Body condition is negatively associated with infection with Syngamus trachea in the ring-necked pheasant (phasianus colchicus)

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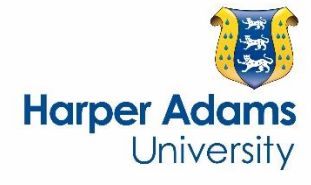

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Body condition is negatively associated with infection with *Syngamus trachea* in the Ring-necked Pheasant (*Phasianus colchicus).*

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Summary

The role that parasites play in regulating animal populations is debated, however recent research hints at their pervasiveness among free-living animal populations. Parasites exert both direct and indirect effects on host populations, and can act to regulate populations. The Ring-necked pheasant is an important game-bird species in the UK, and large numbers of birds are released annually. The impact of the ubiquitous tracheal nematode, *Syngamus trachea* on pheasant populations through effects on host condition was assessed on two pheasant estates in the south west of England. Pheasants infected with *S. trachea* demonstrated a significant reduction in host condition compared with uninfected controls, with as few as one pair of worms per bird. Although there was no difference in worm burden between sexes, analysis of regression slopes revealed there was a significant difference between sexes in the magnitude of the effect of increasing worm burden on host condition, with detectable effects observed in hosts with one and three pairs of worms for males and females respectively. The observed reductions in host condition in birds with even sub-clinical infections could be the cause of poor reproductive success and survival of pheasants post-release.

Keywords

Phasianus colchicus; Pheasant; Body condition; Gapeworm; Syngamus trachea; Reproduction

Introduction

Parasites are well known to play an important role in regulating host population dynamics (Tompkins & Begon, 1999; Irvine *et al.,* 2006; Dunn *et al.,* 2012; Watson, 2013; Granoth-Wilding *et al.,* 2015), although there has been some debate as to the relative importance of predators compared with parasites (Irvine, 2000; Moss & Watson, 2001). Recent research however, has demonstrated that parasites are as, if not more, important than predators in regulating host populations (Watson, 2013). Parasites can have direct impacts on host populations through increases in morbidity and mortality, and they can also indirectly affect host populations through reductions in fecundity (Hudson, 1986; Dunn *et al.,* 2012; Granoth-Wilding *et al.,* 2015). Despite this, very little published research exists on the effects of parasite species on condition and host population dynamics in the ring-necked pheasant. One of the few studies by Draycott *et al.* (2002) assessed the effects of *Syngamus trachea* and *Heterakis gallinarum* on pheasant populations and concluded that infection with these species did not negatively affect host body condition. One major issue with this study is that body condition was assessed in April, whereas the infectious stages of *S. trachea,* and therefore infection pressure do not reach their peak until around June/July (Gethings *et al.,* 2015). A similar issue was observed by Irvine *et al.* (2006). Previous studies failed to find any effect of gastrointestinal nematodes on host condition in Reindeer populations in the High Arctic, however Irvine *et al.* (2006), through the use of delayed-release anthelmintic boluses, demonstrated reductions in host fitness in winter. Reindeer populations were sampled previously when populations were more accessible, which highlights the importance of timing research protocols to account for seasonal dynamics in the transmission of parasites, and therefore any parasite-mediated effects.

Reproductive success of released ring-necked pheasants is generally poor compared with their 'wild' counterparts (Leif, 1994), but it is currently unclear as to why this is the case (Leif, 1994; Draycott *et al.,* 2000; Millan *et al.,* 2002; Draycott *et al.,* 2006; Villanua *et al.,* 2006). A number of factors such

