Long-term declines in eggshell thickness of dutch thrushes Turdus spp.

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LONG-TERM DECLINES IN EGGSHELL THICKNESS OF DUTCH THRUSHES *TURDUS* SPP.

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The thickness of the eggshells of Blackbird *Turdus merula*, Song Thrush *T. philomelos*, Mistle Thrush *T. viscivorus*, and Ring Ouzel *T. torquatus* has previously been shown to have declined in Britain based upon measurements of eggshells in museum collections. A study of eggs of three of the same species collected in the Netherlands shows evidence of a decline in eggshell thickness of similar magnitude to that found in Britain for these species. This is the first time that eggshell thickness declines of such long duration have been found in two geographically separate areas. The cause of the decline is unknown, but began before the introduction of organochlorine pesticides.

Key words: *Turdus merula* - *T. philomelos* - *T. viscivorus* – egg shell thinning - Netherlands

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INTRODUCTION

Green (1998) reported a decline in eggshell thickness over 150 years for Blackbird *Turdus merula*, Song Thrush *T. philomelos*, Mistle Thrush *T. viscivorus*, and Ring Ouzel *T. torquatus* in Britain. The decline appears continuous and does not coincide with the introduction of organochlorine pesticides in the 1940s. He suggested that acid deposition affecting the availability of calcium-rich prey might be the cause of the eggshell thickness decline. Here I investigate whether eggshell thickness declines have occurred in three of these thrushes in the Netherlands (the Ring Ouzel does not occur as a breeding bird), where the soil is less sensitive to acidification (Posch *et al.* 1999), and compare the Dutch data with Green's (1998) data for British thrushes, revised to account for minor errors which did not affect the conclusions.

METHODS

I measured all clutches of Blackbirds, Song Thrushes, and Mistle Thrushes collected within the Netherlands in the collections of the Zoological Museum, University of Amsterdam (ZMA), and National Natural History Museum *Naturalis*, Leiden (RMNH), provided that there were data on at least the year of collection and locality at which the clutch was taken. Collection sites were scattered throughout the Netherlands, but most clutches were collected within the most populated area enclosed by IJmuiden, Zwolle, Arnhem and the mouth of the river Waal, as well as in the vicinity of Leeuwarden, Enschede, Eindhoven and Maastricht. Eggs were excluded if they were broken or rolled unevenly, indicating dried remains of the egg contents. I measured the length, breadth and blowhole diameter with digital callipers and weighed each egg on an electronic balance to the nearest 1 mg. Eggshell thickness was measured directly to 1μm with a modified digital micrometer, similar to that used by Green (1998).

For each clutch I calculated the mean eggshell thickness index (ETI), the Ratcliffe index (EI) and the Moriarty-Nygård index (Green 2000). When comparing the three indices, as suggested by Green (2000), the ETI performed best for British Blackbirds and Song Thrushes as well as Dutch Blackbirds; the EI was best for Dutch Song Thrushes; and the Moriarty-Nygård index performed best for Mistle Thrush. However, the differences were small and similar to those reported by Green (2000), therefore, to make analyses comparable, I used the ETI. Clutch means of ETI and EI of Dutch eggs are closely correlated (Blackbird, r_{224} = 0.966; Song Thrush, r_{177} = 0.983; Mistle Thrush, r_{76} = 0.966; for all species $P < 0.001$), similar to findings for British clutches (Green 1998).

To assess the effect of measurement error, I measured 15% of the Dutch clutches twice (or 18% of Dutch eggs). A complete set of measurements was obtained on the clutch and the records put out of sight before beginning to measure the clutch again. The within-egg standard deviation (SD) of ETI was 0.0036 mg mm^{-2}, 1.63% of the mean; of eggshell thickness 0.52 μm, or 0.49%; of eggshell weight 4.17 mg, or 1.10%; of length 0.144 mm, or 0.51%; of breadth 0.008 mm or 0.04%. Differences between the two sets of measurements were not statistically significant (One-way ANOVA).

