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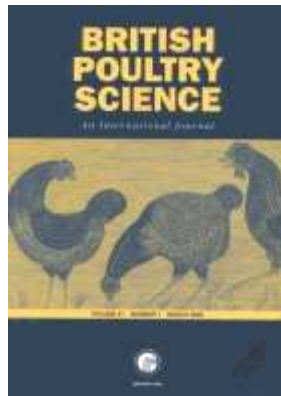
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Effect of sight barriers in pens of breeding ring-necked pheasants (*Phasianus colchicus*) II. Reproductive parameters

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Running head: Sight barriers and reproductive performance

Abstract 1. The effects of sight barriers in the pens of breeding ring-necked pheasants were investigated on a commercial game farm over a 10-week laying season.
2. Reproductive performance was recorded as egg production, numbers of eggs rejected for hatching together with measures of fertility, embryonic mortality and hatchability for 11 pens with barriers and 11 pens that were left open and acted as controls.
3. Egg production per pen and the numbers of rejected eggs were not significantly affected by the presence of the barriers.
4. Fertility was significantly higher and persisted for longer in the barrier pens, particularly towards the end of the laying season.
5. Embryonic mortality was unaffected by the presence of the barriers but hatchability was significantly lower in the open pens, which was associated with lower levels of fertility.
6. Establishing sight barriers in breeder pens for commercial pheasants would appear not only to offer improved welfare but also significant commercial advantages.

Keywords: Pheasant, sight barrier, egg production, fertility, embryonic mortality, hatchability

INTRODUCTION

The game industry based around release of pheasants and partridges is a major contributor the rural economy and is important in implementing conservation in countryside in Britain (PACEC, 2006). Most of the ~35 million ring-necked pheasants released into the countryside for shooting are produced on game farms under intensive conditions (Farm Animal Welfare Council, 2008). It is anticipated that game farms will increasingly face pressure to improve bird welfare and so studies are beginning to investigate the impact of rearing conditions on the welfare of pheasants (Butler and Davis, 2010).

Deeming *et al.* (sub.) described the effects of sight barriers on the behaviour and welfare of breeding pheasants on a commercial game farm. Restricting the view of birds using barriers significantly reduced aggression and plumage damage, which were considered as improvements in welfare. Brown leghorn chickens prefer to use panels placed in their pens as cover and exhibited increased resting and preening behaviours (Newberry and Shackleton, 1997). Cornetto and Estévez (2001) also showed that introducing panels placed in a

staggered pattern along the length of sheds had significant effects on broiler chicken behaviour. Leone and Estévez (2008) showed that the presence of black mesh panels in broiler breeder sheds were associated with improvements in egg production, fertility and hatchability. This was considered to most likely due to an increase in the males' mating opportunities and a reduction in female stress.

Fertility of eggs is a key aspect in the productivity of pheasant breeding operations. Deeming (2009) reported that infertile eggs averaged 10% of eggs set to incubate with the range of values extending up to 23%. Deeming and Wadland (2002) showed that mating ratio is important in determining levels of fertility of breeding pheasants and suggested that the presence of more males allowed for higher mating frequency. Other studies on fertility in commercial pheasants are rare and although Guidobono Calvalchini *et al.* (2004) studied fertility of pheasants in cages it is not clear what their data represent and so they are difficult to interpret. This lack of data is disappointing because fertility impacts upon hatchability of pheasant eggs (Deeming and Wadland, 2002) and is of commercial significance.

Given the effects of sight barriers on pheasant behaviour (Deeming *et al.*, sub.), it was hypothesised that, like in broiler breeders (Leone and Estévez, 2008), sight barriers would have a positive impact on the reproductive performance of the birds. The barriers could provide refuges for birds that would perhaps allow for development of territories by males, more effective courtship and copulation events, or perhaps greater mating frequency. Compared to more typical open pens this should allow the birds to maintain a higher level of fertility over the course of the 10-week laying season.

Despite benefits for bird welfare (Deeming *et al.*, sub.) that provision of sight barriers would be an additional cost to game farmers, which act as a disincentive for their use. It was considered important to investigate whether the barriers could have commercial benefits, *e.g.* on reproductive performance, as is shown in broiler breeders (Leone and Estévez, 2008). The study described here examined our investigation into the effects of sight barriers on egg production, fertility, embryonic mortality and hatchability of commercial pheasants. The data reported here were collected from the same experimental birds and over the same period of time as Deeming *et al.* (sub.).

MATERIALS AND METHODS

Experimental design

A full description of the experimental design for this study is provided by Deeming *et al.* (2011) and so is only briefly described here. Twenty-two pens holding commercially reared ring-necked pheasants (*Phasianus colchicus*) were established at a commercial game farm to provide 11 control pens, and 11 experimental pens that contained sight barriers. Each pen measured 13.2 x 13.2 m and initially contained 56 female and 8 male birds. All birds had been hatched in June 2009 and were in their first breeding season. All pens were comprised of slatted wooden sides up to approximately 0.6 m, and wire mesh above this point, and were roofed with soft nylon mesh. The floors were soil and grass. All pens were provided with pelleted feed *ad libitum*, a drinker-bowl, and a bowl of grit.

Control ("open") pens used the typical open arrangement of commercial pens at the farm and so had only 5 or 6 metal half oil barrels (to provide sheltered nesting sites) that could potentially obscure the view of birds. Experimental ("barrier") pens incorporated tin sheeting and straw bales to act as sight barriers to the height of 60 cm, but other than this they were identical to the open pens. Birds in the barrier pens could only see

up to an approximate maximum of a third of the area of the pen at any time. The experimental design for the study was approved by the Ethics Committee of the Faculty of Agriculture, Food and Animal Sciences, University of Lincoln.

Reproductive parameters

Eggs were collected from the pens once a day. On four occasions during weeks 1, 9 and 10 (twice) the location of eggs within the pen was recorded during collection. It was noted whether eggs were laid in the open pen, or under the barrel nest sites. For all days numbers of eggs from each pen were recorded prior to washing in a commercial machine and grading to remove any ‘defective’ eggs, which were rejected for setting. These were classed as: small; large; very large – double-yolked; with a chalky shell; with a blue shell; or soft-shelled. Eggs were then set on to labelled incubator trays and stored for up to 7 days at 15°C. Prior to setting eggs were pre-warmed overnight at room temperature and then were incubated in a Western 36 game setter operated under a fixed-rack system. Transfer was after 21 days onto hatcher baskets and set into Western hatchers and the hatch was taken off on the 25th day.

After 10–12 days of incubation, each egg was individually candled using a halogen candling lamp to reveal clear eggs, which were removed for examination. At the laboratory eggs were opened with forceps and whether the egg showed evidence of embryonic development was assessed by eye. An infertile egg was deemed to have no evidence of membrane development and with a small blastodisc (Deeming and van Middelkoop, 1999). Eggs containing evidence of embryonic mortality were classified on whether death had occurred during the first four days of incubation or thereafter (Deeming and van Middelkoop, 1999). At take-off of the hatch all chicks were removed from the hatcher baskets and the remaining eggs counted. Numbers of eggs that contained embryos that had died after candling were then recorded together with the number of hatched chicks. Embryonic mortality between 5–25 days was calculated by difference.

