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Source: Wildlife Biology, 14(1) : 36-43

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/0909-6396(2008)14[36:WSOEWS]2.0.CO;2

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Aradis, A., Miller, M.W., Landucci, G., Ruda, P., Taddei, S. & Spina, F. 2008: Winter survival of Eurasian woodcock *Scolopax rusticola* in central Italy. - Wildl. Biol. 14: 36-43.

The Eurasian woodcock *Scolopax rusticola* is a popular game bird in much of Europe. However, little is known about its population dynamics. We estimated winter survival of woodcock in a protected area with no hunting in central Italy. We radio-tagged 68 woodcocks with battery-powered radio-transmitters during 2001-2005. Woodcocks were captured in fields at night from November through February and fitted with radios. Birds were classified on capture as juveniles or adults using plumage characteristics. Woodcocks were relocated daily through March of each year or until they died, disappeared from the study area, or until their radio failed. We constructed a set of eight competing models of daily survival for the period 1 December - 28 February. Estimates of survival were obtained using the program SURVIV and Akaike's Information Criteria. The best model suggested daily survival was a constant 0.9985 (95% CI = 0.9972-0.9998), corresponding to a survival rate of 0.88 (SE = 0.05) for the 90-day winter study period. Our estimate of juvenile survival is higher than previously reported, and may reflect the protected status of the study area. Our estimates of winter survival may be helpful in managing harvested woodcock populations as well as in conserving populations in an increasingly urbanised environment.

Key words: Italy, population, radio-telemetry, Scolopax rusticola, survival, winter, woodcock

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Received 15 December 2005, accepted 25 September 2006

Associate Editor: Mads C. Forchhammer

The Eurasian woodcock *Scolopax rusticola* breeds widely in central, northern and eastern Europe, and winters in much of the western, central and southern portions of the continent (Cramp & Simmons 1983, Cramp 1985). The species may be declining in abundance on both its breeding and wintering grounds, although evidence for such declines is currently debated (Fadat 1994, Tucker & Heath 1994, Hagemeijer & Blair 1997, Ferrand & Gossmann 2000, Heath et al. 2000). Wetlands International (2002) considered the population stable. The breeding population in Italy is estimated to be 100 pairs, and the wintering population is estimated at 50.000-100.000 birds (Gariboldi et al. 2004: 590).

The Eurasian woodcock is a popular gamebird and is harvested during the fall and winter over much of its range (Ferrand & Gossmann 2001) as well as in the spring and summer in Russia (G. Tavecchia, pers. comm.). In Italy, the hunting season starts in the third week of September and usually ends on 31 January, but in some areas it ends on 31 December. The effects of harvest on woodcock annual population dynamics and abundance are unknown. Habitat loss and fragmentation are other factors that may potentially affect the dynamics of the populations.

Little is known about the population dynamics of the Eurasian woodcock outside the UK, where the movement and survival of chicks has been studied (Hoodless & Coulson 1994, 1998). Summer and winter survival has been estimated for the species in France using band recoveries (Tavecchia et al. 2002). Summer and winter survival also have been studied for the congeneric American woodcock *Scolopax minor* (Derleth & Sepik 1990, Krementz & Bruggink 2000, Longcore et al. 2000).

Winter survival is an important parameter in population models. Winter may be a particularly stressful time of the annual cycle if climate is harsh or if food or habitat resources are scarce (Tavecchia et al. 2002). Winter is also the focal period for additive versus compensatory hypotheses regarding the effects of harvest on survival (Anderson & Burnham 1976, Burnham & Anderson 1984, Conroy et al. 2002). The compensatory hypothesis predicts that winter survival is density dependent and increases when populations are reduced through fall harvest or other means. The additive hypothesis predicts that winter survival is density independent. Duriez (2003) found evidence that hunting mortality is additive in the Eurasian woodcock in France.

