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Eggshell Thickness Variation in Red-legged Partridge (*Alectoris rufa*) from Spain

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ABSTRACT.—Eggshell thickness is commonly used as an indicator of habitat quality and effects of environmental pollution on avian reproduction. We present the first data available on eggshell thickness for Red-legged Partridge (*Alectoris rufa*) in Spain. We compared eggshell thickness between eggs collected in an agricultural area (wild eggs) and eggs from game farms (farm eggs). Wild eggs had shells significantly thicker ($\bar{x}$ = 0.32 mm, n = 74) than farm eggs ($\bar{x}$ = 0.28 mm, n = 89), despite game farm partridges being fed a diet rich in calcium and not exposed to agricultural pollutants. Eggshell thickness did not affect hatching success of wild partridges, and population decline observed in this species cannot be linked to reduction in egg viability due to eggshell thickness. *Received 8 February 2008. Accepted 6 May 2008.*

Reduction of egg viability is an important cause of reproductive failure and has been suggested to contribute to decreases of bird populations (Drent and Woldendorp 1989, Cooper et al. 2005). Eggshell quality and reproduction of bird species is greatly affected by levels of calcium availability (Graveland and Drent 1997, Dhondt and Hochachka 2001, Tilgar et al. 2005), which in turn can be affected by levels of pesticides (Dauwe et al. 2006) or acidification (Nybø et al. 1997, Pollentier et al. 2007).

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High levels of pesticides are related to reduction in eggshell thickness in many species (Bunck et al. 1985, Peakall and Lincer 1996, Falk et al. 2006). Thus, eggshells are reasonable indicators of polluted areas, and can be used to monitor health of populations over long periods (Falk et al. 2006). However, long-term thinning of eggshells may not universally be related to pollution. A large decline in eggshell thickness in different species of thrushes (*Turdus* spp.) from different countries has been observed since before the introduction of organochlorine pesticides, but the cause of the decline is still unknown (Green 1998, Scharlemann 2003).

The Red-legged Partridge (*Alectoris rufa*) has been decreasing throughout its range (Meriggi and Mazzoni 2004 and references herein). Lack of reproductive success has been mainly attributed to food scarcity due to agricultural practices and nest predation (Potts 1980). However, the reproductive biology of this species is poorly known (Cabezas-Díaz et al. 2005) and little information is available about eggshell characteristics, which could affect reproductive success.

Our objectives were to measure shell thickness of eggs of Red-legged Partridge from a wild population to compare with those from a population where partridges had no food limitations, were putatively not subjected to agricultural pollution, and were known to have high hatching success. We tested the prediction that eggshells from the wild population should be thinner than those from the game farm population.

METHODS

We collected depredated and deserted eggs of Red-legged Partridge in the wild (Lleida, Catalonia, northeast Spain) during May to September 2002 and 2003. The procedure for locating eggs was to walk slowly through the study area where reproductive pairs and incubating females were previously observed, while looking under bushes and herbs. Most eggs were found isolated and dispersed in the field. Others were collected with the help of hunters, game keepers, and volunteers in an area of 1,500 ha. We were unable to distinguish if isolated eggs belonged to the same nest or not. In the absence of knowledge of predator behavior, substrate inclination, or the distances eggs could roll when pushed from the nest by sheep (e.g., Castilla and Rodriguez 2002), we assumed that all eggs are independent samples. When eggs were found in nests ($n = 19$), only a single egg was used to exclude dependence of data.

The study area is dominated by cultivated areas mainly cereals (barley, wheat, and oats), *Prunus dulcis* and *Olea europaea*, mixed with grasses and woodlands (e.g., *Quercus ilex*, *Q. coccifera*, *Q. humilis*, *Rosmarinus officinalis*, *Thymus* spp.). The area is used for livestock production and agricultural crops (cereal grains, almonds, and olive trees). Seeds treated with fungicides and insecticides are used. These seeds are consumed by partridges (Castilla 2003). A large variety of herbicides and fertilizers (organic and mineral) are applied on farm fields (Castilla et al. 2008b).

We obtained 89 partridge eggs from game farms in central Spain (Burgos, $n = 35$) and northeast Spain (Barcelona, $n = 54$). Each egg originated from a different individual. Non-developed eggs were infertile and unincubated. Unknown eggs were infertile or aborted in different stages after incubation. Both farms were near urban areas and far from agricultural fields.

