PREDICTING WINTER ABUNDANCE OF WOODCOCK *Scolopax rusticola* USING WEATHER DATA: IMPLICATIONS FOR HUNTING MANAGEMENT

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ABSTRACT

The sustainable use of natural resources such as game animals requires adjusting extraction to changes in population abundance. Population abundance monitoring is thus necessary to ensure an adaptive management, but this can be difficult in the case of migratory species where breeding areas are in remote places without local monitoring programs. Predictive models of the winter abundance based in the relation between climate and reproduction success or survival could be a useful alternative to monitoring networks in the breeding areas. In this paper, we evaluate the role of weather variables as indicators of winter abundance estimates. We used Game Abundance Indices (total number of woodcock observed during hunting days, divided by the number of hunting hours), collected by volunteer hunters during 21 seasons, and temperature, rainfall and number of days with snow, calculated in May, June and July in the breeding areas; and December-January in the winter areas. Best models explaining variations in winter abundance included number of rainy days in May and June, temperature in July and temperature in the previous winter as explanatory variables. All variables were positively correlated with abundance except temperature in July. The predictive quality of the best model based on a leave-one-out cross-validation procedure (i.e., the Pearson correlation coefficient between observed values and LOO predicted values) was 0.75. We discuss the applications of this predictive model to develop an adaptive hunting management scheme for the species.

Key words: Climate, game management, population abundance, predictive model,
Scolopax rusticola.

INTRODUCTION

The sustainable use of natural resources such as game animals requires adjusting extraction to changes in population abundance, for example limiting catches in years when productivity is low or mortality from natural causes is higher than normal (Lucio 1998). Knowledge of factors related to population abundance is therefore critical to understand the dynamics of populations and make the right decisions in game management (Williams et al. 2002). There are many historical examples of overhunting, where attempts to maximize catches led to poor conservation status of certain species (Halliday 1980, Berryman 1991). Even nowadays, in many situations the use of game resources is based more on cultural or economic aspects, than on the knowledge of population dynamics or abundance variations (Blanco-Aguilar et al. 2008).

Population abundance monitoring and demographic models are thus necessary to ensure an adaptive management. Population abundance may be estimated directly (assessing density, for example) or using indirect measures of abundance (Tellería 1986, Bibby et al. 2000). Both methodologies are commonly used with quarry species (Hudson 1986, Whitlock et al. 2003, Cattadori et al. 2003). On the other hand, estimating abundance before the hunting season can be particularly difficult in the case of migratory species, for example if the breeding areas are in remote places where there are no local monitoring programs (Ferrand & Gossmann 2001). In these cases, monitoring population abundance once the species are in the wintering areas (and the hunting season has already started) may be inefficient to carry out adaptive hunting management, because time may be needed to modify hunting policies and regulations. In such situations, predictive models based on proxies of population counts may be a preferable alternative to completely uninformed quota setting processes.

The woodcock (*Scolopax rusticola*) is a forest migratory wader whose breeding grounds extend from Fennoscandia to Mediterranean region and from western Europe to eastern Russia (Hagemeijer & Blair 1997). The wintering areas concentrate in western and southern Europe, mainly in France, the UK and the northern parts of the Iberian Peninsula, Italy and the Balkans, where it is highly reputed as a game bird. France is the only European country that has developed monitoring networks in western Russia, the main breeding area of their wintering population, based on evaluation of displaying males and ringing of birds in the post-breeding period (Mongin et al. 2004, Ferrand & Gossmann 2009). However, these schemes are costly and therefore limited in space and time. This means that in most wintering areas in southern Europe (except France), numbers of woodcock hunted are either not regulated or regulations are not related to population abundance estimates.

For bird species with high reproductive capacity, abundance in early fall may depend strongly on variations in reproductive success, so the evaluation of reproductive success could be a good indicator of the autumn abundance and therefore the individuals available for the next hunting season (Ballesteros 1998). Weather conditions have a considerable influence on reproduction and population dynamics of many birds (Elkins 1983, Lucio 1990, Little et al. 1996, Puigcerver et al. 1999, Hogstad et al. 2003), including the woodcock; this species is ground-nesting and feeds on worms and insects (Gils & Wiersma 1996), so weather could affect the abundance of food and exposure of nests. In fact, it is known that the species is sensitive to dry summers with lower availability of soil invertebrates (Hoodless & Coulson 1998). In Norway, a relationship

was found between temperature in May and the number of individuals hunted in early autumn (before migration), indicating a possible relationship between weather and breeding success (Selas 2006). This study also found a negative correlation between winter temperature and population abundance in the subsequent fall (Selas 2006). It is known that winter weather can affect woodcock survival (Tavecchia et al. 2002, Guzmán 2013), since events such as cold-spells can make inaccessible their main food source (Baille 1986). This may affect the number of adults in the following spring, thus also affecting abundance in the following hunting season.

