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Response of Northern bobwhite (*Colinus virginianus*) and two parasitic nematode populations in western Oklahoma to anthelmintic supplemental feed

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ABSTRACT

It has been demonstrated that helminths are capable of critically impacting the fitness of their hosts. This has typically been shown experimentally through the administration of anthelmintic drugs but are rarely performed on a landscape or host population scale. Here, the anthelmintic fenbendazole (FBZ) was mixed in a supplemental feed and provided to a free-ranging population of Northern bobwhite quail (*Colinus virginianus*). Abundances of Northern bobwhite and two nematode parasites commonly found infecting Northern bobwhite were monitored and compared to a neighboring untreated population. The Northern bobwhite population receiving the medicated feed grew substantially from 2019 to 2022, while the neighboring site had no change in abundance. The treated population was also substantially greater than the untreated population in 2021 and 2022. Additionally, the treated Northern bobwhite population had substantially lower abundances of the two nematodes. This research provides evidence of the ability of helminth populations to have a negative impact on Northern bobwhite populations and presents a method for reducing helminth abundance in those populations on a landscape scale.

1. Introduction

The capacity of helminth infections to reduce the fitness of individuals has been demonstrated in several species. For example, blue tits (*Cyanistes caeruleus*) given the antimalarial drug primaquine had significantly greater fledgling success than untreated birds (Merino et al., 2000). Survival of female blue tits was also significantly greater when treated with an antimalarial drug (Puente et al., 2010). Svalbard reindeer (*Rangifer tarandus platyrhynchus*) treated for nematode infections had a higher probability of being pregnant in late winter (Stien et al., 2002). Indeed, evidence indicates that the nematode *Ostertagia gruehneri* is a regulatory factor (i.e., a factor that works to limit population growth and or abundance) in Svalbard reindeer populations (Albon et al., 2002). Wilber et al. (2020) found that as high as 90% of annual mortality in some amphibian populations can be attributed to trematode infections. Nesting American coot (*Fulicula americana*) adults and chicks treated with the anthelmintic fenbendazole showed increased survival compared to controls (Amundson and Arnold, 2010). Female cape ground squirrels (*Xerus inarus*) treated for both ecto- and endoparasites had significantly greater reproductive success and spent less time grooming than untreated controls (Hillegass et al., 2010). Litter size was significantly greater for Columbian ground squirrels (*Spermophilus columbianus*) treated for ectoparasites compared to untreated females in the same colony and a neighboring colony of untreated females (Neuhaus, 2003). Clearly, the impacts of parasitism on individual fitness in wildlife are common and has even prompted efforts to establish a framework for assessing the need for pharmaceutical intervention in wildlife (Wilkinson et al., 2022).

What is less clear is whether the impact on individual fitness translates to a regulatory effect on wildlife populations. A combination of empirical and observational data strongly suggests parasites influence populations of Svalbard reindeer (Albon et al., 2002). Wilkinson et al. (2022) established and used a framework to determine that treating bare nosed wombats (*Vombatus ursinus*) for sarcoptic mange (*Sarcoptes scabiei*) was not only prudent but would likely lead to improved population viability. The best-known example of population regulation by

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helminths is the work by Hudson et al. (1998) with the nematode *Trichostrongylus tenuis* and red grouse (*Lagopus lagopus scoticus*) in Scotland. Researchers were able to significantly dampen naturally occurring population cycles in red grouse by providing a medicated grit. However, examples such as those discussed above are rare, in part due to the difficulty in delivering an anthelmintic to the host population at a magnitude sufficient to affect the abundance of parasites.

