BOBWHITE PRODUCTION, BROOD ECOLOGY, AND BROOD MOVEMENTS IN RESPONSE TO HABITAT RESTORATION IN NORTHERN ARKANSAS

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Bobwhite production, brood ecology, and brood movements in response to habitat restoration in Northern Arkansas

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Abstract:

The Northern Bobwhite Conservation Initiative was a habitat restoration effort aimed at reversing range-wide declines of Northern Bobwhite populations. Habitat restoration in Arkansas began within two focal areas where restoration efforts were concentrated. The central assumption of the Northern Bobwhite Conservation Initiative was that brood rearing and nesting habitats were deficient. Therefore the plan promoted increasing and improving nesting and brood rearing habitats. However, insufficient data addressing chick survival, growth, movements, and habitat use have made it difficult to design and assess habitat management that simultaneously benefits nesting and brood rearing bobwhites. My objectives were to evaluate the effect of habitat restoration on nesting, brood survival and growth, brood movements, and the efficacy of restoration in producing nesting and brood rearing habitat.

To achieve my objectives, I placed radio collars on bobwhite adults and monitored nesting. I used data collected from nesting bobwhites to determine production, nest success, and reproductive effort (nests/hen). After nests hatched, I captured bobwhite broods once at 1-4 days and again at 7-12 days after hatching to evaluate brood survival and chick growth. I intensively tracked brood tending adults to identify locations to sample habitat and to evaluate brood movements in response to restoration. Habitat variables included percent overhead cover, shrub, forb, grass, litter, bare ground, open space 0-5 cm above ground, open space 5-15 cm above ground, number of grass species, and number of forb species visually estimated within a 1 m^2 Daubenmire frame. I also measured vegetation height and used a sweep net to sample arthropod abundance. I used a discriminant function to compare habitat at nest sites, and brood habitat to random

locations in both restoration and unmanaged areas. The discriminant function identified restoration practices that produced habitat similar to those used for nesting and brood rearing. To evaluate brood movements, I used multiple regression to compare movement rates, distances moved away from nests, and index of space use between restored and unmanaged areas. Multiple regression was used to identify habitat features that influenced the index of space use and habitat factors associated with arthropod abundance.

I found that nesting bobwhites did not use restoration areas but nested in unmanaged fescue (*Festuca arundinacea*) dominated fields, and that bobwhites nesting in fescue had higher nest success than estimates of nest success reported by others. Reproductive parameters, such as clutch size, number of eggs that hatched etc., were similar to estimates reported by others. However, low survival of nesting and brood rearing bobwhite adults in unmanaged areas resulted in low reproductive effort and success (number of nests/hen, total number of nests, etc.).

Based upon limited sample sizes, brood survival was higher in restoration areas. However, the difference may not have been due to management efforts. Rather, predation appeared to be higher in the Searcy County focal area where most of the bobwhites used unmanaged areas, than in the Fulton County focal area where most of the bobwhites used managed areas. Adult mortality during brood rearing was the main cause of brood loss in unmanaged areas and appeared to influence recruitment. Despite higher brood survival, chicks in restoration areas had slower growth, moved faster, moved farther from their nest and used more space than broods in unmanaged areas. These results are consistent with my findings that arthropod abundance was lower in restoration than in unmanaged areas. Brood movements were inversely associated with arthropod abundance with greater brood movements occurring when arthropod abundances were low. Habitat factors positively associated with arthropod abundances were more forbs, more forb species/m^2, and more grass species/m^2.

Restoration more often produced habitat structurally similar to brood rearing habitat than nesting habitat. However, availability of nesting habitat increased through time in restoration areas. Although restoration produced habitat that was structurally similar to brood rearing habitat, arthropod abundances were reduced by 63% in restored areas and I did not detect an increase in arthropod abundances between years in restored areas. Orthopteran biomass was reduced by 70% in restoration areas and was responsible for the differences in arthropod biomass. Restoration practices that produced habitat structurally similar to brood rearing habitat were a combination of burning, disking, and planting a variety of native warm season grasses. In contrast, planting or promoting development of a monoculture of grass species (regardless of native origin) did not produce habitat structurally similar to brood rearing or nesting habitat. Burn only treatments in fescue dominated fields produced approximately equal proportions of brood rearing and nesting habitat but brood rearing habitat changed into nesting habitat after only one growing season post treatment.

Chapter 1: Introduction, Objectives and Background:

The Northern Bobwhite (*Colinus virginianus*) has experienced long term population declines range-wide due to habitat losses (Sauer et al. 2000). Those declines have stimulated a large scale habitat restoration effort called the Northern Bobwhite Conservation Initiative (NBCI). The goals of the NBCI are to halt population declines and increase bobwhite population levels to match estimates from the 1980s. A central assumption behind the NBCI is that declines in bobwhite populations are due to degradation of bobwhite brood rearing and nesting habitats (Burger et al. 2006). Therefore, the plan proposes to increase and enhance nesting and brood rearing habitat on private property through farm bill programs (Burger et al. 2006). Since bobwhites generally disperse less than 1 km from their natal site (Lehmann, 1984; Dixon et al., 1996; Taylor et al., 1999) and because of relatively low initial bobwhite numbers, bobwhite population increases will likely occur through reproduction rather than through immigration. However, insufficient data addressing chick survival, growth, habitat use and movements have made it difficult to design and assess habitat management that simultaneously benefits nesting adults and bobwhite chicks. Therefore, determining how habitat management influences bobwhite production, brood survival, brood habitat use and brood movements is essential to future habitat restoration efforts for northern bobwhite quail.

National Bobwhite Conservation Initiative practices in Arkansas provided an opportunity to evaluate effects of restoration efforts on bobwhite production, brood survival and brood ecology. Beginning in 2003, participating property owners within two focal areas in Arkansas (one in Searcy Country and one in Fulton County) began restoration and maintenance of bobwhite habitat on their properties. Habitat management was customized to each property and included one or more of the following: establishing borders around fields, prescribed burning, land clearing (usually by bulldozing), woodlot thinning, planting shrubs, disking, fencing to eliminate grazing, eradication of exotic grasses, establishing food plots, and planting one or more native warm season grasses (NWSG). Some landowners planted only one warm season grass species; usually little Bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), or switch grass (*Panicum virgatum*). Other landowners planted a combination of these three grasses. Managed properties along with adjacent unmanaged properties served as treatments and reference areas for my study.

From 2005 to 2007, I conducted research to evaluate production, nesting success, chick survival, chick growth, habitat use and movements of broods in response to habitat restoration efforts. I equipped adults with radio transmitters so that I could locate nests and brooding adults. To evaluate brood survival, I used methods developed by Smith et al. (2003) to capture entire bobwhite broods and fix a uniquely numbered patagial tag to each chick's wing (Carver et al. 1999). I captured and weighed bobwhite chicks twice; once 1-4 days post hatching and again at 7-13 days post hatch to evaluate the effects of management on their growth.

I intensively tracked foraging bobwhite broods and collected data in order to characterize habitat that they used and to evaluate their movement patterns in response to habitat manipulations. In chapter 4 of this thesis, I present information on bobwhite production, and nest success, from the Searcy County focal area. In chapters 5-7, I present my findings on chick survival and growth, nest habitat, brood habitat use and movements of broods from both the focal areas in Searcy and Fulton Counties.

Objectives

1. Determine whether bobwhite production and nest success increase in response to management in focal areas.
2. Evaluate bobwhite chick survival and growth in response to habitat conditions.
3. Document bobwhite movements and determine how bobwhite brood movements are influenced by habitat conditions.
4. Identify habitat features that brood-tending adults use and determine whether restoration efforts produced brood rearing and nesting habitat.

Background

Nesting and Production

Production may be the most important factor associated with changes in bobwhite populations (Roseberry and Klimstra 1984). Bobwhite populations can produce very large numbers of young given a high percent of nesting adults, large clutch sizes, multiple nesting attempts, double clutching, and ambisexual incubation and brood rearing (Curtis et al. 1993, Burger et al. 1995). In Illinois, the total number of nests attempted in a given area and year was more important in explaining population growth than differences in clutch size, and nest success (Roseberry and Klimstra 1984). Dimmick (1974) also suggested that the total number of nests built per season was the main factor that influenced recruitment into fall populations. Female body condition may influence reproductive effort and appears to influence whether or not a hen nests, number of nests per female, and length of the breeding season; thus average female body condition will indirectly influence population growth (Dimmick 1974, Roseberry and Klimstra 1984, Berger et al. 1995).

Average clutch sizes for northern bobwhites range between 11.9 and 14.4 (Burger et al. 1995, Roseberry and Klimstra 1984, Dimmick 1974, Simpson 1976, Stoddard 1931, DeVos and Mueller 1993) and show latitudinal variation (Rosene 1969, Roseberry and Klimstra 1984). Clutch size declines as the breeding season progresses (Stoddard 1931, Cox et al. 2005). Cox et al. (2005) found that clutch size declined as a function of Julian day regardless of whether a breeding female was attempting a first or second nest.

As in most ground nesting galliformes, individual nest success is low and ranges between 32-44% (Stoddard 1931, Roseberry and Klimstra 1984, Dimmick 1974, Burger et al. 1995). The majority of nest failures are attributed to nest predation or depredation of the adult by predators (DeVos and Mueller 1993, Klimstra and Roseberry 1975, Stoddard 1931). Although nest success per nesting attempt is low, most bobwhite hens compensate by renesting and ultimately 72-76% of hens that survive the breeding season successfully hatch at least one nest (Suchy and Munkel 1993, DeVos and Mueller 1993, Burger et al. 1995).

The proportion of hens that nest varies among years and studies. Suchy and Munkel (1933) found that 33%-100% of hens nested in a given year with an overall average of 88% for a typical year. Burger et al. (1995) found that on average 95% of females nested but the proportion ranged from 88%-100%. Part of the variation in proportion of hens nesting is associated with rainfall. During dry years 52.6% of hens nested while the proportion rose to 100% during wet years (Hernandez et al. 2005).

The number of nests per individual female fluctuates and thus influences total reproductive effort. In Missouri, the average number of nests attempted by females surviving the breeding season was 1.8 nests per female (Burger et al. 1995). Hernandez et al. (2005) reported that the number of nests per female was 2.3 nests/hen. The number of nests attempted per hen increases with precipitation (Hernandez et al. 2005). Hernandez et al. (2005) also reported that the number of nests per hen, breeding season length, adult survival, and proportion of hens nesting fluctuated with precipitation levels.

Brood Survival and Growth

Information on bobwhite brood ecology and survival is scarce (Roseberry and Klimstra 1984, DeMaso et al. 1997, Taylor et al. 1999) despite extensive bobwhite research (Scott 1985). For example, the influence of habitat characteristics on chick survival and growth has not been evaluated in bobwhites (Taylor et. al. 1999). If chick survival influences recruitment (Roseberry 1974, Roseberry and Klimstra 1984, Lusk et al 2005), and if chick survival is associated with habitat features, then habitat manipulations that enhance chick survival would enhance bobwhite recruitment. Consequently, if management efforts are to be effective in increasing production, the effect of habitat structure on productivity should be known in order to present a suitable target for habitat manipulation. Taylor et al. (1999) recommended that research be done to determine the link between habitat selection and brood survival, and that other correlates of fitness (i.e. growth, mass gain, home range size etc.) should also be investigated.

Bobwhite chick survival has not been directly assessed until recently, when methods to capture and mark individual bobwhite chicks were developed (Carver et al.

1999, Smith et al. 2003). DeVos and Mueller (1993) found that 80% of brooding bobwhite adults were successful in rearing at least 1 chick for 2 or more weeks after hatching in Florida. DeMaso et al. (1997) estimated that bobwhite chick survival from 0 to 20 days was 37.9% and from 21 to 39 days was 98.6% in Oklahoma.

