J Ornithol
DOI 10.1007/s10336-016-1393-8

SHORT COMMUNICATION

Effect of tree logging on reproductive performance in Blue Tits (*Cyanistes caeruleus*)

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Received: 11 January 2016 / Revised: 11 August 2016 / Accepted: 12 September 2016

Abstract For birds, habitat quality is largely determined by local vegetation, and reproductive performance can therefore be negatively influenced by anthropogenic activities. A tree logging event enabled us to examine the effect of removing trees of different maturities and types on the reproductive performance of Blue Tits (*Cyanistes caeruleus*). Against expectations, only the logging of small coniferous trees, but not larger and deciduous trees, was associated with a reduction in the number of eggs laid, whereas logging had no significant effect on lay date. Therefore, we conclude that modest logging activity has no or limited negative influence on Blue Tit reproductive performance.

Keywords Anthropogenic · Breeding · Clutch size · Habitat · Laying date · Logging

Zusammenfassung

Auswirkung von Holzeinschlag auf die Reproduktionsleistung von Blaumeisen (*Cyanistes caeruleus*)

Habitatqualität wird für Vögel weitgehend bestimmt durch lokale Vegetation, wodurch die Reproduktionsleistung von Vögeln durch menschliche Aktivitäten negativ beeinflusst werden kann. Wir prüften die Auswirkungen von Holzeinschlag von Bäumen verschiedener Reife und Art auf die Reproduktionsleistung von Blaumeisen (*Cyanistes caeruleus*). Entgegen den Erwartungen hatte nur die Entfernung von kleinen Nadelbäumen einen reduzierenden Effekt auf die Anzahl der gelegten Eier, im Gegensatz zu Laub- und größeren Nadelbäumen. Der Holzeinschlag hatte auch keinen signifikanten Einfluss auf das Legedatum. Daraus schließen wir, dass moderater Holzeinschlag keinen oder nur begrenzten negativen Einfluss auf die Reproduktionsleistung der Blaumeise hat.

Communicated by F. Bairlein.

Electronic supplementary material The online version of this article (doi:10.1007/s10336-016-1393-8) contains supplementary material, which is available to authorized users.

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Introduction

Anthropogenic disturbances such as logging result in habitat loss and fragmentation, and can therefore affect avian biodiversity (Burivalova et al. 2015). For birds, food availability, and thus breeding habitat quality, is largely determined by local forest structure (Lambrechts et al. 2004; Mägi et al. 2009). While several studies have examined the effects of logging on reproduction in birds (Bourque and Villard 2001; Gram et al. 2003), few have used fine-scale indices on the level of individual trees. By relating changes in bird reproduction to the logging of

Published online: 22 September 2016

specific trees of known maturities and types, it is possible to identify the proximate ecological factors that influence avian reproductive performance, which may help to inform forest management.

In winter 2013, trees were logged in a field site inhabited by Blue Tits (*Cyanistes caeruleus*) subject to long-term study. This created an ideal opportunity to investigate the effects of anthropogenic change in forest structure on reproductive parameters (laying date and number of eggs laid). We hypothesized that logging influences reproductive performance and that this effect is stronger for larger trees and for deciduous rather than coniferous trees, given their greater importance in providing food resources for Blue Tits (Amininasab et al. 2016).

Materials and methods

Study population and data collection

We studied a population of Blue Tits inhabiting 188 nest-boxes (around 2 m high) in mixed deciduous and coniferous forest in 'De Vosbergen' in the Netherlands (53°08′N, 06°35′E; 54 hectares). The circumference of all to-be cut deciduous and coniferous trees within a 20-m radius of each nest-box was measured at breast height (small: 30–100 cm, medium: 100–200 cm, large: >200 cm; categories are based on the frequency distribution of logged trees in the area; see Fig. S1) 2 weeks before logging (November–December 2013; 3–4 months before the breeding season). A radius of 20 m was chosen, given the heavy workload of measuring individual trees, as a compromise between efficiency and biological plausibility (since birds are more likely to forage close to their nest-box) (Amininasab et al. 2016). The percentage of nest-boxes around which at least one tree was logged was calculated for four randomly chosen subareas of equal size and containing a similar number of nest-boxes, in order to test for spatial differences in logging activity. Each year, from April through June, nest-boxes were checked daily to record the date of egg-laying onset (with April 1 representing day 1) and the total number of eggs laid.