A highly sought-after quail in North America, with high social and economic value (Johnson et al., 2012), is the Northern bobwhite (*Colinus virginianus*; simply referred to as bobwhite for the remainder of this work). Unfortunately, like many grassland bird species, bobwhite have been declining for over 50 years (Hernández et al., 2013). Two nematodes, *Oxyspirura petrowi* and *Aulonocephalus pennula*, are commonly found infecting bobwhite in the southwestern portions of its range and have been reported to occur at both a high prevalence and abundance in bobwhite (Dunham et al., 2014; Commons et al., 2019; Dunham et al., 2017a,b; Kubečka et al., 2017; Bruno et al., 2019; Wyckoff et al., 2023). Indeed, bobwhite collected in 2013 and examined for *O. petrowi* were found to have a prevalence of 98% and mean intensity of 11.9 (Dunham et al., 2014). In 2014, *A. pennula* was found to occur at a prevalence of 98% and mean intensity of 98.6 (Dunham et al., 2017b). A survey of the two nematodes infecting bobwhite in spring of 2016 and 2017 also found a high prevalence and abundance along with a substantial increase in the trapping effort for bobwhite (Henry et al., 2017). In conjunction with the observed helminth abundance, the state conservation agency, Texas Parks and Wildlife Department (TPWD), reported a precipitous decline in bobwhite numbers in the Rolling Plains, from an average of 52.5 bobwhite/20-mile survey route in 2016, 23.1 in 2017, and 3.7 by 2018. The above evidence led Henry et al. (2020) to conclude that helminth infections were a substantial contributor to bobwhite population fluctuations.

Oxyspirura petrowi is typically found infecting the harderian gland but can also be found under the nictitating membrane and other tissues surrounding the eye (Dunham et al., 2014). Pathological studies found *O. petrowi* feeding on blood and tissue, and it is suspected they ingest the fluids produced by the harderian gland as well (Bruno et al., 2015; Dunham et al., 2016). Pathology associated with infections in bobwhite includes inflammation and atrophy of the harderian gland and edema and erosion of the cornea (Bruno et al., 2015; Dunham et al., 2016). An *Oxyspirura* spp. has even been demonstrated to cause blindness in domestic poultry when infection intensity is extreme (Sanders, 1929). *Aulonocephalus pennula* are found free floating in the ceca and has been associated with reduced amounts of digesta and an increased probability of having poor body condition; however, does not appear to cause pathology in the cecum (Dunham et al., 2017a,b; Wyckoff et al., 2023). It is suspected that the presence of *A. pennula*, particularly at high intensities, impairs the function of the ceca, disrupting digestion and nutrient absorption by feeding on digesta (Brym et al., 2018; Dunham et al., 2017a).

The goal of this study was to assess populations of bobwhite in a semi-arid grassland ecoregion of western Oklahoma where parasite burdens differ spatially. An anthelmintic treated supplemental feed was used to reduce burdens of *O. petrowi* and *A. pennula* on one property while a neighboring property served as a reference. The objectives were 1) Assess bobwhite abundance on a treated and a nearby untreated property and 2) Assess the differences in the parasite burden of bobwhite on the treated and untreated properties. This study was completed in the context of annual climate conditions from 2019 through 2022. It was hypothesized that the treatment site would have a greater bobwhite abundance and the bobwhite population would have a lower helminth abundance than the reference site.

2. Methods

2.1. Study sites

This research was conducted in Ellis County, Oklahoma, USA. The treatment site (TS) is on a privately owned ranch and has historically held bobwhite even during particularly poor years. The TS is approximately 2314 ha and is primarily used for livestock grazing and recreational hunting. The reference site (RS) is a wildlife management area operated by the Oklahoma Department of Wildlife and Conservation (ODWC), located just southeast of the TS (Fig. 1). The RS is approximately 1932 ha, is actively managed for game species including bobwhite, and is used primarily for outdoor recreational activities. An anthelmintic medicated feed was used to treat bobwhite for helminth infections. The feed was formulated at 100 ppm with Safeguard© 20% potency and was delivered to bobwhite via Quail Safe® feeder systems (hereafter, systems). The medicated feed was made available for three weeks in late winter/early spring and for three weeks again in late summer/early autumn, as approved by the U.S. Food and Drug Administration. These time periods were chosen to reduce the helminth burden in bobwhite prior to the high energy demands of breeding and winter. Climate information was obtained from the Mesonet® weather station for Arnett, OK located in Ellis County (Brock et al., 1995; McPherson et al., 2007). Variables considered were number of days below 0 C, number of days above 37.7 C, precipitation from October through February, and precipitation from March through September. This separation was used as it generally separates two distinct life-history stages in bobwhite, namely the reproduction period and the over-winter period when survival rates tend to be the lowest.