as increased parasitic worm infections and reduced food availability/quality are believed to be major components governing life-history traits in game birds (Hudson *et al.,* 1992). *Syngamus trachea,* for example, is a parasitic-tracheal nematode that commonly affects managed pheasant and poultry populations. Morbidity rates are generally very high, particularly when birds are managed under high stocking densities and when proper sanitary measures are not incorporated into management programs (Gethings *et al.,* 2015). There is marked pathology associated with syngamosis (Fernando *et al.,* 1971; Nevarez *et al.,* 2002; Atkinson *et al.,* 2008) and mortality rates of affected birds can be as high as 80 % (Wojcik *et al.,* 1999). Experimental infections with *S. trachea* have demonstrated negative associations between larval challenge and weight gain and condition. Hwang (1964) experimentally infected turkey poults with varying numbers of *S. trachea*-infected earthworms to observe their effect on weight gain and packed cell volume (PCV). Significant differences were identified in weight gain between birds infected with an average of 0.2 worms (n = 10) compared with an average of 55 worms (n = 55), with the heavily infected group gaining an average of 51g compared with 1482g for the lightly infected group (Hwang, 1964). This significant effect on weight gain and condition could potentially influence fecundity directly through parasite-mediated competition for resources or indirectly if the host invests more resources into mounting an immune response (Delahay *et al.,* 1995; Shutler *et al.,* 2012). Indeed, Draycott *et al.* (2006) demonstrated increased breeding success in pheasants treated with Flubendazole, which suggests a possible relationship between fecundity and parasitic infection in the ring-necked pheasant.

Similarly, other studies have demonstrated significant negative parasite-mediated effects on host fitness. Many of these associations are however, correlational, and it is often difficult to disentangle cause and effect in the parasite-host relationship. Tompkins *et al.* (2000), demonstrated a negative relationship between the caecal nematode *H. gallinarum* and body condition in partridges. More relevant perhaps, is the negative association identified between *H. gallinarum* and body mass, breast muscle mass and cloacal fat in ring-necked pheasants (Sage *et al* 2002).

74 The aim of the present study was to evaluate what effect, if any, significant infections with
75 the nematode, *Syngamus trachea* have on pheasant body condition under natural circumstances.

76

77 **2. Materials and method**

78 *2.1 Study sites*

79 Two pheasant estates were selected in the South West of England due to regular problems with
80 clinical syngamosis, as reported by managers. Site 1 was located approximately at grid reference ST
81 97502 39837 and consisted of seven release pens. Site 2 was situated approximately at grid reference
82 SU 17769 30326 and similarly consisted of seven release pens. Both sites release ~15,000 birds
83 annually, undertake thorough predator control measures and provide supplementary grain via feed
84 hoppers. Anthelmintic treatment (Flubendazole – at manufacturers dosage recommendations) ceased
85 after birds were released in June 2015. Sites were matched in order to ensure that any effects on body
86 condition would be parasite-mediated and not a result of intra/inter specific competition for food
87 resources or other environmental factors.

88

89 *2.2 Carcass recovery*

90 One hundred and eighty adult pheasants were recovered following release from June 2015 through
91 April of 2016. Birds were recovered by professional game managers, either as part of crop-protection
92 programs or were shot during the shooting season. Pheasants were either shot whilst flying, or
93 occasionally found dead upon the estate (n = 4). Carcasses that had been scavenged were not
94 included in the analysis and recovered birds were examined for non-parasite related disease that
95 could influence the results. Carcasses were processed immediately upon recovery and assessed for
96 the presence of *S. trachea, Ascaridia galli* and *H. gallinarum* by dissection of the trachea,

97 gastrointestinal tract and abdominal cavity and caeca respectively. Other nematode species were
98 recorded but were not differentiated by species, as they were too few in number. In two instances,
99 severely emaciated pheasants with bulbous, fluid-filled intestines consistent with clinical
100 hexamitiasis and confirmed by the presence of motile protozoa on wet slide preparation were
101 recovered. These birds were excluded from the analyses as they were found to be free of nematode
102 infection, but are mentioned in the discussion.

103

104 *2.3 Worm recovery and body condition assessment*

105 Adult pheasants were weighed to the nearest 0.1g using a digital weighing scales and tarsal length
106 was measured using a digital calliper with accuracy to 0.01 mm. A body condition index was then
107 obtained by dividing body mass by tarsal length (Yom-Tov, 2001), which controlled for body size.