Nutrition may influence wild bobwhite chick survival (Hurst, 1972). Lusk et al. (2005) used a Cox Proportional Hazard Model on DeMaso's (1997) brood survival data to show that chick mass upon capture was a significant covariate of chick survival in Oklahoma. Bobwhite chicks need a high protein diet (~28% Nestler et al. 1942) and obtain most of this protein by eating invertebrates (Hurst 1972, Jackson et al 1987). Stoddard (1931) found that invertebrates constituted 84% of the diet for chicks that were 0 to 2 weeks old Bobwhite broods and other galliforms generally forage in habitats that have more invertebrates than those available within the landscape (DeVos and Mueller 1993, Potts 1986, Sotherton 2000, Hagen et al. 2005). DeVos and Mueller (1993) showed that brood home range size was inversely proportional to insect abundance. Studies on grey partridge have shown that year to year variation in chick survival were related to variation in preferred arthropod abundance (Potts 1986, Sotherton 2000). Chicks of lesser prairie chicken also select habitats that have greater insect abundance than randomly chosen locations (Hagen et al. 2005). Important invertebrate orders consumed by bobwhite chicks include coleoptera, orthoptera, homoptera, hymenoptera (family formicidae), aranea, hemiptera, and lepidoptera (Stoddard 1931, Hurst 1972, Jackson et al. 1987).

While the effect of arthropod abundance on wild bobwhite chick survival and growth has not been documented, laboratory studies have shown that bobwhite chicks raised on a protein deficient diet had reduced growth, development and a compromised immune system (Nestler et al. 1942, Lochmiller et al. 1993). Efforts to evaluate habitat for foraging bobwhite broods based upon arthropod abundances (ex., Hurst 1972, Berger et al. 1993, DeVos and Mueller 1993, Parsons et al 2000) may have been biased because abundance of arthropods in a habitat may not be related to abundance of arthropods actually available to foraging bobwhite chicks (Palmer et al. 2001). Palmer (2001) showed that imprinted bobwhite chick foraging rate and mass gain per day were more consistent indicators of habitat patch foraging value than were indications based on samples of insects from sweep nets. Thus, because bobwhite chick mass is an important predictor of survival (ex. Lusk et al. 2005), evaluating daily growth of wild bobwhite chicks may be a biologically relevant way to assess habitat quality of managed habitats.

Brood Movements

Knowledge of animal movements is essential to understanding the area required for animals to meet their needs and provides an estimate of the scale at which management should be applied (Taylor and Guthery 1994a). Consequently, an organism's movement capabilities will determine whether it can utilize structurally distinct and separate habitat components distributed over a landscape (Taylor and Guthery 1994a, Guthery 1997, 1999). Bobwhites require distinct habitats for nesting, foraging, loafing and roosting (Stoddard 1931, Taylor and Guthery 1994b, Taylor et al. 1999, Palmer et al. 2001). Vegetation in bobwhite nesting habitat is taller, more dense, has more grass and litter cover than non-nesting habitats whereas foraging habitat has relatively more bare ground, more forbs, and supports vegetation with higher moisture content (Stoddard 1931, Taylor and Guthery 1994b, Taylor et al. 1999, Palmer et al.

2001). Roosting habitat has more litter, and taller vegetation than is present at random locations (Taylor et al. 1999). Given that bobwhite broods require habitat patches with distinct vegetation structures for foraging, loafing and roosting, those distinct patches must all be located within a brood's movement capabilities in order to make an area usable (Guthery 1997, 1999).

Reports of brood movements are scarce; consequently recommendations concerning distribution of distinct patches for bobwhite broods are often speculative (Taylor and Guthery 1994a). Movement capabilities of bobwhite broods increase with age (Taylor and Guthery 1994a). DeVos and Mueller (1993) found that home ranges of broods averaged 6.52 ha (16.1 acres) two weeks post hatching and 11.2 ha (24.7 acres) a month post hatching in Florida. Thus, distinct habitat features for young broods must be relatively close compared to habitats for older broods. Taylor and Guthery (1994a) reported average daily home range sizes in south Texas as 0.7 ha for pre fledging broods and 1.4 ha for post fledging broods. Minimum daily distances moved for broods in that study were 277 m and 589 m for prefledging and post fledging broods (Taylor and Guthery 1994). These minimum distances are underestimates of bobwhite brood movements because they were derived from straight line distances between five points taken throughout one day (Taylor and Guthery 1994a). Straight-line distances between consecutive telemetry locations underestimate movements because animals often move in a meandering path.

I did not find published information on how habitat features affect bobwhite brood movements. However, pheasant broods have been reported to move less in fine-grained landscapes than broods in coarse-grained landscapes (Warner 1984).

Nevertheless, habitat may influence bobwhite brood movements given that habitat and home range size are related (Cook et al. 2006). Cook et al. (2006) reported average brood home range sizes of 11 ha for broods that used crop land with fallow field borders and 13 ha for broods that used croplands without field borders. Animals adjust home range size to meet metabolic needs which explains why home range sizes in general, increase with body size as well as decreasing habitat quality (Lindstedt et al. 1986). Habitat patch distribution also influences the distances from the nests that broods must travel to find suitable foraging habitat (Cook et al. 2006). For example the distances from the arithmetic center of brood home ranges to nest sites in Georgia was 200 m in croplands with boarders and 350 m in croplands without boarders (Cook et al. 2006). Managers must understand the relationship between habitat quality and brood movements to manage habitat for bobwhite broods. Since the goals of bobwhite habitat restoration by NBCI practices are to improve and increase brood rearing and nesting habitat, managers must know if these practices are producing brood rearing and nesting habitat in close enough proximity that they are usable by bobwhites. Managers should also understand effects of management on brood movements.

Nesting and Brood Habitat

After bobwhite chicks hatch, the tending adult leads the brood from nesting habitat to distinctly different foraging habitats (Stoddard 1931). Nesting habitat has characteristics that maximize visual obscurity such as taller vegetation, more litter, and more grass percent, than available habitats (Taylor et al. 1999). By contrast, brood habitat has more forbs, more bare ground, more overhead cover, more arthropods, more vegetative moisture, and greater floristic diversity, compared to other habitats (Stoddard 1931, Taylor and Guthery 1994b, Taylor et al. 1999, Palmer et al. 2001).

Structural characteristics of bobwhite brood rearing habitat vary with time of day and activity (Taylor and Guthery 1994b). Bobwhite broods are active from approximately one half hour before sunrise until approximately 10:00 AM at which time they use loafing covert until approximately 1500 hrs. At approximately 1500 hrs they usually resume activity until shortly before sunset when they roost. Vegetation characteristics are distinct for different activities in which bobwhites engage (Taylor and Guthery 1994b). Taylor and Guthery (1994b) found that loafing sites had greater canopy cover which may provide a suitable microclimate and cover from predators. The widely reported preference for bare ground in conjunction with overhead screening cover suggests that predator avoidance, microclimate and ability to move and forage are important to bobwhite broods (Taylor and Guthery 1994b).

Arthropod abundance (or availability) may influence bobwhite chick survival (Hurst, 1972). Although undocumented in bobwhites, studies on gray partridge have shown that year to year variation in chick survival was related to variation in abundance of preferred arthropods (Potts 1986, Sotherton 2000). Bobwhite chicks need a high protein diet (~28% Nestler et al. 1942) and obtain most of this protein by eating invertebrates (Hurst 1972, Jackson et al 1987). Stoddard (1931) found that invertebrates constituted 84% of the diet for chicks up to two weeks old. Bobwhite broods and other galliforms generally forage in habitats that have more invertebrates than those available within the landscape (DeVos and Mueller 1993, Potts 1986, Sotherton 2000, Hagen et al.

2005). Thus, invertebrate abundance and availability are important components of bobwhite brood habitat.

Materials and Methods

Study Areas

Focal areas were established in Searcy and Fulton Counties in Northern Central Arkansas in 2003. These two focal areas consist of more than 15,000 ha each of privately owned farms and contain roughly equal proportions of pasture, hay fields, and hardwood forest. Most of the land in the Searcy County area is comprised of woodlots, cattle/horse pasture, or hayfields. Smaller portions of the areas are composed of roads and buildings. Management practices to restore bobwhite habitat on the focal areas include controlled burns and thinning of forested areas, fence row development, cattle exclusion by fencing, establishing habitat borders around hay fields, strip disking, and conversion of fescue (*Festuca arundinacea*) fields into native warm season grasses. As of September 2005, the Searcy Co. focal area had treated 295.1 ha of privately owned land, and by 2006 318.5 ha had been treated in the Searcy County focal area. As of September 2006, approximately 330.8 ha of restoration had been implemented in the in the Fulton Co. focal area. Treatments that have been performed in the focal areas include; controlled burns of forested areas, planting of native warm season grass, fescue eradication, fencing (to keep cattle out of certain areas to provide a buffer of undisturbed habitat), strip disking, prescribed burning, woodland thinning, combination of thinning and burning, edge/hedgerow development (example, *Lespedeza spp.* planting), and establishment of native warm-season grasses in conjunction with removal of fescue *(Festuca arundinacea*).

The two focal areas differ in their vegetation structure and composition. The Searcy county site contains open areas that are mostly dominated by thick grass stands that are used for hay and pasture lands. Hay fields and pastures in the Searcy Co. site vary widely in quality, density, composition, and height and that variability is largely caused by variation in land use. Grassland areas in the Searcy Co. site are often bordered by forest stands. Fencerow development varies in successional advancement and quality but many properties have well developed fencerows in advanced stages of succession in the Searcy Co. site.

The Fulton Co. site's open areas are largely composed of rangeland that is characterized by rocky open ground dominated by forbs and sapling trees interspersed with native bunch grasses, although fescue dominated fields are present in some areas. Rangelands in the Fulton Co. focal area also vary in quality depending on grazing intensity and mowing regimes. Open areas in the Fulton Co. sites are also bordered by forest edges. Fence row development in Fulton Co. varies in quality and successional advancement but there are notably fewer fences with in the area.

Adult Capture, Production and Nest Success

I captured northern bobwhite in modified funnel traps (Stoddard 1931), by night lighting (Labrisky 1968), and by decoy trapping (Smith et al. 1989). I focused trapping efforts in areas that received habitat manipulations (hereafter restoration or management areas) and adjacent sites that had not undergone treatments to increase bobwhite productivity (hereafter nonrestoration or unmanaged areas). Because one of my major objectives was to evaluate effects of restoration on bobwhite, I trapped restoration areas more intensively than unmanaged areas. I used covey call locations, male singing, and bird-dogs, to identify areas on which to concentrate trapping efforts either within or close to restoration areas.

Funnel traps were used between 1 February and 15 May in both 2005 and 2006. I trapped male bobwhites by decoy trapping between 9 April and 13 July in both 2005 and 2006. Modified night lighting (Labrisky 1968) was used between 9 April and 12 July 2006 to capture female bobwhites that were paired to radio-collared males. In night lighting, transmitter-equipped males were pinpointed after dark, spotlighted and netted. My technicians and I either stretched a 9 × 10 m piece of orchard netting over the bobwhite pair or we threw a 1.524 m radius cast net over them. All captured bobwhites were sexed and fitted with a uniquely numbered aluminum leg band and a necklace style radio transmitter that weighed less than 7 g and was equipped with a mortality sensor (Holohil Systems LTD).

During the winter of 2006, some male bobwhites fitted with radio collars were relocated to areas where coveys had been flushed but had not yet been captured. This allowed us to monitor newly discovered bobwhite coveys and increase trapping success in Searcy County. Mortality of bobwhites was considered to be capture-related if death occurred less than 7 days after capture; such bobwhites were excluded from analysis (Kurzejeski et al., 1987, Pollock et al. 1989). I located transmitter equipped bobwhite adults 3-5 times per week during the winter to monitor habitat use and use of restored and unmanaged areas.

I monitored radio-collared bobwhite adults to evaluate bobwhite production, brood survival and growth, brood movements, and brood habitat use. Methods used to evaluate each (production, survival and growth, brood movements, and brood habitat use) are described below. In order to increase the number of broods available for monitoring in 2007, I captured and successfully imprinted pen-reared chicks to wild-caught adults.

I used radiotelemetry to monitor bobwhites for nesting activity. Female Bobwhites were located once daily between 15 April and 19 August so that nests could be found. Bobwhites were suspected of incubating if they were located in the same place on 3 consecutive days. Once the nest was found, the clutch size was determined and the hatching date was estimated. I determined the percent of hens that nested, nest success, clutch size, proportion of eggs that hatched, nest attempts per all hens fitted with radio collars, nest attempts per hen that survived into the breeding season, percent males incubating, and nest habitat characteristics.