We opened and examined the content of intact eggs to assess if they were developed or not. Eggs having yolk or small embryos <10 days development and depredated eggs having small holes from which a developed chick could not have been taken by predators were classified as not fully developed (Castilla et al. 2008a). Pieces of broken eggs found in the wild were classified as unknown, because we had no evidence that allowed us to infer their developmental stage. Non-developed eggs in game farms were infertile and not incubated. Unknown eggs were aborted during incubation and their developmental stage was not ascertained.

Eggshells were cleaned, the membrane removed, and eggshell thickness measured around the equator. All measurements were performed by the same person using a micrometer (Mitutoyo) to the nearest 0.001 mm.

We used one-way ANOVA to test differences in eggshell thickness by developmental stages and from different sources. Mean values were compared with a post-hoc test (Fischer's protected least significant difference, $P \leq 0.05$). Analyses were performed using SPSS V13 (Statistical Package for the Social Sciences, Chicago, Illinois, USA).

RESULTS

Mean eggshell thickness for eggs collected in the wild was 0.329 mm (SD = 0.047, range = 0.20–0.42 mm, $n = 74$). Eggshell thickness was similar for eggs from the two game farms for development stage 1 ($F_{1,50} = 1.07$, $P = 0.310$) or unknown stage ($F_{1,50} = 0.91$, $P = 0.351$), and we pooled the data. No significant effect of development stage was found on eggshell thickness for game farm eggs ($F_{2,86} = 0.69$, $P = 0.512$). Mean eggshell thickness of game farm eggs was 0.284 mm (SD = 0.03, range = 0.21–0.34 mm, $n = 89$). Eggshell thickness of wild ($n = 74$) versus game farm eggs ($n = 89$) was significantly different ($F_{1,162} = 55.38$, $P < 0.001$) (Table 1).

DISCUSSION

Variation in egg shell thickness has not been reported to our knowledge for any partridge species in the wild, and has only been reported for Rock Partridge (*Alectoris graeca*) in a game farm (0.228 mm) (Tilki and Saatci 2004). Body size and egg size of Rock Partridge are similar to that of Red-legged Partridge (Cramp and Simmons 1980). We found that eggshell thickness was higher for wild birds versus the game farm population, despite females in game farms being fed a calcium-rich diet and were not exposed to farming or agricultural pollution. Egg size and wing size of wild and farm Red-legged Partridge are similar in our study site (Castilla and Pastor 2002, Castilla and Martínez in press), but body mass of game farm partridges (398–496 g) is higher than that of wild partridges (327–448 g) of ~4–6 months of age (Castilla and Pastor 2002). It has been shown that stronger-thicker eggs correspond to heavier bird species (Ar et al. 1979) but, we compared pop-

TABLE 1. Eggshell thickness (mm) of eggs collected in the wild (Sanaüja, Lleida, Spain) or in game farms (Barcelona: B and Burgos: BU, Spain) with different developmental stages.

	Wild (n = 74)			Game farm (n = 89)			
	Not developed		Unknown	Not developed		Unknown	
	Deserted	Depredated	Depredated	B	BU	B	BU
Mean	0.25	0.338	0.332	0.283	0.276	0.290	0.280
SD	0.04	0.04	0.04	0.02	0.03	0.03	0.03
Max	0.29	0.407	0.419	0.337	0.325	0.335	0.331
Min	0.20	0.254	0.202	0.241	0.211	0.239	0.221
n	3	24	47	31	21	23	14

ulations of about the same body size and mass. Female partridges in game farms lay more eggs ($\bar{x}$ = 50) than those in the wild ($\bar{x}$ = 10) (Castilla and Rodriguez 2002; game farms, pers. comm.), which may result in eggshell thinning in game farm populations.

Overall hatching success in game farms is high (>80–90%, game farm data). We observed a large number of chicks (8 to14/brood in the wild population) after the hatching period in May (Castilla and Martínez in press), suggesting that hatching success may also be high in the wild. Eggshell thickness in our wild partridge population does not appear to affect hatching success. Thus, the population decline that has been observed since the early 1970s in our study site should not be linked to the reduction in egg viability due to eggshell thickness.

Eggshell thickness may not be implicated in range-wide declines of Red-legged Partridge. However, our finding should be explored in other studies conducted at larger scales. Eggshell thickness and hardness can be extremely variable due to factors including pollution, individual female, clutch size, sequence of laying, egg characteristics, developmental stage, etc. (Falk and Møller 1990, Burger et al. 1995, Massaro and Davis 2004, Gosler et al. 2005, Higham and Gosler 2006, Kemps et al. 2006, Castilla et al. 2007). However, for many species the causes of eggshell thickness variation remain unknown (e.g., Green 1998, Scharlemann 2003). More basic research is needed to fully understand the factors affecting eggshell thinning in bird populations.

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