first RDA axis clearly structured the Environmental Zones of southern Europe (Figure 4.2.1). The axis positively correlated the southern, northern, and mountainous Mediterranean and the Lusitanian regions (the location of these strata is on the positive end of the axis) and negatively with the Continental, Alpine South, Atlantic Central and Pannonic regions (the strata are located on the negative portion of the axis). The second RDA axis revealed a Nothern-Southern gradient from the Alpine North, Boreal and Nemoral regions through the Continental areas to the Pannonic lower Danube Plains of the former Yugoslavia, Bulgaria and Romania.

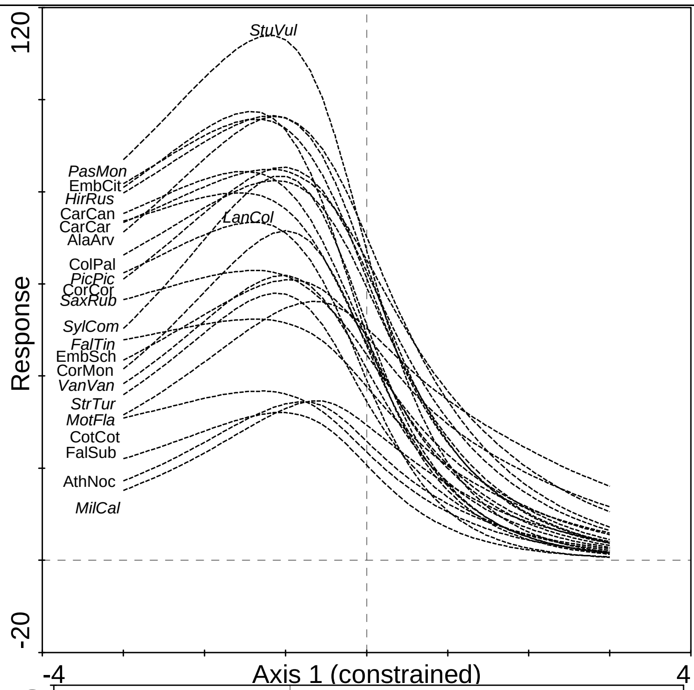
All the species exhibited a negative association to the first RDA axis (similarly to the PCA results) and were plotted on the left hand side of the biplot (Figures 4.2.1 and 4.2.2). The GAM indicated that most of these associations were significant on the $p<0.001$ level, only the associations to Coturnix coturnix and Miliaria calandra were lower (Table in Figure 4.2.2). The second RDA axis clearly separated farmland bird species expressing negative and positive association to the axis (Figures 4.2.1 and 4.2.2). Fourteen species showed significant association ($p < 0.05$) to the second constrained axis (Table in Figure 4.2.2).

Ordination results were similar to the PCA biplot and to the biplot of the RDA with phenological indices. Carduelis carduelis, Coturnix coturnix, Streptopelia turtur formed one group while Athene noctua and Miliaria calandra another one on the lower end of the RDA biplot (Figure 4.2.1). These species mostly breed in hedgerows, orchards and scrubs. Species in the former group migrate to Africa or to the Mediterranean while Athene noctua and Miliaria calandra are residents. All the five before mentioned species showed a negative association to the second RDA axis. Passer montanus, Carduelis cannabina and Corvus monedula formed another group of species of sedentary birds although some individuals of the latter migrate from more northerly breeding areas. These species expressed a significant negative assoxiation to the second RDA axis. Falco subbuteo, Sylvia communis, Lanius collurio and Corvus monedula are species nesting in trees, edges of woods or heathland and woodland margins and migrate to Africa in the winter. These species were plotted in the middle of the gradient formed by the second RDA axis. The latter two species showed a significant negative association to the second RDA axis. Finally, in the upper part of the RDA biplot species with grassland, pastures, moorlands, and parks and gardens as breeding habitats were plotted.

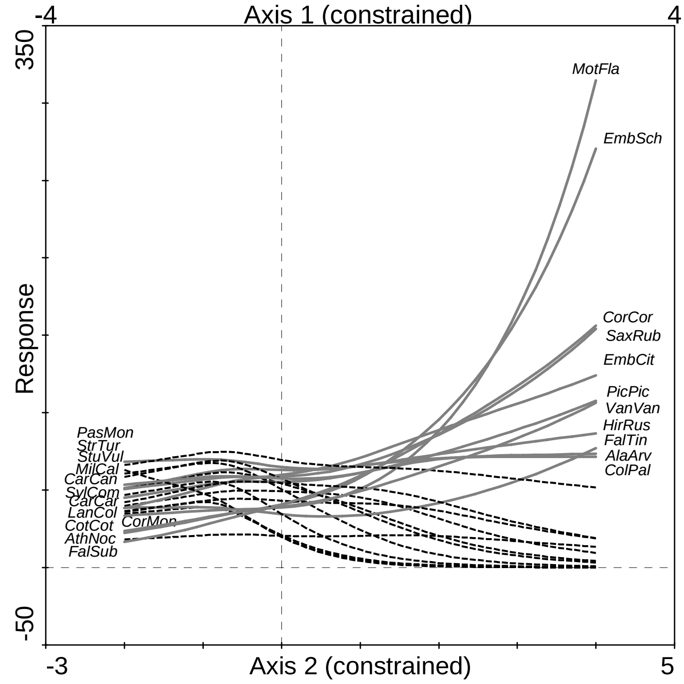


AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 4.2.1: RDA biplot of species and the Strata of the Environmental Zones. Species are plotted with symbols (cross) for easier interpretation of the diagram.



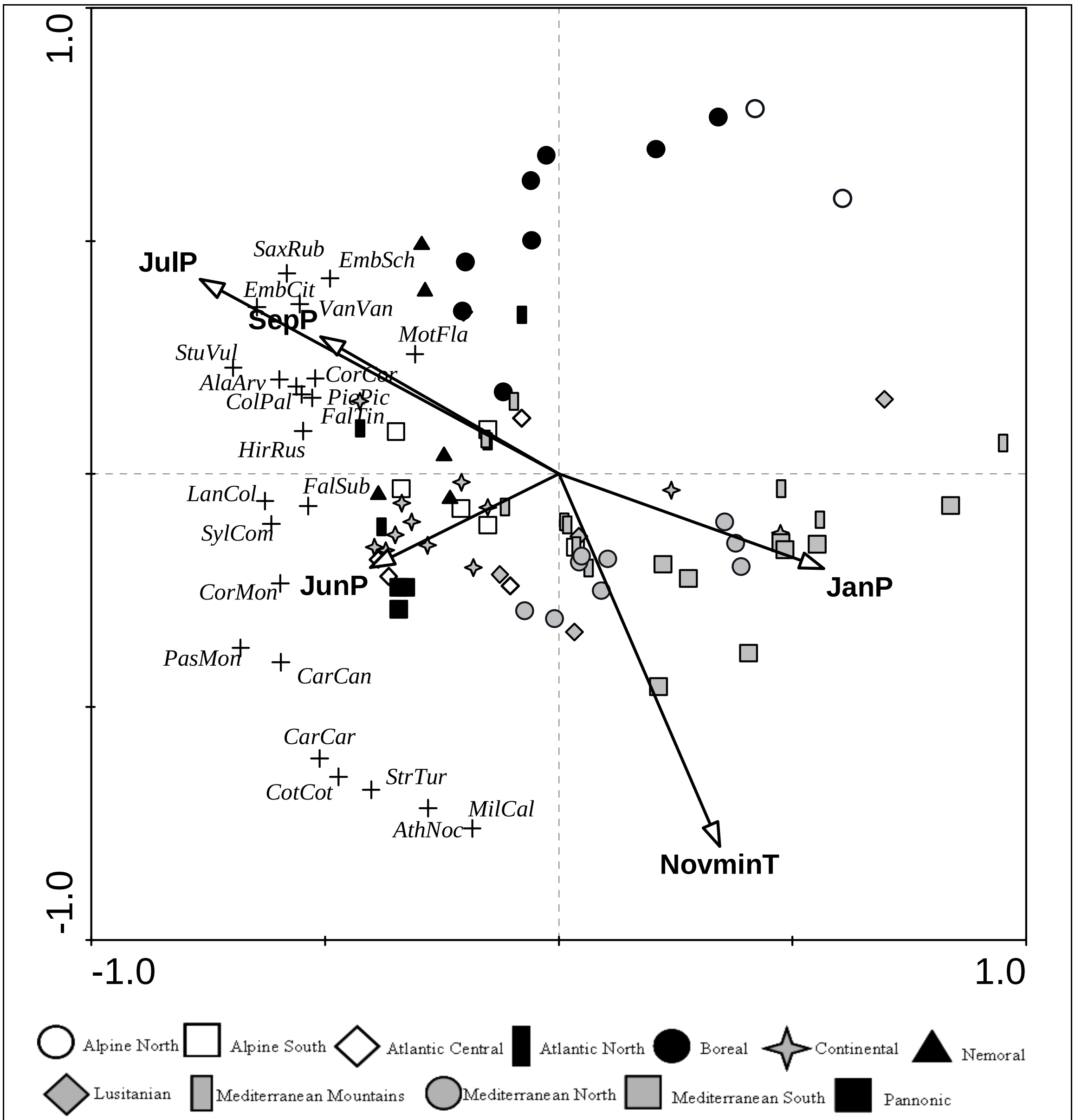
	AXIS1
AlaArv	20.5; ***
AthNoc	8.5; ***
CarCan	23.1; ***
CarCar	17.9; ***
ColPal	16.8; ***
CorCor	104.; ***
CorMon	26.9; ***
CotCot	11.3; ***
EmbCit	16.3; ***
EmbSch	3.7; *
FalSub	20.7; ***
FalTin	9.9; ***
HirRus	16.4; ***
LanCol	27.8; ***
MilCal	5.5; **
MotFla	2.5; /
PasMon	26.2; ***
PicPic	13.9; ***
SaxRub	7.0; **
StrTur	15.4; ***
StuVul	28.0; ***
SylCom	27.3; ***
VanVan	10.3; ***