In all further analyses I used annual means of clutch mean ETI, directly measured eggshell thickness and volume, estimated from length and breadth (Hoyt 1979), to avoid pseudo-replication and problems of heteroscedasticity. I employed general linear models fitting year, year squared and natural logarithm of volume weighted by the number of clutches available per year. The decline of ETI and eggshell thickness could be a consequence of a change in egg volume, as larger eggs might have thicker shells. To account for this I included log(volume) into my models as a log-log relationship is to be expected between ETI/eggshell thickness and volume. Non significant terms were eliminated from the models. Further, I used analyses of covariance (ANCOVAs) to investigate whether there was a difference in eggshell thickness declines between clutches collected in Britain and the Netherlands.

RESULTS

Dutch eggshell thinning

In the Netherlands, ETI declined over the years for all of the three species. This decline was statistically significant for Song Thrush and approaching significance for Blackbird and Mistle Thrush (Table 1a). Similarly, the directly measured eggshell thickness declined for all species in the Netherlands. This effect was significant for Song Thrush and Mistle Thrush and approaching significance for Blackbird (Table 1a). A significant non-linear effect of year was only found for Mistle Thrush. Annual mean ETI and directly measured eggshell thickness were highly significantly correlated for all Dutch thrushes (Blackbird, r_{63} = 0.865; Song Thrush, r_{56} = 0.946; Mistle Thrush, r_{35} = 0.713, all $P < 0.001$).

The decline of ETI and eggshell thickness in the Netherlands was not a consequence of changes in egg volume as egg volume had no significant effect and was therefore deleted from the models. Further, egg volume did not change significantly over time for either of the Dutch thrushes (Blackbird, $F_{1,64}$ = 0.127, P = 0.72; Song Thrush, $F_{1,56}$ = 0.00019, P = 0.99; Mistle Thrush, $F_{1,39}$ = 0.0067, P = 0.94). Also annual mean ETI showed no significant correlation with volume for any species (Blackbird, r_{64} = -0.116, P = 0.35; Song Thrush, r_{56} = -0.193, P = 0.15; Mistle Thrush, r_{38} = 0.153, P = 0.34). As for the British eggs (Green 1998), no significant correlations between ETI and egg volume or between volume and year were observed.

Effects of organochlorine pesticides

I fitted weighted models for both ETI and eggshell thickness with year, year squared and log (volume) for Dutch clutches collected before 1947, thereby excluding any possible effect of organochlorine pollutants. Year squared and

Table 1. Results of weighted least squares regression analyses of annual mean ETI (mg mm^{-2}) and eggshell thickness (μm) for The Netherlands and Britain.

(A) The Netherlands	Model		*F*-value	*P*
Blackbird	ETI	0.386 - 0.000080 * year	$F_{1,64}$ = 3.35	0.072
	thickness	192 - 0.0408 * year	$F_{1,63}$ = 2.90	0.093
Song Thrush	ETI	0.478 - 0.00014 * year	$F_{1,56}$ = 6.11	**0.017**
	thickness	244 - 0.0745 * year	$F_{1,56}$ = 6.49	**0.014**
Mistle Thrush	ETI	24.92 – 0.026 * year + 0.000006655* year^2	$F_{2,38}$ = 2.32	0.114
	thickness	13304 - 13.63 * year+ 0.0035 * year^2	$F_{2,35}$ = 3.90	**0.020**
(B) Britain				
Blackbird	ETI	0.491 - 0.00014 * year	$F_{1,99}$ = 23.50	**<0.001**
	thickness	301 - 0.0990 * year	$F_{1,78}$ = 17.22	**<0.001**
Song Thrush	ETI	0.385 - 0.000092 * year	$F_{1,88}$ = 8.88	**0.004**
	thickness	174 - 0.0393 * year	$F_{1,74}$ = 5.72	**0.019**
Mistle Thrush	log(ETI)	-1.102 - 0.00034 * year + 0.139 * log(volume)	$F_{2,80}$ = 6.30	**0.003**
	thickness	not measured		

Table 2 Results from ANCOVAs comparing Dutch and British data of annual mean ETI (mg mm^{-2}) and eggshell thickness (μm).