Nests were checked once per day, six times per week until hatching occurred or until the nest failed. Checking a nest entailed determining if the tending adult was incubating or off the nest. If the adult was off the nest then the nest was visually inspected. The number of eggs that hatched was determined by counting the small end of all shells in the nest. A nest was considered a failure if it was abandoned, depredated or if no eggs hatched. A nest was considered successful if any eggs hatched. I calculated the proportion of eggs that hatched as the number of eggs hatched divided by the clutch size. The number of radio-tagged hens that nested, divided by the number of surviving radio-tagged hens was the proportion of hens that nested. The total number of nests divided by then total number of bobwhite hens that were fitted with radio collars was the number of nests per hen. The number of nests divided by the number of surviving hens was the number of nests per hen that survived into the breeding season. The proportion of males that incubated a nest was determined by dividing the number of males that incubated a nest by the total number of transmitter-equipped males that entered the breeding season.

Brood Survival and Chick Growth

I used methods developed by Smith et al. (2003) to capture bobwhite chicks within 4 days of hatching and again at 7-12 days post hatching. Broods were located 2 hours before sunrise by triangulating at least 3 bearings within 10 m of the brood. After pinpointing the brood's location a portable fence was erected around the roosting brood before sunrise (fence dimensions are 15.24 m long and 0.61 m tall made of screen covered hinged panels of welded wire). Once the brood was surrounded by the fence, and the fence bottom secured with dirt (to prevent escape), all of the vegetation was removed by hand and chicks were captured. Each captured chick was marked with a uniquely numbered patagial wing tag (Carver et al. 1999). Chicks were released simultaneously less than 15 m from the tending adult immediately after processing. Complete brood capture was concluded when I did not detect the "lost chick call" outside of the fenced area.

Broods were captured a second time between 7 and 12 days of hatching and processed as above. Chicks not captured during the first capture period, but present upon the second capture were marked and measured as above and their ages were estimated by a combination of mass, flight ability and wing and tarsus lengths. By capturing broods, I was able to estimate the frequency of brood amalgamation, individual chick survival rates and growth rates. The number of eggs that hatched in each nest represented the initial brood size. Thus, decreases in brood size between hatching and the brood size at 1-4 and 7-12 days represent an estimate of mortality for each period.

After chicks were able to fly (ca. 13 days post hatching) survival was monitored by flush counts once per week. This method for estimating individual chick survival is flawed because brood adoption, amalgamation, and abandonment biases results (Reed 1975, DeMaso et al. 1997, Faircloth et al. 2005). However, I only used this method to estimate the percent of brood tending adults that raised at least one chick to independence. Total absence of chicks and absence of adult brooding behavior indicated loss of the brood. I did not have sufficient sample sizes to employ the Kaplan-Meier method, so I report survival as a percentage of chicks that survived from hatching until independence. Tending adults sometimes abandon 14-day-old broods to renest (ex., Curtis et al. 1993, DeVos and Mueller 1993, Suchy and Munkle 1993, Burger et al. 1995) so I assume that 14 days is the minimum age required to achieve independence.

I compared the mass gain per day (g) averaged within broods between managed and unmanaged areas (all analyses were conducted in NCSS. Number Cruncher Statistical Systems. Kaysville UT. www.NCSS.com). I also compared mass/tarsus ratios averaged within broods between managed and unmanaged areas to account for variations in chick size due to genetics, and location. Since chick growth follows an exponential curve from 0-12 days after hatching, I log transformed both mass and tarsus length (cm) and then divided the log transformed mass by the log transformed tarsus (log mass (g)/log tarsus (cm)). I chose cm as the units to measure tarsus because the length in mm was a large number compared to chick mass (g) and thus, even small errors in measurement would have a large effect on the mass/tarsus ratio. I subtracted the mass of each chick recorded at the second capture from the mass of each chick on the first capture and divided by the number of days between captures to estimate a daily rate of mass increase.

Because growth of individuals within a brood may not be independent, I used the mean growth rate within each brood as the sampling unit. Broods were captured in both counties and in treated and untreated areas. I used a two tailed t-test to compare mass gain per day for broods captured in 2005 and 2006. Similarly, I used a two sample t-test to compare mass/tarsus ratio growth rates for broods captured in 2006 between treated and untreated areas in both counties. I did not include broods captured in 2005 in the mass/tarsus ratio growth rate comparisons because tarsus lengths were not recorded in 2005.

Since growth follows an exponential curve at ages 0-12 days after hatching, comparing mass gain per day of chicks at different ages may be biased. Therefore, I log transformed the data in order to obtain a linear relationship between age and growth rates. I averaged the log of chick masses within broods. I then compared regression lines of log transformed mass (g) averaged within broods between restoration and unmanaged areas of all wild broods whose ages were known. Because I had small sample sizes, chick growth comparisons were considered significant at alpha = 0.10 as a conservative approach to reduce the probability of making a type II error.

Recall, in 2007 I imprinted pen reared bobwhite chicks on wild bobwhite adults and released them so that I could gather more brood habitat data. I did not include the captive hatched chicks raised by wild surrogate parents in survival or growth analysis.

Evaluation of Brood Movements and Habitat Measurement

I followed bobwhite broods intensively during foraging activities starting day 1 post hatching until 39 days post hatching in both Searcy and Fulton Counties. I used those data to determine movement rates and habitat use by broods. Habitat used by broods in restoration and unmanaged areas and habitat in randomly selected locations in both restoration and unmanaged areas was compared. Thus, I was able to determine which features of the habitat were consistent among areas used by bobwhites and whether management produced habitat with those features.

Tending adults were tracked for 1 to 4 hours either from sunrise until they began loafing, or between 15:00 H (approximately when broods left loafing areas; Taylor and Guthery1994) until they initiated roosting behavior. I attempted to track broods for at least one tracking period approximately every other day. I tracked broods in both restoration and unmanaged areas.

Transmitter equipped brooding adults were carefully monitored to evaluate their precise locations, speed of movements, and habitat use. I determined the exact initial location of tending adults by triangulating their locations from approximately 10 m. I marked a point less than 10 m away from the tending adult’s initial location which helped me to identify the initial location when I returned to measure habitat. After identifying their precise location, I moved to a monitoring site located between 30 and 70 m from the brood and radio-tracked their movements, taking bearings at approximately 5-min intervals. When possible, I chose monitoring locations that were approximately 50 m from broods. I chose monitoring locations so that the landscape would not obstruct the radio signal and where vegetation was sufficiently tall to conceal me. To minimize potential disturbance of the bobwhite brood, I turned the receiver’s volume down so that it was barely audible. I kept a low profile between recording bearings to minimize visual detection by broods. A compass and telemetry were used to obtain bearings of brood-rearing adults. I recorded the time of day and took notes on signal strength for each bearing. Signal strength was determined by adjusting the gain on the telemetry receiver up or down until the signal barely registered on the receiver. At hourly intervals, I moved to within 10 m of tending adults and marked the brood's location by following methods I used to mark the brooding adult's initial location as described above. After obtaining and marking the locations from within 10 m, I resumed monitoring from points that were 30-70 m from the brood. I marked each monitoring location with flagging and recorded the GPS coordinate of monitoring locations.

Between one and 7 days after tracking, I estimated each of the brood locations taken at 5 minute intervals. I flagged each location, and also obtained a GPS coordinate. To do so, I returned to the brood's initial location, and sequentially estimated the brood's locations for each bearing. To estimate each brood location, I used a compass to sight back bearings (corresponding to the sequential bearings recorded during the monitoring session) toward the flagging that marked the location from which I monitored the brood. Notes on signal strength were used to adjust the brood's estimated location either toward or away from the monitoring locations along the back bearings. If the receiver gain had to be turned up to register the signal, I determined that the brooding bobwhite had moved farther away from the monitoring location. Conversely, if the signal registered more strongly, I determined that the brood had moved towards the monitoring location. After determining each location, I tied flagging onto the vegetation, wrote a number on the flag indicating the sequential order that it was recorded during monitoring, and recorded a GPS coordinate. GPS coordinates for each estimated brood location were obtained by using the averaging function on a Garmin 60 model GPS receiver that had WAAS technology (Garmin model GPS 12 XL, Olathe, KS) to increase the accuracy of the coordinate to < 3 m. The accuracy of the estimate as given by the Garmin 60 receiver was recorded for each point. I used the Pythagorean Theorem to calculate the distances between sequential brood location estimates, the distances between hourly brood locations, the straight line distances between a brood's initial location and their location at the end of tracking (described below as the index of space use), and the distances between brood locations and researcher locations. I calculated the rate that broods moved by dividing the distance between sequential locations by the time in minutes that elapsed between bearings.

I assumed that researcher presence while monitoring movements from an average of 50 m away had a minimal effect on brood behavior. Gamble's Quail have been monitored in open desert habitats from a distance of 15-20 meters with no apparent effect on behavior (Goldstein, 1984). To evaluate observer affect on brood behavior, I examined distances that broods approached researchers during monitoring.

I evaluated accuracy of the tracking method used to locate paths taken by bobwhite broods. One observer hid six radio collars irregularly spaced at 5-15 m intervals in habitat similar to that used by bobwhite broods. Bobwhite broods commonly moved 5-15 m in 5 minutes as indicated by tracking in 2005 and 2006. Later two or three observers, who had not observed where the collars were hidden, independently tracked the collars as if they were moving bobwhites and marked their positions using methods described above. Distances between hidden collars and each estimated location were measured with a meter tape and represent an estimate of error in my sampling procedures. I assumed that telemetry accuracy was similar between hidden collars and brood tending adults. I also assumed that telemetry error was similar between restored and unmanaged areas, and I tested if different researchers measuring brood movements were similarly skilled at telemetry.

I assumed broods were foraging while they moved slowly through the habitat along a meandering path. The flagging that marked brood locations represented a series of points scattered along the brood's path. I sampled habitat through the center of the flagged locations, along the course that broods traveled. I sampled habitat at 3 m intervals along each brood's movement path until I had moved the length of the path or until I had collected 30 samples. For each interval, I evaluated habitat within a 1 m^2 Daubenmire frame (Daubenmire 1959) within which I estimated percent overhead cover, grass, forbs, litter, bare ground, percent open space 0-5 cm above ground (chick level), percent open space 5-15 cm above ground (adult level), number of different forb species present within the frame, and number of different grass species within the frame. I measured vegetation height to the nearest cm at 1 m intervals along a 30 m transect beginning at a randomly selected point along the brood's path.

I used a 38.1 cm diameter sweep net to sample invertebrate abundance along routes taken by broods. Each movement path was divided into 20-m intervals and I randomly selected two intervals along each path for arthropod sampling. Arthropod samples consisted of 10 sweeps over 20 m of ground. I attempted to sample the vegetation strata most available to chicks by sweeping as close to the ground as possible. I consciously attempted to complete a full half circle with the net for each sweep. Each sample was placed in a plastic bag and frozen. I later sorted arthropods into orders, dried the samples in a dryer, and recorded dry weight and count for each order.

In 2006, habitat characteristics along randomly located transects placed within 360 m of each brood's home range were collected in the same manner as along paths taken by broods. These transects were located in restoration and unmanaged areas in Searcy and Fulton Co. In Searcy Co., transects were randomly located in areas that represented each of the 8 restoration areas. In Fulton Co., I placed transects in 2 restoration areas. In 2007, I also collected 15 habitat samples at randomly selected points (not within transects) within each of the restoration areas in Searcy County.

Recall in 2007 that I imprinted pen-reared chicks on wild-caught adults. I assumed that wild adults reared their adopted broods in a similar manner as they would their own chicks. Therefore, I included brood habitat-use data from these broods in my analysis.