	AXIS2
AlaArv	0.4; /
AthNoc	23.2; ***
CarCan	5.0; **
CarCar	12.2; ***
ColPal	0.8; /
CorCor	1.9; /
CorMon	1.7; /
CotCot	21.6; ***
EmbCit	1.7; /
EmbSch	6.8; **
FalSub	0.6; /
FalTin	1.5; /
HirRus	0.5; /
LanCol	0.7; /
MilCal	22.8; ***
MotFla	6.5; **
PasMon	5.1; **
PicPic	0.8; /
SaxRub	6.3; **
StrTur	13.2; ***
StuVul	0.6; /
SylCom	1.0; /
VanVan	1.0; /

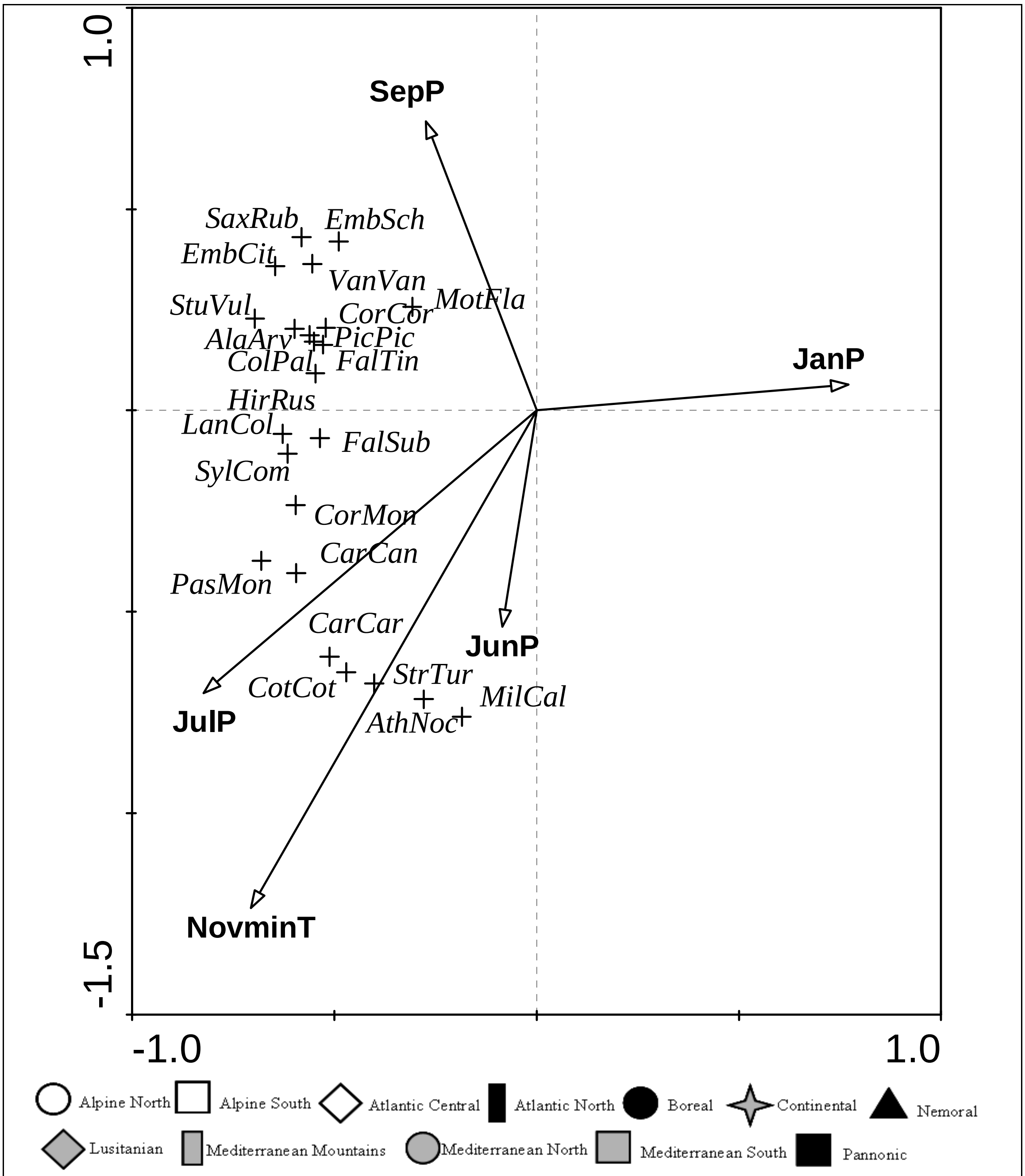
AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 4.2.2: Species response curves modeled by a GAM to the first and second RDA axes. The tables show the F-value and the significance of the relationships. (***: p < 0.001; **: p<0.01; *: p<0.5; /: not significant).



AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 4.2.3: RDA triplot of species and climatic variables. Species are plotted with symbols (cross) for easier interpretation of the diagram, climatic variables are plotted with arrows.



AlaArv: Alauda arvensis (Skylark); **AthNoc:** Athene noctua (Little Owl), **CarCan:** Carduelis cannabina (Linnet), **CarCar:** Carduelis carduelis (Goldfinch), **ColPal:** Columba palumbus (Woodpigeon), CorCor: Corvus corone spp (Carrion Crow); **CorMon:** Corvus monedula (Jackdaw), **CotCot:** Coturnix coturnix (Quail); **EmbCit:** Emberiza citronella (Yellow Hammer), **EmbSch:** Emberiza schoeniclus (Reed Bunting), **FalSub:** Falco subbuteo (Hobbz), **FalTin:** Falco tinnunculus (Common Kestrel); **HirRus:** Hirundo rustica (Swallow); **LanCol:** Lanius collurio (Red-backed Shrike); **MilCal:** Miliaria calandra (Corn Bunting); **MotFla:** Motacilla flava (Yellow Wagtail); **PasMon:** Passer montanus (Tree Sparrow); **PicPic:** Pica pica (Magpie); **SaxRub:** Saxicola rubetra (Stonechat); **StrTur:** Streptopelia turtur (Turtle Dove); **StuVul:** Sturnus vulgaris (Starling); **SylCom:** Sylvia communis (Whitethroat); **VanVan:** Vanellus vanellus (Lapwing).

Figure 4.2.4: RDA regression biplot of species and climatic variables. Species are plotted with symbols (cross) for easier interpretation of the diagram, climatic variables are plotted with arrows.

The spatial mean of the July precipitation (JulP) was the strongest climatic predictor selected by the RDA model (F=25.6, p<0.001, Table 4.2.1 and Figure

4.2.3) with a positive and significant (p<0.05) link to all of the species (Table 4.2.4). This positive link manifests the obvious positive relationship with the increasing amount of precipitation in the peak of the vegetation growing period and the resulting higher biomass. This positive link is well represented when comparing the aggregated distribution of farmland birds breeding pairs (Figure 2.2.3.) and the index aggregated in the Environmental Strata shown in Figure 4.2.5. Most farmland bird species were observed in the Continental, Pannonic and Atlantic, Nemoral and some Boreal regions where the mean July precipitation reaches its highest value.

The minimum November temperature (NovminT) was the second strongest climatic predictor (F=20.1, p<0.001, Table 4.2.1 and Figure 4.2.3) that expressed strong and significant link to all the species This index takes highest values in the southern regions like the Mediterranean and the Lusitanian zones, although some Atlantic Central regions also experience relatively high minimum temperatures in November (Figure 4.2.6). Species plotted on the same half of the biplot correlate positively while those on the opposite half express negative correlation to this index. Accordingly, mostly species distributed in the Pannonic and Continental regions react positively to the increase in the minimum November temperatures. The mean November termperature is much lower over the Boreal, Nemoral and Atlantic North regions, which cerates unfavorable conditions to most of the species. This is well reflected in the biplot where species are plotted along the areas with higher minimum November temperatures.

The zonal variation of the January precipitation (JanP) was a comparable predictor to the minimum November temperature in terms of the F-value and significance. It expressed a negative correlation to all the farmland species (Figure 4.2.3). High precipitation in January is expected in the Alpine North regions of Norway, in the Atlantic North regions of Scotland and Ireland and in the Lusitanian regions of Portugal (Figure 4.2.7). The reason for the negative correlation of the higher January precipitation to the farmland birds species is twofold: in the Northern areas precipitation in January mostly indicate strong snowfall that remains on the surface for a long time. This strong snow cover reduces the region's capacity to supply with food and breeding areas - in fact as shown in Figures 3.2 and 3.3, these regions host the least bird species. In the Lusitanian regions small number of farmland birds were observed and at the same time over these areas high January precipitation can be expected. However, in the southern Lusitanian areas this negative relationship is rather per chance then causative, the observed low number of breeding birds is independent of the amount of precipitation in January.

The zonal variation of the June precipitation (JunP) was a weaker but significant climatic predictor (F=6.0 and P<0.001). Highest precipitation in June is observed in the Mediterranean mountain regions of Spain and Italy and in the Alpine south regions of France, Switzerland and Germany (Figure 4.2.8). The Atlantic central and Lusitanian regions of France and the Continental regions of South Eastern Europe (Croatia, Hungary, Yugoslavia and Bulgaria) also experience higher spatially varying precipitation values in June. Accordingly, mostly those species expressed positive correlation to this index which breed in these regions and were plotted in the same part of the diagram. Species in the northern Boreal, Atlantic and Nemoral parts of Europe expressed a negative correlation to this index. The mean September precipitation were plotted orthogonally to the June precipitation indicating that these two climatic index do not correlate in terms of ordering farmland birds species within the Environmental Zones. The Atlantic Central and North regions of Ireland and Scottland, the Atlantic North regions of Norway and Denmark and the Boreal and Nemoral regions of Sweden and Finland experience high September precipitation values (Figure 4.2.9). As shown in the biplot of Figure 4.2.3, the September precipitation mostly correlates to species breeding in these areas.