2.2. Bobwhite abundance and annual survivorship estimates

Abundance of bobwhite was estimated twice a year using standardized call count protocols. Whistle call counts took place in early June from 2019 to 2023 on the TS and 2021–2023 on the RS. Each of the sites had ten points randomly placed along a designated driving route. The driving routes were chosen based on accessibility, with each point being a minimum of 0.6 km apart. An observer would arrive at one end of the call route at least 40 min before sunrise and begin listening 30 min before sunrise. The observer recorded the total number of bobwhite whistling for 5 min before moving to the next point. This was repeated until all ten points were visited. Each call count transect was repeated three times in this way. Covey call counts were conducted in early November from 2019 to 2022 on the treated site and from 2020 to 2022 on the RS. Three points from the established call route were used for covey call counts. The minimum distance between each point was 1.2 km. An observer would begin listening 40 min before sunrise and record the total number of coveys heard for 20 min, once the first call was heard. Only one point was visited each day during covey call counts. Annual survivorship of bobwhite was done using juvenile to adult ratio (J:A) and equation presented in Guthery (1997). J:A ratios were estimated using hunter harvested bobwhite. The juvenile to adult ratio of hunter harvested bobwhite has been proposed as a viable way to estimate annual mortality with the assumption that bobwhite populations are stable over time (Guthery, 1997).

2.3. Helminth sampling

Estimates of eyeworm and cecal worm abundance were done by collecting hunter harvested bobwhite from both sites. Bobwhite were examined for *O. petrowi* by removing the eye from the socket, flushing the socket with distilled H_2O (diH_2O), and teasing open the harderian and lacrimal glands. The ceca were examined by first removing them from the intestines at the cecocolic junction. The ceca were then opened by making a lateral incision along the full length of the organ.

2.4. Analysis

Because we acknowledge the experimental design in this work represents an example of pseudo replication, 95% confidence intervals based on a normal distribution were used to distinguish differences