To determine the scale at which management should be applied for one day old bobwhite broods, I measured the distance with the measure tool in ArcGIS 9.1 (ESRI GIS and Mapping, 380 New York Street Redlands, CA 92373-8100) from each brood's locations on the first day post hatching to their nests. I used the median distance to describe the distances that bobwhite broods were from their nest. I determined the maximum distance that any brood was from their nest the day after they hatched. I also measured the distance from the nest that broods were initially located at the beginning of each tracking period for up to 39 days. To do so, I used ArcGIS 9.1 to plot UTM coordinates of bobwhite brood locations and nest locations and obtained distances within ArcGIS. I used multiple regression to compare the distance broods were from the nest as a function of age (days post hatching) in restoration and unmanaged areas. These comparisons give an indication of habitat quality and allow an estimate of the scale at which habitat management should be applied to benefit both nesting adults and bobwhite broods. If nesting and brood rearing habitat are closer, then young broods should move less to meet habitat needs which should be better for production and recruitment

I used multiple regression to evaluate effect of age on bobwhite brood movement rates in restoration and unmanaged areas. I compared regression lines of movement rates as a function of brood age between restoration and unmanaged areas. I made two comparisons of movement rates, one comparison to evaluate all movements and one to evaluate movement rates of broods only while foraging. I included all movement rates and graphed the results. Active foragers move more rapidly when prey are scarce and move more slowly when actively foraging for abundant prey (Curio 1976). I assumed that broods were not foraging when they made relatively fast, unidirectional and long distance movements. In order to assess the movement rates of broods recorded only while broods were foraging, I removed intervals I suspected were not foraging movements. I identified these non-foraging movements as statistical outliers (RStudent statistic greater than two in NCSS (NCSS and Pass. Number Cruncher Statistical Systems. Kaysville UT). After 12 outliers from restoration and 13 from unmanaged areas were removed, I compared regression lines that regressed movement rate as broods aged in restoration and unmanaged areas. I included habitat measured from areas where broods moved rapidly in habitat analysis because even though broods were probably not foraging during these rapid unidirectional movements, they still used these areas. Furthermore, I assumed that most of the area that they used would contain some arthropods and be suitable for foraging.

If managers understood how far a young brood is capable of moving, then they would be able to adjust the scale of management to improve habitat restoration. To provide this estimate, I averaged movement rates from which outliers had been removed for all broods in each age class and regressed those movement rates averaged by age to estimate the affect that age has on movements. This regression provides managers with an estimate of the scale at which management should occur to benefit young broods.

I used straight lines that connect the initial and final locations of broods during monitoring sessions (both taken from within 10 m of the brood) as a function of monitoring duration as an index of area use in restored and unmanaged areas (hereafter index of space use, see figure 1 as an example). Multiple regression was used to compare the index of space use as a function of monitoring duration and brood age. At least two reasons could account for a difference in index of space use between broods in the two habitats. Broods could either travel more slowly or they follow a more meandering or tortuous path in one or the other habitat.

I used a stepwise multiple regression to determine habitat variables that influenced space use. Habitat variables used in the stepwise multiple regressions were averaged from vegetation data collected along the movement paths. I averaged each habitat category within each movement path for each day of tracking and included an estimate of arthropod abundance. Habitat variables included in the stepwise regression analysis were: averaged percent overhead cover, average percent shrub, average percent forb, average percent grass, average percent litter, average percent bare ground, average percent open space 0-5 cm, average percent open space 5-15 cm, average height, average number of grass species, average number of forb spp., invertebrate mass, invertebrate count, and brood age. Since the only significant habitat variable explaining the index of space use by broods was arthropod biomass, I graphed the relationship between the indexes of space use as a function of arthropod abundance with linear regression.

I compared regression lines of the index of space use as a function of arthropod mass, monitoring duration (minutes), and brood age (days) in restoration and unmanaged areas. If there are no differences in movements between broods in restored and unmanaged areas when invertebrate biomass is used as an independent variable, then invertebrate biomass was driving the differences in movements.

Habitat Use by Nesting and Brood Rearing Bobwhites

Habitat at each nest was measured within two weeks of nest success or failure. I estimated, vegetation height, percent overhead cover (cover taller than 15 cm above ground), percent bare ground, percent forbs, percent grass, percent litter, percent open space 0-5 cm above ground, open space 5-15 cm above ground, number of forb species and number of grass species at the nest within a 1 M square Daubenmire frame (Daubenmire 1959) centered at the nest bowl and determined nest composition.

The structural characteristics of habitat used by broods during tracking and by nesting bobwhites were compared to each other and to habitat at random locations in both restoration and unmanaged areas. I used a stepwise discriminant function analysis to select variables that distinguish among habitats used by broods in restored and unmanaged areas and random locations in both treated and untreated areas. I discriminated among 5 habitat classes: 1) habitat used by broods in restoration areas, 2) habitat used by broods in unmanaged areas, 3) random locations in restoration areas, 4) random locations in unmanaged areas and 5) habitat at nest sites. I used $P = 0.10$ as the selection criterion for entering into the model and $P = 0.20$ as the criterion to remain in the model. In follow up analyses, I pooled habitat data for broods from restoration and unmanaged areas because they were similar and the discriminant function did not effectively discriminate between those two habitats.

The discriminant function model was also used to identify habitat at randomly selected locations (or from points within randomly located transects) within restoration areas that had habitat characteristics similar to those used for nesting and brood rearing. The proportion of randomly selected points identified by the discriminant function as nesting habitat is an estimate of the availability of nesting and brood rearing habitat in restoration areas. To determine the proportion of habitat that classified as brood and nesting habitat within the restoration areas, I ran the discriminant function procedure 15 times. I used one sample from each transect for each iteration but used a different sample from each transect each time I ran the discriminant function. Each time the procedure ran, the discriminant function classified the samples (based on structural characteristics) as either nesting, brood rearing in restoration areas, brood rearing in unmanaged areas, randomly located points in restoration or randomly located points in unmanaged areas. I then examined the randomly located samples in restoration areas that were reclassified by the discriminant function as brood rearing or nesting habitats. I determined the percent of random habitat samples in the restoration areas that classified as brood rearing or nesting habitat by dividing the number of samples from all iterations that reclassified as brood habitat by the total number of samples run in the analysis. Note, however, that the resulting proportions reflect only the structural similarity of those points to habitats actually used by quail for nesting and brood rearing. Finally, I recorded the habitat categories that the discriminant function used to differentiate the samples and listed them in order of the number of times out of 15 that they occurred. I assumed that the most frequently selected variables were the most important in discriminating among different habitats.

I tested the discriminant function against a test data set to determine the original model's general applicability. I selected the 4th samples from each transect to construct the model and used the 11th sample from each transect to compose the test data set. If the model is overly specific, it will correctly classify the data from the 4th sample (i.e., the dataset used to produce the model) but will not perform very well on the test dataset (i.e., the 11th sample).

I used a Kruskal–Wallace test on each habitat variable to describe how habitat differs between brood habitats and habitat at random locations in restored and unmanaged areas. These comparisons will also help explain the discriminant function's performance in discriminating among habitat categories. I ran nonparametric comparisons because most of the habitat variables were not normally distributed or did not have equal variances. Since samples lacked spatial independence, I again used only the 4th sample from each transect in comparisons. All comparisons were considered significant at $p < 0.05$.

Because sweep sample data were not normally distributed, I used a Mann-Whitney U test to compare arthropod biomass between restoration and unmanaged areas, and between years. Orthopteran biomass dominated in samples so I also compared samples without orthopteran biomass between years and management states. I also compared the numbers of arthropods between restoration and unmanaged sites with and without orthoptera. Finally, I used a stepwise multiple regression procedure to identify habitat features that influence arthropod abundances.

Chapter 3: Results

Adult Capture, Production and Nest Success

Relative capture success in restored and unmanaged areas of the Searcy Co. focal area suggested that bobwhite were more common in unmanaged areas than in restoration areas during the breeding season. Despite trapping more heavily in restoration areas, I captured most of my bobwhites in unmanaged areas. Bobwhite adults used restoration areas heavily in the winter but left the restoration areas and did not return during the breeding season even though 65 of 67 bobwhite summer home ranges were located within 1 km of a restoration area (unpublished data from this study).

I captured 38 out of 90 bobwhites in restoration areas from 2005-2007. Of 90 bobwhites captured in Searcy County from 2005-2007, 26 were females and 64 were males. Two hens and one male died within 7 days of capture and were excluded from analysis. An additional hen was lost, or her collar failed, within 4 days of capture. Twenty-five of the 38 bobwhites captured in restoration areas were captured by funnel trapping and the remaining 13 were captured by call back decoy trapping. The bobwhites captured in restoration areas by decoy trapping were captured during the breeding season and originated from and returned to adjacent unmanaged areas after release. In 2005, I captured 16 bobwhites, 8 males and 8 females, of which 1 female and 1 male were captured in restoration areas. In 2006 I captured 17 females and 34 male bobwhites in Searcy County of which 30 were captured within managed areas and 21 in adjacent unmanaged areas.

In 2007, I captured 23 bobwhites (22 males and 1 female) in the Searcy County focal area and offered each a brood of 1-day old chicks for adoption. Of the 23 bobwhites captured in 2007, 11 (48%) adopted one day old captive hatched chicks. Of 11 adopting bobwhites only 3 retained their chicks after being released. One of the adults that adopted an artificial brood was found depredated 3 days after release. The other two adopted broods were monitored for approximately 25 days and probably reached independence.

I found and monitored 17 nests incubated by 19 bobwhites. I did not include one nest from which a hen was flushed before egg laying commenced and after which the nest was immediately abandoned. One or more chicks hatched from 53% of 17 nests. Depredation of incubating adults was the main cause of nest failures (78% of 9 failed nests). Thirty three percent of 15 nesting bobwhites were depredated within 5 m of the nest (probably while incubating) which was the cause of 55% (5 of 9) of all nest failures. Two bobwhites died at a point greater than 5 m from a nest that they were incubating. Two males incubated 2 nests after the attending females were depredated while off the nest. Thus, predation on incubating adults was a major cause of nest failure and also reduced the number of nesting attempts by females.

I found 17 nests initiated by 25 hens that were monitored during the breeding season (0.68 nests per hen). However, of hens that survived into the breading season, I found 17 nests initiated by 15 hens (1.13 nests per hen).

Overall, 14 of 25 bobwhite hens fitted with radio collars survived into the breeding season. All 14 surviving bobwhite hens that used fescue dominated habitat attempted to nest. Fourteen attempted to nest at least once and 2 attempted to nest at least twice. One second nest was abandoned by the hen after she was disturbed by observers and one first nest was abandoned with no apparent observer disturbance. Of the hens that did not attempt to breed, 8 died before the breeding season, one was lost or her collar failed, and 2 died before a nest was located.

From 2005-2006, 42 males were fitted with radio collars of which 38 entered the breeding season and 3 (8%) incubated nests. In 2005, none of the 8 males fitted with radio collars incubated a nest. In 2006, 30 out of 34 males entered the breeding season and 3 (10%) incubated a nest. After two incubating females died, two radio-collared males took over incubation duties and one of them successfully hatched the nest. One male incubated and hatched chicks from a nest that was laid by a non-radio-collared female. I did not find any nests in 2007 but 2 males were found tending broods.

Nests were initiated between 6 June and 26 August 2006 while in 2005 3 nests were found on 3 June and one second nest was found July 18th. Mean clutch size was 12 eggs and ranged from 6-16. In 2005, mean clutch size from 3 nests was 15 eggs and ranged from 14 to 16. In 2006, mean clutch size for 13 completed clutches in Searcy County was 10.6 eggs and ranged from 6 to 16 eggs. In 2006, clutch size tended to decline as the breeding season progressed and 11 of 13 nests were initiated from late June through late August. The median nest incubation initiation date was June 3 in 2005 and was June 29 in 2006. Eighty five percent of the eggs in successful nests hatched. Mean number of eggs that hatched from successful nests was 10.25 and ranged from 6 to 15.

Chick Survival and Chick Growth

I captured 91 chicks among 14 wild broods and two pen reared broods adopted by wild bobwhite adults. Seven wild broods were captured twice, two broods in treatment areas and five broods in untreated areas. Broods not captured twice were either too old upon first capture to be captured a second time or died before the second capture was made.

Fifty six percent of 88 chicks in four broods were lost as an entire brood whereas 20% of 88 of chicks were lost individually. Most of the cases where the entire brood was lost in unmanaged areas occurred when the tending parent was depredated. In unmanaged areas, two entire broods were lost before three days and two additional broods were lost between day 3 and 9 post hatch. Two entire broods were lost because of depredation of the tending parent, while in the other two entire brood losses, the tending parents survived after the brood was gone. Forty one percent of 39 chicks were lost from broods that had at least one chick survive to 12 days.

Chick's survival in restoration areas was higher than in unmanaged areas. In restoration areas 100% of the chicks from two broods survived from hatching to 3 days post hatching. In contrast 61.4% of chicks in unmanaged areas survived from 0 to 3 days post hatching. Percentage of chicks surviving to 12 days post hatch was 100% in two broods for restoration areas and 24.1% for unmanaged areas. Within broods that were captured twice, approximately 58% of 69 of chicks were present at the second capture which usually occurred 6 days after the first capture. In unmanaged areas 43% of 54 chicks survived from the first capture to the second capture while in restoration areas, all of the 17 chicks survived from the first to the second capture.