Table 4.2.4: Significant positive (+) and negative (-) relationships between species and environmental variables. Significance was assessed based on a Generalised Additive Modell. The table shows the F-value and the significance of the relationships. (***: p < 0.001; **: p<0.01; *: p<0.5; /: not significant).

	JulP	**NovminT**	**JanP**	**JunP**	**SepP**
AlaArv	25.14; ***	11.6; ***	18.7; ***	5.0; **	5.7; **
AthNoc	5.2; **	9.9; ***	2.9; /	11.3; ***	2.9; /
CarCan	9.5; ***	9.9; ***	7.0; **	6.0; **	4.2; *
CarCar	5.8; **	11.6; ***	5.8; **	9.1; ***	2.8; /
ColPal	22.3; ***	8.7; ***	13.9; ***	4.5; *	6.4; **
CorCor	24.5; ***	12.1; ***	17.6; ***	4.0; *	6.0; **
CorMon	15.0; ***	11.9; ***	12.5; ***	6.3; **	4.4; *
CotCot	3.6; *	9.2; ***	5.7; **	11.1; ***	3.5; *
EmbCit	37.5; ***	19.1; ***	22.5; ***	3.7; *	7.7; ***
EmbSch	37.7; ***	18.4; ***	18.5; ***	6.4; **	5.7; **
FalSub	15.5; ***	10.2; ***	25.3; ***	4.1; *	11.8; ***
FalTin	17.0; ***	7.0; **	10.2; ***	5.8; **	4.1; *
HirRus	17.6; ***	7.7; ***	17.2; ***	5.7; **	5.7; **
LanCol	16.9; ***	19.9; ***	32.9; ***	3.3; *	6.7; **
MilCal	4.0; *	10.2; ***	2.8; /	8.7; ***	3.9; *
MotFla	21.6; ***	15.9; ***	30.9; ***	6.3; **	13.8; ***
PasMon	10.9; ***	15.0; ***	13.8; ***	7.0; **	5.0; **
PicPic	23.0; ***	10.3; ***	24.7; ***	6.6; **	9.5; ***
SaxRub	39.2; ***	34.3; ***	32.9; ***	2.1; /	5.4; **
StrTur	3.6; **	9.3; ***	8.2; ***	9.0; ***	6.3; **
StuVul	22.8; ***	11.5; ***	13.5; ***	6.2; **	5.7; **
SylCom	19.3; ***	12.9; ***	19.0; ***	5.2; **	6.6; **
VanVan	31.6; ***	13.2; ***	19.7; ***	6.2; **	5.8; **

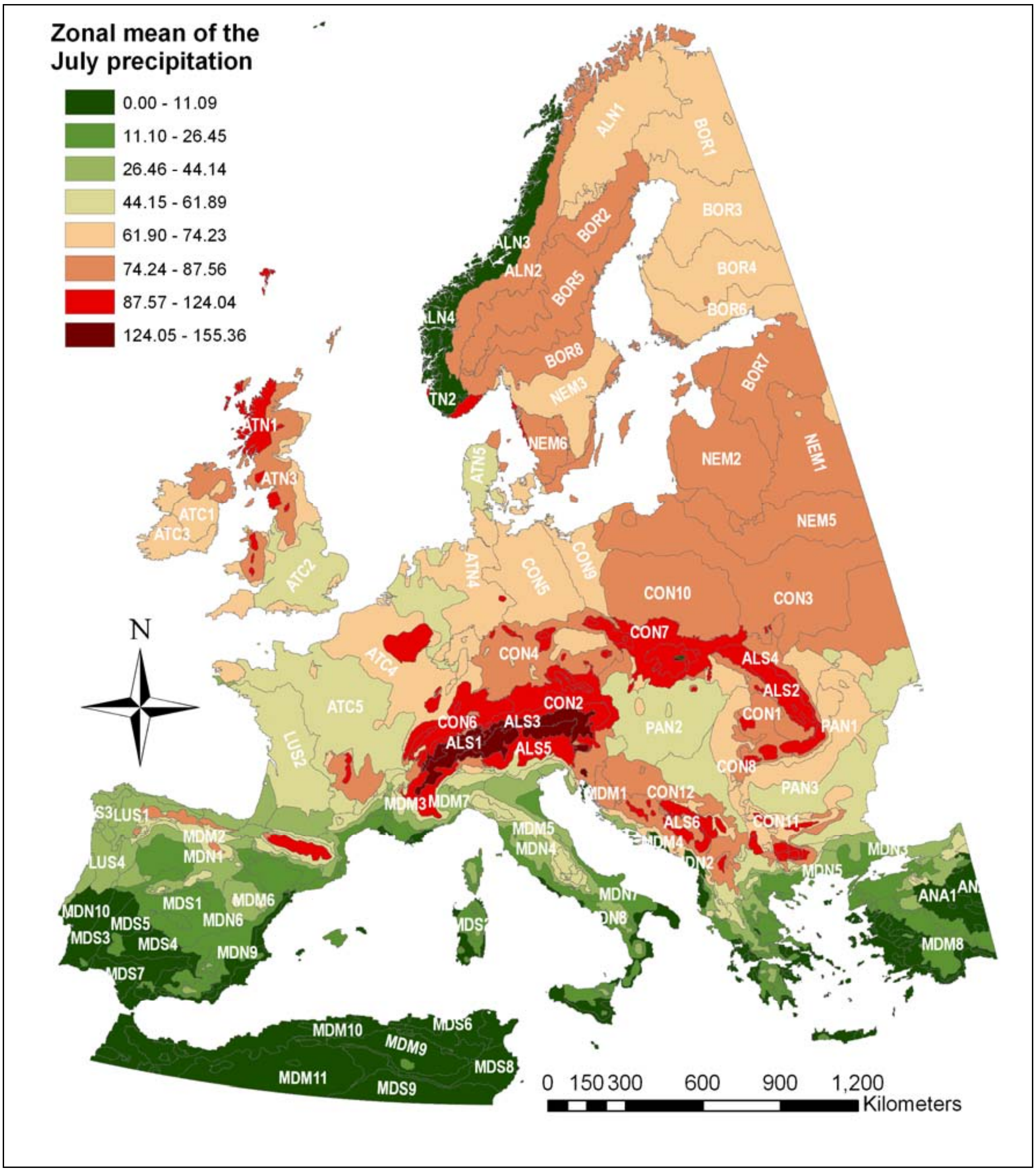


Figure 4.2.5: Zonal mean of mean July precipitation.

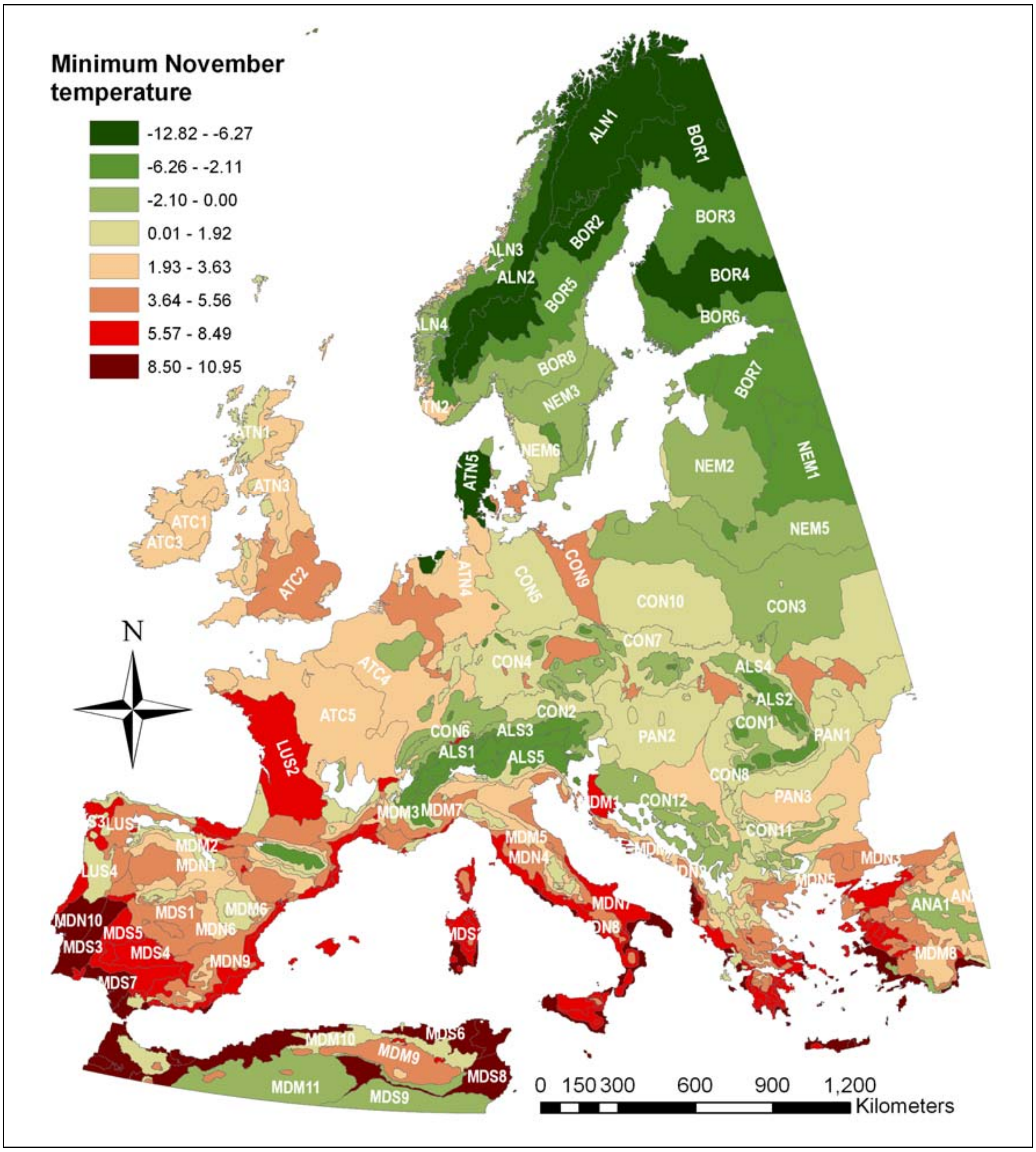


Figure 4.2.6: Zonal mean of the minimum November temperature.