Statistical analyses

For each nest-box, we calculated the pre-logging (average over 2001–2013) and post-logging (2014) laying date and total clutch size, and the change in these parameters was obtained by subtracting post-logging from pre-logging values. Because breeding parameters may differ between years (e.g., initiation of breeding in 2013 was extremely late), we calculated standardized values using the following equation:standardized $x = \frac{x-\bar{x}_{\text{year}}}{\text{sd}_{x_{\text{year}}}}$ where x is the laying date or number of eggs laid, and $\bar{x}_{\text{year}}$ is the average laying date or number of eggs laid in all nest-boxes in a given year.

Considering those territories where logging occurred in at least one category, linear models were used to test for the effect of logging (whether one or more trees were cut in each category [deciduous and coniferous trees of small, medium, and large sizes]) on the change in laying date or number of eggs laid before (average over 2001–2013) and after logging (2014) in these territories (as response variable in different models). From all possible models (including the null model), we identified the best fitting model (lowest corrected Akaike information criterion [AICc] score) and all other models where ΔAICc <2 (Burnham and Anderson 2002; Tables S1, S2), and we averaged the parameter estimates based on the weight of these best models (Grueber et al. 2011); see Tables S3, S4) using the package 'MuMIn' in R version 3.1.1 (R Development Core Team 2015). P values <0.05 were considered significant.

Results

Coniferous and deciduous trees were removed in 25.7 and 27.5 % of 109 territories, respectively, that were occupied in the subsequent spring. There was no strong spatial effect of logging, indicated by approximately equal logging activity among four randomly assigned plots ($F_{3,105} = 3.87$, $P = 0.052$). A total of 18 small (mean per territory = 1.55, range 1–3), 22 medium (mean = 3.27, range 1–11) and 9 large (mean = 1.44, range 1–3) coniferous trees, and 19 small (mean = 3.26, range 1–17), 20

Table 1 Results of a linear model testing the relationships between change in standardized laying date of Blue Tits and logging of deciduous and coniferous trees of different sizes

	Change in laying date			
	Estimate	SE	z-value	P value
(Intercept)	0.107	0.109	0.98	0.33
Medium deciduous	−0.488	0.252	1.91	0.06
Small coniferous	0.323	0.253	1.26	0.21
Large deciduous	−0.362	0.380	0.94	0.34
Small deciduous	0.218	0.303	0.71	0.48
Medium coniferous	0.148	0.237	0.62	0.54

The estimated coefficients (with associated standard errors, z and P-values) are based on averaging the models that gave the best fit (based on AICc)

The order of variables is based on ranking by relative importance (sum of Akaike weights). The large coniferous variable is not present in the final model, because it was not in the top model set

