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# Monitoring Northern Bobwhite (*Colinus virginianus*) Populations in the Rolling Plains of Texas: Parasitic Infection Implications

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ABSTRACT

The Northern bobwhite quail (*Colinus virginianus*) is an important gamebird among hunters that has been experiencing a nationwide decline for > 50 yr. In West Texas, one of the last regions to experience this downward trend, research on bobwhite populations has focused on habitat variables and, increasingly, on parasitic infection. In bobwhite, two of the most common parasites are the caecal worm (*Aulonocephalus pennula*) and eyeworm (*Oxyspirura petrowi*). To better document the state of bobwhite populations in the Rolling Plains Ecoregion, trapping, summer rooster counts, fall covey counts, and parasitic infection assessments were conducted in three counties during 2018. These efforts were compared with previous years for a longitudinal perspective. In 2018, bobwhite populations experienced a widespread decline, although some counties surveyed fared slightly better than others. More effort was required to trap fewer total bobwhite, and fewer roosters and coveys were counted than in previous years. In addition, in 2018, parasitic infection levels of caecal and eyeworms were higher than or similar to levels in previous years. Additional research is necessary to understand which factors influence bobwhite populations in allopatric locations and over time.



## Introduction

The Northern bobwhite quail (*Colinus virginianus;* hereafter bobwhite), a gamebird highly sought after by hunters (Hernández et al., 2002; Johnson et al., 2012), has been experiencing a nationwide decline since the 1960s (Sauer et al., 2013). In Texas, specifically the Rolling Plains Ecoregion, the nationwide pattern of decline for bobwhite was not documented until the 1980s (Brennan, 1991; Rollins, 2002). Bobwhite are a species known to have irruptive population growth (Rollins, 1999a), but additional factors may exacerbate these natural "boom and bust" cycles. Possible explanations for this continued decline in the Rolling Plains Ecoregion have ranged from the loss of habitat and decreasing habitat quality (Brennan, 1991; Hernández et al., 2013) to predators (Rollins, 1999b; Rollins and Carroll, 2001) and fire ants (Allen et al., 1995). Although other factors, such as parasitic infection, have been hypothesized to have a low impact on quail populations (Olsen et al., 2016), the continued decline of quail in favorable habitats has led to a reevaluation of this hypothesis. As such, an increasing number of studies have been done to determine the potential impact of parasites (Dunham et al., 2017a; Henry et al., 2017; Bruno et al., 2018).

Two of the most common parasites of bobwhite in the Rolling Plains Ecoregion, the caecal worm (*Aulonocephalus pennula*) and eyeworm (*Oxyspirura petrowi*), have been known to occur in bobwhite for nearly 50 years (Kellogg and Calpin, 1971; Olsen et al., 2016; Dunham and Kendall, 2017; Bruno et al., 2018). While prevalence of caecal and eyeworms has been shown to vary by time of year (Villarreal et al., 2016), they are still among the most prevalent parasites found in bobwhite (Bruno et al., 2018). In some areas of Texas, bobwhite have had 80–100% prevalence of caecal and eyeworms (Dunham et al., 2017a; Henry et al., 2017). In a survey by Kubečka et al. (2017) of bobwhite in 9 states, those individuals sampled from the Rolling Plains of Texas had the highest prevalence and intensity of eyeworm infection. Despite their high prevalence, it is currently not completely understood how these parasites affect the survival of bobwhite. It has been proposed that heavy infection by caecal worms could lead to malnutrition in bobwhite (Dunham et al., 2017b), which may hinder survival, whereas eyeworms, which are found in the tissues around the eye, can cause cellular damage to the eye tissues, as well as scarring and interstitial keratitis of the cornea (Bruno et al., 2015; Dunham et al., 2016). Bobwhite infected with eyeworms have therefore been hypothesized to have impaired vision, which is supported by anecdotal reports of abnormal behavior like bobwhite flying into large structures (Brym et al., 2018a).

As such, these parasites have the potential to impact individual bobwhite, but their ability to impact bobwhite populations has only

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recently been addressed. For example, Henry et al. (2017) found evidence of a die-off among bobwhite that corresponded to higher infection levels of caecal and eyeworms than seen in previous years. Furthermore, drought is suggested to exacerbate caecal worm intensity in bobwhite (Lehmann, 1984), and high caecal worm intensities have been reported in bobwhite during periods of drought (Brym et al., 2018a; Brym et al., 2018b). These high intensities may have negative impacts on bobwhite populations considering drought has increased in the past decade and will continue to increase in the Rolling Plains (Modala et al., 2017).

This study expands on the narrative of Henry et al. (2017), by including more study locations, analyzing trapping effort between these locations, and using additional metrics to monitor bobwhite populations. Although the number of individuals trapped can be a useful metric, measuring the amount of effort required to trap those individuals provides necessary context (McDonald and Harris, 1999). Likewise, monitoring populations at any one time of year, or using any one method, will not be completely representative of their population dynamics. This is especially true for bobwhite as their social organization varies depending on their breeding cycle (Williams et al., 2003). To better understand bobwhite population dynamics in the Rolling Plains Ecoregion of Texas on a qualitative level, trapping effort, summer rooster counts, fall covey counts, and parasite intensity data were collected and compared among three counties in the Rolling Plains in 2018, as well as compared with data collected between 2014 and 2017 from one of the counties to assess potential population changes over time.