Statistical analysis

Data were recorded weekly on a per pen basis to calculate average values for the number of eggs collected and the number of rejected eggs. Statistical analysis was performed using PSAW (SPSS Inc., version 17.0). Average percentages of eggs laid under nest sites or in the open were compared using a Mann Whitney U test. Values for fertility, embryonic mortality for the first four days and thereafter, together with hatchability, were all recorded as percentages of the eggs incubated. Means were calculated in order to compare data from the barrier and open pens. Data were tested for normality using one-sample Kolmogorov-Smirnov tests prior to analysis. Mean numbers of eggs collected per pen and the number of rejected eggs were log₁₀ transformed prior to analysis but values for fertility, mortality and hatchability were expressed as proportions and arcsin transformed to normalise the data (Fowler *et al.*, 1995). The effectiveness of this calculation was tested using Kolmogorov-Smirnov tests. The effect of the pen type on all variables was tested using repeated measures analysis of variance (ANOVA) using the Greenhouse-Geisser test for sphericity. Comparison of means for fertility and hatchability were compared per week using independent two sample t-tests. Means are presented for untransformed data, but analyses were conducted on all raw data as transformed values.

RESULTS

Eggs were laid under the metal half barrel nest sites but also alongside the side walls of the pen and alongside the barriers as well as in vegetation. Mean values for the percentage of eggs laid in nest sites provided, averaged over the four time periods for observations, were significantly lower in barrier pens than in the open pens (means \pm SE: 51.4 ± 2.6 and 70.7 ± 2.7 , respectively; Mann Whitney test: $U = 0.0$, $N_1 = 4$, $N_2 = 4$, $P < 0.05$).

Egg production

Just over 60,000 eggs were laid by birds in this study and egg production expressed as eggs laid per pen per day showed an initial rapid rise at the start of the laying season with a slow decline after peak during week 4 (Figure 1). This was not affected by the presence of barriers in the pens (repeated measures ANOVA $F_{1,20} = 0.12$, $P = 0.767$).

A total of around 8,300 eggs were rejected over the course of the laying season. The number of rejected eggs was initially low but increased as the laying season progressed (Figure 2). Although when expressed as a percentage there was a slight reduction in rejected eggs during the early part of the season, this steadily increased to a plateau of ~20% of eggs laid by the last two weeks of lay. There was no effect of treatment on the numbers of rejected eggs (repeated measures ANOVA $F_{1,20} = 0.23$, $P = 0.634$). The increase in rejected eggs was mainly due to an increase in small eggs (50-70% of the total) but there was also a rise in chalky eggs over the course of the laying season reaching around 10% of rejected eggs by week 10 of lay. There was no effect of the presence or absence of the barriers on the numbers of the different types of rejected egg.

Fertility

Around 7,000 eggs were candled out of the trays over the 10-week laying period of which 4,350 were deemed to be infertile. True fertility expressed as a percentage of eggs set to incubate rose to a peak during week 3 but then declined thereafter (Figure 3). The presence of sight barriers was associated with higher fertility from week 3, which declined thereafter more slowly than for eggs from the control pens. The difference in fertility during week 3 was 1% but this difference progressively increased as weeks proceeded to a value of 4% during week 10. Repeated measures ANOVA showed that this pattern approached significance ($F_{1,20} = 3.90$, $P = 0.062$).

In both types of pens, as the birds came into full reproductive performance egg production was low during weeks 1 and 2 and fertility did not peak until week 3. For these reasons, data for fertility from the first two weeks of lay were excluded and a second repeated measures ANOVA was conducted. Over weeks 3–10 fertility on average was 2.7% higher in pens with barriers and with this restricted data set there was a significant effect of the presence of sight barriers ($F_{1,20} = 6.58$, $P = 0.018$). For individual weeks, pairs of means were only statistically different on weeks 8, 9 and 10 (Figure 3).

Embryonic mortality and hatchability

Early embryonic mortality (0-4 days) averaged around between 4.5–5.0% of eggs set and was unaffected by week of lay. There was also no consistent pattern with respect to the presence or absence of barriers or not (Figure 4). Repeated measures ANOVA confirmed that compared with the control pens there was no effect of barriers on this measure of mortality ($F_{1,20} = 2.99$, $P = 0.099$). Mortality between 5-25 days of incubation averaged 15–16% for both types of pens and was 2-3% higher at the end of the laying season (Figure 4). Again

repeated measures ANOVA confirmed no effect of barriers on this measure of embryonic mortality ($F_{1,20} = 0.38$, $P = 0.545$).

Hatchability of eggs set was typically above 70% over the first half of the laying season but slowly declined thereafter (Figure 5). It was unclear why there was variation in the pattern during weeks 9 and 10 but this was probably due to management of the incubators involved. Hatchability was between 1 and 4% higher in the barrier pens during all weeks of lay except for weeks 1, 2 and 4 (Figure 5). Repeated measures ANOVA for data from all weeks only approached significance ($F_{1,20} = 3.50$, $P = 0.076$). As for fertility, hatchability did not peak until week 3 and between weeks 3-10 the barrier pens had hatchability values that were on average 3.0% higher than control pens. Repeated measures ANOVA for data collected between 3–10 weeks showed that the difference in hatchability was significantly affected by the presence of the barriers ($F_{1,20} = 6.58$, $P = 0.013$). For individual weeks pairs of means were only statistically different on weeks 7 and 8 (Figure 5).

DISCUSSION

This is the first time that environmental complexity has been shown to impact upon fertility in pheasants and is similar to results shown for comparable kind of environmental enrichment in broiler breeder sheds (Leone and Estévez, 2008). Our hypothesis that sight barriers would have a positive impact upon the fertility of pheasant eggs was supported by data reported here. Fertility was not only higher in the pens with barriers but also persisted for longer over the laying season. The barriers were also associated with an improvement in hatchability that was associated with higher fertility rather than changes in embryonic mortality.

Panels within broiler breeder houses improve egg production by 2% over the laying period of the flock (Leone and Estévez, 2008). In the present study egg production was not significantly affected by the presence of the barriers and at peak of lay was comparable to levels reported for pheasants by Deeming and Wadland (2002). However, by the end of the laying season egg production in the present study was higher with each female producing approximately one more egg per week. Deeming and Wadland (2002) studied pheasant flocks of 250 females in pens with an area of 1,250 m² and included sight barriers, compared with 56 females in pens measuring 174 m² in the present study. Whether the observed difference in egg production between studies reflects on the difference in pen size or flock size is unclear. The decline in egg production post peak has been reported previously in pheasants (Mashaly *et al.*, 1983; Baglicca *et al.*, 1990; Deeming and Wadland, 2002).

It was interesting that, when expressed as a percentage of eggs collected, the levels of egg rejection described here were very similar to that reported by Deeming and Wadland (2002) although the types of problems reported were different. Deeming and Wadland (2002) found that blue-shelled eggs were most commonly rejected and small eggs, which formed the bulk of the reject eggs in this study, were relatively rare. This may reflect the different emphasis placed on egg quality at these two different game farms. Blue-shelled eggs are relatively thin and have structural defects (Richards and Deeming, 2001) but the factors affecting their production are unknown. Categorising eggs as small may be subjective because in this study the eggs were not weighed but it may reflect nutrient availability to the females. For whatever reasons rates of egg rejection in pheasants appears to be generally high and research is needed to better understand how husbandry and nutrition contribute to variability in egg quality.

The level of fertility found in this study were produced with a 7:1 female:male sex ratio and peaked at over 94% for the pens with barriers. These values were ~2% higher than the fertility reported for pheasants kept

in large groups and in larger pens at a 8:1 sex ratio and around ~8% higher than for pens with a sex ratio of 12:1 (Deeming and Wadland, 2002). Bates *et al.* (1987) reported that fertility was lower for pens with an 18:1 sex ratio than for a 12:1 ratio. Guidobono Calvalchini *et al.* (2004) reported that sex ratio significantly affected fertility in caged pheasants but presented no data to support this claim. In general, the evidence is that lower sex ratios (fewer females per male) produce greater fertility.