We estimated the survival of Eurasian woodcocks wintering in a protected area of central Italy. Estimates of winter survival in a protected area might be viewed as a possible maximum survival rate for that period, particularly if hunting mortality is additive. As such, our estimates are a further step that may ultimately enable setting up competing population models of this species to be used in optimal management decision making (Anderson 1975, Johnson et al. 1997, Johnson et al. 2002).

Material and methods

We marked woodcocks at the Presidential Estate of Castelporziano, a protected area of approximately 6,000 ha located 20 km south of Rome (41°44'N-12°24'E). This area was approximately 80 m a.s.l. The vegetation consists of broad-leaf forest dominated by holm oak *Quercus ilex*, Turkey oak *Q. cerri*, pedunculate oak *Q. robur*, cork oak *Q. suber*, Hungarian oak *Q. farnetto*, as well as Mediterranean scrub, domestic pine *Pinus pinea*, large grazing areas and oats farming (Anzalone et al. 1991, Pignatti et al. 2001). Weather in the study area was relatively mild during the winter (mean daily temperature: 9°C). Minimum daily temperature was $\leq$ 0°C on 4-5 days during December-February, 2001-2004, at a weather station in Castelporziano.

Wintering woodcocks started to arrive on the study area in early November. Each year during 2001-2005, woodcocks were captured from the first week of November until 20 February. In 2001 the first bird was radioed in mid-January. The first birds were radioed in mid-to-late November in all other years.

Woodcocks were captured mainly in grazed areas and other open areas using nightlighting methods modified from Glasgow (1958). Captured birds were fitted with aluminum leg bands and classified as adults or juveniles according to plumage characteristics and moult status (Clausager 1973). A radio-transmitter (TW-3, CR2032 cells, Biotrack Ltd.), weighing 9 g (i.e. <5% of body mass) was attached to each bird's back with a single loop wire harness secured with a metal crimp and livestock tag cement (McAuley et al. 1993). Woodcocks were located with a 4-element Yagi antenna every day from the day of capture until mid-March of each year or until the birds died, disappeared from the study area, or their radio failed. Radios were equipped with a mortality sensor that indicated whenever a bird had not moved for three hours. Birds were closely approached and their status visually determined whenever a mortality signal was received. We restricted our analysis of winter survival to 1 December-28 February.

We created a set of eight competing models of daily survival (Burnham & Anderson 2002). Data were formatted with SAS (SAS Institute 1997) and analysed using the program SURVIV (White 1983, White & Garrott 1990). Survival potentially may vary among years or days, and juvenile birds may have lower survival than adults (Tavecchia et al. 2002, Duriez 2003). Our most general model, φ_{General}, allowed daily survival to vary between adult and juvenile birds, φ_{Age}, among years, φ_{year}, and among days of the season, φ_{Day}, where 1 December was Day 1 and 28 February was Day 90. While this most general model, φ_{General}, admittedly contained an unrealistically large number of parameters it was included as an important baseline for more constrained models. The second most general model only included a day effect, φ_{Day}. Other models with only a single effect included one with an age effect, φ_{Age}, one with a year effect, φ_{year}, and one in which daily survival varied only among months, φ_{Month}. One model allowed daily survival to differ between adults and juveniles and among years, $\varphi_{\text{Age,Year}}$. The most constrained model, $\varphi_{.}$, estimated a single constant daily survival. We estimated model fit, $\hat{c}$, of the most general model using 500 bootstrap simulations in the program SURVIV (Anderson et al. 1994, Burnham & Anderson 2002).

Weather conditions can affect woodcock winter survival in northern portions of their range (Tavecchia et al. 2002). In central Italy winter climate is generally colder in December and January than in February. Therefore we created a model in which daily survival was constrained constant in December and January but allowed to differ from a constant February survival, $\varphi_{\text{DJ\_vs\_F}}$.