## Methods

### *Ethics Statement*

All work was performed under Texas Parks and Wildlife Department (TPWD) permits SPR 1098-984 and SPR-0715-095 and consistent with Texas Tech University Animal Care and Use Committee protocols 13066-08, 14027-04, and 16071-08.

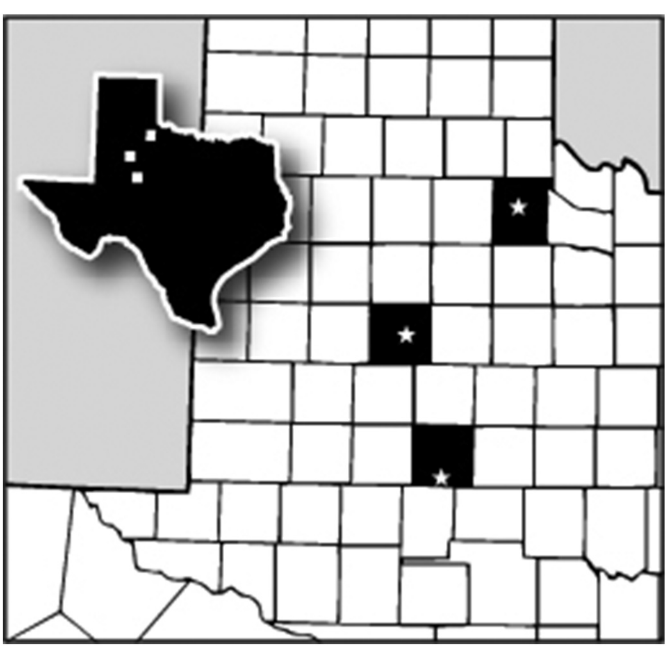

**Figure 1.** Location of study sites (from north to south) in Cottle, Garza, and Mitchell Co. in West Texas. Stars designate study site locations in each county.

### *Study Areas*

This study was performed at three sites within the Rolling Plains Ecoregion of West Texas (Fig. 1). In Mitchell County (32°7′45″N 100°59′6″W), a 120000-ha privately owned cattle ranch has been trapped for bobwhite since 2014. In 2018, trapping was performed in two additional counties. These included the Matador Wildlife Management Area (MWMA), an 11400-ha public land operated by the TPWD in Cottle Co. (34°7′3″N, 100°20′41″W) and a 6880-ha privately owned cattle ranch in Garza Co. (33°12′32″N, 101°15′25″W). In 2017, weather stations at or near the sites all reported annual rainfalls between 50.8 and 55.8 cm, average July temperatures between 28.3°C and 29.4°C, and average January temperatures between 6.1°C and 7.2°C (Lawrimore, 2018). The sites are dominated by honey mesquite *(Prosopis glandulosa)*, juniper *(Juniperus pinchotti)*, sand shinnery oak *(Quercus havardii)*, and prickly pear (*Opuntia* spp.), which is characteristic to the Rolling Plains Ecoregion (Rollins, 2007).

### *Trapping*

Bobwhite were typically trapped between March and October from 2014 to 2018. Bobwhite trapping followed procedures outlined in Dunham et al. (2014). This included the use of wire, walk-in, double funnel traps (91.4 × 60.9 × 20.3cm) baited with milo *(Sorghum bicolor)*. Traps were also covered with nearby vegetation to decrease the chance of bobwhite mortality due to weather and temperature. In addition, bobwhite have a low mobility (< 0.4 km; Hernández et al. 2007), and in Mitchell Co. traps were set in the same locations within and between years and at distances between 0.4 km (Dunham et al., 2014) and 0.1 km apart (McGrath et al., 2017). In Cottle and Garza Co., traps were placed in areas where bobwhite were reportedly seen or heard with traps spaced at a minimum distance of 0.1 km to increase success of trapping bobwhite in this area (McGrath et al., 2017). In all years, traps were typically only moved when ants were present or the trap was repeatedly disturbed by other animals. Upon capture, bobwhite were fitted with an aluminum leg band, weighed, aged, sexed, and given a body condition score on the basis of visual assessment. Individuals were either kept for assessment of parasite intensity or released at the location of capture. While trapping objectives over the years varied between nesting success and parasite assessments, the aims of all studies involved the same systematic trapping methods to appropriately assess bobwhite populations in the Rolling Plains Ecoregion.

Trapping effort in this study is defined as the quotient of trapping sessions and number of birds captured (Henry et al., 2017). In other words, trapping effort is the number of trapping sessions necessary to catch one bobwhite. Trapping sessions are defined for each site as the number of times each trap was checked in a given period of time (e.g., morning, afternoon, and evening; Henry et al., 2017). Although Dunham et al. (2014) checked traps two times per day, an afternoon check was added in 2018 to increase chances of bobwhite capture, as well as to prevent mortality from weather and temperature. This resulted in three trapping sessions per day in 2018: in the morning (10:00 ± 30 min), afternoon (15:30 ± 30 min), and evening (20:30 ± 90 min). In addition, the number of days in which trapping occurred each month varied between and within years, and in 2018, each site was visited for 5 consecutive d of trapping. On average (± SE), 61.4 ± 1.0, 31.0 ± 2.2, and 30.1 ± 1.5 traps were set in Mitchell, Cottle, and Garza Co., respectively, each month in 2018.