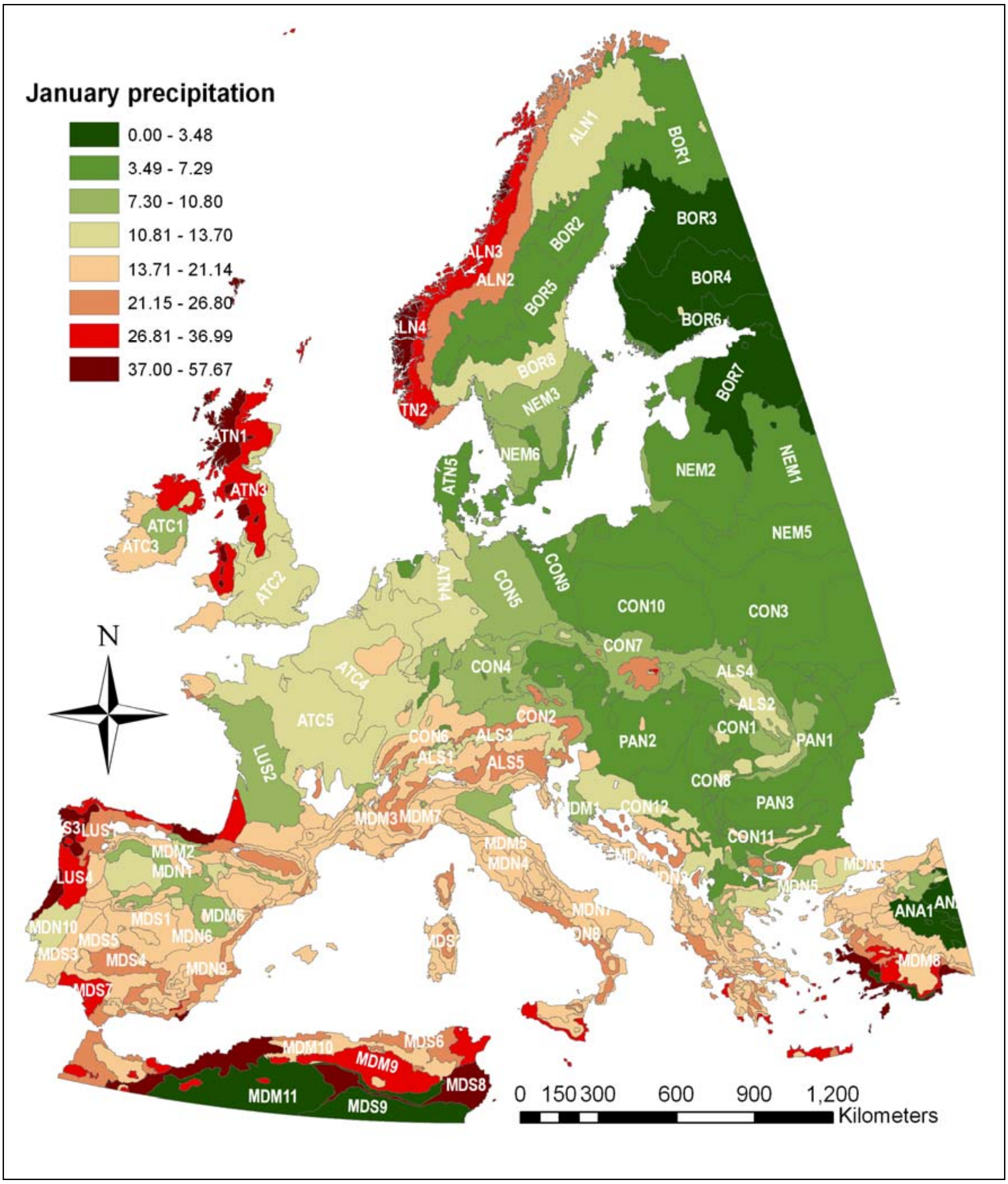


Figure 4.2.7: Zonal variation of the January precipitation.

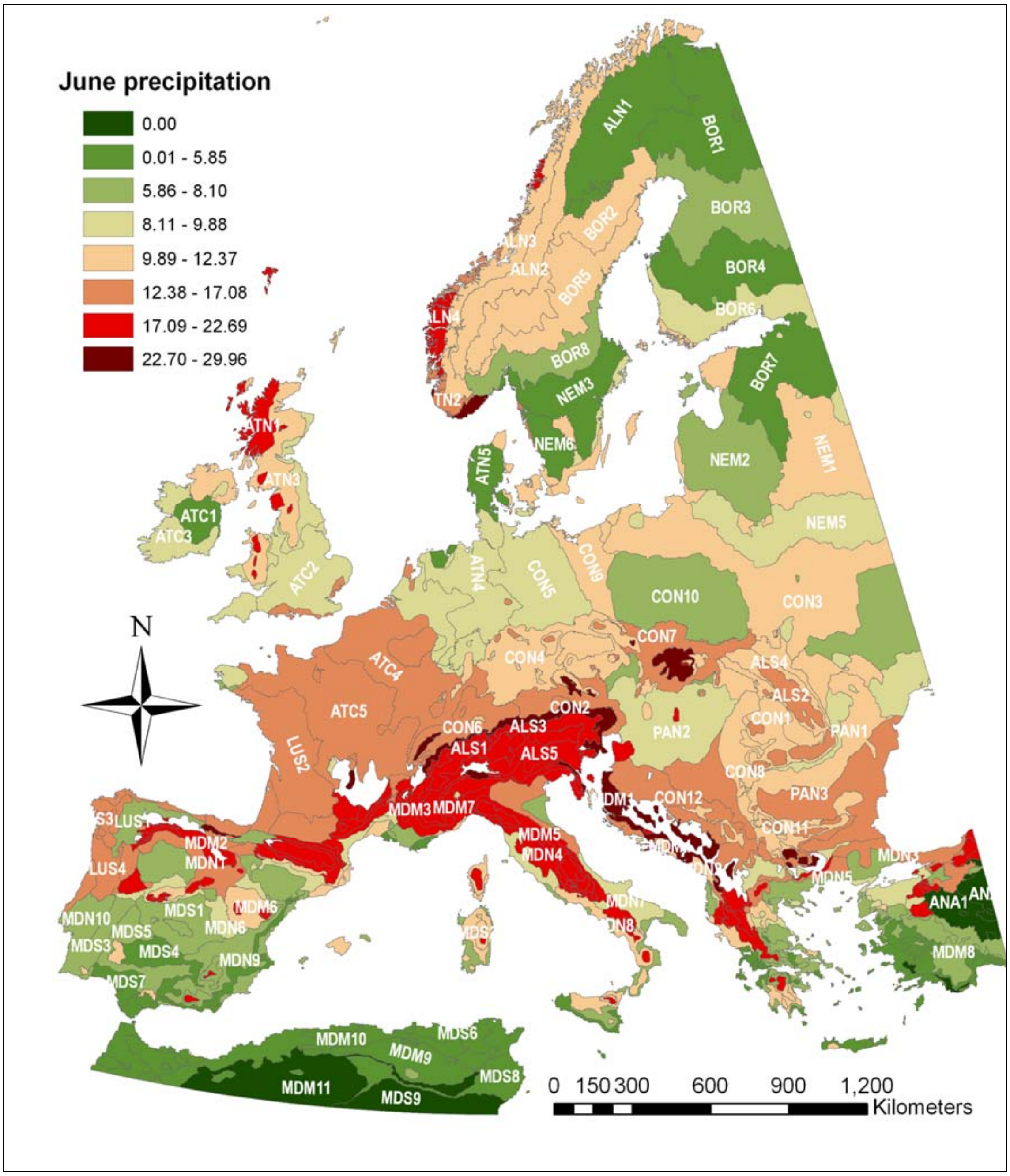


Figure 4.2.8: Zonal variation of the June precipitation.