ETI	Term	*F*-value	*P*
Blackbird	year	$F_{1,164}$ = 24.82	**<0.001**
	country	$F_{1,164}$ = 26.01	**<0.001**
	year * country	$F_{1,163}$ = 1.12	0.292
Song Thrush	year	$F_{1,146}$ = 14.88	**<0.001**
	country	$F_{1,145}$ = 0.16	0.687
	year * country	$F_{1,144}$ = 0.66	0.417
Mistle Thrush	year	$F_{1,121}$ = 5.62	**0.019**
	country	$F_{1,120}$ = 0.90	0.902
	year * country	$F_{1,119}$ = 0.21	0.213
Eggshell thickness			
Blackbird	year	$F_{1,142}$ = 15.96	**<0.001**
	country	$F_{1,142}$ = 12.48	**<0.001**
	year * country	$F_{1,141}$ = 2.70	0.103
Song Thrush	year	$F_{1,131}$ = 10.23	**0.002**
	country	$F_{1,131}$ = 4.62	**0.033**
	year * country	$F_{1,130}$ = 1.24	0.268
Mistle Thrush	not measured		

log(volume) were not significant for any of the species. The signs of the slopes for year versus ETI or shell thickness were still negative for all species, but only statistically significant for Song Thrush and approaching significance for Mistle Thrush (Blackbird, $F_{1,41/40}$ = 0.06/0.34 [ETI/ eggshell thickness], P = 0.80/0.56; Song Thrush, $F_{1,42/42}$ = 4.92/6.60, P = 0.03/0.01; Mistle Thrush $F_{1,31/28}$ = 3.55/6.22, P = 0.07/0.02). The data after 1947 were too limited, due to collecting being made illegal, to allow statistically meaningful comparisons with eggs collected before the introduction of organochlorine pesticides.

Comparison of Dutch and British trends

In Britain, the ETI and directly measured eggshell thickness declined highly significantly over the years for all three thrushes (Table 1b), as previously shown by Green (1998). Egg volume had no significant effect on ETI or shell thickness for Blackbird and Song Thrush, but significantly affected ETI of Mistle Thrush. However, egg volume did not change significantly over time for any of the British thrushes (Blackbird, $F_{1,99}$ = 1.65, P = 0.203; Song Thrush, $F_{1,88}$ = 0.0071, P = 0.933; Mistle Thrush, $F_{1,81}$ = 0.021, P = 0.886) and ETI was not significantly correlated with volume for any species (Green 1998).

To assess the magnitude of the decline in Britain and the Netherlands, I compared the mean ETI and thickness values between 1850 and 1890 with an estimate from the fitted models for 1960, as suggested by Green (1998). The decline in ETI (eggshell thickness) of Dutch clutches was 1.12% (2.20%) of the 1850-1890 value for Blackbird, and 5.20% (6.35%) for Song Thrush. There are insufficient data for Dutch Mistle Thrush between 1850 and 1890 to calculate a mean. For British clutches the decline was 5.94% (7.27%) for Blackbird, 3.48% (3.28%) for Song Thrush, and 2.23% for Mistle Thrush.

When comparing changes in eggshell thickness between countries, there were no statistically significant differences in slopes of ETI and eggshell thickness for Dutch and British clutches (Table 2). The quadratic effect of year, initially included for Dutch Mistle Thrush (Table 1a), was