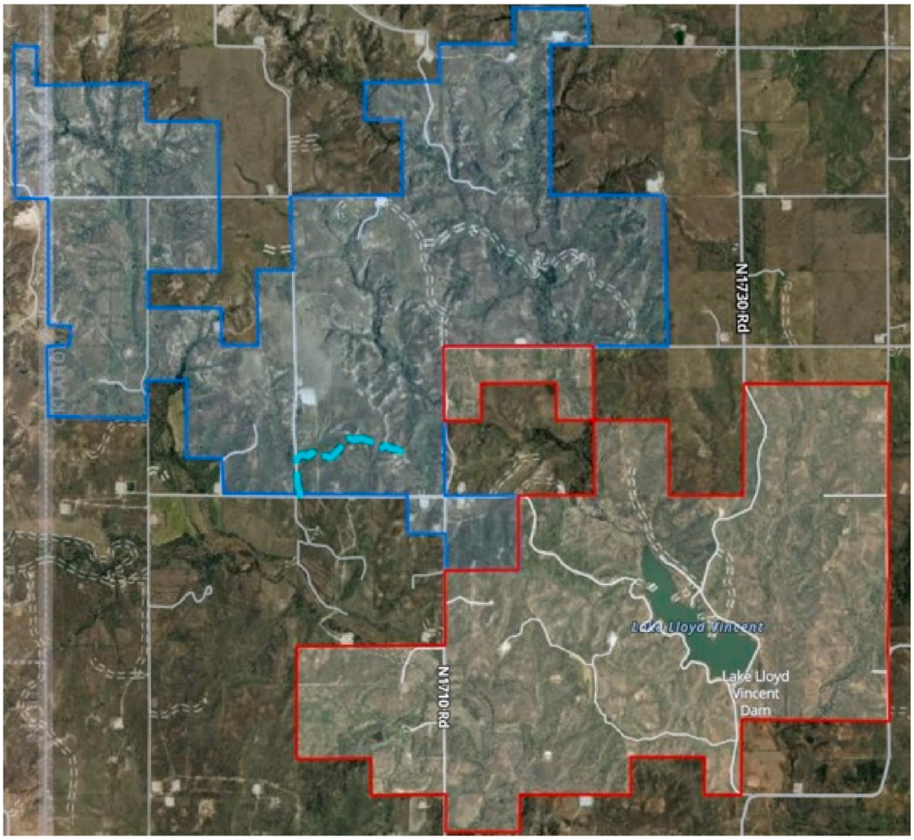

Fig. 1. Aerial image of the two study sites. The treated site is outlined in blue and received an anthelmintic treated medicated free beginning in 2019. The reference site is outlined in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

between the treatment and reference site and between years for each site with respect to bobwhite abundance in lieu of formal statistical analysis. Counts were considered not different if confidence intervals did not overlap and only marginally different if confidence intervals overlapped but did not overlap the mean. Helminth count data was transformed using $\log_3 (1 + x)$ to approximate a Poisson distribution. 90% confidence intervals were then calculated around the mean, based on a Poisson distribution, of the transformed data. 90% confidence intervals were used in leu of 95% intervals because of a large discrepancy in the number of adult bobwhite sampled between the sites. Helminth counts were considered different if the confidence intervals didn't overlap and were considered only marginally different if the intervals overlapped but did not overlap the means.

Table 1
Climate data from Ellis County, OK for the duration of this study. Oct–Feb precipitation and days less than or equal to 0 C are taken from the October of the listed year minus one through February of the listed year. The long-term average was calculated from 1997 through 2022.

Year	Mar–Sep Precip (mm)	No. Days $\geq$37.7 C	Oct–Feb Precip (mm)	No. Days $\leq$0 C
Long-term Avg.	452.8	14	150.9	116
2019	481.1	12	205.7	123
2020	315.2	16	205.8	120
2021	399.8	6	46.2	105
2022	382.0	25	56.1	93

3. Results

3.1. Climate data

A summary of the climate conditions is displayed in Table 1. March through September precipitation was below the long-term average in 2020–2022, but October through February precipitation was below the long-term average in 2021 and 2022 only. The number of days exceeding 37.7 C was greater than the long-term average in 2022 (25 vs. 14), less than average in 2021, and similar in 2019 and 2020. 2022 also had fewer days where temperatures dropped below 0 C than the long-term average.

3.2. Bobwhite abundance

Bobwhite on the TS increased for the study period during both the whistle and covey call counts (Fig. 2). The average number of bobwhite heard during whistle call counts on the TS from 2019 to 2023 was 2.8 (95% CI = 2.0,3.7), 6.6 (95% CI = 5.7,7.6), 9.8 (95% CI = 8.5,11), 21.7 (95% CI = 19.7,23.7), and 14.3 (95% CI = 12.7,15.9). The average number of bobwhite heard during whistle counts on the RS in 2021–2023 was 5.2 (95% CI = 4.2,6.2), 14.9 (95% CI = 13.5,16.2), and 7.3 (95% CI = 6.6, 8). The average number of coveys per point also increases on the TS from 2019 to 2022. The average number of coveys heard on the TS from 2019 to 2022 was 3 (95% CI = 1.9,4.1), 7.3 (95% CI = 4.0,10.6), 17 (95% CI = 13.6,20.4), and 18.3 (95% CI = 11.1,25.6), respectively. The RS averaged 4.7 (95% CI = 1.9,8.3) in 2020, 8 (95% CI = 6.9,9.1) in 2021, and 7.3 (95% CI = 4.1,10.6) in 2022.