Trapping effort was estimated in Mitchell Co. for 2015 − 2017 from the number of traps set, the number of checks per day, and the number of trapping days in a given month. In 2015, 48 traps were used throughout the year. An average of 41 ± 6.2 traps were used in 2016 with number varying by month. In 2017, 35 traps were used throughout the year. The number of trapping days was estimated from dates in the banding record, with both the day before and after recorded bandings being included to ensure that trapping sessions were not omitted. At most, this method added 3 d of trapping to a given month. These banding records were also used to determine the number of new bobwhite caught for each trapping month from 2015 to 2017.

The trapping effort estimates from 2015 to 2017 may have inconsistencies in the estimates for several reasons. First, a static number of traps are assumed for up to an entire yr (i.e., 2015 and 2017); however, exact trap numbers likely varied slightly at a finer scale due to field conditions such as livestock and wildlife disturbing traps. Using the criteria described earlier, the actual number of days in which trapping occurred may have been higher if multiple consecutive days occurred with no bobwhite trapped. There were also additional studies occurring in March and April from 2015 to 2017 and in July 2016 that gave additional bobwhite trapping effort data. Also, a small portion of bobwhite in 2015 and 2016 were not recorded in the banding record due to multiple bobwhite being trapped in the same location when a representative sample (i.e., ~5–10) had already been achieved. Finally, in 2015, trapping became difficult after March and necessitated additional methods for trapping bobwhite that are not comparable with other years or locations and therefore are not presented here.

### Rooster Counts

From 30 May to 7 June 2018, rooster counts were conducted at each of the three sites. Each site consisted of three transects totaling 6 to 10 points that were chosen following similar guidelines to rooster counts covered in Hernández and Guthery (2012). Transects were placed on the basis of availability of ranch roads and appropriate lengths and distances apart. Points within each transect were at least 0.7 km apart, and transects were separated by at least 1.6 km to prevent double counting individuals. A designated operator was assigned to each transect so that counts were conducted on each transect over 3 consecutive d. In Cottle Co., inclement weather prevented a third day of counts. Beginning 30 min before sunrise, operators began listening following the first *bob-white* call heard. Operators listened for 5 min at each point, recording the number of roosters heard by using a spot map to prevent double counting. Rooster counts in Mitchell Co. in June 2017 used identical methods, transects, and points as those used in 2018.

### Covey Counts

From 11 October to 16 November 2018, covey counts were conducted at each site. Transects were identical to those used for rooster counts but only contained three stations per transect. Stations were separated by at least 1.6 km and were chosen in such a way that transects were separated by at least 2.3 km. As per Hernández and Guthery (2012), three operators listened at one station per transect per day over 3 consecutive d. Therefore, there were no repeat observations per station. Beginning 45 min before sunrise, operators listened for 20 min after the first *koi-lee* covey call heard or for 40 min if no calls were heard (Stokes, 1967). Operators recorded the number of independent coveys heard. After listening, operators drove the transect and recorded the number of coveys flushed, as well as the number of quail in those coveys. Covey counts in Mitchell Co. in October 2017 used identical methods, transects, and points as those used in 2018.

### Parasite Intensity Assessment

To assess bobwhite for the presence of caecal and eyeworms, up to nine live birds were collected from each site each month in 2018. If dead bobwhite were found, they were also collected and assessed for parasites. Typically, the first six bobwhite were kept, with no more than five taken from the same trap each month. Birds were held in crates ($66.0 \times 43.2 \times 12.7$ cm) for $1 - 4$ d, depending on their time of capture, and provided milo and water *ad libitum*. At the end of trapping, bobwhite were transported to The Institute of Environmental and Human Health Aviary at Texas Tech University. Bobwhite were held for no more than 3 d in individual $25 \times 61$ cm cages and fed milo and water *ad libitum* before euthanasia via a carbon dioxide chamber.

After euthanasia, bobwhite were immediately necropsied following procedures from Dunham et al. (2016, 2017b). Caecal and eyeworms were identified via morphological traits (Dunham et al., 2016; Kalyanasundaram et al., 2017). Caecal worms were collected from both arms of the caecum and a portion of the ileum. Eyeworms were collected from tissues in and around the orbital cavity. The number of both caecal worms and eyeworms were counted and recorded for each bird. Parasite intensity assessment methods from 2014 to 2017 followed the same procedure.

From 2014 to 2017, additional bobwhite were collected from an area in Mitchell Co. designated for parasite assessment. These bobwhite were not included in trapping effort estimates. Therefore, the number of bobwhite trapped may differ from the number of bobwhite sampled for parasitic infection. In addition, juvenile bobwhite were included in the trapping effort but were not included in the parasite assessment. This is because it has been demonstrated that juveniles are less infected than adults (Dunham et al., 2017a; Bruno et al., 2018) and would have lowered the parasite intensity for the last half of the trapping season.