Here we showed that the presence of barriers in the pen had a significant effect on the level and persistence of fertility. The reason for this is unclear because copulation behaviour was not observed on a frequent basis (see Deeming *et al.*, sub.) and pen type had no effect on the number of matings observed. The observed higher fertility in the barrier pens is strong indirect evidence that, compared with open pens, either copulations rates (observed or not) are higher, or the efficacy of mating is higher, when birds are in pens with barriers. Leone and Estévez (2008) showed that fertility persisted for longer in broiler breeder sheds with panels, which were considered to increase mating opportunities for males, reduce forced matings and so reduce female stress. The barriers may provide seclusion for courting pheasants, which leads to an efficient mating climax, or may allow males to establish and defend territories or perhaps control harems of females (Deeming *et al.*, sub.). The mechanism by which this simple change to the environment affects a change in fertility in pheasants requires further investigation.

Patterns of embryonic mortality reported here are very similar to that reported by Deeming and Wadland, (2001). The level of early mortality was near identical to that reported for pheasants by Deeming and Wadland (2001) although laying week had no significant effect in the present study. Early embryonic mortality is also comparable to other bird species (Deeming and van Middelkoop, 1999; Deeming, 2009). Levels of late mortality were lower than previously reported (Deeming and Wadland, 2001), which is reflected in the higher hatchability reported here. Indeed reported hatchability in commercial pheasants are typically around 65% or less (Deeming and Wadland, 2002; Demirel and Kirikçi, 2008; Deeming, 2009) and the higher values (69-71% averaged over 10 weeks) recorded in the present study may reflect the quality of the incubator used or the operation of the hatchery. Hatchability of other eggs laid and incubated at the game farm was generally 2% lower than the trial eggs and this may reflect better scrutiny of eggs prior to setting. These results highlight the continued need for research into the factors causing embryonic mortality after 5 days of incubation in pheasants (Deeming and Wadland, 2001) because a better understanding of these factors would have significant effect on profitability of many game farms.

The presence of barriers in the breeding pens affected hatchability but this was unrelated to levels of embryonic mortality. Rather, females in the barrier pens simply produced more fertile eggs and this allowed a higher hatchability. It is interesting to note that panels placed inside broiler breeder sheds also significantly increased hatchability after the peak at 35 weeks of age (Leone and Estévez, 2008); by 60 weeks of age the difference in hatchability was 2.6%.

The presence of barriers in a breeding pen for pheasants is associated with an economic cost of provision and maintenance of the structures. That there were more eggs laid outside of nest sites provided could impact upon the time and cost involved for collecting the eggs. Such additional costs may restrict the adoption of barriers within the game industry despite the apparent benefits to pheasant welfare (Deeming *et al.*, sub.). That there is an increase in fertility and hatchability associated with the presence of barriers would go a long way in promoting their benefits overall. Increases in hatchability of 2-3% seen in this study, and in the study of broiler

breeders by Leone and Estévez (2008), are of significant commercial significance and may yield profits that far out weigh the costs of providing barriers.

ACKNOWLEDGEMENTS

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Figure 1. Egg production per pen per day for the barrier and control pens. Values are means (N = 11 in each case) and standard errors.

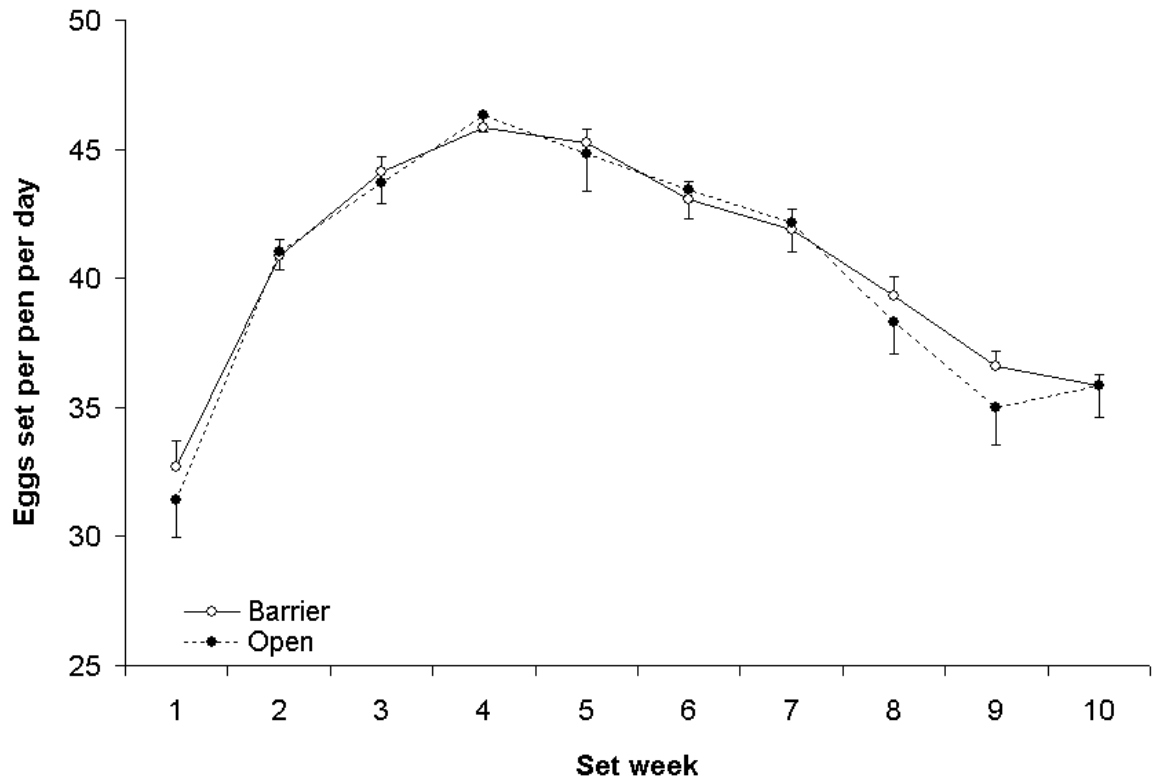


Figure 2. Mean numbers of rejected eggs produced per week for the barrier and control pens (N = 11 in each case). Data are also shown as mean percentage values of the eggs collected.