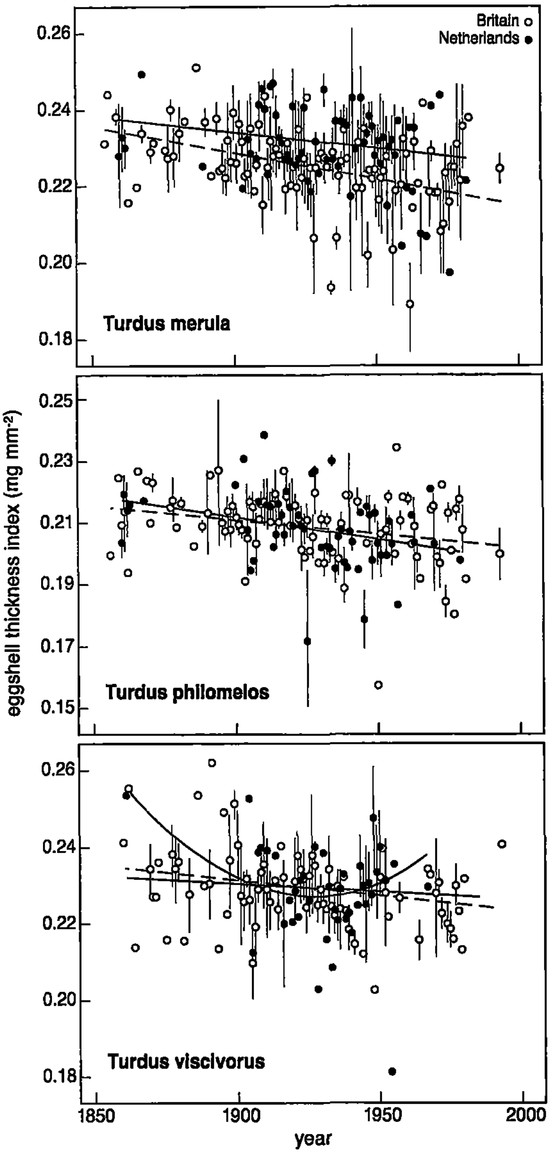

Fig. 1 Relationship between annual mean eggshell thickness index (mg mm^{-2}) (± SE) and year of collection for British (o) and Dutch (•) Blackbird *Turdus merula*, Song Thrush *T. philomelos*, and Mistle Thrush *T. viscivorus*. Weighted regression lines for year shown for Dutch (—) and British (- - -) data; for full models see Table 1. For Mistle Thrush the weighted regression lines for both linear and quadratic effect of year are shown. British data from Green (1998).

removed from the ANCOVA after inclusion of country effects, as the quadratic effect of year was non significant ($F_{1,120} = 0.095, P = 0.758$) as well as its interaction with country ($F_{1,118} = 1.51$, $P = 0.221$). Similarly, the effect of egg volume was non significant once country effects were allowed for ($F_{1,119} = 3.43$, $P = 0.066$). Further, there was no statistically significant difference between the intercepts for ETI of Dutch and British Song Thrush and Mistle Thrush eggs (Table 2), i.e. one intercept and slope were sufficient for both countries. The ETI of Blackbird declined similarly in Britain and the Netherlands, but eggs were 1.4% thicker in the Netherlands compared to Britain as indicated by the significant difference in ETI between countries (Table 2). The eggshell thickness declined similar in both countries for Blackbird and Song Thrush (Table 2), but a significant effect of country remained, indicating differences in eggshell thickness between the two countries. Eggshells of Blackbird and Song Thrush were thicker in the Netherlands by 1.2% and 0.9%, respectively.

The ETI and shell thickness of British and Dutch Song Thrush and Mistle Thrush declined similar in both countries prior to the widespread introduction of organochlorine pesticides in 1947. The slopes for ETI and eggshell thickness were not significantly different between the two countries prior to 1947 (ANCOVA: year * country interaction for Song Thrush, $F_{1,103/96}$ = 0.387/0.137 [ETI/eggshell thickness], P = 0.54/0.71; Mistle Thrush, $F_{1,92} = 0.773, P = 0.38$, thickness not measured), but were significantly different between countries for Blackbird ($F_{1,106/95} = 4.79/6.61$, $P = 0.03/0.01$).