108

109 *2.4 Statistical analysis*

110 To determine whether the data were aggregated, adult worm counts were compared with an
111 estimated Poisson distribution ($\mu = \sigma^2$) with n−1 d.f. using the chi.sq test function in R available in
112 the MASS package. Data were then compared with both an estimated Poisson and a Negative
113 Binomial distribution using the fitdistr function (fitdistrplus package) and goodness of fit was
114 assessed using Maximum Likelihood Estimation using AIC as a determinant. As the number of
115 factors in each model were equal, the model with the lowest AIC score was considered a better fit.
116 All data were analysed using *R* for Macintosh. The effect of parasite burden on host body condition
117 was assessed using ordinary least-squares regression using log(*n+1)* transformed parasite count data.
118 Though the inclusion of the four dead-found birds could be a potential confounder, there was no
119 change in model accuracy when they were excluded. Non-constant error variance was assessed using
120 the Breusch-Pagan test and 'ratio' data were transformed to the appropriate power transformation

121 (y^0.15). The transformed data were then assessed for non-constant error variance, which confirmed
122 that the power transformation was successful (x^2 = 0.54, df = 1, p = 0.51). Differences in parasite
123 burden between sexes (including zero counts) were assessed using Welch's *t-test* for unequal
124 samples.

125

126 **3. Results**

127 *3.1 Prevalence of S. trachea – Pheasants*

128 Parasite count data were significantly different from the estimated Poisson distribution (x^2 = 2175, d.f
129 = 153, p = <0.001) and comparison of models demonstrated the data were aggregated, and consistent
130 with the negative binomial distribution (x^2 = 4.87, d.f = 3, p = 0.18). The overall prevalence of *S.*
131 *trachea* within this study population was 33%, with 32% of males (n = 148, n = 48 infected) and 38%
132 of females (n = 32, n = 12 infected) being infected with at least 1 pair of worms. Males had a mean (±
133 SEM) worm burden of 3.01 ± 0.54, and females had a mean (± SEM) worm burden of 4.78 ± 1.68,
134 however no significant differences were found between sexes in mean worm burden ($t^{35.78}$ = -1.26, p
135 = 0.21).

136

137 *3.2 Effect of S. trachea on body condition*

138 Worm burden and the associated effects on pheasant body condition are presented in tables 1 and 2.
139 The regression of log parasite burden on body condition revealed a significant inverse relationship
140 between increasing worm burden and body condition in pheasants ($F^{3,176}$ = 216.2, R^2 = 0.78, P = <
141 0.001). Similarly, the effect of 'sex' was significant (coef = 1.1002, t = 2.84, p = 0.005) with
142 regression slopes of b = -4.18 (95% CI = -4.034) and b = -3.23 (95% CI = -2.67) for males and
143 females respectively, with slopes being statistically different from each other (t^{176} = 2.38, p = 0.01).

Comparison of regression coefficients for minimum worm burden requirements for identifiable reductions in body condition revealed 1 and 3 pairs were required for males (coef = -1.73, t = -4.69, p = <0.001) and females (coef = -3.24, t =-2.80, p = 0.04) respectively. Stepwise deletion of the lowest parasite burdens suggested a 'flattening off' in body condition reduction above 11 worms per bird.

4. Discussion

Pheasants infected with *Syngamus trachea* demonstrated significantly reduced body condition when compared with uninfected birds, and a negative association was identified between the number of *S. trachea* pairs per bird and body condition. This is the first study to observe such profound reductions in host body condition in pheasants naturally infected with *S. trachea.* Although Hwang *et al.* (1964) found that infection with *S. trachea* negatively affected weight gain in turkey poults, this was a result of an experimental infection, which does not accurately represent conditions faced by wild birds in terms of encounter rates and parasite load. Similarly, the provision of feed *ad libitum* in an experimental setting could increase host fitness and enable the production of a stronger immune response compared with birds under natural conditions.

The presence of parasites within these study populations, and the apparent parasite-mediated effects on body condition in post-release adult pheasants could have far-reaching ecological consequences (Delahay *et al.,* 1995). It is well documented that reared pheasants have reduced survival and reproductive success compared with their wild counterparts (Leif, 1994; Draycott *et al.,* 2000; Millan *et al.,* 2002; Draycott *et al.,* 2006; Villanua *et al.,* 2006), and the high occurrence of *S. trachea* on pheasant estates could be a significant limiting factor on populations; especially considering that even relatively low numbers of adult worms (well below those at which clinical effects would be observed) are sufficient to produce statistically-significant reductions in host