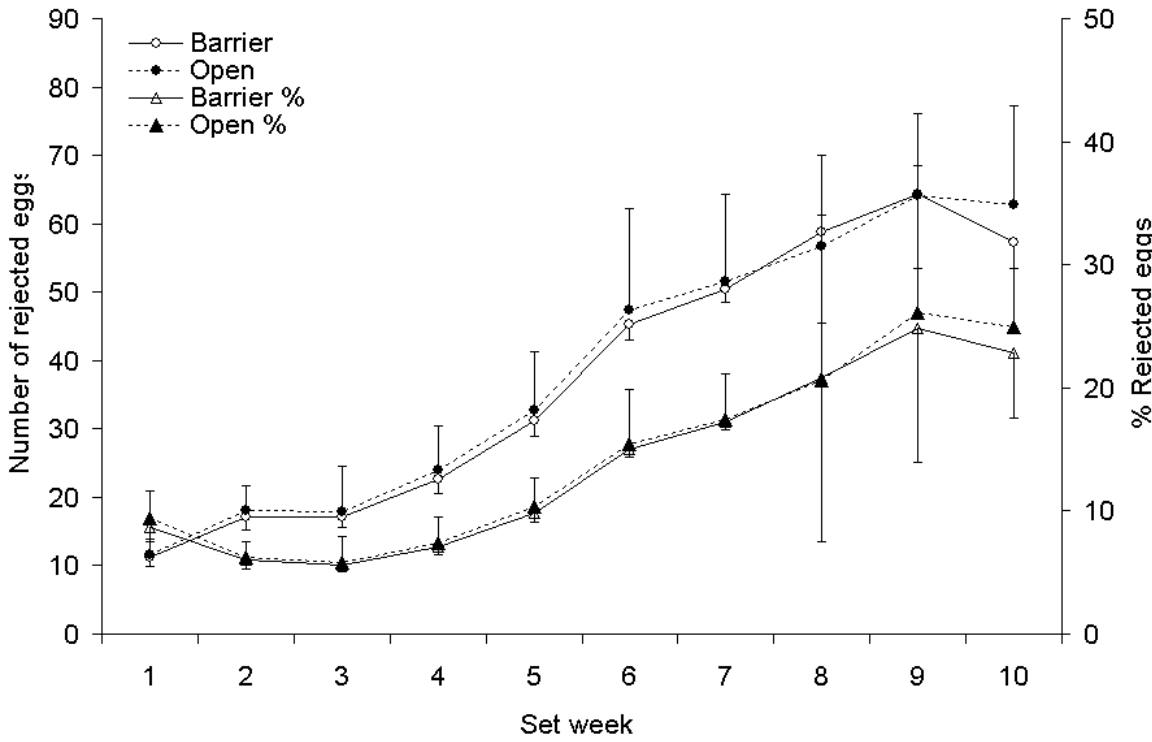


Figure 3. Percentage of fertile eggs produced per week for the barrier and open pens. Values are means (N = 11) and standard errors. Asterixes indicate that for the week mean levels of fertility were significantly different between treatments at $P < 0.05$.

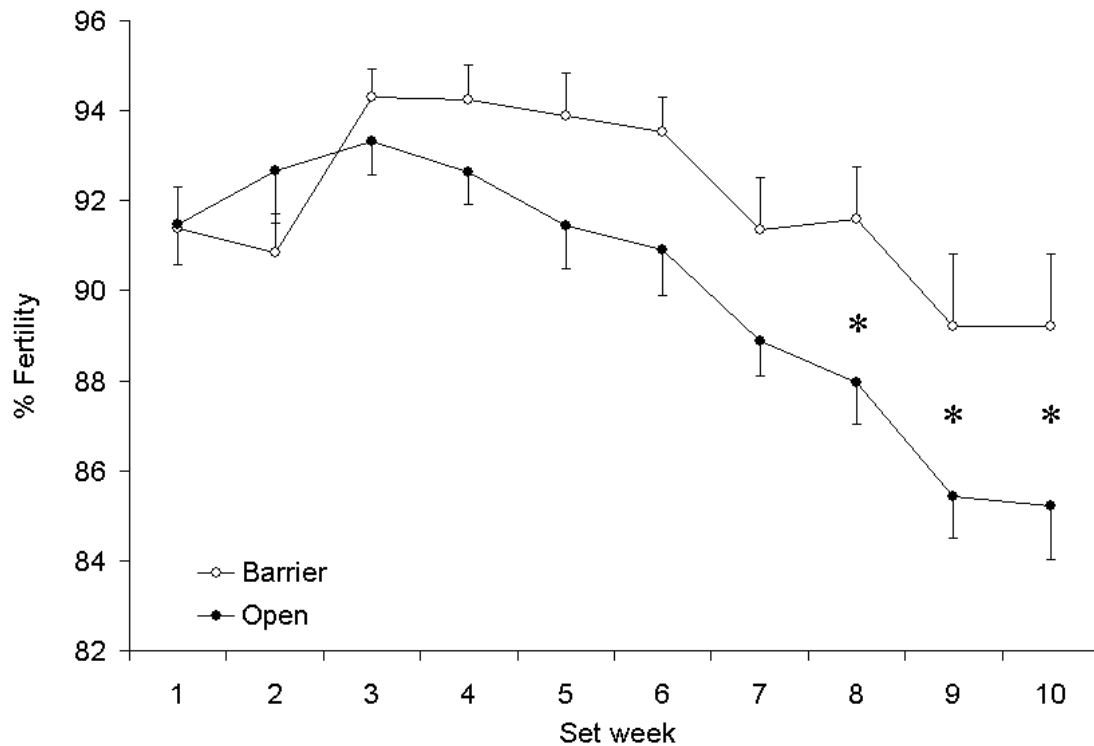


Figure 4. Percentages of eggs exhibiting embryonic mortality between 0-4 days ("Early") and 5-25 days ("Mid-late") of incubation per week of lay for the barrier and open pens. Values are means (N = 11) and standard errors.

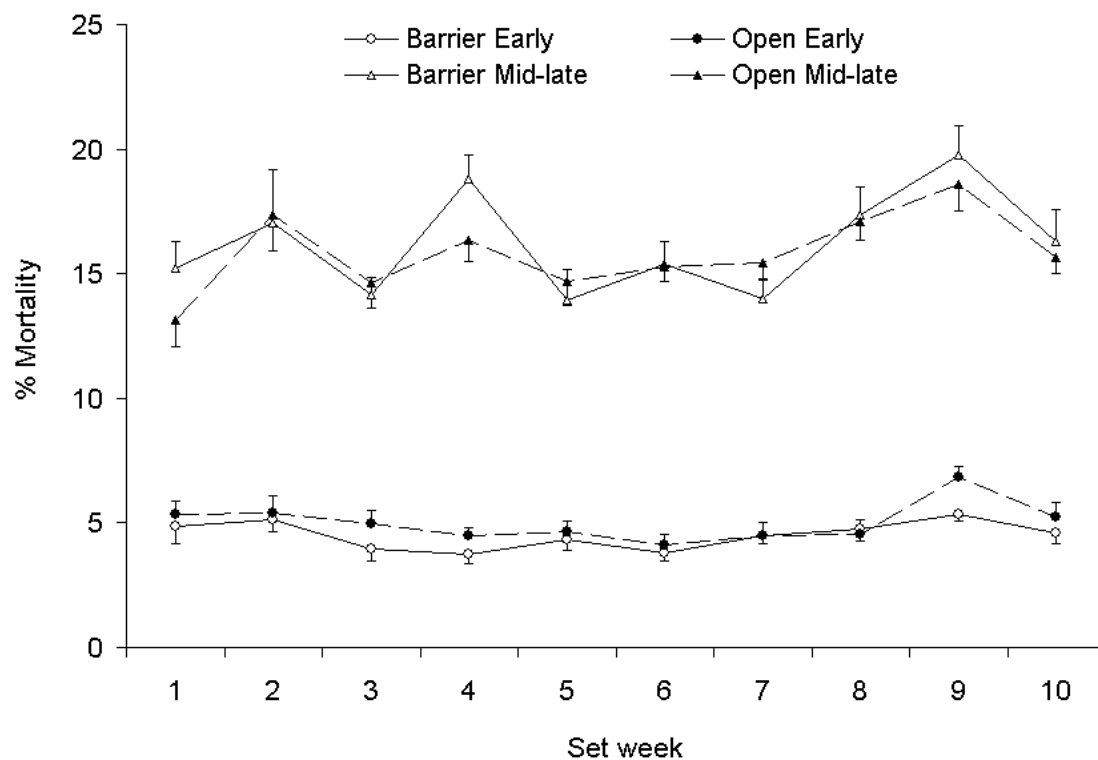
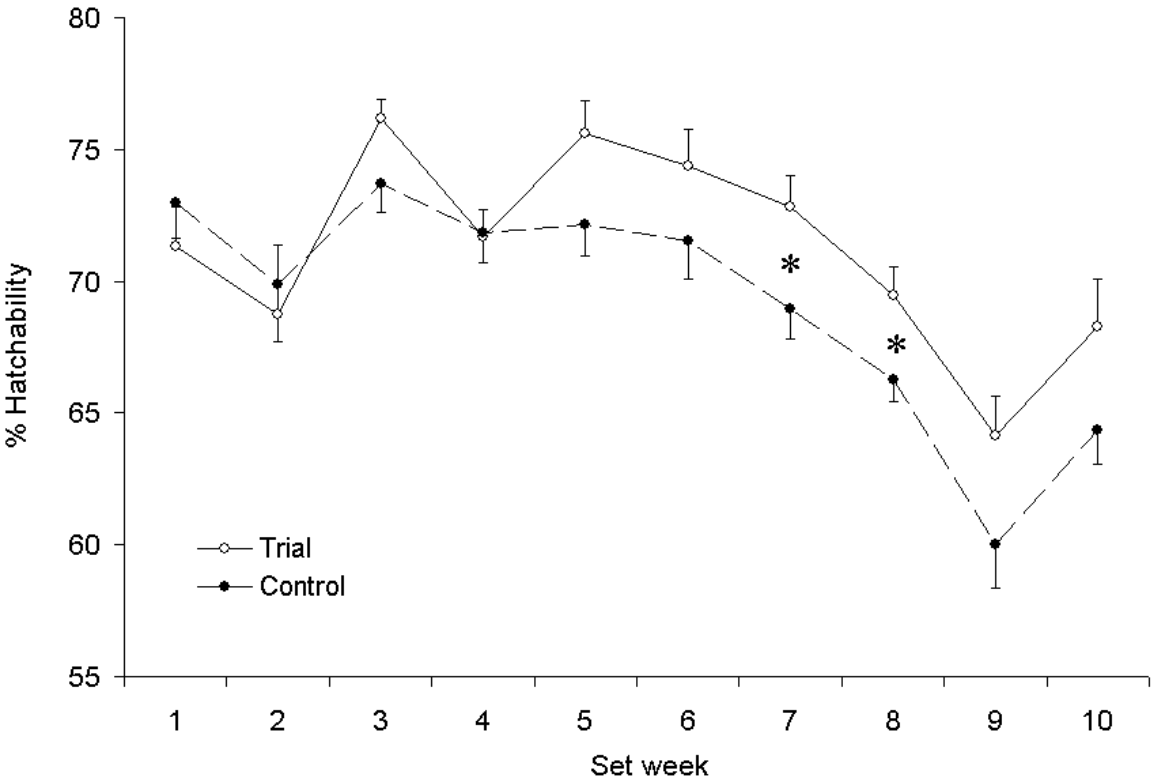