DISCUSSION

Eggshell thickness of three species of thrush has declined over the past 150 years. The decline in the Netherlands is very similar to that observed in Britain, though not always statistically significant. It should be noted that the small samples and the scarcity of clutches obtained in the 19th century from the Netherlands reduce the statistical power of the models compared with those for Britain. This might explain the non-significant declines in shell thickness for Blackbird and the difference in shell thickness declines in Britain and the Netherlands before 1947.

The observed declines were probably not caused by organochlorine pesticides that caused a step-wise decline in raptor eggshell thickness (Ratcliffe 1970; Anderson & Hickey 1972; Newton 1979). Eggshell thickness of thrushes declined gradually, starting well before the introduction of DDT. The trends might be artefacts of egg preparation methods or museum storage. Thinner shelled eggs might break more easily during preparation and handling, however there is no reason to assume that preparation techniques or care during handling would have changed over time. Also, thin shelled or abnormal eggs might have been removed or eaten by birds before these could have been collected, such behaviour has been reported for Great Tits *Parus Major* (Graveland & Berends 1997), however I cannot control for this effect. Further, eggshell fragments were not measured, as I could not determine which part of the egg such fragments came from. Because of these potential biases the observed trends might be a rather conservative estimate of actual declines of eggshell thickness in the wild.

During museum storage, the probability of egg breakage might depend on shell thickness and might be constant over time. If this was the case, then more of the older thin-shelled eggs might have broken, potentially giving rise to the observed declines in eggshell thickness over time. However, egg breakage occurs rarely in collections and is likely to be accidental, affecting eggs irrespective of their shell thickness. Further, accumulation of dust or the application of preservatives to suppress the growth of mould would alter eggshell weight and hence the ETI. However, similar trends were found for measured eggshell thickness, which is not affected by such contamination (Green 1998).

Shell defects of passerines have been related to the calcium content of soil (Graveland *et al.* 1994) and shell thickness to the acidity of stream water (Ormerod *et al.* 1988; Nybø *et al.* 1997).

Reduced calcium availability caused by acid deposition is thought to affect invertebrates, especially snails that form an important calcium source in the diet of Great Tits prior to laying (Graveland & van der Wal 1996). However, Blue Tits *Parus cearuleus* on acid-sensitive soils in Scotland appear less affected by acidification than Dutch birds (Ramsay & Houston 1999). Both the Netherlands and Britain have been affected by acid rain, with the Netherlands having slightly less sensitive soils than Britain (Posch *et al.* 1999). However, the decline of eggshell thickness in both countries is similar for all three thrushes. Metal pollution is also known to affect eggshell quality (Nyholm 1981; Eeva & Lehikoinen 1995), but is unlikely to have affected birds over such long time periods and spatial scale, as metal pollution tends to be concentrated around sources (e.g. smelters) and affects birds locally (Eeva & Lehikoinen 1995).

The causes of the eggshell thickness decline are unknown, but eggs are affected similarly in both Britain and the Netherlands. Further research is required to investigate geographical differences in eggshell thickness and environmental properties to find a possible cause of the observed eggshell thickness decline.

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SAMENVATTING

In Groot-Brittannië is bij vier soorten lijsters (Merel *Turdus merula*, Zanglijster *T. philomelos*, Grote Lijster *T. viscivorus* en Beflijster *T. torquata*) de schaaldikte van eieren in museumcollecties in de loop van de afgelopen 150 jaar afgenomen. In dit artikel analyseert de auteur de dikte van eischalen van drie soorten lijsters uit Nederlandse musea en vergelijkt deze met de Britse gegevens. In Nederland werd bij alle drie soorten een afname in eischaaldikte gevonden, die vergelijkbaar was met de in Groot-Brittannië gevonden trends. Hoewel de trends door de jaren heen vergelijkbaar zijn,

zijn de eieren van Nederlandse Merels dikker dan die van Britse Merels. Dit is de eerste keer dat een afname in eischaaldikte over een zo'n lange periode in twee geografisch gescheiden gebieden is gevonden. De oorzaak van de afname is niet duidelijk, maar zij begon voordat in de landbouw organochloorverbindingen bevattende pesticiden werden geïntroduceerd. (CB)

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