Given all this, we hypothesized that it would be possible to build predictive models of the winter abundance based on weather variables (through the relation between climate and reproduction success or survival), which could be useful for adaptive management purposes when monitoring networks in the breeding areas do not exist.

The objectives of this paper are thus 1) to describe the interannual variation in winter abundance of woodcock in Spain and 2) to assess whether the use of climatic variables can be used to predict it. Finally, we discuss how results can be integrated in an adaptive management plan of the species.

MATERIAL AND METHODS

Winter abundance estimates

As an estimate of the winter abundance of woodcock, we used the abundance index obtained in hunting sessions (Game Abundance Index, GAI). This is the total number of woodcocks observed in hunting days, divided by the hunting effort (number of hunting hours). Collection of this information by volunteer hunters started as part of a research project developed in the 90s (Lucio & Saenz de Buruaga 2000), and is currently coordinated by the Spanish Woodcock Hunters Club (CCB) (<http://www.ccbp.org/es/>). This abundance index has been used in France for many years, strongly correlates with other indices of abundance such as those obtained in ringing sessions, and has thus been demonstrated that it is a valid approach to study winter abundance variations (Ferrand et al. 2006 and 2008).

We obtained an average annual GAI for 21 hunting seasons, referring to the period 1991-2012. When the information was available to daily level ($n = 11$ hunting seasons), it was calculated as the average of all individual observations from the third ten-day period of November to the second ten-day period of February (period when this index is maximum and stable in Spain, reflecting winter abundance and not migratory movements, Guzman 2013). For other 3 seasons, the data were available as average data for sets of ten days, so we calculated an annual GAI as the averages of the values for the same period (late November to mid-February). For the remaining 7 seasons, the data were only available as an average annual GAI (one value per season), so it was not possible to calculate it for our selected maximum abundance period. Estimated abundance values for these seasons could thus be underestimated (as it also included information from October, when woodcock are still arriving to the wintering grounds). However, for the seasons with more detailed information ($n = 11$) we observed that both sets of data (full season GAI vs. maximum abundance period GAI) were highly correlated ($r = 0.96$).

Abundance estimates came from 9 Autonomous Regions, covering a large part of the winter distribution of woodcock in Spain (Figure 1 B). For the Regions for which we had data for at least 9 hunting seasons ($n = 7$), we assessed that global annual abundance estimates correlated positively with that in each region (Pearson r values ranging from 0.29 to 0.88), and regional values correlated positively between them (Pearson r values ranging between 0.31 and 0.88). Thus, annual fluctuations appeared to be relatively synchronous among regions, and we assume that our estimates of annual abundance were good reflections of overall abundance variation, and not simply the reflection of different sampling effort in different regions and spatial movements. Annual sample size was 2022.33 ± 847.44 hunting seasons. Sample size by region and season for the regions for which we had more detailed data ($n = 7$, see above) was 283.27 ± 226.14 hunting seasons.

Weather data

Weather variables were obtained from meteorological stations located in the main breeding area of the Spanish wintering population (Guzmán et al. 2010, Hobson et al. 2013), as well as from the regions of the wintering area where information of winter abundance was obtained (Figure 1 A). The data were obtained from the website <http://www.tutiempo.net/clima>. These meteorological stations were chosen in relation to location and weather information available (not all stations had available data for the whole of the study period).

We initially included as predictors the following variables: average temperature (T), number of rainy days (R) and number of days that snowed (S) in both the breeding and the wintering seasons. As mentioned above, weather during the breeding season could affect productivity (Hoodless & Coulson 1998), and winter weather could affect woodcock survival in winter (Tavecchia et al. 2002, Selas 2006, Guzmán 2013), through affecting food (invertebrate) availability. We calculated the monthly average of May, June and July for stations in the breeding area, because these are the months when weather is more likely to have a major influence on reproductive success, as they coincide with egg laying and nestling development (Hoodless 1995). We also calculated the average of December and January data for stations in the wintering region, as representative of winter conditions.