3.3. Helminth abundance

Sample size, mean intensity, mean abundance, and prevalence of

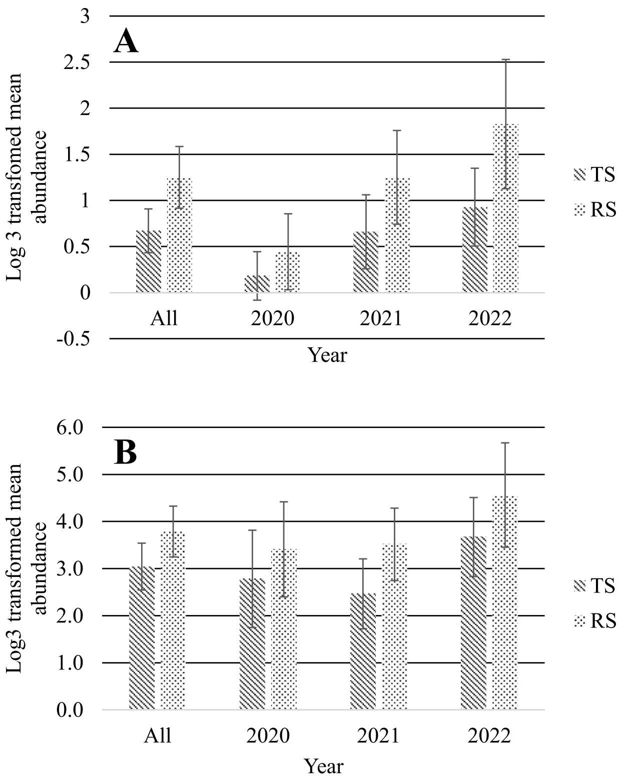

Fig. 2. Mean number of male bobwhite (A) and coveys (B) heard during bobwhite surveys on the two sites during this study with 95% CIs.

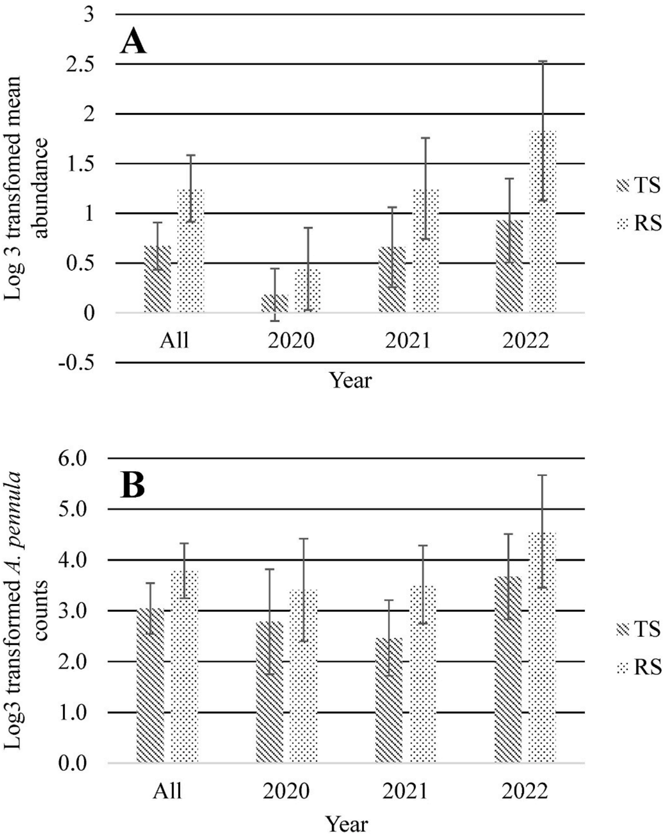

Fig. 3. Mean $\log_3$ transformed helminth counts of *O. petrowi* (A) and *A. pennula* (B) from bobwhite collected from TS and RS during this study.