Figure 5. Percentage of hatched eggs produced per week for the barrier and open pens. Values are means (N = 11) and standard errors. Asterixes indicate that for the week mean levels of fertility were significantly different between treatments at $P < 0.05$.



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Running head: Sight barriers and reproductive performance

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Fertility of eggs is a key aspect in the productivity of pheasant breeding operations. Deeming (2009) reported that infertile eggs averaged 10% of eggs set to incubate with the range of values extending up to 23%. Deeming and Wadland (2002) showed that mating ratio is important in determining levels of fertility of breeding pheasants and suggested that the presence of more males allowed for higher mating frequency. Other studies on fertility in commercial pheasants are rare and although Guidobono Calvalchini *et al.* (2004) studied fertility of pheasants in cages it is not clear what their data represent and so they are difficult to interpret. This lack of data is disappointing because fertility impacts upon hatchability of pheasant eggs (Deeming and Wadland, 2002) and is of commercial significance.

Given the effects of sight barriers on pheasant behaviour (Deeming *et al.*, sub.), it was hypothesised that, like in broiler breeders (Leone and Estévez, 2008), sight barriers would have a positive impact on the reproductive performance of the birds. The barriers could provide refuges for birds that would perhaps allow for development of territories by males, or more effective courtship and copulation events, or perhaps greater mating frequency. Compared to more typical open pens this should allow the birds to maintain a higher level of fertility over the course of the 10-week laying season.

Despite benefits for bird welfare (Deeming *et al.*, sub.) that provision of sight barriers would be an additional cost to game farmers, which act as a disincentive for their use. It was considered important to investigate whether the barriers could have commercial benefits, *e.g.* on reproductive performance, as is shown in broiler breeders (Leone and Estévez, 2008). The study described here examined our investigation into the effects of sight barriers on egg production, fertility, embryonic mortality and hatchability of commercial pheasants. The data reported here were collected from the same experimental birds and over the same period of time as Deeming *et al.* (sub.).

MATERIALS AND METHODS

Experimental design

A full description of the experimental design for this study is provided by Deeming *et al.* (2011) and so is only briefly described here. Twenty-two pens holding commercially reared ring-necked pheasants (*Phasianus colchicus*) were established at a commercial game farm to provide 11 control pens, and 11 experimental pens that contained sight barriers. Each pen measured 13.2 x 13.2 m and initially contained 56 female and 8 male birds. All pens were comprised of slatted wooden sides up to approximately 0.6 m, and wire mesh above this point, and were roofed with soft nylon mesh. The floors were soil and grass. All pens were provided with pelleted feed *ad libitum*, a drinker-bowl, and a bowl of grit.

Control ("open") pens used the typical open arrangement of commercial pens at the farm and so had only 5 or 6 metal half oil barrels (to provide sheltered nesting sites) that could potentially obscure the view of birds. Experimental ("barrier") pens incorporated tin sheeting and straw bales to act as sight barriers to the height of 60 cm, but other than this they were identical to the open pens. Birds in the barrier pens could only see up to an approximate maximum of a third of the area of the pen at any time. The experimental design for the

study was approved by the Ethics Committee of the Faculty of Agriculture, Food and Animal Sciences, University of Lincoln.

Reproductive parameters

Eggs were collected from the pens once a day. On four occasions during weeks 1, 9 and 10 (twice) the location of eggs within the pen was recorded during collection. It was noted whether eggs were laid in the open pen, or under the barrel nest sites. For all days numbers of eggs from each pen were recorded prior to washing in a commercial machine and grading to remove any 'defective' eggs, which were rejected for setting. These were classed as: small; large; very large – double-yolked; with a chalky shell; with a blue shell; or soft-shelled. Eggs were then set on to labelled incubator trays and stored for up to 7 days at 15°C. Prior to setting eggs were pre-warmed overnight at room temperature and then were incubated in a Western 36 game setter operated under a fixed-rack system. Transfer was after 21 days onto hatcher baskets and set into Western hatchers and the hatch was taken off on the 25th day.

After 10–12 days of incubation, each egg was individually candled using a halogen candling lamp to reveal clear eggs, which were removed for examination. At the laboratory eggs were opened with forceps and whether the egg showed evidence of embryonic development was assessed by eye. An infertile egg was deemed to have no evidence of membrane development and with a small blastodisc (Deeming and van Middelkoop, 1999). Eggs containing evidence of embryonic mortality were classified on whether death had occurred during the first four days of incubation or thereafter (Deeming and van Middelkoop, 1999). At take-off of the hatch all chicks were removed from the hatcher baskets and the remaining eggs counted. Numbers of eggs that contained embryos that had died after candling were then recorded together with the number of hatched chicks. Embryonic mortality between 5–25 days was calculated by difference.