Radio-telemetry is a form of capture-recapture where live animals detected on day i are considered to be captured and released. When those animals are detected again on day i + 1 they are considered to be recaptured. Radio-telemetry studies typically assume that on each visit to a study area the researcher detects all animals present with functional radios (White & Garrott 1990). We made such an assumption at the beginning of our present study. If a radio signal was not detected for seven days in a row the animal was assumed to have left the study area except during the last field season when we checked for all radios every day. Pollock et al. (1995) developed a capture-recapture model that allows estimation of detection probability for radio-telemetry studies when detection probability is not one. Only once did it happen that a radio signal disappeared and was relocated the next day or later in the field season. As such we have not employed the Pollock et al. (1995) model. Although we are comfortable assuming that our detection probability was one, we used a capture-recapture model in which detection probability was known to be one as explained below.

Six birds lost their radios during the season and the signal for some other birds disappeared before 28 February. These latter birds may have left the study area or their radios may have failed. In our model we only 'released' birds on a given day if we knew their fate on the following day. In other words, we estimated daily survival by including a given bird in the analysis on day i only if we could determine without error whether that bird was alive or dead on day i + 1. If we did not know with certainty whether a bird was alive or dead on day i + 1 that bird was removed from the analysis on day i. For example, suppose 10 birds were detected alive on Day 20. If eight of those 10 birds were detected alive again on Day 21, and one of those 10 birds was detected dead on Day 21, and one of those 10 birds had not been detected by Day 21, we then estimated survival for the interval Day 20-21 using only the nine birds that were detected on both Day 20 and Day 21. This enabled us to include birds in our analysis that lost their radios right up until and including the day before their radio fell off and to include birds that left the study area right up until and including the day before they left. We also included birds that died right up to and including the day they died. Using this approach our detection probability was, by definition, one every day. We used simulated data to test this approach, which we suggest is analogous to the Kaplan-Meier method with within-season censuring (White & Garrott 1990). Program SURVIV returned survival estimates which exactly matched the survival values used to generate the artificial data when non-integer counts were permitted to eliminate rounding error. Not all of our birds were fitted with radios on the same day in a given season. However, our modeling approach readily accommodates a staggered entry design (Pollock et al. 1989).

The best survival models were selected using Akaike's Information Criterion adjusted for small sample size (AIC_c; Anderson et al. 2001, Burnham & Anderson 2002). The model with the lowest AIC_c was considered most parsimonious. Akaike weights, w_i, were constructed to evaluate support for each model. Akaike weights were also used to model average estimates of daily survival (Burnham & Anderson 2002).

Estimates of survival over a longer time span than one day were obtained by raising estimated daily survival to a power equal to the number of days in the period of interest minus one. For example, an estimate of 90-day winter survival was obtained as $(\text{daily survival})^{89}$. The standard error of this 90-day winter survival was obtained using the Delta Method (Seber 1982). We compared our estimates of survival to estimates from other studies using the program CONTRAST (Sauer & Williams 1989) after raising our estimate of daily survival to a value that best approximated the period used in those other studies.

We constructed a preliminary annual population model of female woodcock abundance in late summer, N_{t+1}, to estimate population growth rate, λ. We used our estimated winter survival and based estimates of other population vital rates on the literature. Some of those latter estimates had to be raised to a power to match our season lengths. Our population model was:

$$
\begin{aligned}
N_{t+1} = {} & N_{\text{Adult } t} \times \varphi_{\text{Adult fall } t} \times \varphi_{\text{Adult winter } t+1} \\
& \times \varphi_{\text{Adult spring } t+1} \times \varphi_{\text{Adult summer } t+1} \\
& + N_{\text{Young } t} \times \varphi_{\text{Young fall } t} \times \varphi_{\text{Young winter } t+1} \\
& \times \varphi_{\text{Young spring } t+1} \times \varphi_{\text{Adult summer } t+1} \\
& + N_{\text{Adult } t} \times \varphi_{\text{Adult fall } t} \times \varphi_{\text{Adult winter } t+1} \\
& \times \varphi_{\text{Adult spring } t+1} \times p_{\text{Adult summer } t+1} \\
& + N_{\text{Young } t} \times \varphi_{\text{Young fall } t} \times \varphi_{\text{Young winter } t+1} \\
& \times \varphi_{\text{Young spring } t+1} \times p_{\text{Adult summer } t+1}
\end{aligned}
$$

where p is the number of young females alive in late summer per adult female alive at the end of spring.