168 condition. Infection with *S. trachea* could affect host populations directly; though parasite or host-
169 mediated reductions in fecundity via responses to developing and established worms; direct
170 competition for resources; or via (hypothetically) disruption of yolk proteins synthesised in the liver.
171 Similarly, indirect effects such as increased predation rates in infected birds could significantly affect
172 population structure and size (Hudson *et al.,* 1992). Though the overall prevalence of disease was
173 low, it may still be exerting a negative pressure on population density if infected hosts have reduced
174 life expectancy compared with uninfected hosts (Anderson, 1995). Indeed, *S. trachea* has a high
175 mortality rate among juvenile, immunologically-naïve birds (Wojcik *et al.,* 1999) and an increase in
176 parasite-induced mortality in juvenile birds could stabilise the parasite-host interaction by a net loss
177 of parasites from the system (Anderson & May, 1978). Similarly, as pheasants are extremely
178 susceptible to infection with *S. trachea*, the small proportion of the population susceptible to
179 infection could ensure the persistence of the disease through constant reseeding of infectious stages
180 (Anderson, 1995).

181 It has been suggested that in order to initiate egg laying, birds must reach a body condition
182 threshold, and that individual host body condition necessarily delays or advances threshold
183 attainment (Drent & Daan, 1980). For example, parasites that undergo hepato-pulmonary migration
184 and/or cause anaemia via exsanguination compete with the host for protein during the time when
185 energy input is concentrated on egg production (Allander & Bennett, 1995). Proteins required for
186 yolk production are synthesised within the liver, and the migration of *S. trachea* larvae across the
187 liver parenchyma could impair the production of these proteins (Allander & Bennett, 1995) thus
188 potentially affecting the onset of laying. Indeed, Jones and Ward (1976) demonstrated that reduced
189 yolk proteins delayed the onset of breeding in Red-Billed Quaeleas. Female pheasants generally lay
190 their eggs between April and June, incidentally when *S. trachea* larval availability is increasing
191 (Gethings *et al.,* 2015). The development and migration of *S. trachea* across the liver parenchyma
192 could disrupt the formation of vital proteins responsible for chick development directly, or indirectly

193 through competition for host-resources during a period when hen body condition is already reduced
194 (Breitenbach & Mayer, 1959). Indeed, a number of empirical studies have demonstrated increased
195 survival and reproductive success of birds treated with anthelmintics compared with control birds
196 (Hudson, 1986; Draycott *et al.,* 2006). Woodburn *et al.* (2002) demonstrated that birds dosed with
197 anthelmintics reared twice as many chicks as un-dosed controls. It is unknown however whether the
198 anthelmintic had a direct effect on breeding success by reducing parasite challenge, or because the
199 treatment was associated with greater bird survival due to reduced predation (Hudson, *et al.,* 1992;
200 Millan, *et al.,* 2002; Woodburn *et al.,* 2002). Similarly, It has been shown in Red Grouse populations,
201 that the number of eggs laid is directly related to host body condition and energy intake in the
202 preceding weeks (Delahay *et al.,* 1995). Delahay *et al.* (1995) showed that infection with
203 *Trichostrongylus tenuis* reduced host body condition and could explain poor breeding performance of
204 wild birds. Furthermore, Newborn and Foster (2002) demonstrated that birds with access to grit
205 medicated with Fenbendazole had lower *T. tenuis* burdens and higher body condition scores than
206 control birds. Interestingly, birds from the treated plots had significantly higher breeding success and
207 reared twice as many chicks as birds from control plots. Chick survival was also significantly greater
208 in treated plots compared with control (Newborn & Foster, 2002). This, in conjunction with the
209 findings of the present study appear to suggest that parasite infection does indeed have some
210 measurable effect on host populations, whether that be through parasite-mediated competition,
211 reductions in host fecundity mediated by effects on body condition, or other factors is currently
212 unclear. Although currently only speculative, the tentative link between *S. trachea* infection and
213 pheasant fecundity warrants further consideration. Indeed, Holand *et al.* (2015), found that house
214 sparrows (*Passer domesticus)* infected with *S. trachea* demonstrated reduced reproductive success
215 compared with uninfected controls. They found a reduction in the proportion of eggs within a nest to
216 hatch as faecal egg counts of mothers increased. Similarly, juvenile females with high faecal egg
217 counts demonstrated significantly reduced lifetime reproductive success compared with uninfected
218 birds.