### Data Analysis

Mean and standard error were calculated for trapping effort (Table 1), rooster counts (Table 2), covey counts (Table 3), and parasite intensities (Table 4) for comparison. The number of bobwhite trapped does not include recaptured bobwhite, of which there were 10 in 2018, 11 in 2017, 77 in 2016, and 52 in 2015. Recaptured bobwhite were not included in the comparisons.

## Results

Trapping in 2018 required the highest amount of effort of years sampled (see Table 1). For all three counties in 2018, 102.3 trap checks were necessary to trap a single bobwhite, an order of magnitude higher than previous years in Mitchell Co. Even when broken down by county and year, the effort required to trap one bobwhite was higher for each county in 2018 than in any previous year (see Table 1). Overall, Mitchell Co. in 2018 required the most effort with 16 bobwhite caught over 4906 sessions, while Mitchell Co. in 2017 required the least effort (115 bobwhite trapped over 1 820 sessions). Cottle Co. had the highest trapping success in 2018 with 52 bobwhite trapped over 2287 trapping sessions but still required more effort than Mitchell Co. did in any year from 2015 to 2017. While Garza Co. fared better than Mitchell Co. in 2018 with 27 bobwhite trapped over 2525 sessions, the amount of effort required was still double that of the most effort required in Mitchell Co. from 2015 to 2017.

Second, an average of $3.4 \pm 0.9$ roosters were heard over 255 counts for all three counties in 2018, which is lower than the $6.8 \pm 0.9$ roosters heard over 78 counts in 2017. Each county in 2018 had fewer roosters per count than that of 2017 as well (see Table 2). Cottle Co. had the highest average, followed by Garza Co., and then Mitchell Co. In addition, far fewer coveys were counted in 2018 from all three locations than from a single county in 2017. A total of 25 coveys were counted from all three locations in 2018 compared with 56 coveys from Mitchell Co. in 2017 (see Table 3). Again, there were fewer coveys in each county when compared with 2017. Cottle Co. averaged the highest number of coveys counted while Mitchell and Garza Co. were similarly low in their average numbers for 2018 (see Table 3). There were also no coveys flushed in 2018, so a comparison of average covey size cannot be made (see Table 3).

Finally, parasitic infection burdens varied with parasite, year, and county. Average caecal worm counts were similar between all 3 counties in 2018 and Mitchell Co. in 2017, but more worms were counted in all counties in 2018 than Mitchell Co. from 2014 to 2016 (see Table 4). Caecal worm infection ranges from mild (1–50 worms),

**Table 1**
Bobwhite trapping effort from March to October in Mitchell County, Texas, from 2015 to 2018 and in Cottle and Garza Co. in 2018. Trapping effort (TS/B) is the number of trapping sessions necessary to catch one bobwhite. NA values represent months where no trapping occurred.

| Yr | County | Effort | Mar | Apr | May | June | July | Aug | Sept | Oct | Average | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | Mitchell | Sessions | 1248 | 864 | 672 | 288 | 192 | NA | NA | NA | 652.8 | 3264 |
| | | Bobwhite | 65 | 7 | 2 | 1 | 2 | NA | NA | NA | 15.4 | 77 |
| | | TS/B | 19.2 | 123.4 | 336.0 | 288.0 | 96.0 | NA | NA | NA | **42.4** | |
| 2016 | Mitchell | Sessions | 2984 | 550 | 280 | 140 | 950 | NA | 70 | 70 | 720.6 | 5044 |
| | | Bobwhite | 108 | 27 | 7 | 5 | 18 | NA | 7 | 10 | 26.0 | 188 |
| | | TS/B | 27.6 | 20.4 | 40.0 | 28.0 | 52.8 | NA | 10.0 | 7.0 | **27.7** | |
| 2017 | Mitchell | Sessions | 350 | 420 | 210 | 210 | 210 | 70 | 140 | 210 | 227.5 | 1820 |
| | | Bobwhite | 34 | 20 | 4 | 4 | 17 | 9 | 17 | 10 | 14.4 | 115 |
| | | TS/B | 10.3 | 21.0 | 52.5 | 52.5 | 12.4 | 7.8 | 8.2 | 21.0 | **15.8** | |
| 2018 | Mitchell | Sessions | 480 | 712 | 682 | 609 | 660 | 600 | 598 | 565 | 613.3 | 4906 |
| | | Bobwhite | 13 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 16 |
| | | TS/B | 36.9 | 712.0 | – | – | 660.0 | – | 598.0 | – | **306.7** | |
| 2018 | Cottle | Sessions | NA | 305 | 317 | 238 | 418 | 351 | 330 | 328 | 326.7 | 2287 |
| | | Bobwhite | NA | 3 | 18 | 3 | 12 | 12 | 3 | 1 | 7.4 | 52 |
| | | TS/B | NA | 101.7 | 17.6 | 79.3 | 34.8 | 29.3 | 110.0 | 328.0 | **44.1** | |
| 2018 | Garza | Sessions | 324 | 439 | 232 | 304 | 277 | 330 | 329 | 290 | 315.6 | 2525 |
| | | Bobwhite | 2 | 13 | 5 | 5 | 0 | 1 | 0 | 1 | 3.4 | 27 |
| | | TS/B | 162.0 | 33.8 | 46.4 | 60.8 | – | 330.0 | – | 290.0 | **92.8** | |
| Average | | Sessions | 2 222.2 | 777.3 | 510.1 | 317.3 | 584.8 | 324.2 | 334.5 | 303.8 | | |
| | | Bobwhite | 45.4 | 20.9 | 11.6 | 6.7 | 8.5 | 9.6 | 9.2 | 7.0 | | |
| | | TS/B | 48.9 | 37.2 | 44.0 | 47.4 | 68.8 | 33.8 | 36.4 | 43.4 | | |