Statistical analysis

Data were recorded weekly on a per pen basis to calculate average values for the number of eggs collected and the number of rejected eggs. Statistical analysis was performed using PSAW (SPSS Inc., version 17.0). Average percentages of eggs laid under nest sites or in the open were compared using a Mann Whitney U test. Values for fertility, embryonic mortality for the first four days and thereafter, together with hatchability, were all recorded as percentages of the eggs incubated. Means were calculated in order to compare data from the barrier and open pens. Data were tested for normality using one-sample Kolmogorov-Smirnov tests prior to analysis. Mean numbers of eggs collected per pen and the number of rejected eggs were log₁₀ transformed prior to analysis but values for fertility, mortality and hatchability were expressed as proportions and arcsin transformed to normalise the data (Fowler *et al.*, 1995). The effectiveness of this calculation was tested using Kolmogorov-Smirnov tests. The effect of the pen type on all variables was tested using repeated measures analysis of variance (ANOVA) using the Greenhouse-Geisser test for sphericity. Means are presented for untransformed data, but analyses were conducted on transformed values.

RESULTS

Eggs were laid under the metal half barrel nest sites but also alongside the side walls of the pen and alongside the barriers as well as in vegetation. Mean values for the percentage of eggs laid in nest sites provided, averaged

over the four time periods for observations, were significantly lower in barrier pens than in the open pens (means \pm SE: 51.4 ± 2.6 and 70.7 ± 2.7 , respectively; Mann Whitney test: $U = 0.0$, $N_1 = 4$, $N_2 = 4$, $P < 0.05$).

Egg production

Just over 60,000 eggs were laid by birds in this study and egg production expressed as eggs laid per pen per day showed an initial rapid rise at the start of the laying season with a slow decline after peak during week 4 (Figure 1). This was not affected by the presence of barriers in the pens (repeated measures ANOVA $F_{1,20} = 0.12$, $P = 0.767$).

A total of around 8,300 eggs were rejected over the course of the laying season. The number of rejected eggs was initially low but increased as the laying season progressed (Figure 2). Although when expressed as a percentage there was a slight reduction in rejected eggs during the early part of the season, this steadily increased to a plateau of ~20% of eggs laid by the last two weeks of lay. There was no effect of treatment on the numbers of rejected eggs (repeated measures ANOVA $F_{1,20} = 0.23$, $P = 0.634$). The increase in rejected eggs was mainly due to an increase in small eggs (50-70% of the total) but there was also a rise in chalky eggs over the course of the laying season reaching around 10% of rejected eggs by week 10 of lay. There was no effect of the presence or absence of the barriers on the numbers of the different types of rejected egg.

Fertility

Around 7,000 eggs were candled out of the trays over the 10-week laying period of which 4,350 were deemed to be infertile. True fertility expressed as a percentage of eggs set to incubate rose to a peak during week 3 but then declined thereafter (Figure 3). The presence of sight barriers was associated with higher fertility from week 3, which declined thereafter more slowly than for eggs from the control pens. The difference in fertility during week 3 was 1% but this difference progressively increased as weeks proceeded to a value of 4% during week 10. Repeated measures ANOVA showed that this pattern approached significance ($F_{1,20} = 3.90$, $P = 0.062$).

In both types of pens, as the birds came into full reproductive performance egg production was low during weeks 1 and 2 and fertility did not peak until week 3. For these reasons, data for fertility from the first two weeks of lay were excluded and a second repeated measures ANOVA was conducted. Over weeks 3–10 fertility on average was 2.7% higher in pens with barriers and with this restricted data set there was a significant effect of the presence of sight barriers ($F_{1,20} = 6.58$, $P = 0.018$).

Embryonic mortality and hatchability

Early embryonic mortality (0-4 days) averaged around between 4.5–5.0% of eggs set and was unaffected by week of lay. There was also no consistent pattern with respect to the presence or absence of barriers or not (Figure 4). Repeated measures ANOVA confirmed that compared with the control pens there was no effect of barriers on this measure of mortality ($F_{1,20} = 2.99$, $P = 0.099$). Mortality between 5-25 days of incubation averaged 15–16% for both types of pens and was 2-3% higher at the end of the laying season (Figure 4). Again repeated measures ANOVA confirmed no effect of barriers on this measure of embryonic mortality ($F_{1,20} = 0.38$, $P = 0.545$).

Hatchability of eggs set was typically above 70% over the first half of the laying season but slowly declined thereafter (Figure 5). It was unclear why there was variation in the pattern during weeks 9 and 10 but

this was probably due to management of the incubators involved. Hatchability was between 1 and 4% higher in the barrier pens during all weeks of lay except for weeks 1, 2 and 4 (Figure 5). Repeated measures ANOVA for data from all weeks only approached significance ($F_{1,20} = 3.50$, $P = 0.076$). As for fertility, hatchability did not peak until week 3 and between weeks 3-10 the barrier pens had hatchability values that were on average 3.0% higher than control pens. Repeated measures ANOVA for data collected between 3-10 weeks showed that the difference in hatchability was significantly affected by the presence of the barriers ($F_{1,20} = 6.58$, $P = 0.013$).

DISCUSSION

This is the first time that environmental complexity has been shown to impact upon fertility in pheasants and is similar to results shown for comparable kind of environmental enrichment in broiler breeder sheds (Leone and Estévez, 2008). Our hypothesis that sight barriers would have a positive impact upon the fertility of pheasant eggs was supported by data reported here. Fertility was not only higher in the pens with barriers but also persisted for longer over the laying season. The barriers were also associated with an improvement in hatchability that was associated with higher fertility rather than changes in embryonic mortality.

Panels within broiler breeder houses improve egg production by 2% over the laying period of the flock (Leone and Estévez, 2008). In the present study egg production was not significantly affected by the presence of the barriers and at peak of lay was comparable to levels reported for pheasants by Deeming and Wadland (2002). However, by the end of the laying season egg production in the present study was higher with each female producing approximately one more egg per week. Deeming and Wadland (2002) studied pheasant flocks of 250 females in pens with an area of 1,250 m² and included sight barriers, compared with 56 females in pens measuring 174 m² in the present study. Whether the observed difference in egg production between studies reflects on the difference in pen size or flock size is unclear. The decline in egg production post peak has been reported previously in pheasants (Mashaly *et al.*, 1983; Baglicca *et al.*, 1990; Deeming and Wadland, 2002).

It was interesting that, when expressed as a percentage of eggs collected, the levels of egg rejection described here were very similar to that reported by Deeming and Wadland (2002) although the types of problems reported were different. Deeming and Wadland (2002) found that blue-shelled eggs were most commonly rejected and small eggs, which formed the bulk of the reject eggs in this study, were relatively rare. This may reflect the different emphasis placed on egg quality at these two different game farms. Blue-shelled eggs are relatively thin and have structural defects (Richards and Deeming, 2001) but the factors affecting their production are unknown. Categorising eggs as small may be subjective because in this study the eggs were not weighed but it may reflect nutrient availability to the females. For whatever reasons rates of egg rejection in pheasants appears to be generally high and research is needed to better understand how husbandry and nutrition contribute to variability in egg quality.

The level of fertility found in this study were produced with a 7:1 female:male sex ratio and peaked at over 94% for the pens with barriers. These values were ~2% higher than the fertility reported for pheasants kept in large groups and in larger pens at a 8:1 sex ratio and around ~8% higher than for pens with a sex ratio of 12:1 (Deeming and Wadland, 2002). Bates *et al.* (1987) reported that fertility was lower for pens with an 18:1 sex ratio than for a 12:1 ratio. Guidobono Calvalchini *et al.* (2004) reported that sex ratio significantly affected fertility in caged pheasants but presented no data to support this claim. In general, the evidence is that lower sex ratios (fewer females per male) produce greater fertility.