Overall, 64% of 14 bobwhite broods monitored from hatching had at least one chick that survived to at least 14 days post hatching. In Searcy County, 66% of 9 broods monitored since hatching had at least one chick survive to at least 14 days and 60% of 5 broods in Fulton County monitored since hatching had at least one chick that lived to at least 14 days. An additional 3 broods in Fulton County were discovered when they were almost 14 days old and are not included in the total Fulton County estimate. One of these older broods contained a chick that weighed 5.3 grams less than the average weight of its brood mates and could barely hold its head up. This chick was probably not from another brood because its tarsus and wing lengths were similar to the other chicks. Two days after capture, one chick was missing from that brood and the tending adult from this brood was depredated 7 days later. Arthropod abundance where that brood foraged (Haringer restoration area, see figure 17) was low compared to foraging areas used by other broods. I note that the other two older broods that were captured lived well beyond 14 days. Most broods that survived were tended by adults much longer than 14 days (up to at least 39 days). However, my field seasons ended before I knew the fate of some of my broods and I only know that they survived to at least 14 days.

Brood amalgamation occurred in 2 of the 9 broods (22%) that I captured twice. The only brood captured twice in 2005 had seven chicks on the first capture and an additional 13 chicks upon the second capture and that brood was raised to independence. I did not detect brood amalgamation during 2006. In 2007 two of the adopted commercially hatched chicks switched to another artificial brood after their first capture.

I used a logistic growth curve to characterize bobwhite chick growth for all 91 captured bobwhite chicks (figure 2). The equation for the growth curve is Mass = (174.0283)/(1+(28.40927)*EXP{-(.1140282)*(age upon capture)}). The R^2 value for the growth curve is 0.95. Mass gain per day averaged within each brood tended to be substantially lower in restoration (0.96 g/day) compared to unmanaged areas (mean =

1.32 g/day; figure 3). The difference in average mass gain per day for chicks (averaged within broods) between restoration and unmanaged areas was statistically significant (n = 7, p = 0.0905, df = 4 alpha = 0.1). For comparison, the mean mass gain/day of all individual chicks whose exact age was known (n = 30) in both restoration and unmanaged areas was 1.12 g/day and ranged from 0.5 to 1.9 g/day. Differences in mass/tarsus ratios were statistically different between managed and unmanaged areas (n = 6, p = 0.08445, df = 4) but had a slightly lower p-value than did mass only comparisons.

Slopes of the log transformed mass (g) averaged within broods of all bobwhite chicks captured from 2005-2006 whose ages were known (figure 4) were statistically significant (n = 15, t = 2.169, p = 0.0509, df = 13). The R^2 values of the two regression lines for restoration and unmanaged areas were 0.98 and 0.9839 respectively. The equations of the lines are y = 0.0414(age) + 0.7857 for restoration areas and y = 0.0465(age) + 0.7851 for unmanaged areas. The lines diverge as age increases with chicks in the unmanaged areas gaining more weight than those in restored areas (figure 4).

Evaluation of Movements

Broods tended to follow landscape contours and did not move directly up slope or down slope. They also followed distinct habitat patches such as the banks of dry streambeds, fencerows, disked strips, or other visually distinct habitat patches within fields and pastures. Periodically, broods made rapid unidirectional movements for relatively long distances followed by reduced movement rates after they entered a different patch. Upon entering the new patch they began moving back and forth within that patch. Movements just prior to loafing or roosting were also rapid and in one direction toward shrubs or other dense vegetation. On several occasions broods moved directly towards me or my assistants, and approached to within 19 meters before changing direction. The direction change often involved an oblique or perpendicular angle relative to the researcher's position and usually followed habitat features rather than moving directly away from researchers. Although researchers may have had some effect on brood movement behavior, the affect was probably small given that broods sometimes moved towards researchers and approached closely before changing direction.

I calculated 511 movement rates collected from 9 broods during 34 tracking periods. I found that bobwhites moved from <1 m to 13 m per minute (figure 5) and that broods in restoration areas moved faster than broods in unmanaged areas (figures 6 and 7). Figure 6 shows all brood movement rates in both restoration and unmanaged areas from 2005-2006 while figure 7 shows movement rates after some of the non-foraging movements were removed (see methods for a description of how I identified non-foraging movements). Differences in brood movements are most pronounced when broods were young (see intercepts on figures 6 and 7). For the comparison when no movements were removed (figure 6), day old broods in restoration areas were estimated to move 2.2031 m/min while broods from unmanaged areas yielded an estimate of 1.2174 m/min. but movement rates converged as broods aged (regression lines cross at about 33 days old). With non-foraging movements removed, the intercepts were 1.68 m/min. in restoration and was 1.138 m/min in unmanaged areas. The regression lines also converge when all data are included but do not cross until well after 39 days. Broods on day one post hatch moved 0.8 m/min faster ($n = 511$, $F = 15.253$, $p = 0.0001$) in restoration areas than in unmanaged areas when all observations were used (figure 6). After non-foraging movements were removed from the data, the difference in movement rates decreased to 0.56 m/min faster in restoration areas and the difference remained statistically significant (figure 7, n = 483, t = 4.071, p = 0.0001). Because the statistical criterion used to identify non-foraging movements (recall I used Rstudent to identify outliers) did not classify all rapid movements as outliers, some non-foraging movements still remained in all of the datasets. Figures 6 and 7 show considerable overlap in movement rates but the difference appears to stem from faster and more frequent rapid unidirectional movements by broods in restoration areas.

Broods increased their rate of movements as they aged (figure 5). Figure 5 is a regression of the average rates that broods moved by age. The equation for averaged brood movements for all broods tracked from 200-2006 was: Rate (m/min) = (1.2117) + (.059) (age in days). The R^2 value (0.66) indicated that age accounts for a majority of variation in movements but additional factors play a role.

The nest location influenced habitat available to the broods because broods had limited movement capabilities. For example, no brood was located more than 90 m from the nest on the first day of monitoring. From day one to day three, the median distance that broods were located increased to 150 m and then stabilized at 140 m from day 4 to day 29. Restoration significantly increased the distance from the nests that bobwhite broods moved after hatching (figure 8). Regression lines comparing distances between broods and their nests as a function of age differed significantly (n = 45, p = 0.026, df = 44) between broods in restoration areas and unmanaged areas (figure 8). The intercept of regression lines for broods in restoration areas was approximately 70 m greater than broods in unmanaged areas (105 unmanaged, 170 restored). However, I note that no broods were actually further than 90 m away from the nest on day 1 post hatch. The regression line intercepts are inflated because broods increased the distances from their nests in a nonlinear fashion as they aged (Figure 8). The estimate for 20 day-old-broods in restored areas was 175 m farther from the nest compared to broods in unmanaged areas (figure 8). From 4 – 29 days, median distances between broods and their nests were twice as far in managed compared to unmanaged areas (restoration 213 m and ranged from 14 to 576 m, unmanaged 113 and ranged from 22 to 552).

Habitat also affected space use by broods because it affected the straightness of the path that they traveled and thus affected the distances between their initial and final locations during a tracking session. Figure 9 shows the relationship between monitoring duration and index of area use (i.e., the distance between the initial and final location, see figure 1) during a tracking session in restoration and unmanaged areas. The slopes of the regression lines regressing the index of area use as a function of age and monitoring duration were significantly different ($n = 32$, $F = 8.974$, $p = 0.0056$) indicating that broods used more space in restoration than in unmanaged areas (figure 9). For example the index of space use by bobwhites after 150 minutes was 60 meters greater (25 m unmanaged, 85 m restored) in restored areas than in unmanaged areas. The paths of broods in unmanaged areas were more tortuous than the paths of broods in restoration areas. Consequently, broods in managed areas probably used more space than did broods in unmanaged areas.

Invertebrate abundance was the only habitat feature that was associated with variation in distances moved by broods during a monitoring session (i.e., my index of area use). Figure 10 shows the relationship between the index of area use and arthropod biomass. The slope of the regression line is significant. The equation of the line is distance = (52.831)+(-4.712)*(arthropod biomass) ($n = 29$, $t = 2.0619$, $p = 0.049$, $df = 29$; $R^2 = 0.1360$). The low R^2 value is due to high variability in movements when arthropod abundances were low. As arthropod abundances increased both the index of area use and variability in the index decreased. The largest and most variable values of the index in area use were found among broods that foraged in areas where less than 2 g of arthropod biomass were collected per sample (i.e. 10 sweeps over 20 m with a 38.1 cm diameter net). Movements of broods were shortest when invertebrate biomass was high (20 meters moved when 7 g of arthropods/sample were present).

A multiple regression analysis indicated that arthropod biomass was more important than management state in influencing movement rates. Management state was not a significant predictor of distance moved during monitoring when insect biomass, brood age and monitoring duration (min.) were used as independent variables in the multiple regression ($n = 29$, $p = 0.102$, $df =29$). However, because restoration practices significantly reduced arthropod biomass, restoration indirectly influenced movement rates.

Tracking accuracy was quite good. The mean error from 50 m away ($n = 33$) between estimated locations and hidden radio collars was 3.23 m (SD = 2.604), and ranged between 8.42 m and 0.16 m. Tracking accuracy was similar among researchers ($n=31$, $F_{3,27} = 0.62$, $p = 0.6063$). Most of the error was in estimating the position of hidden transmitters along the back bearing. I used differences in signal strength, which decreases with distance, to aid in locating transmitters along the back bearing. Variation in the signal strength of the 6 transmitters probably resulted in a slight decrease in precision. On average my tracking bearings were accurate to within 2.2 degrees and ranged from 0 to 4 degrees off of the true bearing. At 50 m, 2.2 degrees error represents 1.9 m from the actual location of a hidden collar and 4 degrees error represents 3.4 m from the true bearing. Because habitat patches (identified by differences in vegetation density, composition etc.) in which broods foraged were larger than the error associated with my tracking method (personal observation), and because I sampled habitat along a course through the center of the estimated brood locations, my data accurately characterize habitat used by bobwhite broods.

Habitat Use by Nesting and Brood Rearing Adults

Bobwhites used fescue fields for nesting more often than other habitats in Searcy County. In fact, 17 of 18 nests were located in fescue-dominated fields and were constructed from fescue grass. The lone nest not located in fescue was in an oak woodland savanna habitat that had an understory of native bunch grasses. That nest was located under a low dense shrub and was successful.

I tracked eight broods in Searcy County and seven in Fulton County. One brood in Searcy County entered a restoration area on day 3 post hatch and three broods in Fulton County were tracked in restoration areas. I measured habitat on 34 brood paths, 20 in unmanaged habitats and 14 for broods in restoration areas. I used 92 habitat samples (20 samples from habitats used by chicks in unmanaged habitat; one point for each transect, 14 samples from habitats used by chicks in restoration areas; one point from each transect, 21 samples from randomly-located points in unmanaged areas, 27 samples from randomly-located points in unmanaged areas, and 10 samples from the nest vicinity) in each stepwise discriminant function analysis to identify structural features of bobwhite brood habitat.

A discriminant function was used to identify habitat characteristics that would discriminate among habitats at nesting, brood foraging and random locations. The model correctly classified 100% of nesting areas, indicating that nesting habitat is distinct from habitats used by broods as well as randomly selected habitat samples in restoration and unmanaged areas. The discriminant function model revealed that nesting habitat was largely absent from restoration areas in 2006. The model also revealed an increase in nesting habitat from 2006-2007 as indicated by the percent of randomly selected points classified as nesting habitat (figure 11).

Compared to brood and random locations, nest sites had more overhead cover (76% cover compared to 48% in habitat at random locations), more litter (35% cover compared to 18-20% in habitat at random locations), more grass (66% cover compared to 45% for restored and 70% for unmanaged habitat at random locations), taller vegetation (67 cm compared to 32-36 cm for random areas), less bare ground (3% cover compared to 12% unmanaged, and 28% restored) and less open space 0-5 cm and 5-15 cm above ground (25% and 30% respectively compared to 44 and 55 for open space 0-5cm, and 57% and 53% for open space 5-15 cm above ground in habitat at random locations in unmanaged and restored areas respectively)(Tables 3 and 4).

The discriminant function model was fairly efficient at identifying foraging habitat for broods (figures 12 and 13). It correctly distinguished 44% of the randomly located samples in unmanaged patches, 33% of points in randomly-selected patches in restoration areas, 55% of brood locations in restoration areas, and 54% of brood locations in unmanaged areas. It performed best at distinguishing nesting habitat (96% correctly classified) from all other categories. Conversely the discriminant function performed poorly at identifying random points in restoration areas (33% were correctly identified).