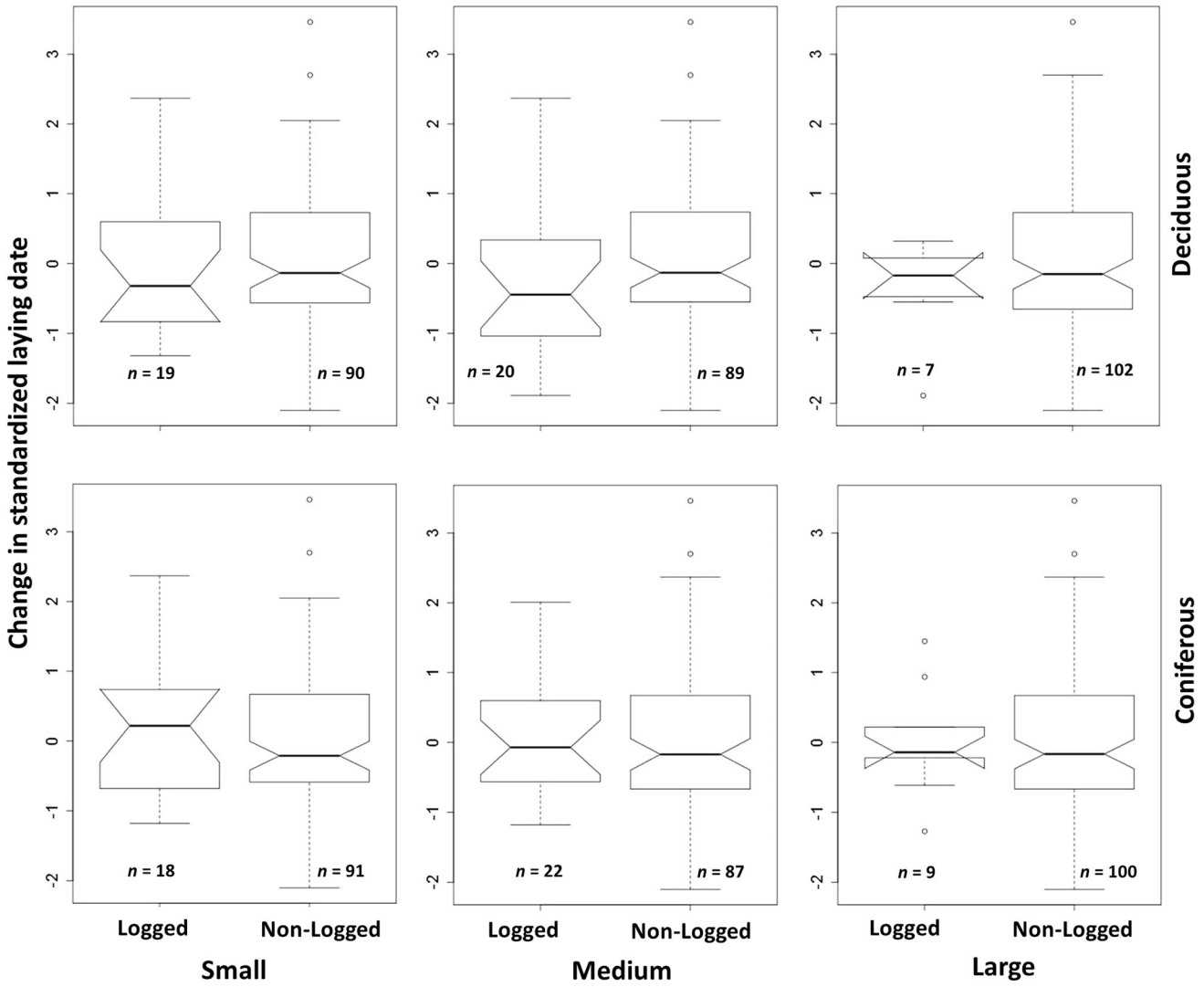

Fig. 1 Notched *box-plots* showing the influence of logging deciduous and coniferous trees of different sizes on change in standardized laying date of Blue Tits. Notches represent confidence intervals around the median, which is based on the median ±1.57 interquartile range/$\sqrt{n}$. Notches overlap in all plots, indicating that there is no strong evidence (95 % confidence) that the medians differ

medium (mean = 2.40, range 1–8) and 7 large (mean = 1.14, range 1–2) deciduous trees were logged.

No change in laying date was found for Blue Tits with deciduous or coniferous trees of any size logged near their nest-boxes (Table 1; Fig. 1). Logging of deciduous or coniferous trees also did not affect the number of eggs laid (Table 2), with the exception of marginally significantly smaller clutches in territories where small coniferous trees were logged ($P = 0.046$; Table 2; Fig. 2).

Discussion

Our results suggest that modest logging of trees has a limited effect on Blue Tit reproductive performance. Based on longitudinal analyses, we show that logging of coniferous or deciduous trees had no effect on laying date, and we found indication of only a small negative effect of logging of coniferous trees on the number of eggs laid. Although we could not incorporate other parameters of breeding performance (like fledging success), due to other experiments in this population (see Amininasab et al. 2016), laying date and clutch size are considered good predictors of reproductive performance, because they usually correlate with other traits like number of fledglings (Lambrechts et al. 2004) and recruitment (Boyce and Perrins 1987).