We checked for potential collinearity and redundancy of these explanatory variables by analysing the Variable Inflation Factor (VIF). We removed explanatory variables with the highest VIF until all remaining variables had a $VIF < 5$ (Quinn & Keough 2002, Zuur et al. 2007). Through this process, we removed May temperature and Snow days in winter from further analyses.

Statistical analysis

We built General Linear Models (GLM) with annual winter abundance as a response variable, fitted to a Gaussian error structure, and using an identity link according to the normal distribution of residuals (Zuur et al. 2007). GLM are widely used in ecological research as predictive models (Guisan & Zimmermann 2000). We compared models including different combinations of the summer and previous winter weather variables, using AICc differences between models as selection criterion. This index takes into

account the degrees of freedom and the number of parameters of each model, so it is appropriate to compare models with different degrees of complexity when the sample size is relatively small in relation to the number of estimated parameters (Burnham & Anderson 2002). Models with less than 2 Δ AICc points in relation to the best model are considered to have the same empirical support (Burnham & Anderson 2002). However, we implemented the averaging process including those models with less than 4 Δ AICc to include a larger candidate set of competing models (Arnold 2010). We present the model-averaged coefficients of the explanatory variables included in those models, as well as the relative variable importance, based on the sum of the weights of each of the models that included this variable (Burnham & Anderson 2002). Assumptions of normality and homoscedasticity were met by final models. Analyses were carried out with R 2.12.2 (R Core Team 2010), using the package "Mumin" (Barton 2011).

Finally, in order to evaluate the predictive quality of our selected models, we used a Leave-One-Out cross-validation procedure (Zuur et al. 2009): the final model was fitted 20 times, omitting data for each of the years, and using the resulting regression coefficients to calculate an expected value for the omitted year. Afterwards, we compared observed values with the LOOCV predicted values, and used the Pearson correlation coefficient as an indicator of the predictive quality of the model.

RESULTS

The average GAI in the study seasons was 0.38 ± 0.09 (mean $\pm$ SD). This value largely fluctuated among years, but no clear temporal trend in abundance was observed during the study period (Figure 2).

The best model explaining variations in winter abundance included number of rainy days in May and June and temperature in July as explanatory variables; an alternative model (in terms of Δ AICc) also included temperature in the previous winter (Table 1). Other models received less support (difference in AICc were much higher). Rainy days in May and June, and the previous winter temperature were positively correlated with the abundance of the following season, while the temperature in July was negatively correlated (Table 2).

The best model had high (0.76) predictive capacity according to cross-validation. Correlation between predicted and observed values was higher for the model including winter temperature of the previous season (Figure 3).

DISCUSSION

Bag data have been used both historically (e.g. Middelton 1934, MacLulich 1937) and recently (e.g. Cattadori et al. 2003, Whitlock et al. 2003) to study game species abundance, but it has been objected that these may be biased due to changes in hunting effort (Lambin et al. 1999). As our index is based on observations, and not hunted birds, and also takes into account effort, it does not have these biases and has already been used for woodcock migration studies (Birtsas et al. 2013). However, potential biases to consider are that samples are not randomly designed, as they are based on volunteer hunters, and that there may be density-dependent effects in sampling effort due to

changes in the abundance (Ferrand et al. 2008). The fact that spatial distribution of our samples is very large gives, however, support to our annual estimates to evaluate abundance at a large (Northern Spain) spatial scale, although more work should be done to ascertain local variations in abundance (see below).

Our results show that winter abundance of woodcocks in Spain at the scale of this paper (Northern half of Spain) is significantly related to the weather in the breeding areas the previous spring, suggesting that climate affects reproductive success. The positive effect of summer precipitation and the negative effect of July temperature suggest that these variables may be indicators of the food abundance during the breeding period through the availability of water. For other species, such as quail (*Coturnix coturnix*), that also nest on the ground and feed on invertebrates, previous studies have described that dry summers are related to lower breeding success (Puigcerver et al. 1999). In the case of the woodcock, chicks are especially sensitive to dry summers, with lower availability of soil invertebrates (Hoodless & Coulson 1998), so these climatic variables could be indicators of the availability of such invertebrates and, indirectly, of the woodcock reproductive success. Other authors have also pointed the relationship between hot summers and a detriment in breeding success, as happened in 2010 in Russia (Fokin et al. 2010).