The discriminant function performed consistently for each of the 15 replicates (recall that I repeated the procedure 15 times and used different habitat samples for each replicate, figure 13). But, the procedure often selected different variables for use in the discriminate function. Selected variables, listed in order of the number of times they occurred, were: open space 0-5 cm high (chick height) (11 out of 15) , % forbs (10 of 15), vegetation height (10 of 15), overhead cover (9 of 15), number of grass species per m^2 (9 of 15), litter (8 of 15), bare (4 of 15) , open space 5-15 cm (adult height) (3 of 15), shrub (2 of 15), and number of forb species per m^2 (1 of 15).

I found that management practices associated with producing brood rearing or nesting habitats differed among practices instituted by participants in Searcy County (Table 1). Again, I assessed availability of brood rearing and nesting habitat by taking the percent of random points in restoration areas that were classified by my discriminant function as brood rearing or nesting habitat. I graphed the change in availability of nesting and brood rearing habitat on the individual restoration sites in order to evaluate management procedures and to evaluate changes between years in the proportion of habitat samples that classified as brood rearing and nesting habitats (table 1, figures 11 and 14).

Habitats used by broods were similar in restoration and unmanaged areas. For example, when the model misclassified a brood habitat from a restoration area, it was usually mistaken for a brood habitat from an unmanaged area (55% of samples from brood used unmanaged areas were misclassified as brood used habitats in restoration areas, while 25% of samples from restoration areas were misclassified as brood used in unmanaged). I pooled the two brood habitats and reconstructed a discriminant function. The resulting model correctly classified 69% of brood locations. The increased efficiency of the model reflects the similarity in brood habitat in restoration and unmanaged areas.

The discriminant function applied to a test data set performed well at discriminated among most habitat categories but did not perform well at distinguishing brooding habitat in restored areas (Figure 15). The original model developed from the 4th sample from each transect performed as follows on the test data composed of the 11th sample from each transect: habitat used by broods in unmanaged areas (model 68.5 % compared to 61% for the test data), habitats used by broods in restoration areas (model 64% compared to 35% for the test data), randomly located habitat in unmanaged areas (model 62.5% compared to 53% for the test data) and random habitat in restored areas (model 23 % compared to 28% for the test data).

The discriminant function performed best at distinguishing between nesting habitat because nesting habitat was the most structurally different from the other habitats. Many of the habitat variables used by the discriminate function in distinguishing between habitat types were those that are most distinct for nesting habitat (Table 2).

Univariate comparisons (Kruskal-Wallace test) were consistent with the discriminant function in showing that brood habitats in restoration areas and unmanaged areas were similar structurally but differed in arthropod biomass. Brood habitats tended to have more bare ground, more forbs, less grass, more open space 0-5 cm (chick height), less litter, and less overhead cover than nest habitat and habitat at random locations.

Univariate comparisons and the discriminant function showed that restoration favors brood habitat but not nesting habitat (figure 11 and 14, table 1) because habitat at random locations in restoration areas was similar in structure to brood habitat (table 3 and 4). Nesting habitat was distinct from habitat at random locations in restored areas and those used by broods. However, structural characteristics at nesting habitats were more similar to habitat at randomly selected locations in unmanaged areas than to brood rearing habitats and restored habitats. Several restoration areas had only a few points that classified as nesting habitat, especially shortly after treatment (Figure 11). Nesting habitat increased in restoration areas with time.

Invertebrate biomass from 2006-2007 was significantly greater in unmanaged than in restored areas in both counties (Mann-Whitney U test, $n = 74$, $Z = 3.0889$, $p = 0.002$, figure 16). Figure 17 shows the arthropod biomass collected from random locations within each restoration area. Median arthropod mass was 1.305 g/sample in unmanaged areas and ranged from 0.062 to 8.02 g/sample while in restoration areas median arthropod mass was 0.479 g/sample and ranged from 0.015 g/sample to 5.175 g/sample. The difference in arthropod abundance between restoration and unmanaged areas was not evenly distributed across invertebrate orders. Orthoptera were more numerous (Mann-Whitney U test, $n = 74$, $Z = 3.1765$, $p = 0.001$) in unmanaged areas than in restoration areas and accounted for 95% of total invertebrate weight in unmanaged areas compared with only 84% in restoration areas. I found that restoration reduced orthopteran abundance by 70% and total arthropod mass by 63%. When orthopterans were removed from the analysis, I found a significant difference in arthropod biomass (Mann-Whitney U test n = 75, Z = 2.1690, p = 0.03) with mass being greater in restoration areas (median of 0.105 g/sample) than in unmanaged areas (median of 0.05535 g/sample). I did not find a significant difference in count between restoration and unmanaged areas after orthoptera were removed (Mann – Whitney U test, n = 75, Z = 1.5939, p = 0.11). Nor did I detect a difference in arthropod abundances between years (Mann-Whitney U test, n = 76, Z = 0.7837, p = 0.433). Table 3 shows the arthropod biomass per sample for each restoration area and shows the associated restoration practices that were used.

The stepwise multiple regression found a significant relationship between habitat factors and arthropod biomass (Root MSE = 1.60, $R^2 = 0.42$). Significant variables positively influencing arthropod biomass were number of grass species counted per m^2, percent forb cover, and number of forb species counted per m^2.

Chapter 3: Discussion

Adult Habitat Use and Production

Habitat management for Northern Bobwhites in Searcy County did not produce habitat that was used by northern bobwhites during the breeding season. Although bobwhites appeared to avoid restoration areas during the breeding season, they commonly used restoration areas during the winter. Landowners in Searcy County mow their land in late summer and fall to reduce brush, which reduces or eliminates suitable cover for bobwhites. Furthermore, most open fields in Searcy County are grazed heavily by cattle during the winter which leaves little cover and reduces the amount of usable space (Guthery 1997) available for bobwhite during the winter. Bobwhite winter home ranges usually contain more brush cover (Bell et al. 1985, Kassinis and Guthery 1996). In addition, foraging during winter usually occurs within 20-50 meters of woody cover (Bell et al. 1985, Kassinis and Guthery 1996). Heavier use of restoration areas by bobwhites during winter may reflect the greater cover available in restoration areas which were not grazed or mowed. Thus, restoration areas may benefit bobwhites during the winter by providing suitable winter habitat

The habitat structure of restored areas may have been inappropriate for nesting. Although restoration areas were used during the winter, most of the bobwhites (24 of 30) captured in restoration areas in winter left the restoration areas at the beginning of the breeding season and did not return. Further, many of the bobwhites that were captured in restoration areas during the breeding season were males captured by decoy trapping. Because this technique involves broadcasting the female's call, some of these males may have been lured into the restoration areas from a distance, making it difficult to determine their original location.

Habitat in unmanaged areas had structure that was appropriate for nesting bobwhites. Fescue fields utilized by bobwhites for nesting had thick vegetation, abundant grass litter to build nests, and had tall enough vegetation for nest concealment. Restoration areas generally lacked thick grass and abundant grass litter that bobwhites used for nesting. Bobwhites may selectively nest in areas with more grass and litter (Taylor et al. 1999), which may explain why nesting bobwhites did not use restoration areas. In addition, adults in my study selected nesting habitat in close proximity to foraging habitat. Restoration areas that lacked the proper spatial distribution of nesting and brood-rearing habitats may have been avoided by bobwhites during the breeding season.

Mean clutch size in Searcy County may have been influenced by weather. My estimate of (12 eggs/nest) was similar to estimates reported by others (11.9-14.4 eggs per nest; e.g., Dimmick 1974, Roseberry and Klimstra 1984, Lehman 1984, Burger et al. 1995), however most of the clutches I observed were laid later in the breeding season which probably resulted in smaller clutch size since clutch size declines as the season progresses (Roseberry and Klimstra 1984, Burger et al.1995). During 2006 a spring season drought was followed by mid- and late-summer rains which may have delayed nesting. Drought may decrease survival, the proportion of hens that nest, nesting rates (nests per hen), the length of the breeding season, and percent juveniles in the fall populations (Hernandez et al. 2005). A drought occurred during 2005-2006 and may have reduced bobwhite productivity. The drought was followed by abundant mid to late summer rains in 2006 which may have induced late season nesting.

Production appeared to be limited by adult survival. Nesting success within fescue dominated fields in Searcy County was higher than values commonly reported (my estimate was 53% compared to 32-44%; e.g., Stoddard 1931, Dimmick 1974, Roseberry and Klimstra 1984, Burger et al. 1995) indicating that fescue habitat was appropriate for nesting bobwhites in 2005 and 2006. However, the number of nests/hen was less in my study than reported in other studies (1.8 nests/hen reported by Burger et. al 1995, 1.2 nests/hen in dry years and 2.3 nests/hen during wet years reported by Hernandez et. al 2005). Although all females fitted with radio collars that survived into the breeding season nested, most of them attempted only one nest before they were depredated.

Depredation on incubating adults was higher in my study (33% of all nests, and 55% of failed nests) than those reported by others (4% of all nests, and 11% of failed nests reported by Roseberry and Klimstra 1984, 13.4% reported by Burger et al. 1995).

Predation on hens reduced the number of nesting attempts in my study because most of the hens I monitored died before they could attempt a second nest (or before they attempted a first nest). Consequently, high predation rates on nesting and brood rearing hens probably limited population growth and size in Searcy County. Thus, bobwhite productivity in exotic grass dominated habitats may be limited by predation on adults. I speculate that the thick fescue cover may reduce the ability of bobwhite adults to escape predators. Given that the number of nesting attempts per female is more important for recruitment than individual nest success (Roseberry and Klimstra 1984) and that females in my study were limited in nesting attempts by predators, recruitment would have increased if females survived to attempt more nests. Thus, if restoration decreases predation rates, then bobwhite population would probably increase by increasing the number of nests/hen (Roseberry and Klimstra 1984).

Habitat Use by Nesting and Brood Rearing Bobwhites

Contrary to some reports (Barns et al. 1995, Madison et al. 2001), tall fescue provided suitable habitat structure for nesting bobwhites. My results are consistent with findings by Burger et al. (1994) that fescue fields where structurally similar to habitat used by nesting bobwhites. In fact, most of my bobwhite nests were located in and made of fescue. My findings support the assertion made by Lusk et al. (2006) that vegetation composition is not as important as nest concealment for nest site selection and nest success. Bobwhites in my study nested in habitat that was favorable for nest concealment (dense vegetation, high percent overhead cover, abundant grass litter, tall vegetation) and many restoration areas did not provide these habitat features. The average vegetation height (67 cm) around nests in my study was taller than the minimum threshold (>40 cm for successful nests and ≤40 cm for unsuccessful nests) for successfully nesting bobwhites in Texas (Lusk et al. 2006) and were much taller than vegetation at random sites within my study area (32 cm at randomly selected unmanaged area and 36 cm at random restored areas).

Bobwhite nesting habitat isolated from brood rearing habitat may represent an ecological trap (Dwernychuk and Boag 1972) because adults may be attracted to these areas to nest but without appropriate brood rearing habitat, broods would not survive. Conversely, managing for brood habitat without providing nesting habitat will be futile. The juxtaposition of nesting and foraging habitats is important because day-old broods generally move less than two meters per minute while foraging (figures 5, 6 and 7) and may be incapable of traveling long distances immediately after hatching. Further, adults that nested close to foraging areas would expend less energy traveling to and from foraging areas, would spend less time away from their nests, and would probably be subject to less predation than individuals that nested farther from foraging areas.

Habitat restoration favored creating large areas of brood rearing habitat with little nesting habitat. Habitat in randomly located restored areas was more similar to brood rearing habitat than it was to nesting habitat because restoration activities increased bare ground which in turn increases forb cover, and open space at ground level by reducing vegetation density and grass liter. However, nesting habitat developed in restoration areas as they aged. Thus, restoration areas may develop into areas used by both nesting adults and broods.