Previous studies on Blue Tits show that reproductive performance is influenced by food availability (Svensson and Nilsson 1995). Deciduous trees support more caterpillars and insects as food sources during the brood-rearing phase than coniferous or evergreen trees, possibly due to

Table 2 Results of a linear model testing the relationships between change in standardized number of eggs laid by Blue Tits and logging of deciduous and coniferous trees of different sizes

	Change in number of eggs laid			
	Estimate	SE	*z*-value	*P*-value
(Intercept)	−0.006	0.103	0.06	0.95
Small coniferous	−0.534	0.265	1.99	0.046
Large deciduous	0.539	0.384	1.38	0.17
Medium coniferous	0.294	0.267	1.09	0.27
Large coniferous	0.315	0.320	0.97	0.33
Medium deciduous	0.134	0.235	0.56	0.57
Small deciduous	0.101	0.246	0.41	0.68

The estimated coefficients (with associated standard errors, *z* and *P*-values) are based on averaging the models that gave the best fit (based on AICc)

The order of variables is based on ranking by relative importance (sum of Akaike weights)

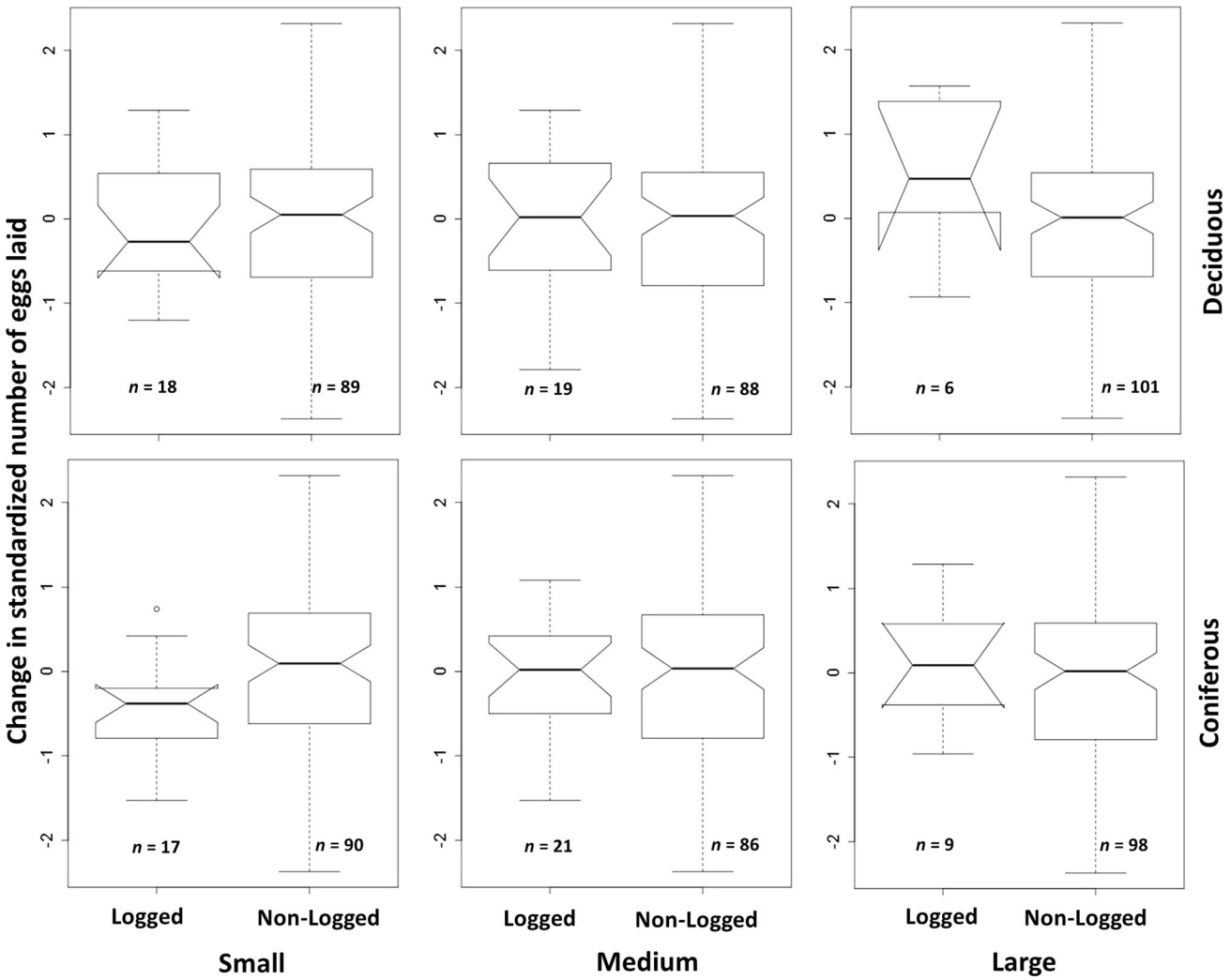

Fig. 2 Notched *box-plots* showing the influence of logging of deciduous and coniferous trees of different sizes on change in standardized number of eggs laid by Blue Tits. Notches represent confidence intervals around the median, which is normally based on the median ±1.57× interquartile range/$\sqrt{n}$. Notches do not overlap when testing logging of small coniferous trees, indicating that the medians differ (95 % confidence)

differences in leaf shape, branch surface, and sap production (Perrins 1979; Lambrechts et al. 2004). Therefore, we expected to find a larger effect of logging deciduous versus coniferous trees on reproductive performance of Blue Tits, but our results did not provide any evidence that modest logging of deciduous trees had an effect. Similarly, logging of large trees was suspected to have the greatest impact on reproductive performance, because larger canopies provide more food resources for Blue Tits, but we found no effects of logging large trees.

The only significant effect we found was that of logging of small coniferous trees on the number of eggs laid. Although the effect was small, and this explanation does not explain why logging of larger coniferous trees did not affect clutch size, the relative importance of evergreen trees may increase because Blue Tit populations may adapt to foraging in coniferous habitats, depending on the environmental context (Tremblay et al. 2003; Mägi et al. 2009). Alternatively, evergreen trees may provide other benefits like year-round refuge against predators (Lambrechts et al. 2004). Removing these evergreens near nest-boxes may therefore have resulted in increased 'stress-related' hormones, leading to reduced clutch sizes (Julliard et al. 1997). Furthermore, at the onset of egg laying, males