to strong (101–200 worms), to extreme intensities (> 300 worms; Dunham et al., 2017a). Bobwhite averaged between strong and extreme caecal worm infection intensity in both 2018's 3 locations (235.7 ± 24.2) and Mitchell Co. in 2017, while strong infection intensity was recorded for Mitchell Co. from 2016 to 2014 (see Table 4). Bobwhite averaged an extreme intensity of caecal worm infection in Mitchell Co., between a strong and extreme intensity of infection in Cottle Co. and a strong intensity of infection in Garza Co. in 2018 (see Table 4). In 2018, the average number of worms counted in Mitchell Co. was higher than any other county or yr (Fig. 2a). In 2018, Cottle and Garza Co. had similar caecal worm counts. However, when compared with Mitchell Co. from 2014 to 2017, both counties were similar to 2017 and 2016 but had higher averages than in 2015 and 2014 (see Fig. 2a and Table 4).

Average counts of eyeworms for the three locations were higher in 2018 than in Mitchell Co.'s 2017 and 2016 counts but were similar to 2015 and 2014 in Mitchell Co. Eyeworm infection ranges from mild (1 − 10 worms), to strong (21–40 worms), to extreme intensities (> 60 worms; Dunham et al., 2017a). Bobwhite averaged strong eyeworm infection intensity in 2018 over three locations (22.5 ± 3.1), as well as in Mitchell Co. in 2015 and 2014 (see Table 4). In 2017 and 2016 infection intensity was between mild and strong for Mitchell Co. (see Table 4). In 2018, the average number of worms counted was not similar between any county (see Fig. 2b). In 2018, bobwhite in Mitchell Co. had between strong and extreme infection intensities, while Cottle and Garza Co. had between mild and strong intensities (see Table 4). In 2018, Mitchell Co. had higher average worm counts than any other county or yr (see Fig. 2b). Cottle Co. had slightly higher infection intensities than in 2017, and Garza Co. had lower intensities than any other yr (see Fig. 2b).

**Table 2**
Bobwhite rooster counts from May to July in Mitchell County, Texas from 2017 to 2018 and in Cottle and Garza Co. in 2018.

| Yr | County | Transect | Total counts | Average ± SE | Total average ± SE |
|---|---|---|---|---|---|
| 2017 | Mitchell | 1 | 145 | 8.1 ± 0.5 | 6.8 ± 0.9 |
| | | 2 | 219 | 7.3 ± 0.5 | |
| | | 3 | 152 | 5.1 ± 0.2 | |
| 2018 | Mitchell | 1 | 42 | 2.3 ± 0.3 | 1.8 ± 0.4 |
| | | 2 | 57 | 1.9 ± 0.3 | |
| | | 3 | 34 | 1.1 ± 0.2 | |
| 2018 | Cottle | 1 | 135 | 4.5 ± 0.5 | 4.7 ± 0.4 |
| | | 2 | 126 | 4.2 ± 0.4 | |
| | | 3 | 165 | 5.5 ± 0.5 | |
| 2018 | Garza | 1 | 118 | 3.9 ± 0.3 | 3.7 ± 0.2 |
| | | 2 | 99 | 3.3 ± 0.3 | |
| | | 3 | 106 | 3.9 ± 0.3 | |

## Discussion

All the data presented here are in congruence with TPWD (2018) reports of reduced bobwhite in the Rolling Plains Ecoregion. On the basis of roadside surveys, TPWD (2018) reported the third lowest number of bobwhite heard since 1978. This is a stark contrast given that 2 years ago TPWD reported the highest number of bobwhite in the same time period. Although this decline has been attributed to reduced breeding (TPWD, 2018), the trapping efforts presented here suggest that bobwhite began to decline before the 2018 breeding season. In fact, the decline likely began before trapping started in March 2018 based on hunter-shot bobwhite data by Brym et al. (2018b) from Mitchell and Garza Co. Of those hunter-shot bobwhite, 57% had extreme caecal worm infection intensities (300+ worms) and 74% had strong eyeworm infection intensities (21–60 worms) (Dunham et al., 2017a; Brym et al., 2018b). Hunters also reported fewer and smaller coveys during the 2017–2018 hunting season (Brym et al., 2018b). When Dunham et al. (2017a) trapped bobwhite in 2014 and 2015, it was found that only 4% and 43% of bobwhite had similar infection intensities of caecal and eyeworms, respectively. Given that the probability of host