Results

A total of 68 woodcocks (43 young and 25 adults) were radioed during the study period. We radioed six woodcocks (three adults and three juveniles) in the 2001/02 field season, 17 (six adults and 11 juveniles) were radioed in the 2002/03 field season, 23 (nine adults and 14 juveniles) in 2003/04, and 22 (seven adults and 15 juveniles) in 2004/05. Of these, five birds are known to have died during the study (three adults and two juveniles), six birds lost their collars, and the radio signal of 11 birds disappeared before 28 February.

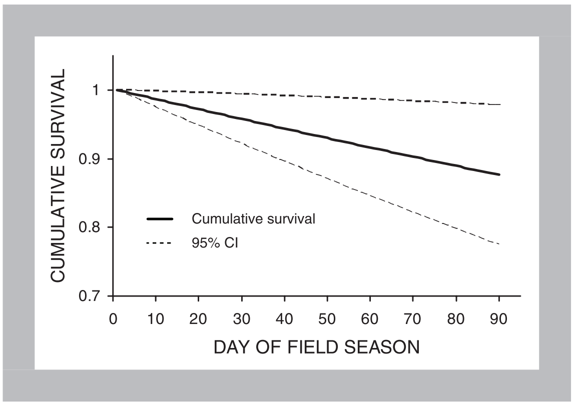

Figure 1. Cumulative estimated woodcock winter survival (and 95% CI) in central Italy during 1 December -28 February, 2001-2005, based on the lowest AIC_c model.

For the most general model $\hat{c} = 1$, so we used AIC_c for model selection. The most constrained model, $\varphi.$, had the lowest AIC_c and suggested that daily survival was a constant 0.9985 (95% CI = 0.9972-0.9998; Fig. 1, Table 1). This corresponded to a monthly survival rate of $0.9985^{30} = 0.96$ (SE = 0.02) for adults and immature birds. Since there were 90 days in the study, our daily survival estimate corresponded to a winter survival probability of $0.9985^{89} = 0.88$ (SE = 0.05) during 1 December-28 February.

The model with the second-lowest AIC_c included only an age effect, φ_{Age}. In model φ_{Age} estimated daily survival was 0.9991 (95% CI = 0.9979-1.0003) for young birds and 0.9972 (95% CI = 0.9940-1.0004) for adults. These estimates of daily survival

Table 1. Models of daily survival of woodcock wintering in central Italy during 1 December-28 February, 2001-2005.

Model	Parameters	AIC_c	Delta	Akaike weight
$\varphi.$	1	62.61	0.00	0.35
φ_{Age}	2	62.93	0.32	0.30
$\varphi_{\text{DJ\_vs\_F}}$	2	64.61	2.00	0.13
φ_{Year}	4	65.23	2.62	0.09
φ_{Month}	3	65.79	3.18	0.07
$\varphi_{\text{Age,Year}}$	8	66.08	3.47	0.06
φ_{Day}	89	215.27	152.65	0.00
φ_{General}	589	1437.76	1375.15	0.00

Table 2. Model-averaged estimates of daily survival (SE) of woodcock wintering in central Italy during 1 December-28 February, 2001-2005.

Year	Age	December	January	February
2001-2002	Adult	-	0.99454 (0.00807)	0.99448 (0.00806)
	Immature	-	0.99804 (0.00899)	0.99798 (0.00903)
2002-2003	Adult	0.99779 (0.00158)	0.99790 (0.00155)	0.99784 (0.00156)
	Immature	0.99854 (0.00102)	0.99865 (0.00094)	0.99859 (0.00099)
2003-2004	Adult	0.99821 (0.00396)	0.99833 (0.00391)	0.99826 (0.00394)
	Immature	0.99871 (0.00088)	0.99882 (0.00080)	0.99876 (0.00085)
2004-2005	Adult	0.99802 (0.00141)	0.99813 (0.00137)	0.99807 (0.00139)
	Immature	0.99879 (0.00290)	0.99890 (0.00282)	0.99884 (0.00287)

equate to an adult winter survival of $0.9972^{89} = 0.78$ (SE $= 0.11$) and a juvenile winter survival of $0.9991^{89} = 0.92$ (SE $= 0.05$). This model, φ_{Age}, had almost as much Akaike weight as did the lowest AIC$_c$ model, φ.