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Here we showed that the presence of barriers in the pen had a significant effect on the level and persistence of fertility. The reason for this is unclear because copulation behaviour was not observed on a frequent basis (see Deeming *et al.*, sub.) and pen type had no effect on the number of matings observed. The observed higher fertility in the barrier pens is strong indirect evidence that, compared with open pens, either copulations rates (observed or not) are higher, or the efficacy of mating is higher, when birds are in pens with barriers. Leone and Estévez (2008) showed that fertility persisted for longer in broiler breeder sheds with panels, which were considered to increase mating opportunities for males, reduce forced matings and so reduce female stress. The barriers may provide seclusion for courting pheasants, which leads to an efficient mating climax, or may allow males to establish and defend territories or perhaps control harems of females (Deeming *et al.*, sub.). The mechanism by which this simple change to the environment affects a change in fertility in pheasants requires further investigation.

Patterns of embryonic mortality reported here are very similar to that reported by Deeming and Wadland, (2001). The level of early mortality was near identical to that reported for pheasants by Deeming and Wadland (2001) although laying week had no significant effect in the present study. Early embryonic mortality is also comparable to other bird species (Deeming and van Middelkoop, 1999; Deeming, 2009). Levels of late mortality were lower than previously reported (Deeming and Wadland, 2001), which is reflected in the higher hatchability reported here. Indeed reported hatchability in commercial pheasants are typically around 65% or less (Deeming and Wadland, 2002; Demirel and Kirikçi, 2008; Deeming, 2009) and the higher values (69-71% averaged over 10 weeks) recorded in the present study may reflect the quality of the incubator used or the operation of the hatchery. Hatchability of other eggs laid and incubated at the game farm was generally 2% lower than the trial eggs and this may reflect better scrutiny of eggs prior to setting. These results highlight the continued need for research into the factors causing embryonic mortality after 5 days of incubation in pheasants (Deeming and Wadland, 2001) because a better understanding of these factors would have significant effect on profitability of many game farms.

The presence of barriers in the breeding pens affected hatchability but this was unrelated to levels of embryonic mortality. Rather, females in the barrier pens simply produced more fertile eggs and this allowed a higher hatchability. It is interesting to note that panels placed inside broiler breeder sheds also significantly increased hatchability after the peak at 35 weeks of age (Leone and Estévez, 2008); by 60 weeks of age the difference in hatchability was 2.6%.

The presence of barriers in a breeding pen for pheasants is associated with an economic cost of provision and maintenance of the structures. That there were more eggs laid outside of nest sites provided could impact upon the time and cost involved for collecting the eggs. Such additional costs may restrict the adoption of barriers within the game industry despite the apparent benefits to pheasant welfare (Deeming *et al.*, sub.). That there is an increase in fertility and hatchability associated with the presence of barriers would go a long way in promoting their benefits overall. Increases in hatchability of 2-3% seen in this study, and in the study of broiler breeders by Leone and Estévez (2008), are of significant commercial significance and may yield profits that far out weigh the costs of providing barriers.

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Figure 1. Egg production per pen per day for the barrier and control pens. Values are means (N = 11 in each case) and standard errors.

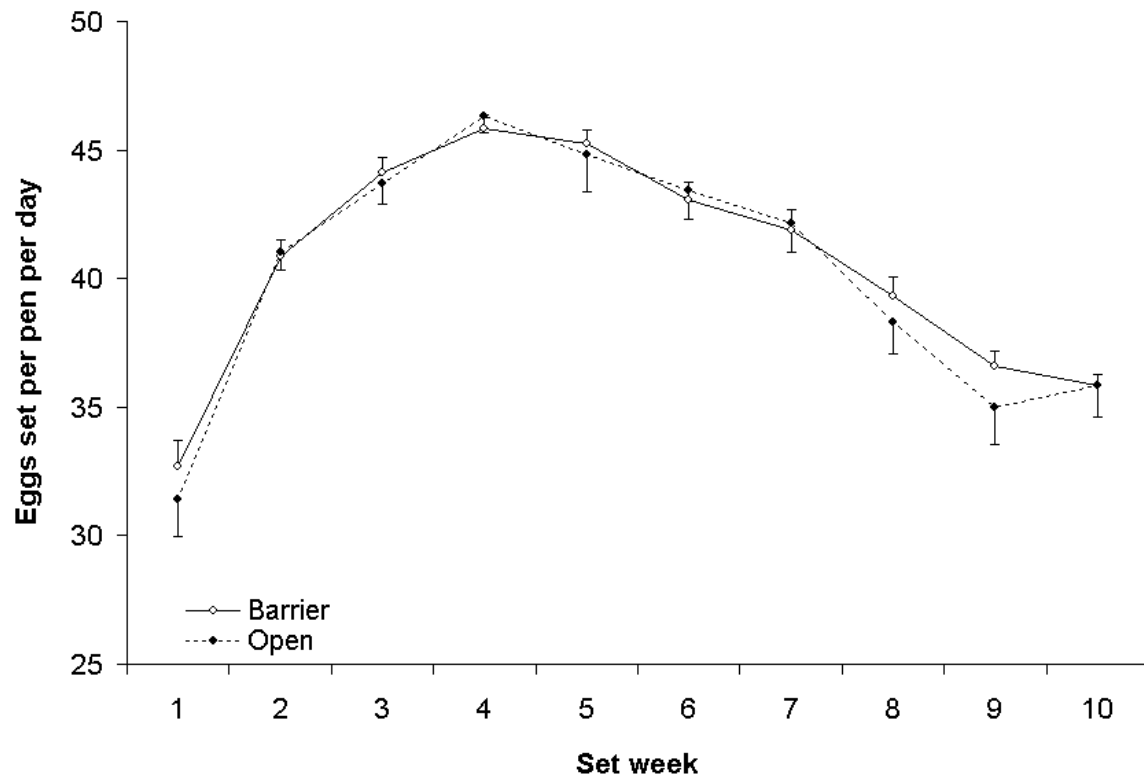


Figure 2. Mean numbers of rejected eggs produced per week for the barrier and control pens (N = 11 in each case). Data are also shown as mean percentage values of the eggs collected.