A recent study found a strong correlation ($R^2 = 0.9$) between the proportion of chicks that have undergone complete moult of the secondary coverts at the end of the summer in Russia and the winter abundance in France (Ferrand & Gossmann 2009). In this case, the relationship was interpreted in relation to the reproductive phenology: a higher proportion of chicks that have finished moulting the secondary coverts by August could indicate a larger proportion of early clutches, whose chicks would be had enough time to perform moult before migrating. It was therefore assumed that the years when laying starts earlier, reproductive success is higher, something that happens in many species (Newton & Marquiss 1984, Frederiksen 2004).

Additionally, our results also indicate that weather during the previous winter season may also influence abundance in the following winter, once taking into account summer weather. These results are consistent with those reported by other authors (Selas 2006), and could be related to the effect of low temperatures in the winter survival of the species (Tavecchia et al. 2002, Guzmán 2013). However, this variable had very low explanatory power (see R^2 in Table 1), and its effect was not significant when considering the 95% confidence interval of the parameter estimate (Table 2), and could thus be an example of uninformative parameter (Arnold 2010). More studies with a larger data set could clarify if the winter temperature has an ecological effect in population dynamics.

One further thing to take into account is that there are other ways in which weather conditions could influence winter abundance. Several authors have described how woodcocks make large movements in winter in relation to cold-weather (Gossmann & Ferrand 2000, Péron et al. 2011a), or how weather conditions during autumn and early winter may influence the winter distribution of the populations (Fadat 1983, Birtsas et al. 2013). It is thus possible that annual variations in abundance in different regions may also depend on the prevailing weather during winter. This may also explain why the correlation between annual estimates in abundance was stronger for some regions than others. Consequently, further studies would be necessary, including more detailed

spatial information, as well as including data from a larger geographical region (e.g. including regions from southern Spain) to clarify the effect of the winter and autumn weather in the winter distribution.

According to our results, the abundance of the Spanish winter woodcock population in the last two decades does not seem to follow any clear trend, although strong annual fluctuations are observed (Figure 2). This situation is similar to that reported in France (Ferrand et al. 2008), which according to these authors could be indicative of stability of the French wintering population, suggesting that the current hunting pressure is not excessive. However, according to other studies (Péron et al. 2011b and 2012) it seems plausible that there are population sinks associated with hunting pressure. Therefore, stability may depend on the spatial scale at which abundance is evaluated.

Consequently, it seems necessary to keep monitoring the species, both through hunting abundance indices, and through specific studies on the impact of hunting on abundance at different spatial scales, to determine the appropriate levels of extraction of the species to maintain sustainable populations.

Management implications

The proposed predictive model could be useful to improve the hunting management of woodcock, because it could provide an estimate of the winter abundance at least two months before the beginning of the hunting season when direct monitoring of breeding abundance or success is not possible. This could allow developing regulations in relation to the expected abundance. For example, it would be possible to implement restrictions when predicted abundance is much lower than average, in order to avoid population depletion and allow a faster population recovery to normal levels. It would, however, be necessary to evaluate which mechanisms would be useful to restrict catches in these cases (spatial, temporal or daily limits), and the ecological and social implications of those (Bischof et al. 2012, Kaltenborn et al. 2012).

An advantage of a predictive method based on information that is available online is that it is economic and easy to implement. Direct monitoring (using counts or demographic data) is much more robust and thus preferable to inform quotas. However, such direct data (such as that arising from ringing campaigns in Russia, REF) may be unavailable or limited in many cases, due to economic costs. In such cases, predicted data may be useful, and a better alternative than uninformed management. These predicted values could be complemented and confirmed with direct monitoring: the observations of juveniles in September in the breeding areas or GAIs implemented early in the autumn could ratify or modulate the results of the predictive model.

In any case, it would be recommendable to revise the current predictive model as new winter abundance data is available. Similarly, it would be useful to assess whether predictions could be developed at different spatial scales: on the one hand, and as expressed above, there may be local or regional variations in abundance that may be useful to understand and integrate in management. On the other hand, it would be interesting to develop a predictive model for the winter contingent in the whole Franco-Iberian area because of the strong relationship and connection of both populations (Guzmán 2013), which would also allow evaluating and implementing joint hunting management plans.