Only one other model had an Akaike weight ≥ 10: the model with $\varphi_{DJ\_vs\_F}$. However, in this model daily survival estimates were identical to the fourth decimal among periods.

Model-averaged estimates of daily survival ranged from 0.9945 (SE $= 0.0081$) - 0.9989 (SE $= 0.0028$; Table 2). Estimated daily survival estimates from all eight models were included in these model-averaged survival estimates.

Our estimated survival from the lowest AIC model was significantly higher than similar estimates in France (Tavecchia et al. 2002, Duriez 2003) and in the southeastern USA (Krementz & Berdeen 1997; Table 3).

Discussion

Our estimates of monthly winter survival (0.96) from model φ. were similar to those for adult birds in previous studies. Tavecchia et al. (2002) estimated mean monthly winter survival to be 0.95 (SE $= 0.012$) for adults and 0.90 (SE $= 0.024$) for juveniles. Juvenile birds in our study did not have a lower estimated survival than adults. Perhaps juvenile survival was higher in our study than in the study of Tavecchia et al. (2002) because those authors defined winter as October-February, i.e. two months longer than our winter period. However, the overall winter survival of Eurasian woodcocks in western France was also estimated to be higher for adults than for juveniles, i.e. 0.80 (SE $=$ 0.08) and 0.64 (SE $= 0.06$ for adults and juveniles, respectively; Duriez 2003). Duriez (2003) used 1 December-20 February as his winter period, very similar to our 1 December-28 February winter period. Duriez's (2003) estimates correspond to a monthly survival of $0.92 = (0.80^{(1/81)})^{30}$ for adults and $0.85 = (0.64^{(1/81)})^{30}$ for juveniles since there were 82 days in his winter period.

The second best model in our study, φ_{Age}, suggested that juveniles might have had higher survival than adults. However, this result may have occurred by random chance since only five birds died during

Table 3. Comparison of Eurasian woodcock winter survival in central Italy with previously published winter survival estimates for Eurasian and American woodcock. Estimated winter survival in central Italy was higher than in both France and the USA.

Age	φ (SE)	Period	Location	Study	Contrast	χ^2 (df)	P
Adult	0.95 (0.01)	Monthly, in fall and winter	France	Tavecchia et al. 2002	Young $_{France}$ vs Young $_{Italy}$	6.4 (1)	0.04
Young	0.90 (0.02)						
Adult	0.96 (0.02)	Monthly, in winter	Italy	This study			
Young	0.96 (0.02)						
Adult	0.80 (0.08)	1 December-20 February	France	Duriez 2003	Young $_{France}$ vs Adult $_{France}$ vs Combined ages in Italy	13.0 (2)	0.001
Young	0.64 (0.06)						
Adult	0.89 (0.05)	82-day winter period	Italy	This study			
Young	0.89 (0.05)						
Adult	0.72 (0.11)	25 December-7 February	Georgia, USA	Krementz & Berdeen 1997	Georgia vs Italy	7.4 (1)	0.006
Young	0.72 (0.11)						
Adult	0.94 (0.03)	45-day winter period	Italy	This study			
Young	0.94 (0.03)						

Table 4. Parameter values used in our annual population model of Eurasian woodcock to estimate rate of population growth, λ, under two scenarios.