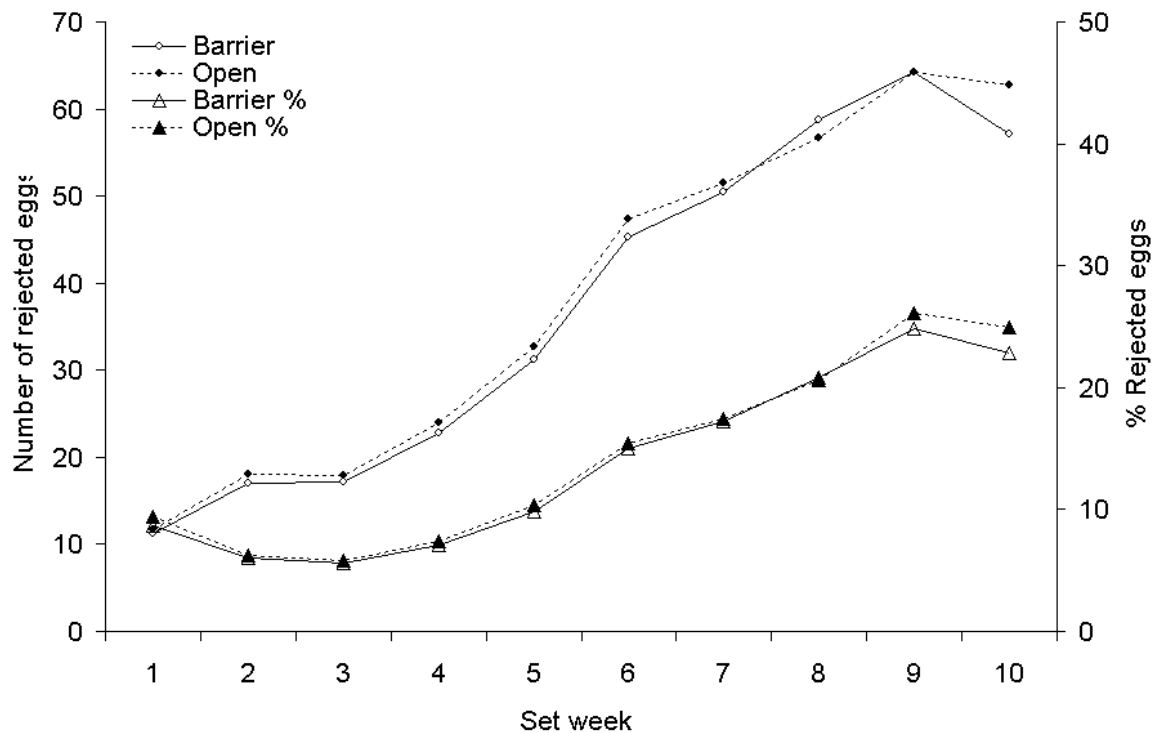


Figure 3. Percentage of fertile eggs produced per week for the barrier and open pens. Values are means (N = 11) and standard errors.

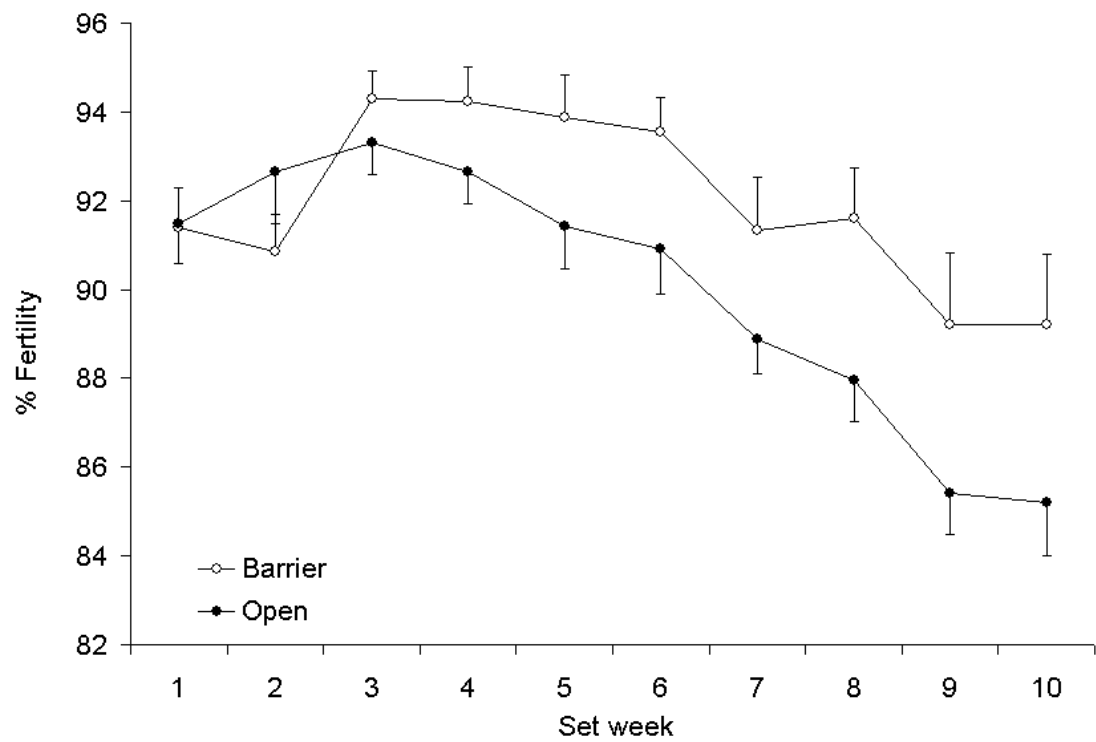


Figure 4. Percentages of eggs exhibiting embryonic mortality between 0-4 days ("Early") and 5-25 days ("Mid-late") of incubation per week of lay for the barrier and open pens. Values are means (N = 11) and standard errors.

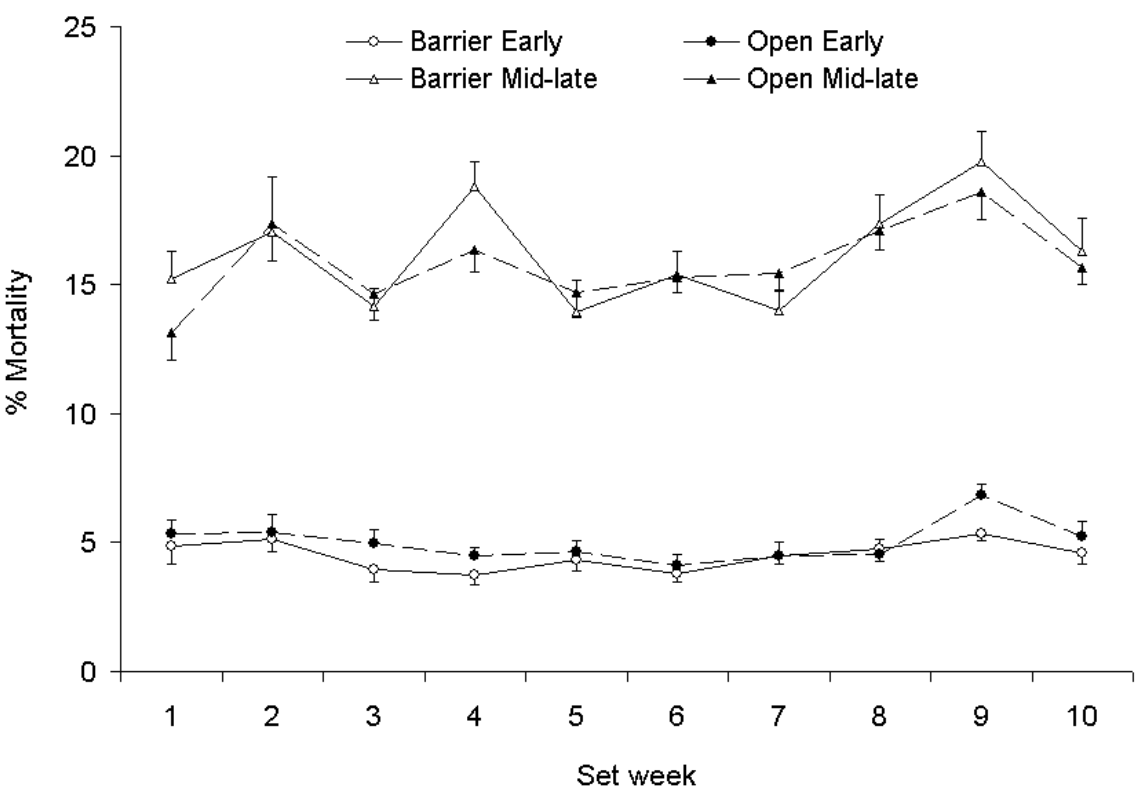


Figure 5. Percentage of hatched eggs produced per week for the barrier and open pens. Values are means (N = 11) and standard errors.