**Table 3**
Bobwhite covey counts in October in Mitchell County, TX from 2017 to 2018 and in Cottle and Garza Co. in 2018. The number of coveys flushed and the covey count are summed across points in each transect. The number of quail per covey are averaged.

| Yr | County | Transect | Coveys flushed | Quail per covey | Covey count | Total average covey count ± SE |
|---|---|---|---|---|---|---|
| 2017 | Mitchell | 1 | 5 | 10.0 | 14 | 18.7 ± 5.7 |
| | | 2 | 0 | 0.0 | 30 | |
| | | 3 | 3 | 11.0 | 12 | |
| 2018 | Mitchell | 1 | 0 | 0 | 0 | 0.7 ± 0.7 |
| | | 2 | 0 | 0 | 0 | |
| | | 3 | 0 | 0 | 2 | |
| 2018 | Cottle | 1 | 0 | 0 | 8 | 6.3 ± 0.9 |
| | | 2 | 0 | 0 | 5 | |
| | | 3 | 0 | 0 | 6 | |
| 2018 | Garza | 1 | 0 | 0 | 2 | 1.3 ± 0.7 |
| | | 2 | 0 | 0 | 2 | |
| | | 3 | 0 | 0 | 0 | |

**Table 4**
Average (±SE) number of caecal worms *(Aulonocephalus pennula)* and eyeworms *(Oxyspirura petrowi)* found in adult northern bobwhite quail *(Colinus virginianus)* in Mitchell County in 2014−2018 and in Cottle and Garza Co., Texas, in 2018. The sample size of bobwhite may differ from the total number caught for that month and is therefore listed below the averages. For months and locations with only one bobwhite sample, the count is given without SE. NA values represent months where no trapping occurred; "—" values represent months where data for both parasites was not collected.

| County | Species | March | April | May | June | July | August | September | October | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| Mitchell 2014 | Caecal worm | NA | 121.5 ± 31.1 | 155.5 ± 36.1 | 158.3 ± 54.3 | 135.0 ± 14.0 | 145.3 ± 26.4 | 117.1 ± 21.2 | 155.5 ± 49.5 | 136.5 ± 11.9 |
| | Eyeworm | NA | 19.6 ± 5.4 | 26.8 ± 7.3 | 32.3 ± 6.3 | 34.5 ± 7.5 | 35.0 ± 8.2 | 31.3 ± 4.1 | 25.0 ± 4.0 | 29.0 ± 2.7 |
| | Bobwhite | NA | 8 | 6 | 3 | 2 | 9 | 9 | 2 | — |
| Mitchell 2015 | Caecal worm | — | 138.8 ± 34.8 | 223.0 ± 36.0 | 131.6 ± 20.0 | 115.5 ± 18.1 | 93.0 ± 14.5 | 132.0 ± 68.9 | 89.2 ± 16.8 | 136.2 ± 11.5 |
| | Eyeworm | — | 29.0 ± 5.9 | 23.2 ± 9.1 | 27.6 ± 3.7 | 22.6 ± 3.2 | 22.6 ± 6.5 | 67.5 ± 7.3 | 41.2 ± 12.4 | 28.1 ± 2.5 |
| | Bobwhite | — | 9 | 9 | 16 | 13 | 5 | 2 | 5 | — |
| Mitchell 2016 | Caecal worm | 146.5 ± 18.3 | 216.0 ± 17.7 | 110.9 ± 20.1 | 237.2 ± 44.0 | 143.0 ± 28.5 | NA | 164.0 ± 54.5 | 223.0 ± 47.5 | 166.9 ± 12.1 |
| | Eyeworm | 9.9 ± 3.0 | 11.7 ± 3.7 | 16.4 ± 7.4 | 15.0 ± 5.2 | 13.6 ± 2.2 | NA | 26.0 ± 10.4 | 17.2 ± 7.6 | 14.3 ± 1.8 |
| | Bobwhite | 15 | 10 | 7 | 5 | 17 | NA | 6 | 5 | — |
| Mitchell 2017 | Caecal worm | 262.0 ± 28.4 | 321.3 ± 49.2 | 264.5 ± 46.5 | 243.3 ± 53.6 | 207.3 ± 71.5 | — | 339.0 ± 60.6 | 173.0 ± 45.0 | 260.3 ± 19.5 |
| | Eyeworm | 14.8 ± 2.7 | 14.1 ± 4.0 | 20.2 ± 4.9 | 19.3 ± 4.6 | 11.1 ± 2.2 | — | 27.3 ± 5.0 | 31.0 ± 6.6 | 17.5 ± 1.7 |
| | Bobwhite | 12 | 8 | 6 | 3 | 7 | — | 3 | 4 | — |
| Mitchell 2018 | Caecal worm | 369.9 ± 93.5 | 562 | — | — | 258 | — | 244 | — | 366.1 ± 72.5 |
| | Eyeworm | 49.3 ± 8.8 | 2 | — | — | 49 | — | 4 | — | 41.6 ± 8.3 |
| | Bobwhite | 9 | 1 | — | — | 1 | — | 1 | — | — |
| Cottle | Caecal worm | NA | 510.7 ± 182.7 | 213.8 ± 51.0 | 138.0 ± 60.9 | 206 ± 63.5 | 234.6 ± 33.5 | 249.3 ± 43.4 | 160 | 197.3 ± 69.7 |
| | Eyeworm | NA | 16.3 ± 8.0 | 32.3 ± 9.5 | 12.7 ± 11.2 | 19.3 ± 7.4 | 22.2 ± 3.9 | 10.7 ± 7.3 | 51 | 20.3 ± 9.9 |
| | Bobwhite | NA | 3 | 8 | 3 | 8 | 3 | 3 | 1 | — |
| Garza | Caecal worm | 83.8 ± 30.4 | 144.0 ± 31.5 | 186.6 ± 47.1 | 276.2 ± 84.0 | — | 90 | — | — | 171.1 ± 27.8 |
| | Eyeworm | 2.8 ± 2.1 | 11.7 ± 6.6 | 14.2 ± 14.0 | 19.6 ± 9.1 | — | 0 | — | — | 11.9 ± 4.3 |
| | Bobwhite | 4 | 6 | 5 | 5 | — | 1 | — | - | — |
| Average | Caecal worm | 272.3 ± 40.3 | 220.0 ± 24.2 | 193.8 ± 17.5 | 179.8 ± 19.5 | 157.5 ± 18.7 | 136.4 ± 18.7 | 179.6 ± 23.7 | 160.2 ± 21.5 | |
| | Eyeworm | 25.3 ± 5.0 | 17.1 ± 2.3 | 22.8 ± 3.6 | 23.1 ± 2.6 | 18.3 ± 2.0 | 27.2 ± 5.1 | 28.8 ± 4.2 | 30.1 ± 5.0 | |