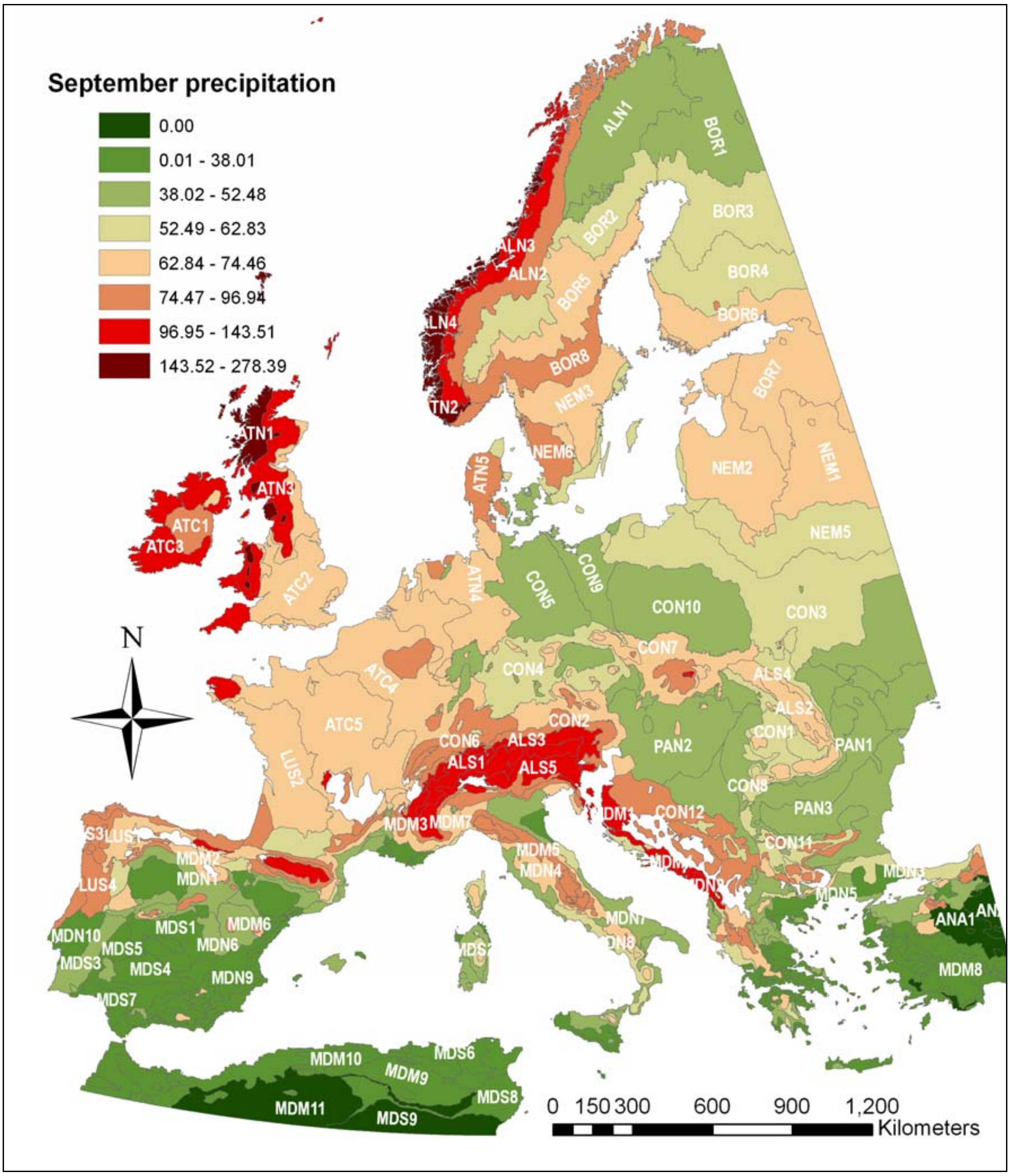


Figure 4.2.9: Zonal mean of the September precipitation.

5. Discussion and Conclusions

Detrended Correspondence Analyses revealed a linear response of the farmland bird species to the underlying environmental gradient. Principal Component Analysis (PCA) showed that the Environmental Classification of Europe supplied a good representation of the environmental gradient structuring the bird community. There were two strong gradients that explained the distribution of the avian community and that these two gradients explained 87% of the variation in the species data. The first Principal Component was a gradient from the Continental regions through the Pannonic and Atlantic areas to the Mediterranean while on the second axis the Boreal, Nemoral, and Alpine regions followed a South-North gradient.

The biplot of the species and the Environmental Strata gave insight into the spatial distribution of the species. All the farmland birds expressed a high negative score on the first axis and mostly corresponded to the Continental regions of the Check republic and Poland, the middle and lower Danube plains of Hungary, Slovakia, Austria, Serbia, Romania and Bulgaria. High number of breeding pairs occurred also in the Continental regions of Germany (Brandenburg, Sachsen, Pfalz), of the Romanian Moldova, in South Eastern England, in the Benelux states, in Northland Westfalend in Germany, in the North-Eastern part of France and the Nemoral regions of Latvia and Lithuania. These findings well correspond to the map in Figure 2.2.3 representing the observed sum of the estimated breeding pairs in the regions of the Environmental Strata. On top of it, Principal Component Analysis describes the spatial distribution of each single species according to the Environmental Strata thus is a very useful method to gain insight to the total picture.

Partial Redundancy Analysis of birds on the phenological indices, with the area of the Environmental Strata as covariate, revealed that phenology can well explain the observed environmental gradient and can explain 47% variation in the species distribution pattern. From all the variation phenology did explained, the first two RDA axes accounted for 95% and these axes had the highest eigenvalues indicating the two strong environmental gradients. The RDA biplot with the farmland species and the Environmental Strata strongly resembled the PCA biplot, with the species ordered along the same Strata and on the same side of the diagram. Climatic variables performed similarly to phenology as regards to explaining the variance in the farmland bird community and explaining the spatial distribution of the species. However, it is very important to note two facts. One main input for the delineation of the Environmental Strata was climate thus the good performance of these indices explaining the distribution of the species within the Strata is evident. It is very important to note that phenological variables performed comparably well on this spatial scale although no phenological information was used for the definition of the Strata. Moreover, phenological indices deliver information on a much higher spatial resolution and on a continuous spatial scale, which is not the case for the climate data. Last but not least, next to the here presented direct link of phenology to farmland birds, these indices can deliver information on the habitats itself that climatic data cannot offer.

The spatial heterogeneity of the average first minimum day was the strongest phenological predictor, which indicates the first time when surface vegetation enters the greening phase. This index does not necessarily indicate the start of the growing season but rather the first appearance of green vegetation, and as such is rather an indicator of agricultural areas with strategic management actions as an indicator of natural areas. The strong negative link to all the species indicates that species tend to concentrate in regions where the vegetation greens up earlier and where the greening up date is stable through time. This index has a strong ecological interpretation and its relation to the spatial distribution of the farmland birds community is evident. The Start of Season day, which was calculated by moving averages and denotes significantly increasing vegetation index values, is rather an indication of the start of the growing season including the natural vegetation. This index correlated positively to all the species, but the association was strongest to Motacilla Flava, Emberisa Schoeniculus, Emberise Citrinella, Saxicola Rubetra, Vanellus Vanellus. These species are mostly observed over the Boreal regions of Finland, Russia, Eastern Latvia and Estonia, in the Atlantic North regions of Ireland, South East Scotland, Wales Denmark and Netherlands and in the Northern periphery of the Alps (France, Switzerland, Germany, Austria and Slovenia). In these regions the growing season starts later then over more temperate or over the Mediterranean areas and this is the reason for the positive relation to the Start of Season day index. The positive link to the species presented in the biplot is rather the result of the fact that the index is higher over those areas where most species were found rather then showing a direct causative link between the index and farmland bird species.

Next to the greening up dates three productivity measures were important predictors of farmland birds, which although calculated similarly indicated different regions of Europe and thus the spatial distribution of birds. The portion of Total Cyclic Fraction from the Total Biomass expressed a significant and strong negative correlation to all the species, much like the first minimum day. The RDA biplot however revealed that the Total Cyclic Fraction mostly indicates Southern Mediterranean regions of the Albanian and Italian costs, the Western Algarve and Eastern Portugal, northern Mediterranean regions. Furthermore, the northern Mediterranean regions of Italy (Padua, Apennines, Po valley), of Spain (Cantabria, Beira Baixa, Castilla Leon), Greece (Paikon, Rodopi, Egean and Ionian costs), Turkey and France (Massif Central and Corsica) were indicated by this measure. Rather then a causative relation this indicator reveals that few species were observed in these Mediterranean regions whereas the amount of cyclic vegetation fraction is an important measure here.

The normalized Total and normalized Seasonal Cyclic Fractions describe season length dependent productivity measures. The two indices were plotted in a perpendicular angel in the RDA triplot indicating no or very weak correlation between these variables. Indeed, the two index correlated to very different Environmental Strata and were therefore important to different species. The season length dependent Total Cyclic Fraction had its highest values in the

Lusitanian regions of Northern Portugal and South West France, in the Atlantic Central regions of the UK and in the Continental regions of the Black Forest (Germany). The index best indicated species that were abundant in the Pannonic regions of the Balkans, of the Carpathians and in the Middle and lower Danube Plains of Hungary, Slovakia, Austria, ex-Yugoslavia, Romania and Bulgaria. The season length dependent Seasonal Cyclic Fraction on the other hand strongly related to the Boreal regions of Central Finland, Sweden, Norway and Russia. The former index is defined by the first and last Minimum points and thus indicates all the vegetation with a fluctuating pattern that is on the surface from the very first greening up. The seasonal cyclic fraction on the other hand is defined by the Start of Season point denoting significantly increasing vegetation values, thus indicates the cyclical fraction of the growing season biomass. In the northern regions the shorter growing season and the biomass availability is a limiting factor and thus this measure is a better indicator of these regions.

Spatial mean of the July precipitation was the strongest climatic predictor with a significant and positive link to all the species. This positive association is a result of the obvious link of the increasing amount of precipitation and the resulting higher biomass. This index, together with the mean September precipitation, reached highest values over the Atlantic Central and North regions of Ireland and Scotland, the Atlantic North regions of Norway and Denmark and the Boreal and over the Nemoral regions of Sweden and Finland. Accordingly, only species breeding over these areas had a strong significant link to these indices while the association of the other species was weaker. The first Minimum day, the strongest phenological predictor, on the other hand is an indicator that expressed strong and significant link to all the species and all the Environmental Zones therefore it seems to be a better indicator of the farmland birds community distribution.