O. petrowi and *A. pennula* by site and year are displayed in Table 2. A total of 33 bobwhite were donated and surveyed from TS and 35 from RS. The mean abundance of *O. petrowi* from TS across all years was 3.1 and prevalence was 43.75% for *A. pennula* mean abundance was 102.3 with a prevalence of 81.8%. Mean abundance of *O. petrowi* from the RS across all years was 6.5 and prevalence was 66.6%. Mean abundance of *A. pennula* from the RS was 161.5 and prevalence was 91.4% on RS across all three years. Mean abundance of the $\log_3$ transformed *O. petrowi* counts from TS was 0.67 (90% CI = 0.43,0.91) and 1.25 (90% CI = 0.92,1.59) from the RS. Mean abundance of the $\log_3$ transformed *A. pennula* counts from the TS was 3.04 (90% CI = 2.54,3.54) and 3.79 (90% CI = 3.25,4.33) from the RS. By-year comparisons are shown in Fig. 3. More adult birds were sampled from the TS each year than from the RS. An additional 10 hunter-harvested bobwhite were reported but not donated from RS in 2022 and are included in the J:A ratio. The treated site maintained a lower prevalence, abundance, and intensity than the reference site in all years sampled for both parasites. However, helminth abundance did increase across sampling years on both sites.

4. Discussion

Here we report on bobwhite abundance on two sites that differ in abundance of two commonly occurring helminths. Both the treated and reference site showed increases in bobwhite and helminth abundance during the course of this study; however, the treated site had consistently greater bobwhite abundance and lower abundance of the two helminths of interest. CI intervals did not overlap for whistle call counts in any year and covey counts only overlapped in 2020. 2020 was also the only year in which CIs of helminth abundances overlapped the means of both sites. When helminth abundance within sites was pooled across all three years, the CIs of *O. petrowi* did not overlap and the CIs for

Table 2
Summary statistics of hunter harvested and donated bobwhite from both sites. Samples could not be obtained from either site in 2019. Not all donated bobwhite were donated with intact heads so were not examined for *O. petrowi*. No adult bobwhite were donated for this study from RS in 2020 or 2022 so the J:A ratio is displayed as >the number donated. Not all donated bobwhite had intact heads, so examination for *O. petrowi* could not occur. Site-Year combinations when this occurred are denoted by #. N = number examined, J:A = Juvenile:Adult, SD = standard deviation.

Site-Year	*O. petrowi* N	*O. petrowi* Prevalence	*O. petrowi* Mean Abundance	*O. peetrowi* SD	*O. petrowi* Range	*A. pennula* N	*A. pennula* Prevalence	*A. pennula* Mean Abundance	*A.pennula* SD	*A. pennula* Range	J:A Ratio
TS-2020	7	28.6%	0.29	0.49	0–1	7	85.7%	71.4	90.1	0–218	6:1
TS-2021#	11	36.4%	3.5	6.64	0–23	12	72.7%	101.8	237.3	0–840	1:1
TS-2022	14	57.1%	4.2	7.73	0–27	14	92.9%	118.1	102.2	0–277	1.3:1
RS-2020#	7	42.9%	1	1.53	0–4	9	88.9%	142.7	160.7	0–373	>10:1
RS-2021#	13	61.5%	7.2	9.68	0–30	16	87.5%	141.4	235.5	0–975	4.3:1
RS-2022	10	90%	9.5	7.19	0–22	10	100%	210.5	159.9	15–520	>20:1

A. pennula did overlap but did not overlap the means. Additionally, the TS maintained lower mean abundance, prevalence, and a narrower range for *A. pennula* in all three sampling years than RS. Mean abundance and prevalence of *O. petrowi* on the TS were also lower than RS in all three years and the range only exceeded that of RS in 2022. These findings become more substantial when considering that appreciably more adult bobwhite were sampled from TS than RS in all three years despite other research findings that adult bobwhite tend to have a greater abundance of these helminths than juveniles (Dunham et al., 2017a,b; Commons et al., 2019; Bruno et al., 2019; Wyckoff et al., 2023).