Finally, regularly updating the predictive model and its predictive ability may be also important as climate changes (e.g. mild winters) may influence the future distribution of the wintering area in relation to the breeding range of woodcock.

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Table 1 Results of the models explaining winter abundance in relation to weather variables in the breeding and winter area. Those models more relevant (with ΔAIC less than 2 points) are showed in italics. P= precipitation; T= temperature; S= Snow; W = weight of the model; R^2 = Adjusted R-squared of the model.

Models	K	AICc	$\Delta AICc$	W	R^2
<i>~ P (May) + T (July) + P (June)</i>	5	-52.3	0	0.30	0.63
<i>~ P (May) + T (July) + P (June) + T (Winter)</i>	6	-51.8	0.49	0.24	0.67
<i>~ P (May) + T (July) + P (June) + S (July) + T (July)</i>	6	-49.3	3.02	0.07	0.63
<i>~ P (May) + T (July)</i>	4	-49.1	3.14	0.06	0.52
<i>~ P (May) + T (July) + P (June) + P (Winter)</i>	6	-49	3.27	0.06	0.62
<i>~ P (May) + T (July) + P (June) + S (June)</i>	6	-48.8	3.46	0.05	0.62
<i>~ P (May) + T (July) + P (June) + P (July)</i>	6	-48.6	3.67	0.05	0.62
<i>~ P (May) + T (July) + P (June) + T (June)</i>	6	-48.4	3.87	0.04	0.61
<i>~ P (May) + T (July) + T (Winter)</i>	5	-48.3	3.94	0.04	0.46
<i>~ P (May) + T (July) + P (June) + P (July) + T (Winter)</i>	7	-48.3	3.94	0.04	0.67
<i>~ P (May) + T (July) + P (June) + S (May)</i>	6	-48.3	4	0.04	0.61

Table 2 Model-averaged coefficients of the variables explaining woodcock winter abundance. RVI= relative variable importance. Significant variables (i.e. those where the 95% confidence interval of the parameter estimate does not include zero) are showed in italics. -CI and +CI: lower and upper confidence limits for coefficient estimates at the 95% confidence interval.

Variables	Coefficient	SE	-CI	+CI	RVI
Intercept	0.583	0.236	<i>0.120</i>	<i>1.046</i>	-
<i>P (May)</i>	<i>0.014</i>	<i>0.005</i>	<i>0.004</i>	<i>0.024</i>	<i>1</i>
<i>T (July)</i>	<i>-0.031</i>	<i>0.009</i>	<i>-0.049</i>	<i>-0.013</i>	<i>1</i>
<i>P (June)</i>	<i>0.014</i>	<i>0.006</i>	<i>0.002</i>	<i>0.026</i>	<i>0.89</i>
T (Winter)	0.021	0.012	-0.003	0.045	0.32
P (July)	0.003	0.005	-0.007	0.013	0.09
S (July)	-0.329	0.376	-1.066	0.408	0.07
P (Winter)	0.003	0.004	-0.005	0.011	0.06
S (June)	-0.105	0.164	-0.426	0.216	0.05
T (June)	0.005	0.014	-0.022	0.032	0.04
S (May)	-0.001	0.040	-0.079	0.077	0.04

Figure legends

Figure 1 A: Location of the weather stations (black dots) used to calculate climatic variables used in our analyses, for the summer (top right) and winter months (bottom left). B: Spanish regions where the hunting statistics came from (dark grey).

Figure 2 Average ($\pm$ SD) woodcock winter abundance estimate in Spain in the study years. Standard deviation is not depicted for those seasons where information was available only as an annual value.

Figure 3 Results of the LOO cross-validation for the 2 best models explaining winter abundance variation. Black line, observed values; grey line, predicted values.
Average annual GAI $\sim 0.637 + 0.013 * P(\text{May}) + 0.014 * P(\text{June}) + -0.032 * T(\text{July})$
Average annual GAI $\sim 0.551 + 0.014 * P(\text{May}) + 0.014 * P(\text{June}) + -0.031 * T(\text{July}) + 0.021 * T(\text{Winter})$

Figure 1

Figure 2

Figure 3