The January precipitation and the minimum November temperature were comparable predictors of the avian community in terms of F-value and significance. January precipitation mostly indicated the Southern, Northern and Mountainous Mediterranean areas where the least amount of farmland birds were sampled and accordingly the index correlated negatively to all the species. The minimum November temperature indicated an obvious southern-northern temperature gradient. Species that breed over southern regions, i.e. where the minimum November temperature is high, correlated positively to this index. The Boreal, Nemoral and Atlantic species with low November temperatures expressed a negative relationship, indicating that with decreasing temperatures in November less species will be observed.

As a summary, this study showed that the Environmental Stratification of Europe is very appropriate to describe the spatial distribution of farmland birds. The Stratification supplies two strong environmental gradients that describes the distribution of the avian community. Furthermore, we showed that phenological indicators, especially the start of the growing season, the first greening up measures and productivity measures are good indicators of the distribution of the European farmland birds and that they are comparable to climatic measures. This is even more important when considering that the Environmental Stratification includes the climate variables whereas phenological information was not included to delineate the Strata. The inclusion of start of season and productivity measures would most probably result in Environmental Strata that are better adjusted to phenological variations and therefore even better explanatory values could be expected there. Furthermore, satellite derived phenology delivers information on a continuous scale and on a much higher spatial resolution then climate data and can supply information on the habitats that precipitation or temperature cannot.

Seeing the comparable performance of phenology to climatic indicators it is strongly recommended to follow up this study on higher spatial scales. This is even more important when considering the valuable information phenology can deliver on the habitats itself that climatic data cannot offer. The study explored Redundancy Analysis and showed that this method is a proper tool because next to the species-indicator associations the spatial distribution of species, samples and the environmental predictors can be simultaneously assessed. Trends data on farmland birds is not accessible over the sampling plots at the moment, however general Europe wide trends of the species are made public. Based on the investigated spatial distribution the trends of phenology and climate variables can be related to the species birds distribution as well, which will supply indispensible information on environmental change that has led to the reported dramatic decrease of the species.

6. Appendices

Appendix 1: Strata of the Environmental Classification

ALN1 Alpine North Swedish-Finnish Lappland
ALN2 Alpine North Norwegian coast north of Lofoten, Swedish-Norwegian High Mountains (Jottunheimen)
ALN3 Alpine North Lofoten-Nordland Naerdale, Romsdal, Sogneflford Telemark (Norway)
ALN4 Alpine North Norwegian fjords Alesund-Stavanger (Norway)
ALS1 Alpine South High Alps (France, Switzerland, Austria)
ALS2 Alpine South Southern and Eastern Carpathians (Czech Republic, Poland, Slovakia, Romania, Ukraine)
ALS3 Alpine South Northen periphary of Alps (France, Switzerland, Germany, Austraia, Slovenia.
ALS4 Alpine South Lower parts of Western and Eastern Carpatians (Germany, Czech Republic, Poland, Slvakia, Romania, Ukraine)
ALS5 Alpine South Pyrenees (Spain, France), and South-Western Alps (France, Italy, Switzerland, Austria, Slovenia, Croatia)
ALS6 Alpine South Picos de Europa, Sierra de la Demanda (Spain), Massif Central (France), outer ranges of western Alps (Switzerland), Outer ranges of Eastern Alps (Austria, Slovenia, Croatia), Dinaric Alps (Croatia, Bosnia, Albania, Macedonia, Greece)
ANA1 Anatolian West Anatolia (Turkey)
ANA2 Anatolian Central Anatolia (Turkey)
ATC1 Atlantic Central Central Ireland
ATC2 Atlantic Central Sout Eastern England (UK), South-Western Dutch lowlands (Netherlands), Northrhine-Westphalia (Germany)
ATC3 Atlantic Central Western Ireland, Southwest Wales, Cornwall (UK), Western Brittany, Dordogne (France)
ATC4 Atlantic Central Flanders (Belgium), Picardie, Champagne, Haute Marne (France)
ATC5 Atlantic Central Bassin de Paris, Normandy (France)
ATN1 Atlantic North Faroes, Shetlands, Orkneys, Western Isles, Scottish Highland, Grampian Mountians, Lake District, Snowdonia (UK)
ATN2 Atlantic North South-West Norwegian coast
ATN3 Atlantic North Northern Ireland, South-East Scotland, Pennines, Lancashire, East Wales (UK)
ATN4 Atlantic North Schleswig Holsten, Niedersachsen, Sachsen Anhalt, Sauerland (Germany), Tyne region, Edinburgh (UK)
ATN5 Atlantic North Jutland (Denmark), Groningen (Netherlands)
BOR1 Boreal Southern Finnish Lappland, Murmanskaya Oblast (Russia)
BOR2 Boreal Västerbotten-Norbotten (Sweden), Soer- Froendelag Hedemark (Norway)
BOR3 Boreal Central Finland, North-Eastern Sweden, North-Western Russia
BOR4 Boreal Central and Southern Finland, North-Western Russia
BOR5 Boreal Swedish Botnian coast, Jämtland Koppaberg, Soloer Halligdal (Norway)
BOR6 Boreal Turku-Pori, Salpauselkä (Finland), Ladoga Lake, Lovat valley (Russia)
BOR7 Boreal Novgorod (Russia), Eastern Latvia and Estonia
BOR8 Boreal Westfold-Oestfolen (Norway), Vänern- Örebro, South Botnian coast (Sweden)
CON1 Continental Carpathian foothills and Transilvanian uplands (Romania)
CON10 Continental Great Polish plain, Lubland plateau, Silesian plateau (Poland), Western Ukraine
CON11 Continental Low mountains of South-Eastern Europe (Bosnia-Herzegovina, Yugoslavia, Bulgaria, Romania)
CON12 Continental Low mountains and undulating plains of South-Eastern Europe (Croatia, Hungary, Yugoslavia, Bulgaria)
CON2 Continental Medium elevation mountains and foothills Germany, Switzerland, Austria, Czech republic, Poland, Slovenia, Croatia, Bosnia Herzegovina, Yugoslavia, Bulgaria, Greece, Albania, Macedonia.
CON3 Continental Northeastern Poland, Northern Ukraine, central Czech Republic, Northeast Jutland (Denmark), Balitic Swedish coast.
CON4 Continental Northern Bavaria, Thüringen (Germany),Baltic coast (Lithuania, Latvia), Carpathian foothills (Czech Republic, Slovakia, Poland, Romania, Ukraine)
CON5 Continental Brandenburg, Sachsen, Pfalz (Germany), Romanian Moldavia
CON6 Continental Ardennes (Belgium), Vosges (France), Schwarzwald-Schwaben (Germany), Bosnian Plateau (Bosnia Herzegovina)
CON7 Continental Bavarian Plateau (Germany), North-Eastern Alpine foothills (Germany, Austria). Foothill of Tartra (Czech Republic, Slovakia, Poland)
CON8 Continental Foothills of Southern Carpathians (Romania, Bulgaria), Northern Balkan (Bulgaria)
CON9 Continental North German plain (Germany, Poland), Middle Danube Plain (Hungary, Slovakia, Ukraine), Moldavian Plateau (Moldavia, Romania, Ukraine)
LUS1 Lusitanian Foothills of the Cantabrian Mountains and West Pyrenees (Spain)
LUS2 Lusitanian Atlantic plains of France (Vendée, Saintonge, Médoc, Graves)
LUS3 Lusitanian Foothills and low mountains in Galicia and Cantabria (Spain) and Beira Litoral (Portugal)
LUS4 Lusitanian Les Grandes Landes (France), West Cantabrian Coast (Spain), Minho-Beira Baixo (Portugal)