survival decreases as parasite intensity increases (Wilber et al., 2016), Dunham et al. (2017a) suspected that higher proportions of highly parasitized individuals would suffer attrition. Consequently, the high parasite intensities found both during (Brym et al., 2018b) and just after the hunting season may have contributed to the decline of bobwhite in early 2018. Although infection in Garza and Cottle Co. appeared comparable with previous years in Mitchell Co., those areas may have had lower infection overall and/or the birds with higher infections had already dropped out during the winter, particularly given the high level of infection reported from Garza Co by Brym et al. (2018b).

Furthermore, parasites are known to negatively interact with environmental stressors (Lafferty and Kuris, 1999). In the winter of 2017–2018, some areas of the Rolling Plains experienced 100 consecutived with no precipitation, limiting food availability (TPWD, 2018). Although drought could not be considered in this study, caecal worm infection has been documented to intensify with drought (Lehmann, 1984), which may correlate with the persistently high caecal worm burdens observed in 2018. High caecal worm intensities may have also increased nutrient stress on bobwhite given that caecal worms are suspected to impede caecal function and absorb nutrients from their hosts (Dunham et al., 2017b). The high parasite loads observed in 2018 may have compounded with the drought and scarcity of food to impact overwinter survival of bobwhite. If these factors did indeed compound, increased mortality of bobwhite in general and, specifically females, as adult female survival is a key driver of bobwhite population dynamics (Sandercock et al. 2008), during the winter of

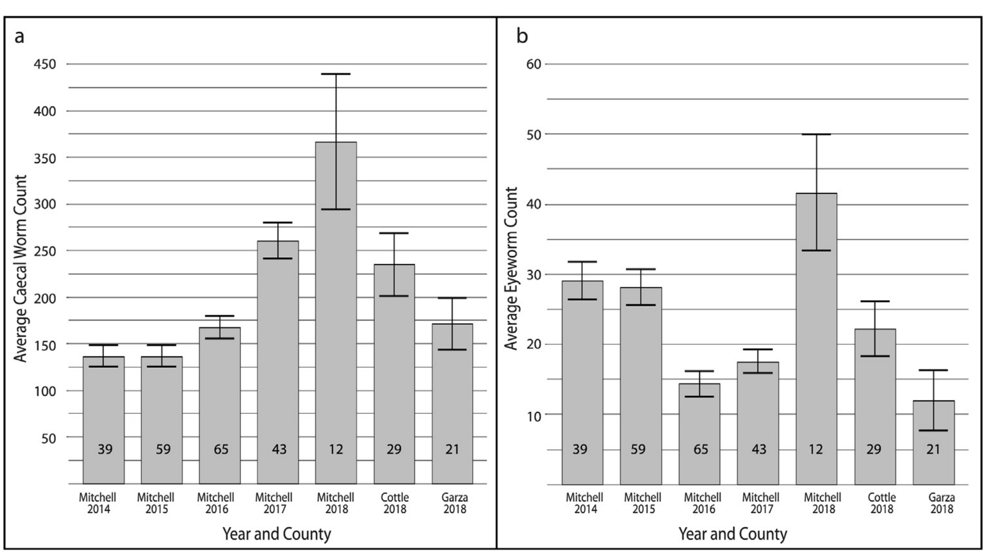


**Figure 2.** The average number of **a,** caecal worms *(Aulonocephalus pennula)* and **b,** eyeworms *(Oxyspirura petrowi)* found in northern bobwhite quail *(Colinus virginianus)* caught in Mitchell County, Texas from 2014 to 2018 and in Cottle and Garza Co. in 2018. Error bars represent SE. Sample sizes are given for each column.