Parameter	Estimate	Period	Study	λ
$\varphi_{Adult\ fall}$	0.81	September-November	Tavecchia et al. 2002	1.01
$\varphi_{Young\ fall}$	0.66	September-November	Tavecchia et al. 2002	
$\varphi_{Adult\ winter}$	0.88	December-February	This study	
$\varphi_{Young\ winter}$	0.88	December-February	This study	
$\varphi_{Adult\ spring}$	0.96	March	Assumed	
$\varphi_{Young\ spring}$	0.96	March	Assumed	
$\varphi_{Adult\ summer}$	0.74	April-August	Longcore et al. 2000	
$p_{Adult\ summer}$	0.90	Breeding	Hoodless & Coulson 1998	
$\varphi_{Adult\ fall}$	0.81	September-November	Tavecchia et al. 2002	0.82
$\varphi_{Young\ fall}$	0.66	September-November	Tavecchia et al. 2002	
$\varphi_{Adult\ winter}$	0.80	December-February	Duriez 2003	
$\varphi_{Young\ winter}$	0.64	December-February	Duriez 2003	
$\varphi_{Adult\ spring}$	0.96	March	Assumed	
$\varphi_{Young\ spring}$	0.96	March	Assumed	
$\varphi_{Adult\ summer}$	0.74	April-August	Longcore et al. 2000	
$p_{Adult\ summer}$	0.90	Breeding	Hoodless & Coulson 1998	

our study (three adults and two juvenile birds). Estimates of daily survival for the two age classes were similar in model φ_{Age}, but they corresponded to a fairly large difference in estimated winter survival between age classes over the 90-day study period. As such, our model-averaged survival estimates (see Table 2) might be particularly useful in future woodcock population models given that our two best models had similar weights. Duriez (2003) detected reduced survival of juvenile birds in a hunted area compared to a protected area. Our area was closed to hunting, which might explain the higher survival rate of juvenile birds in our study compared with the studies of Tavecchia et al. (2002) and Duriez (2003).

We did not include an effect of sex on survival. Male and female Eurasian woodcock are difficult to distinguish and sex effects have not been included in other studies of survival. Nor did we include minimum daily temperature as a covariate. Tavecchia et al. (2002) found that survival of Eurasian woodcock was lowered by harsh winter weather in northern France, but was not affected by weather in milder southern France. Winters in coastal central Italy are relatively mild and we doubt that weather would significantly affect woodcock survival in our study area. Two of the five birds that died during our study were presumably killed by a red fox *Vulpes vulpes* on nights when the minimum temperature was 7°C. Given that only five birds died during our study period, we feel it unlikely that a model with a continuous temperature covariate would have much data-analytic support. Our model intended to address a possible effect of winter weather on daily survival, $\varphi_{DJ\_vs\_F}$, had little support (Akaike weight = 0.13). Although we, *a priori*, did not expect this model to have much support, we felt it prudent to include it and allow Akaike weights to estimate its support.

Tavecchia et al. (2002) developed a matrix population model for woodcock. We developed a slightly expanded annual population model of female Eurasian woodcock population abundance (Table 4). This model is preliminary and limited for several reasons. We had to use survival estimates from periods of the year that did not always exactly match the period for which we used them. Survival estimates were raised to a power to match the season length for which we used them. The studies we used were from widespread areas and summer survival of adults was based on the American Woodcock. We also selected survival and production values to be somewhat conservative (Hoodless & Coulson 1998, Tavecchia et al. 2002). Nevertheless, our preliminary model suggests a stable population is possible for Eurasian woodcock when winter survival is high, even when that population is experiencing relatively low production and survival outside of the winter period. Abundance might decrease when winter survival is reduced. Future studies of woodcock vital rates may help improve population modeling efforts and may eventually lead to competing population models that allow addressing additive and compensatory hypotheses of mortality (Anderson & Burnham 1976), as well as optimal harvest management (Johnson et al. 1997).

Acknowledgements - we acknowledge the Direction of Tenuta Presidenziale di Castelporziano for permission to carry out the Woodcock Project. We thank S. Montanino, F. Moreschini, A. Peperoni, C. del Brocco, V. Capraro and M. Falcinelli for assistance with fieldwork. G. Tavecchia, M. Forchhammer and two anonymous referees provided valuable comments on earlier drafts of the manuscript. A. Aradis was supported by the Ministero delle Politiche Agricole e Forestali.

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