Like most wildlife, temperature and precipitation are known to impact bobwhite abundance (Guthery et al., 2002; Lusk et al., 2001). While the effects of precipitation and temperature are not straightforward or linear (Guthery et al., 2002; Lusk et al., 2001), in general, both below average rainfall and above average summer temperatures produce conditions that are not conducive to bobwhite reproduction and survival. Thus, such conditions can lead to lower bobwhite abundances. The proximity of the treated and reference site provided for similar climate patterns between the two sites, meaning these factors would not influence the conclusions of this study. Throughout the course of this research, only 2019 had weather conditions that were conducive for bobwhite populations. 2020 had substantially less precipitation during the bobwhite nesting period but greater than average in the winter. 2021 precipitation totaled only 79.8% of the long-term average but had fewer days with extreme temperatures. 2022 precipitation was only 72.6% of the long-term average and had substantially more days with extreme temperatures during the bobwhite nesting period. All this to say that those two years should have shown a decrease, or at best, no substantial change in bobwhite abundance. There was a particularly high increase in spring whistle call counts on both sites between 2021 and 2022. The number of days with extremely low temperatures and precipitation were below average in 2022, possibly allowing for greater overwinter survival. However, only the TS showed an increase in fall abundance estimates over the same time frame. There was a substantial increase in the number of coveys heard on the TS between 2020 and 2022 as evidenced by the nonoverlapping CI intervals. The 95% CIs of 2020 covey counts on the RS overlapped the mean number of coveys heard in 2021 and 2022. Thus, despite the subpar climate conditions, fall bobwhite abundance did indeed increase on the TS but not the RS over the course of this research.

The abundance of *O. petrowi* in bobwhite on the RS was lower than reports from similar ecoregions in Texas (Brym et al., 2018; Dunham et al., 2017a,b; Dunham et al., 2014; Henry et al., 2017). The highest mean abundance of *O. petrowi* from the RS in this study was 9.5 and the average across all three years was 6.5; however, the lowest mean abundance reported from bobwhite surveyed in similarly arid regions was 11.9 (Dunham et al., 2014). *Aulonocephalus pennula* was, however, more consistent with burdens reported in those same studies. Bobwhite donated from the reference site in 2021 averaged 141.4 worms per bird, with a three-year average of 161.5. Reported mean abundance of *A. pennula* from similar regions ranges from 98.6 to 599 worms per individual (Brym et al., 2018; Dunham et al., 2017b).

The bobwhite population on the RS used in this study did appear to be stable over time and had a juvenile to adult ratio of 9.3:1 over all three years. If this ratio is representative of the actual ratio, it indicates the annual survivability of bobwhite in that area is around 10% (Guthery, 1997). This value is about half that of previous survivability estimates from western Oklahoma (Cox et al., 2004), but considering the climate conditions during the course of this research, this survival estimate is still reasonable. The bobwhite population on the TS however did not appear to be stable over the course of this study. CIs from year-to-year fall estimates of bobwhite abundance only overlapped between 2021 and 2022. CIs from those two years not only overlapped but also overlapped the means. If we take the abundance estimates from those two years to indicate the population was stable, then the juvenile to adult ratio in 2022 would be 1.3 to 1. Using this value, we would estimate the survivability of bobwhite on the TS to be around 43%, far greater than the RS and previous reports of survivability from the area (Cox et al., 2004). Indeed, an estimate of around 40% would be more consistent with survival estimates from southern latitudes (Lehmann, 1984). Ignoring the assumption of stability and pooling the juvenile to adult ratio from the TS across all three years, we would get a juvenile to adult ratio of 1.5 to 1 and would still have an annual survival estimate of around 40%. Thus, not only did the TS have a greater bobwhite abundance than the RS, but also a greater annual survival rate.

The efficacy of the anthelmintic feed used in the study at reducing helminth burden in individual bobwhite has been demonstrated and the results from this study indicate that effect translates to overall reduction of helminth burdens in the bobwhite population (Henry et al. In-press). A greater number of adult bobwhite were sampled for helminths from TS than RS in all three years. However, the TS still maintained a lower abundance of both helminths, providing evidence of the effectiveness of the medicated feed to suppress helminth abundance. Theoretical models indicate that greater host abundance leads to greater helminth abundance (May and Anderson, 1979). However, in this study, the site with the lower helminth abundance had substantially greater host abundance. Previous research has found that adult bobwhite have a higher prevalence of *O. petrowi* than juvenile bobwhite, while no such pattern was found for *A. pennula* (Dunham et al., 2014, 2017b). The substantially lower juvenile to adult ratio from TS than RS and lower overall helminth abundance further indicate the medicated feed was able to suppress helminth abundance, as higher *O. petrowi* prevalence would be expected if there were no effect. The above evidence, taken together, suggests an anthelmintic treated feed is a viable and effective tool for treating helminth infections in bobwhite.