may sing more during the dawn chorus in evergreen trees, which may indirectly have a positive effect on clutch size. The fact that only logging of young coniferous trees had a relatively small effect on clutch size may be due to the greater toughness and higher levels of secondary components like tannins in the needles of mature coniferous trees, rendering them unappetizing to caterpillars and other insects (Hatcher 1990). Hence, young coniferous trees may provide better food resources for Blue Tits compared to mature trees. We can only speculate why logging of larger deciduous trees had no effect on reproductive performance, especially since a previous correlational study in this population showed that egg laying started earlier and clutch sizes were larger in habitats with more mature deciduous trees (Amininasab et al. 2016). It is possible that the small number of deciduous trees cut per territory did not significantly affect food supply, and most territories still had sufficient food resources available despite logging. Alternatively, given that vertical flight is more costly than horizontal flight, it could be that higher trees cause foraging to be more energetically costly, balancing the benefits of greater food supply.

Regardless of the mechanism, however, we show that small changes in coniferous, rather than deciduous, habitats can have effects on the reproductive performance of Blue Tits. This counter-intuitive result highlights the need for further studies to elucidate the specific ecological mechanisms (e.g., food availability, trees providing refuge, differential energetic costs of foraging) behind our results. Similarly, disturbance from noise and machinery during the logging event itself could have been an important confounding factor. However, logging occurred 3–4 months before the breeding season, which suggests that disturbance because of logging is unlikely to explain our results.

In conclusion, while we did observe borderline effects of logging small coniferous trees on Blue Tit clutch size, overall, our results suggest that modest logging did not have substantial detrimental effects on Blue Tit reproductive performance.

Acknowledgments We thank Kraus-Groeneveld Stichting for permission to work in De Vosbergen. We also thank our team of colleagues and students for assistance with field work, Peter Korsten and Han Olff for general advice, Frank Groenewoud and Kat Bebbington for statistical advice, two anonymous referees for useful comments, and Martje Birker for the summary in German. This study complies with the current laws of the Netherlands. Permission was granted by the Animal Experiments Committee of the University of Groningen. Research was supported by the Netherlands Organisation for Scientific Research (NWO-ALW 821.01.008) and other grants to J.K.

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