MDM1 Mediterranean Mountains East Cantabrian Mountains (Spain), Kapela Mountains (Croatia, Bosnia-Herzegovina)
MDM10 Mediterranean Mountains Sierra de Ronda (Spain), Massif de Maures (France), Ionian islands (Greece)
MDM11 Mediterranean Mountains Algeria
MDM2 Mediterranean Mountains Cevennes, Turin, Valane, Grenoble (France), Meseta Burgos-Leon (Spain), Pohorje (Slovenia), Northern Croatia, Matra (Hungary), region Ohrid-Prespa (Macedonia), Kaïmakchalan (Greece, Macedonia)
MDM3 Mediterranean Mountains Ardeche, Drome, Alpes Maritime (France), Sierra cabrera, Gredos, de Molina, de Gudar (Spain), Abruzzo, Alto Adige, Appeninos liguros, Mountains Torino (Italy), Pindos (Greece)
MDM4 Mediterranean Mountains Foothills of Central and Eastern Alps (Italy, Slovenia, Croatia), and the western ranges of the Dinaric Alps (Croatia, Bosnia Herzegovina, Montenegro, Albania)
MDM5 Mediterranean Mountains Eastern Montes de Toledo, southern foothills of Cordillera Cantabrica and Pyrenees (Spain), Southern foothills of Massif Central (France), Appenines (Italy)
MDM6 Mediterranean Mountains Western Montes de Toledo, Sierra de Albarrracin, Sierra de Guadar, southern periferee of the Pyranees (Spain), Olypus (Greece)
MDM7 Mediterranean Mountains Peaks of the Sierra Nevada, Sierra de Segovia (Spain), Corsican mountains (France), Calabrian Apennines (Italy), South Pindos and Erymanthos (Greece)
MDM8 Mediterranean Mountains Rey Dalari, Bulgaz (Trurkey), Sierra Nevada, Sierra de Segura (Spain)
MDM9 Mediterranean Mountains Gölgel Dag (Turkey)
MDN1 Mediterranean North Northern Sierra de la Demanda, Ppadua-Venetian Plain (Italy), Southern foothills of Cordillera Cantabrica (Spain), Paikon (Greece), East Rodopi (Bulgaria and Greece), low mountain of North Western Analtolia (Turkey)
MDN10 Mediterranean North Ribatejo, Alentejo (Portugal)
MDN2 Mediterranean North Coastal plains of East adriatic coast (Croatia, Bosnia-Herzegovina, Montenegro, Albania)
MDN3 Mediterranean North Middle Duoro (Portugal, Spain), Gascogne (France), coast of Maroc (Italy), Dinara coast (Croatia), Western Black Sea coast of Turkey.
MDN4 Mediterranean North Eastern Beira Baixa (Portugal and Spain). Southern foothills of Massif Central (France), foothills of the Apennines (Italy), Tomorr and Ostrovice (Albania)
MDN5 Mediterranean North Plains of the Castilla Léon (Spain), Po Valley (Italy), Northern Egean coast (Greece).
MDN6 Mediterranean North Low mountains of Sierra de Guadarrama, Sistema Ibérica, and Southern Pyranees (Spain), Chalkidiki, Vermion, Oluympus, Ossa (Greece).
MDN7 Mediterranean North Serra de Gata (Portugal), Sierra de Moncaya (Spain), Herault (France), Coast of Livorno-Roma Pescara Brindisi (Italy), Central Albania, South coast sea Marmara (Turkey)
MDN8 Mediterranean North Coast of Corsica (France), Central Sardinia, Coast of Rome region (Italy), Ionian coast (Greece)
MDN9 Mediterranean North Sierra de Toledo, Coastal mountains Catalunya, mountains Murcua, Albacete (Spain), Vaucluse, Aix en Provence (France), Low Dinarian Alps, Velebit (Hungary), Thessalin (Greece), Akhisar Usna (Turkey)
MDS1 Mediterranean South Southern Meseta, Zaragoza-Tarragona (Spain), Tessaloniki, Tessalia (Greece), Turkish coast north of Lesbos, Balehesir (Turkey)
MDS2 Mediterranean South South Peleponessos (Greece), North Sicily, Sardinian Lowlands (Italy), Majorca, Sierra de Frenegal, da Ronda, coast Barcelona Perpigan (Spain), Camargue (France)
MDS3 Mediterranean South Central Albanian coast, South Italian coast, South Sardinian coast (Italy), Western Algarve, Eastern Alentejo (Portugal)
MDS4 Mediterranean South Turkish valleys, Sierra Morena and coastal mountains Southern and Eastern Spain
MDS5 Mediterranean South Euboia-Attica -Nauplion (Greece), Southern Sicily (Italy), Estremadura-Quadalquivir, Cartagena-Valencia (Spain)
MDS6 Mediterranean South Cadiz, Males-Crete, Zakinthos Kefalinia (Greece)
MDS7 Mediterranean South Aegean Islands (Greece), South Sicily coast (Italy), Las Marismas (Coto Doñana) (Spain)
MDS8 Mediterranean South Cabo de Gato (Spain), Turkish coast
MDS9 Mediterranean South Tunisia, Algeria
NEM1 Nemoral Jönkoping (Sweden), Aland (Finland), Western Estonia, Pskov (Russia), Northern Belarus
NEM2 Nemoral Saarema (Estonia), Latvia, Lithuania
NEM3 Nemoral Oestfold (Norway), Skaraborg, Kalmar, Öster Gotland, Stockholm (Sweden)
NEM5 Nemoral Southern Lithuania, Southern Belarus, Gdansk (Poland)
NEM6 Nemoral South-West Sweden
PAN1 Pannonian Balkans (Romania), Foothils of the Carpahians (Romania, Moldavia), Vosges (France)
PAN2 Pannonian Middle Danube Plain (Hungary, Slovakia, Austria, Yugoslavia), Black Sea Lowland (Moldavia, Ukraine), Valley of Struma (Bulgaria, Greece)
PAN3 Pannonian Middle and Lower Danube Plain (Hungary, Yugoslavia, Romania, Bulgaria), Southern Ukraine lowlands

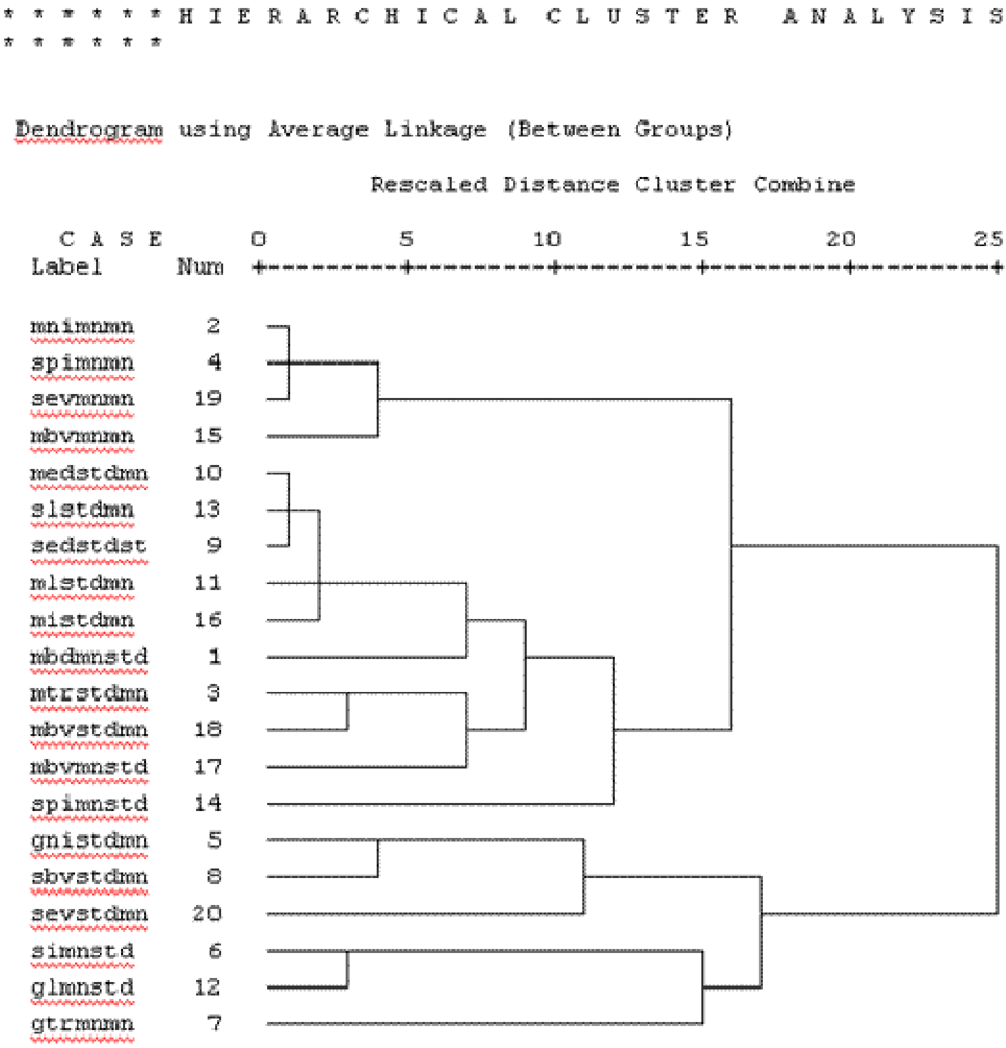
Appendix 2: Species scores of the PCA

	Eigenvalues			
	AX1	**AX2**	**AX3**	**AX4**
	0.6645	0.2016	0.0326	0.0257
Species				
AlaArv	-0.9505	0.1708	0.0722	0.0289
AthNoc	-0.443	-0.8056	0.2543	-0.1034
CarCan	-0.7875	-0.4648	-0.1716	0.2753
CarCar	-0.6321	-0.7014	-0.0239	0.2125
ColPal	-0.9363	0.1837	0.1192	0.0759
CorCor	-0.9286	0.1814	0.1546	-0.0026
CorMon	-0.8537	-0.2316	-0.22	0.2836
CotCot	-0.6329	-0.7349	0.0772	-0.0739
EmbCit	-0.9036	0.3263	-0.0453	-0.0358
EmbSch	-0.8225	0.4646	0.1963	0.0919
FalSub	-0.875	-0.0438	-0.1887	-0.261
FalTin	-0.9261	0.1294	0.2532	-0.0074
HirRus	-0.947	0.0647	0.1378	0.0231
LanCol	-0.8108	-0.0594	-0.4258	-0.3789
MilCal	-0.393	-0.84	0.2484	-0.1215
MotFla	-0.8267	0.2717	0.2318	-0.2774
PasMon	-0.8162	-0.4282	-0.1675	0.1187
PicPic	-0.9388	0.1342	0.132	-0.0692
SaxRub	-0.856	0.4268	-0.0773	-0.0602
StrTur	-0.599	-0.7441	0.0525	-0.0952
StuVul	-0.9031	0.2287	-0.0633	0.0179
SylCom	-0.9223	-0.1186	-0.2258	0.1252
VanVan	-0.8662	0.4087	0.0736	0.105