Bobwhite broods did not appear to select habitat randomly. Rather they were found in habitat patches that differed substantially from habitat at random locations as well as habitat around nests. The differences in habitat structure probably reflect requirements of broods for foraging, ease of movement, moisture content, and thermal constraints (Lehman 1984, DeVos and Mueller 1993, Burger et al. 1994, Taylor and Guthery 1994, Taylor 1996). My bobwhite broods used habitat that was similar to brood habitat described by others (20-50% bare ground, more forbs, high arthropod abundances, and shrubs or other dense vegetation for thermal refuge) (Lehman 1984, DeVos and Mueller 1993, Burger et al. 1994, Taylor and Guthery 1994, Taylor 1996). These habitat characteristics probably provide foraging opportunities and thermal cover. Thus, I assumed that broods were foraging in areas where I collected habitat samples because I tracked them when they were active.

Brood habitats in restored and unmanaged habitats were fairly similar. The discriminant function performed poorly in discriminating brood habitats in restored and unmanaged areas because several habitat characteristics in brood habitats were similar regardless of management states (Table 3). The discriminant function's reduced accuracy in identifying randomly located points within restoration areas reflects substantial variation in habitat structure among different restoration areas. Therefore restoration areas did not develop into a characteristic and identifiable habitat structure and vegetation composition.

Although the discriminant function was fairly good at identification of foraging habitat, roughly 30 percent of the habitat points used by broods were misclassified (I pooled data collected on brood use in restoration and unmanaged areas for this analysis). These misclassified samples might have been located in habitats used for loafing, roosting or escape from predators. Such areas would necessarily be structurally distinct from foraging habitats (Taylor and Guthery 1994). My method for sampling brood rearing habitat did not allow me to determine the function of different habitats used by bobwhite chicks. However others have shown that bobwhite broods require different habitat structures for loafing, roosting and foraging (Taylor and Guthery 1994b) and this variation in habitat may be a necessary habitat component for bobwhite chicks for these activities. I also suspect that brood tending adults select a patchy matrix of foraging and loafing habitats because my brood paths were near areas that transitioned between thicker vegetation and areas with more bare ground.

The habitat variables selected as discriminating variables should not be interpreted as habitat that is best for bobwhites. For example, bare ground is important to bobwhite quail (Stoddard 1931, Taylor and Guthery 1994b, Taylor et al. 1999, Palmer et al. 2001). However, I found that other variables were more important than bare ground for discrimination between all habitat categories, probably because broods used habitats that had similar proportions of open ground in both managed and unmanaged areas and because management created more bare ground. Therefore three of the habitat categories had similar amounts of bare ground and thus that variable was not a good discriminator. This is an example of how the discriminant function used the variables that are most different and not necessarily those that are best for bobwhite quail. Therefore the discriminate function results should not be used to infer that the discriminating variables are those best for bobwhite quail habitat quality. However the discriminant function does perform well in classifying habitats as nesting and brood rearing, therefore I can infer habitat quality and usable space (Guthery 1997) by the reclassification of samples within restoration areas.

Arthropod Abundances

Arthropods are an important component of the diet in breeding female bobwhites (Harveson et al. 2004) and the primary item in the diet of chicks (Hurst 1972). Although some restoration areas were structurally similar to brood habitat in unmanaged areas, brood habitat in restoration areas and randomly located habitats in restoration areas supported fewer arthropods. If restoration areas develop sufficient arthropod populations and continue to increase in nesting habitat while maintaining structural similarity to brood foraging habitat on the majority of each restoration area, then restoration areas may increase bobwhite populations. Results from my study indicate that habitat suitable for nesting increased but arthropod populations did not increase through time in restoration areas. Some restoration areas maintained high arthropod abundances after they were managed (see table 3). Restoration practices that had higher arthropod abundances after treatment were those that were planted with a variety of grass species. Therefore considering arthropod abundances during restoration planning may be advantageous.

The relationships that I found between forb abundance, plant diversity and arthropod abundances have also been found in other studies (Blenden 1986, Brush 1986, Shelton and Edwards 1983, Nelson et al. 1988). Arthropod abundances generally increase with increased forb abundance (Blenden 1986, Brush 1986) and invertebrate abundance and diversity are higher in mixed plant communities than in monocultures (Shelton and Edwards 1983, Nelson et al. 1988). Thus, managers should promote invertebrate abundance with management practices that maximize plant species diversity and include forb patches in management prescriptions.

Several orders of arthropods are consistently cited as important bobwhite chick food items among which are orthoptera, Coleoptera, Hemiptera, and Homoptera (Burger et al. 1993, DeVos and Muller 1993). Thus, reduction of orthoptera likely had a negative effect on foraging habitats for bobwhite chicks, even though restoration had a positive effect on biomass of non-orthopteran orders. Non orthopteran biomass was higher in restoration areas. Although I found a positive response to restoration by non-orthopteran orders, the magnitude of the difference was very small and did not compensate for the large decrease in orthopteran biomass. Since orthoptera made up the majority of arthropod biomass, and because a single orthopteran represents a comparatively large food item for a chick compared to most other arthropod groups, reduced orthoptera biomass probably was detrimental to foraging bobwhite broods.

I acknowledge that insect abundance evaluated through sweep net samples may not represent invertebrates actually available to bobwhite chicks (Palmer et al. 2001). Palmer et al. (2001) showed that mean mass gain per day by foraging bobwhite chicks more accurately reflected foraging value of habitat patches than sweep samples. I recognize that my sampling methods may not have represented arthropods available to chicks (Palmer et al 2001). Despite the shortcomings, sweep net sampling does adequately sample relative invertebrate biomass and arthropod taxonomic diversity (Evans et al. 1983). In addition, chick mass gain/day was lower in restoration areas, which supports my conclusion that insect abundance was lower in restoration areas.

Consequently, restoration produced habitat of lower foraging value to bobwhite broods. Again, management treatments on my study areas were recent and insect availability may change as the treatment areas mature. Note however, that I did not detect an increase in arthropod biomass from 2006 to 2007.

Chick Survival and Growth

Survival rates of bobwhite broods may be influenced by restoration. Bobwhite chicks appear to survive better in restored areas as compared to unmanaged areas. Short-term survival of broods in restoration areas was higher (100%) than those in unmanaged areas. Further, chick survival within the unmanaged areas (26 % survived to 12 days) was considerably lower than survival rates reported by others (53-75% of chicks survived to 16 weeks, Roseberry and Klimstra 1984, 52% survival to 16 weeks, Suchy and Munkel 2000, 61.7% to 16 weeks Lusk et al. 2005). These previous estimates of brood survival were over 16 weeks versus my survival estimate over only 12 days. Roseberry and Klimstra's (1984) and Suchy and Munkel's (2000) studies differed from my study because they did not capture and mark individual chicks. Lusk et al. (2005) did capture individual chicks but marked them by attaching a radio transmitter. Predation rates on adults appeared to be higher in Searcy county where most of my broods used unrestored habitat than in Fulton County. I don't know whether or not the difference in predation rates was due to restoration or some geographically based factor. Also, small sample sizes reduce the confidence one can place on my conclusions. However, differences in brood survival estimates between restored and unmanaged areas appeared to be related to adult survival as 2 of 4 cases where the entire brood was lost in unmanaged areas occurred because the tending parent was depredated.

Two patterns of brood loss are evident in my data: complete brood loss and individual chick attrition. Complete brood loss was the most common pattern. Several possibilities could account for complete brood loss before age 12 days. Among these is mortality of the tending adult, which occurred in 2 of 4 broods in my study that were completely lost. Other possible causes of complete brood loss are disturbance of a roosting brood by a predator were uncaptured chicks die of exposure, a predator captures all chicks, all chicks become entangled, broods are abandoned by the adult or all chicks become amalgamated into another brood. I suspect that other causes of complete brood loss exist, but the ones I mentioned above are the most likely explanations. Individual chick losses probably occur for a variety of reasons such as entanglement (Hurst 1972), exposure, malnutrition, and individual or partial brood depredation or brood amalgamation. I suspect that restoration may reduce complete brood loss by reducing mortality of tending adults and likely reduces individual chick losses from exposure facilitated by entanglement.

Management that produces good brood foraging habitat close to nesting sites might reduce predation on broods and ultimately, increase bobwhite recruitment. Two of four complete brood loses in unmanaged areas occurred because the tending adults were depredated. Interestingly, those two broods that were lost to predators had moved the farthest from the nest on the first day post hatch. Higher predation is often associated with greater movements by prey (Baker 1978, Swingland and Greenwood 1983, Rappole et al. 1989, Woodland and Harris 1990, Bensch et al. 1998). Thus, foraging habitat located closer to nesting sites would reduce the initial movements of broods and might reduce their exposure to predators.

Mowing of fescue fields during the breeding season probably influences predation. I noticed that one brood disappeared the day after part of its home range was mowed. In another instance a pair of brood rearing bobwhites was depredated within 18 days of their home range being mowed. Thus brood survival will increase if landowners avoid mowing their fields during the peak of the brood rearing season (approximately June – July, Cox et al. 2005).

Bobwhite chicks may become entangled and exhausted in thick vegetation (Hurst 1972). Vegetation density was lower in restoration areas which may have allowed broods to move and forage more freely than in unmanaged areas (and thus avoid entanglement). Entanglement may have been the cause of some of the individual chick attrition found in unmanaged areas. However, some of my tending adults raised complete broods that survived to at least 29 days in a fairly dense fescue dominated field.

Inadequate nutrition may influence quail chick survival (Cantu and Everett 1982, Potts 1986, Lochmiller et al. 1993, Hernandez et al. 2005). Inadequate prey availability has been correlated with low chick survival in the grey partridge (Potts 1986). I observed one chick that appeared to be starving in an area that had few arthropods; its brood had one fewer chick a few days later. Bobwhite chicks exhibit compromised immune systems when fed a protein deficient diet (Lochmiller et al. 1993). Thus, mortality could also be indirectly associated with low prey availability.

Bobwhite chick mortality has been known to fluctuate widely and responds to poor range conditions (Cantu and Everett 1982). Cantu and Everett (1982) found that brood survival was higher in light to moderately grazed pastures but low in heavily grazed pastures. Finally, the percentage of juveniles in the fall population was lower in dry years than in wet years (Hernandez et al. 2005), which may indirectly relate to food availability since rainfall and arthropod abundance are related (Tananka and Tananka 1982).

The first 14 days post hatch may be the most critical time period for young chicks (Stoddard 1931, Roseberry and Klimstra 1984, Suchy and Munkel 2000). However, Lusk et al. (2005) reported that the critical period for broods extends to 30 days, which was very close to the point where chicks reached maximum growth. Lusk et al. (2005) concluded that survival became independent of mass at capture and thus became independent of age at capture at about the time when chicks reached maximum growth rates (at ~30 days). In other words, survival increased with mass gain until about 30 days (Lusk et al. 2005). Survival has also been shown to relate to growth rate in wild willow ptarmigan (*Lagopus lagopus*) (Myrberget 1977), red grouse (*Lagopus lagopus scoticus*) (Park et al. 2001), mallard ducklings (*Anas platyrhynchos*) (Cox et al. 1998), and ring-necked pheasants (*Phasianus colchicus*) (Stokes 1954). Others have shown increased growth and survival associated with increased invertebrates consumed in captive sage grouse (*Centrocercus urophasianus*) and willow ptarmigan chicks (Johnson and Boyce 1990, Jorgensen and Blix). I found that chicks in restoration areas tended to grow more slowly than chicks in managed areas. Consequently, chicks in restoration areas may take longer to reach maximum growth rates and thus be exposed to lower survival rates for a longer period of time than chicks in unmanaged areas. As mentioned above, I witnessed older broods with chicks that appeared to be near death because of malnourishment in restoration areas. For bobwhites in my study, better early survival in restoration areas may be offset by lower late survival associated with slower growth due to low arthropod populations.

My data indicate a possible trade off between increasing chick survival, and reducing chick growth and arthropod biomass. Although chick survival was greater in restoration areas, the body condition of chicks that used restoration areas was poorer than those in unmanaged areas as evidenced by their lower weights. Weights of chicks in restoration versus unmanaged areas diverged as broods aged (figure 4) suggesting that the effects of poor nutrition may intensify as broods age. If the slopes from my log transformed growth lines are representative of the populations, then chicks at age 12 days would weigh on average 2.87 grams less (12.9% lower) in restoration areas than in unmanaged areas. The differences in chick growth between broods in restored and unmanaged areas are probably biologically significant. Lower arthropod biomass in restoration areas (figure 16) supports the conclusion that foraging value may be compromised in restoration areas.