This work supports earlier claims that helminths, *O. petrowi* and *A. pennula* in particular, can be a regulatory factor in bobwhite populations (Brym et al., 2018; Dunham et al., 2014; Henry et al., 2020). Land and habitat management practices on both sites remained consistent for over a decade preceding this research and were unchanged during research. The only practice that changed on the TS was the use of the medicated feed. Only 2019 had weather conditions that could be considered favorable to bobwhite production. 2020 was a particularly poor year for bobwhite production and the TS still saw a substantial increase in bobwhite abundance from 2019. Neither 2021 nor 2022 had good climatic conditions for bobwhite production; however, the bobwhite abundance increased on the TS but not on the RS.

Finally, it is important to consider potentially negative consequences of using anthelmintics and other pharmaceuticals on wildlife (Wilkinson et al., 2022). No pharmaceutical or chemical intervention is without risk but, we assess the risk of using fenbendazole to treat helminth infections in wild bobwhite to be low using the methodology presented in this research. Recent research into the health and pathological effects of fenbendazole on bobwhite found no evidence of disruption of physiological processes or pathology associated with treatment (Henry et al., 2024). The risk to reproductive health or potential in bobwhite is also low because the feed was not available during the timeframe of peak reproduction. The environmental risk was also determined to be low for several reasons. First, the concentration of the drug in the medicated feed and short time periods the feed is in the field greatly limits the amount that is available for environmental contamination. Second, fenbendazole has a much higher affinity for helminth β-tubulin (the target receptor of fenbendazole) than for vertebrates and many terrestrial invertebrates (Abonwga et al., 2017). Thirdly, the U.S. Food and Drug Administration registration recommends the use of strategic feeding stations (such as the ones reported in this study) further lowers the risk of unintended contamination or exposure to non-target organisms. The risk associated with the evolution of anthelmintic resistance has also been assessed as low. Among factors that have been identified as substantial contributors towards the evolution of anthelmintic resistance is a high frequency of treatment and treating all or most hosts are frequently cited (Falzon et al., 2014; Fissiha and Kinde 2021). We don't know the proportion of bobwhite that were receiving treatment on the TS in this study, but we know it was not 100%. Additionally, there were some individuals with a high abundance of both helminths were found on TS and RS during this study, indicating a substantial refugia of unexposed helminths in some bobwhite. Thus, any resistance that may evolve will be less likely to become a dominant trait in those helminth populations. This has also been seen in the case of *T. tenuis* infecting Red grouse treated with an anthelmintic grit in Scotland (Cox et al., 2010).

5. Conclusion

Here, an anthelmintic was administered to bobwhite via supplemental feed to treat helminth infections in free-ranging populations. The population receiving the medicated feed was substantially larger than the reference population, grew over a three-year period of below average precipitation, had substantially lower abundance of *O. petrowi*, marginally lower abundance of *A. pennula*, and substantially greater annual survival. This research was the first to use a medicated feed to manipulate helminth abundance in bobwhite at a landscape scale and has provided evidence that helminths can have regulatory effects on bobwhite populations in semi-arid regions of the bobwhite range.

CRediT authorship contribution statement

Jeremiah Leach: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hannah N. Suber:** Writing – review & editing, Investigation. **Regan Rivera:** Writing – review & editing, Investigation. **Katelyn A. Conley:** Writing – review & editing, Investigation. **Shannon P. Lukashow-Moore:** Writing – review & editing, Methodology, Investigation. **James G. Surles:** Writing – review & editing, Supervision, Formal analysis. **Ronald J. Kendall:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of interest

Park Cities Quail Coalition, Rolling Plains Quail Research Foundation, Texas Tech University, and R. Kendall have a financial interest in the medicated feed. Otherwise, all co-authors of the manuscript declare no conflict of interest.

CoI Statement

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