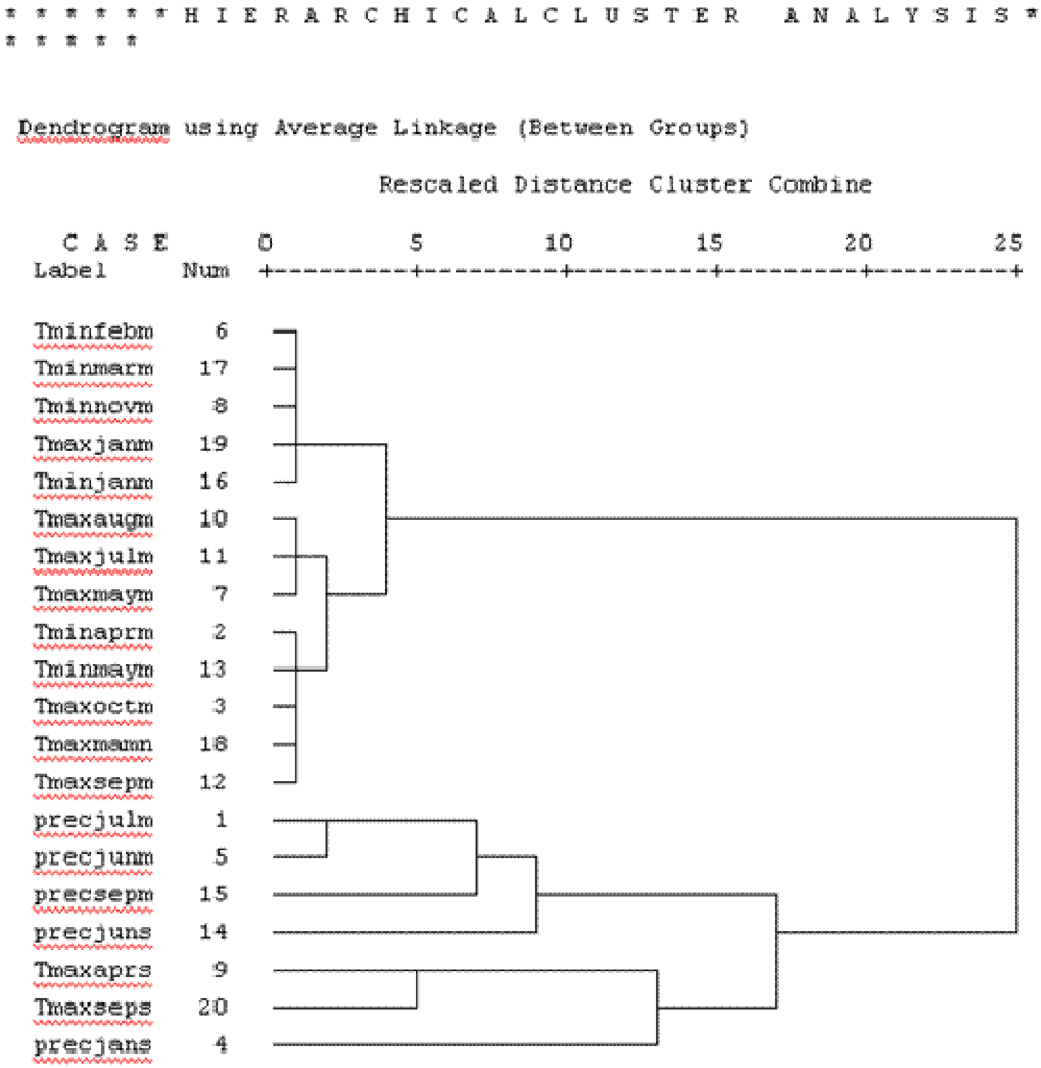
Appendix 3: Sample scores of the PCA

	Eigenvalues			
	AX1	AX2	AX3	AX4
	0.6645	0.2016	0.0326	0.0257
Strata				
ALN1	0.3376	2.9088	3.6478	-1.2908
ALN2	1.0487	2.24	2.61	-0.7993
ALS1	0.1816	0.162	-0.8052	-0.2636
ALS2	-0.1349	-0.3866	-1.1682	-0.0082
ALS3	-0.2791	0.1171	-0.8076	0.3004
ALS4	-0.4614	-0.2614	-0.5736	-0.015
ALS5	-0.1894	-0.4732	-0.5485	-0.4166
ALS6	-0.2255	-0.4694	-0.3225	-0.3685
ATC1	0.3744	0.964	0.0995	4.0138
ATC2	-1.5292	-0.5964	1.2821	0.3854
ATC3	-0.1536	0.3758	1.318	3.2985
ATC4	-1.5402	-0.7042	0.9459	-0.1384
ATC5	-1.0587	-0.6826	0.9413	0.0659
ATN1	0.3391	1.0443	0.6558	3.3641
ATN3	-0.6607	0.2477	1.9597	3.4424
ATN4	-1.4645	-0.3572	0.4225	0.154
ATN5	-0.5564	0.1372	0.4597	0.9076
BOR1	0.0591	2.8713	2.0458	-2.2628
BOR2	0.0031	2.5731	0.8936	-1.4812
BOR3	-0.6422	2.5068	-0.4052	-1.4432
BOR4	-0.9342	1.6606	-1.5876	0.2042
BOR5	-0.5763	2.2896	-0.9622	-0.3244
BOR6	-0.6906	1.2355	-1.6978	0.491
BOR7	-0.7581	0.7145	-1.6124	0.5236
BOR8	-0.1546	1.7626	-1.543	0.0552
CON1	-0.1452	-0.437	-0.4812	-0.5199
CON10	0.1808	-0.1081	-0.2005	-0.1295
CON11	0.2836	-0.4296	-0.2536	-0.6935
CON12	0.6763	-0.0833	-0.4844	-0.1254
CON2	-0.5595	-0.0854	-0.5016	0.1715
CON3	-1.6599	-0.4649	0.1571	-0.1471
CON4	-1.4529	-0.5307	0.2418	-0.3014
CON5	-1.5943	-0.4904	0.3393	-0.4517
CON6	-0.9735	-0.3783	0.1145	-0.0906
CON7	-1.2101	-0.447	0.0656	-0.2014
CON8	0.4891	0.1216	-0.816	-0.0084
CON9	-1.2066	-0.4738	0.2254	-0.3146
LUS1	2.5051	0.555	-0.2228	-0.2553
LUS2	-0.6647	-0.6978	0.3448	-0.093
LUS3	0.8318	-0.6344	1.1401	-0.0459
LUS4	0.4359	-1.283	1.2745	-0.093
MDM1	1.1167	0.2295	-0.7051	-0.1268
MDM10	1.528	-0.2508	-0.5115	-0.4065
MDM2	0.1016	-0.3566	-0.4056	-0.406
MDM3	0.361	-0.6155	-1.1055	-0.4956
MDM4	0.7948	-0.028	-0.7479	-0.1855
MDM5	0.1265	-0.7018	-0.3805	-0.8866
MDM6	0.6209	-0.4844	-0.1011	-0.449
MDM7	0.4341	-0.4729	-0.5281	-0.3988
MDM8	1.5415	-0.0935	-0.4234	-0.2838
MDM9	2.4497	0.4319	-0.3779	0.0604
MDN1	0.0491	-0.6445	0.36	-0.558
MDN10	0.7513	-1.2768	2.2341	0.5276
MDN3	-0.2091	-1.0463	-0.5233	-0.7566
MDN4	0.2693	-0.8738	-0.6284	-0.7861
MDN5	0.1974	-0.5895	0.3564	-0.0195
MDN6	1.3423	-0.5208	-0.1054	-0.3747
MDN7	0.9787	-0.2982	-0.2145	-0.2945
MDN8	0.5857	-0.7195	-0.4091	-0.6426
MDN9	0.8983	-0.5959	-0.5866	-0.5497
MDS1	0.5313	-0.6795	0.073	-0.1219
MDS2	0.8405	-0.6858	0.3813	0.4763
MDS3	0.7396	-1.6149	1.2403	0.4341
MDS4	1.2237	-0.4061	0.2945	0.2323
MDS5	0.9952	-1.256	0.3848	0.0684
MDS6	1.3482	-0.4754	0.03	0.1315
MDS7	1.6271	-0.4587	-0.1023	0.8347
MDS8	1.8285	0.0111	-0.3025	-0.143
NEM1	-1.2654	0.2455	-0.676	0.1152
NEM2	-1.5226	-0.0992	-0.4017	0.0197
NEM3	-0.8665	1.3665	-2.0627	1.236
NEM5	-1.1805	-0.0904	-0.1869	-0.0291
NEM6	-0.0026	1.5143	-1.8249	1.1272
PAN1	-1.3701	-0.8062	0.3912	-0.9139
PAN2	-1.6064	-0.7385	0.5516	-0.7348
PAN3	-1.5278	-0.9323	0.8226	-0.7953
ORIGIN	2.5723	0.6992	-0.6545	-0.1665

Appendix 4: Hierarchical cluster analysis of the best 20 (Monte Carlo permutation test) phenological indices



Appendix 5: Hierarchical cluster analysis of the best 20 (Monte Carlo permutation test) climatic indices



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Abstract
This report presents research in establishing linkages between remotely sensed information of vegetation cover and biological diversity, specifically focusing on farmland birds. The vegetation cover was investigated via phenological indices derived from time series of satellite images. The quantification of phenological processes is very important for understanding ecosystems and ecological development. Such factors determine population growth and influence species-species interactions (competition, predation, reproduction) and species distribution. Birds have long been used to provide early warning of environmental problems, because they are the best known and documented major taxonomic group, especially in terms of the sizes and trends of populations and distributions. Common farmland birds are in decline throughout Europe, with the cumulative populations of all 33 species of farmland birds suffering a decline of 44 per cent between 1980 and 2005. For the link between vegetation dynamics and farmland birds distribution phenological indices and their spatial statistical characteristics were calculated from the time series of the SPOT Vegetation images. The farmland birds species data were selected from the European Bird Census Counsel (EBCC) Atlas of European breeding birds. Both datasets were then statistically analyzed using the Environmental Stratification of Europe. The study shows that this stratification is very appropriate to describe the spatial distribution of farmland birds. Furthermore it was shown that phenological indicators, especially the start of the growing season, the first greening up measures and the productivity measures are good indicators of the distribution of the European farmland birds and that these indicators are comparable to climatic measures. The importance of using phenological indicators is argued by the illustrated fact that phenological indicators can deliver information on the habitat on a higher spatial resolution that cannot be obtained through climatic data. This combination of information supplies indispensible measures to monitor those environmental changes that most probably lead to the reported dramatic decrease of the species.

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