2017–2018 would have had a profound effect on overall bobwhite numbers.

For those bobwhite that survived, drought conditions and high parasite intensities may have further negatively impacted their breeding. Bobwhite are known to have lower reproductive effort and success during dry periods (Hernández et al., 2005), and the drought that hit the Rolling Plains in October 2017 peaked during the breeding season in May 2018 (National Integrated Drought Information System, 2018). Heavily parasitized red grouse (*Lagopus lagopus scoticus;* Hudson, 1986) and house martins (*Delichon urbica;* De Lope et al., 1993) have reduced reproductive output and clutch size. House martins have further reduced clutch sizes when conditions are unfavorable (De Lope et al., 1993). As such, it is plausible that a similar scenario occurred in bobwhite due to unfavorable conditions and high parasite loads. Indeed, during 2018 fewer males were heard giving the *bobwhite* call during summer rooster counts. This call represents sexual vocalization, typically given by unmated males seeking female mates (Stokes, 1967). It is possible that low counts indicate a high proportion of mated males at the time of counting. However, given the reports of low breeding and small broods by TPWD (2018) and the data presented here, it seems more likely that breeding was poor. In fact, only 11% of bobwhite trapped in 2018 were juveniles, which is far below the 70% required to prevent population declines (Hernández et al., 2005). Consequently, the reduction in breeding would have hindered the recovery of already low bobwhite populations and furthered the decline first noted by Henry et al. (2017).

Although the data presented here suggest a general decline in bobwhite populations in the Rolling Plains during 2018, it is also important to consider the potential for bias in this data set due to site differences that were not accounted for in the analysis and results. For example, while habitat across the Rolling Plains is reported to be relatively consistent (Rollins, 2007), specific habitat metrics were not recorded in this study. The incorporation of habitat metrics would have allowed for more precise inferences regarding bobwhite population dynamics and better comparisons between locations. However, these considerations were beyond the scope of this study as the purpose was to provide a relative comparison among study sites and not an absolute metric of population size. Nevertheless, trapping success was reduced in all three locations during 2018 despite consistent trapping effort in areas that provide quail hunting and a designated wildlife management area. This corresponds with TPWD (2018) reports of decreased bobwhite abundance throughout the Rolling Plains, as well as significant reductions in bobwhite populations on the intensively managed Rolling Plains Quail Research Ranch (Rollins, 2018). Thus, it is plausible that the inference of decreased bobwhite populations reported here is generally representative of quail abundance in the Rolling Plains during 2018. These data are also useful in bringing attention to other factors potentially affecting bobwhite population dynamics, as well as encouraging more comprehensive future studies.

Given the drought, reduced food availability, and high parasite loads documented in 2018, it is not surprising that trapping effort was elevated, fewer males were heard in summer, and fewer coveys were heard in fall; considering these things, breeding may have been insufficient to offset a population decline. Though it is likely that parasites had some direct effect on bobwhite populations in 2018, their ability to interact with and be compounded by a variety of factors likely also influenced bobwhite population trends in the Rolling Plains. For instance, there were discrepancies between sites in 2018. Bobwhite populations at MWMA in Cottle Co. fared the best of those studied in 2018, especially when compared with Mitchell Co., which had the highest parasite burdens, lowest trapping success, and lowest call counts. These discrepancies may be due to intense and regular land management conducted at MWMA, as is done with other public lands. Not only would management improve overall conditions for bobwhite, but practices such as prescribed burning could reduce endoparasites (Scasta, 2015), which could potentially ameliorate the impact of parasites on bobwhite populations in these areas. However, it is unknown whether landscape factors, climate, increased parasite intensities, or a combination of these were responsible for the differences in bobwhite metrics reported in this study. Therefore, in addition to traditional landscape metrics, such as rainfall and vegetative cover (Rollins, 2007), researchers should also consider the effect of parasites and how land management practices interact with infection intensities.

## Implications

Although the definitive causes remain unknown, it is undeniable that bobwhite populations in the Rolling Plains have experienced a decline in 2018. Systematically documenting trapping effort offers the most detailed record of the decline, as effort is a more comparable metric than number of bobwhite trapped alone. In addition, the level of understanding that was achieved by using supplementary population metrics, such as summer and fall counts, further emphasizes the need to use multiple methods when generalizing population trends. Researchers must also consider the impacts of parasites, like caecal and eyeworms, on bobwhite populations. Achieving a more comprehensive understanding of bobwhite populations would require sampling over both a wider geographic area and longer time period. However, expanding the means and scope of sampling will increase the resources and time needed to collect data. Therefore, the future of sustainable bobwhite populations in the Rolling Plains Ecoregion of West Texas will depend on continued collaborative efforts between researchers and land managers while also considering additional understudied factors, such as parasites.

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