Visually, infected birds were emaciated with reduced breast muscle mass and prominent keel bones, however no quantitative measurements were taken. Although it is not overly surprising, given the highly pathogenic nature of this parasite, that reductions in host body condition were observed, it is surprising that just one pair of worms was associated with an 11% reduction in body condition compared with uninfected birds. Similarly, these effects were observed in immunologically naïve birds and birds with evidence of previous exposure. The threshold for detectable reductions in host body condition in the present study was particularly low, which could implicate sub-clinical infections as a causal factor of the poor breeding status of released pheasants.

Although there was no detectable difference in mean worm burden between males and females, there was a significant difference in the magnitude of the effect of increasing worm burden. Females, in contrast to males, appear to be able to withstand relatively low worm burdens not suffer any negative effect on body condition below three pairs of worms per host. In contrast, males were often found with single pairs of worms (whereas single infections were not identified in females in this study) and that level of infection already began to affect body condition. The differences between sexes could be explained by differences in resource allocation, and it has been demonstrated that immunocompetence is often sacrificed in favour of the expression of sexual ornaments, particularly in males (Hamilton & Zuk, 1982; Verhulst *et al.,* 1999). Whether females are able to successfully mount an immune response in the presence of one or two pairs of worms requires further investigation. The apparent "flattening off" of parasite-mediated reductions in body condition above eleven worms per bird can perhaps be attributed to the density-dependent reductions in worm length observed at higher densities (Gethings *et al.,* 2016). Density-dependent reductions in worm length peaked at eleven worms per bird before flattening off. This appears to provide evidence of a reduced *per capita* effect above the density threshold.

The findings presented here are in stark contrast to the results of Draycott *et al* (2002), who found that *S. trachea*, along with *H. gallinarum* and *Capillaria* spp. had no real observable effect on

pheasant body condition. This can, however, be explained by the fact that body condition in the Draycott *et al* (2002) paper was assessed in spring, whereas *S. trachea* larval availability, and therefore clinical cases of syngamosis, generally do not reach their peak until June/July (Gethings *et al.,* 2015). All birds used in the present study were recovered between March and October, when stress levels are likely to be elevated due to release (Villanua *et al.,* 2006), which also coincides with peak larval availability (Gethings *et al.,* 2015). These conditions are typical of the vast majority of pheasant estates, so results presented here are likely to be comparable with and representative of other intensively reared pheasant populations. Although other parasite species were quantified, there were no similar reductions in pheasant body condition: with the exception of *Hexamitia* spp., *Heterakis gallinarum,* along with a few cestoda, were the only other parasite species recovered from these pheasant populations; however, no effect was observed between their densities and body condition, even when total worm burden included *S. trachea.*

Although it is intuitively likely that the reduction in body condition was a result of significant *S. trachea* infections, it is difficult to disentangle cause and effect. The problem with cross-sectional studies is that it is difficult to establish whether these negative effects were a result of *S. trachea* infection as opposed to other forms of competition, or, whether birds acquired these parasites because they had reduced condition (Irvine, 200) and less ability to mount an effective immune response. The abundance of supplementary feed, predator control and reduced stocking densities suggests however, that parasites may have been the underlying cause of the observed reductions in body condition. Birds are known to lose a considerable amount of body condition during egg laying and incubation (Breitenbach & Mayer, 1959), however, the reductions in body condition in infected birds were still apparent when compared with uninfected birds, which would likely be facing similar environmental stressors.

5. Conclusion

The findings presented here appear to suggest a difference in the magnitude of the effect of worm burden on adult pheasant condition, with females able to withstand higher worm burdens before suffering any negative effects. Similarly, the results of the present study, in conjunction with the findings of Sage *et al.* (2002) demonstrate significant parasite-mediated effects on pheasant condition in birds following release and could be the cause for poor breeding success. However, it should be noted that these birds were examined out of the breeding season, and subsequent stress and alternative resource allocation during the breeding season could reduce this threshold in female pheasants.

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