The disparity between survival and growth exhibited by wild broods in restored and unmanaged areas may be explained by three possibilities: 1) Predation risk of tending adults was lower in broods that used restoration areas, 2) The detrimental effects of lower growth were not severe enough to cause higher mortality, or 3) Lower survival due to lower growth was not detected during the time in which I monitored survival (0-12 days) but may be manifested later. However, growth and survival of precocial broods are strongly associated (Myrberget 1977, Jorgensen and Blix 1985, Potts 1986, Johnson and Boyce 1990, Park et al. 2001, Cox et al. 1998, Lusk et al. 2005). Consequently, I might have documented a difference if I was able to monitor chicks for more than two weeks.

Growth rates of chicks may be associated with habitat. For example, growth of sage grouse chicks was influenced by forb abundances (Huwer 2004). Like bobwhites, sage grouse chicks require a high protein diet that they acquire by consuming arthropods (Klebenow and Gary 1968, Peterson 1970). Sage grouse chicks in Huwer's (2004) study probably responded to increased abundance of arthropods associated with greater forb cover (Huwer 2004, Blenden 1986, Brush 1986). Similarly, differences in growth of bobwhite chicks in restoration and unmanaged areas are probably caused by differences in arthropod availability associated with different habitat. I found that unmanaged areas supported much larger arthropods biomass as compared to managed areas. I suspect the decreased availability in restored areas was due to management practices. In restoration areas, landowners often planted only one species of native warm season grass. Invertebrate abundance and diversity are higher in mixed plant communities than in monocultures (Shelton and Edwards 1983, Nelson et al. 1988). Invertebrate abundances also increase with increased forb abundances (Blenden 1986, Brush 1986). Greater invertebrate abundances in my study were positively associated with percent of forbs, number of forb species per m^2 and numbers of grass species per m^2. Consequently, management activities to promote development of brood rearing habitat should strive to establish diverse grassland communities that support a mixture of forbs and grasses.

Evaluation of Movements

Presence of researchers did not appear to have a substantial influence on movements of bobwhite broods. For example, several broods moved towards monitoring locations during tracking and one brood approached to within 19 m before changing direction. Broods didn't respond strongly to researcher presence because their vision was probably obscured by the tall vegetation that surrounded them and because the researcher maintained a low profile behind tall vegetation when not obtaining bearings. In Colorado, researchers observed Gamble's Quail, in open desert habitats from a distance of 15-20 meters with no apparent effect on behavior (Goldstein, 1984). Thus, I suspect that my presence did not greatly disrupt movements of broods and that most brood movements were influenced by factors other than researcher presence.

I noticed a response by bobwhite chicks to approaching researchers. If broods were approached slowly (when I avoided flushing them) they were found in habitat that had thicker vegetation and more overhead cover, whereas if they were approached quickly (when I was flushing them for a survival estimate) they were found in more open habitats (personal observation). I suspect that when bobwhite chicks were approached slowly they had time to move to thicker vegetation to hide, but when they were approached quickly they flushed directly from the habitat they were using. This casual observation may indicate a bias in bobwhite brood habitat selection studies and should be tested by other researchers performing similar studies. My analysis likely avoided this bias because I sampled brood locations along the course that broods traveled.

Bobwhite broods often moved back and fourth within habitat patches, probably to increase time spent in those patches for foraging. Movement rates and search paths by birds often reflect differences in prey availability. When actively foraging among abundant prey, birds move slower (Smith 1974, Zack and Falls 1977, Zack and Falls 1976, Graber and Graber 1983) and move shorter distances than birds foraging in patches that have fewer prey (Baker 1974, Pienkowski 1983, Kellner 1990). Predators are known to remain in an area longer after capture of prey and to increase frequency of turning in an "area concentrated search" pattern (Smith 1971, Curio 1976). Predators avoid areas where prey are absent by moving more rapidly through these areas (Curio 1976).

The age of bobwhite broods was an important factor to consider when evaluating brood movements. Bobwhite broods in my study increased movement rates and space use as they aged. My findings are consistent with those of Taylor and Guthery (1994) who showed that post-fledging broods moved farther than did pre-fledging broods (both located 5 times per day). Broods probably move faster when they are older because they are larger and because they may increase foraging efficiency as they age.

Broods in restoration areas moved further and faster than broods in unmanaged areas, especially when broods were young. In addition, broods in restoration areas made more frequent and longer non-foraging movements. The more frequent non-foraging movements made by broods in restoration areas could be an indication of poor foraging habitat. Finally, birds in restoration areas tended to turn less frequently and consequently used more space than broods in unmanaged areas whereas broods in unmanaged areas tended to move back and forth within habitat patches whereas broods in managed areas did not. These differences in movement and space use patterns are probably due to lower arthropod availability in restoration areas which indicate that bobwhite broods spent more energy in restoration areas than in managed areas to acquire resources. Generally, active foragers move more slowly and turn more frequently when prey are abundant (Curio 1976).

Arthropod abundances may affect bobwhite brood movements. DeVos and Mueller (1993) found that brood home range sizes are inversely related to invertebrate abundances. Movements by broods in my study were influenced by invertebrate biomass as that was the only significant habitat variable associated with the index of space use during monitoring. When invertebrate abundance, age and monitoring duration were used as the independent variable in multiple regression comparisons, differences in index of space use during tracking in restoration and unmanaged habitats were not significant because some broods in unmanaged areas moved long distances when arthropod abundances were low and some broods in restoration areas did not move far when arthropod abundances were high. These findings indicate that arthropod abundances where causing the differences. Thus brood movements are at least partially controlled by arthropod abundance and broods in restoration areas probably had to move further for arthropod resources. Thus, managers should consider arthropod abundance when managing for bobwhite broods.

Movement patterns of quail suggest that distinct habitat patches with favorable foraging, roosting and loafing characteristics are farther apart in restoration areas. Others have noted the importance to bobwhites of high variability among habitat patches (Kopp et al. 1998). Theoretically, closer habitat patches would allow bobwhite broods to meet their habitat needs in a smaller area and also reduce the distances moved which would reduce their risk of exposure to predators. They would also not have to expend as much energy to obtain the resource needs and would grow faster. Thus, the dispersion and arrangement of patches within home ranges probably has a significant impact on survival and growth.

Brood survival is probably inversely related to frequency of brood movements given that prey are more susceptible to predation while they are moving (Baker 1978, Swingland and Greenwood 1983, Rappole et al. 1989, Woodland and Harris 1990, Bensch et al. 1998). Broods where all chicks were lost before they were 3 days old occurred in those broods that were furthest from the nest on the first day post hatching (up to 90 m). Thus, broods that have to travel longer distances from the nest to foraging patches are more vulnerable to predation. Consequently, having brood habitat close to the nest site may increase brood survival.

A full understanding of the link between habitat and brood survival and other correlates of fitness such as movements would allow us to manage more effectively for bobwhite brood habitat (Taylor et al. 1994).

Because young broods may be incapable of moving far, habitat use by broods is limited to habitats located close to the nest. My results suggest that proximity of brood foraging habitat to the nest may be most important for the first three days post hatching. Consequently, distances between nesting habitat and brood rearing habitat should be no greater than the distance that broods moved in 3 days and ideally would be no farther than the distance that broods moved in one day.

I noticed that bobwhite broods initiated loafing earlier and returned to foraging later in the day when temperatures were high. I also noticed that bobwhites would periodically stop moving or would move so small a distance that movements were undetectable when temperatures where high. Temperature is a major factor determining daily movements and loafing behavior of Gamble's quail (Goldstein 1984). Goldstein (1984) reported that Gamble's quail in desert environments began loafing earlier and came out of loafing later on hot days. On cool days Gamble's quail periodically resume foraging throughout the day whereas on hot days they remain in the shade through mid-day (Goldstein 1984). However, adult Gamble's quail were not observed thermal regulating by alternating between sunny and shaded habitats (hereafter shuttling) probably because Gamble's quail adults are better able to thermally regulate than bobwhite chicks (Goldstein 1984). Palmer et al. (2001) noted that temperature had a large effect on his imprinted chicks. He observed that neither overheated nor chilled chicks forage effectively (Palmer et al. 2001). I suspect that the pauses in movements of my foraging broods may represent shuttling behavior, or thermal regulation of chicks by the tending adult. Broods in both areas also made relatively rapid, unidirectional movements before they initiated roosting and loafing. Thus the distribution of thermal refuges relative to brood foraging habitat may be an important habitat characteristic for bobwhite broods. A greater understanding of brood thermal ecology in the context of usable space would allow us to better manage for bobwhite broods.

Effectiveness of Restoration in Producing Brood Rearing and Nesting Habitat

Managers should consider effects of habitat treatments on both nesting and brood rearing habitat simultaneously. All management practices implemented in Searcy County reduced grass litter and many practices also reduced grassy cover, both of which were important features of nesting habitat in my study. Managers should leave small fallow areas to provide nesting habitat when managing habitat for bobwhites broods. Management practices aimed at creating a patchy mosaic of different habitat structures within open fields would benefit bobwhite chicks and nesting bobwhite adults. Such practices might include burning when conditions favor a patchy burn, disc stripping in a checker board pattern through large fields, and planting many species of plants including forbs and bunch grasses to promote plant diversity and structure or, alternating management between years on a small scale (1 ha sized plots) in adjacent restoration areas. These smaller plots should be proportioned so that the nesting plots are within 150 meters which is within the movement capabilities of broods 1-3 days old.

Some management practices in Searcy County produced a mixture of brood rearing and nesting habitat. For example, land clearing (i.e., converting woodlands into habitat borders, usually by bulldozing) or disking, followed by spring burning then planting two or more species of native warm season grasses generally produced habitats that were structurally similar to habitats used by bobwhites for rearing chick and nesting. Nevertheless, management prescriptions in Searcy County did not produce habitat that was actually used by brooding bobwhites.

I observed two practices that did not produce brood rearing or nesting habitat. First, fescue eradication when Bermuda grass was dominant did not allow for establishment of native warm season grasses (ex., S. W. Treat). Solid mats of Bermuda grass were not identified by my discriminant function as brood rearing habitat and were not used as such by any of the broods or adults that I monitored. Second, planting a monoculture of native warm season grasses such as switch grass (*Panicum virgatum*), (ex., Holstead Switch) tended not to produce brood rearing or nesting habitat and had low insect abundances (Tables 1 and 3). These two practices produced relatively low proportions of both nesting and brood rearing habitat (figures 11 and 14, table 1).

I also found that the outcomes of restoration practices change over time. Some restoration areas initially developed relatively large areas of brood habitat but had little to no nesting habitat during the first year post restoration (figures 11 and 14). In the second year, more nesting habitat was present but most random samples were structurally similar to brood habitat. Consequently, such areas may be developing into suitable habitat for breeding and may eventually be utilized by quail. However, burn only treatments in fescue that initially developed a mix of brood rearing habitat (40% coverage) and nesting habitat (7% coverage) had virtually no brood rearing habitat three years after the burn (Lower Shannon for example). Restoration efforts that eradicated fescue followed by burning and establishment of a variety of native warm season grasses were better at producing large areas of brood rearing habitat with small areas of nesting habitat that persisted for three years.

Despite the creation of habitat structurally similar to brood rearing and nesting habitat in Searcy County, bobwhites did not use these areas during the breeding season. Other important characteristics such as patch configuration, patch size, nesting habitat or sufficient arthropods may have been inappropriate. Restoration areas that were identified as brood-used habitat by my discriminant function may be suitable for foraging but may lack other critical habitat features such as roosting or escape cover or suitable nesting sites. For example, absence of nesting habitat in many restoration areas in 2006 may explain why nearly all of the adults I monitored, even those whose home ranges were close to restoration areas, did not use these areas during the breeding season. These areas may develop appropriate structural characteristics to attract adults in future breeding seasons.

Based on my observations and analysis of brood movement, I believe that habitat used by broods is not independent of nest location. Nest location probably determines the amount of usable space to which a brood has access based on the distribution of foraging patches around the nest site. Thus, brood rearing habitat is only utilized if it is located near nesting habitats. I believe that patches of brood foraging habitat should be located within 65 and 151 m of nesting habitat which reflects the movement capabilities of 1 - 3 day old broods. After 3 days post hatching, the median distances broods were located away from the nest remained approximately 140 m. Some broods moved as much as 574 meters away from nest sites. However, I suspect that closer distribution of nesting habitat to brood rearing habitat is better for bobwhite broods because it would lower the risk of predation.

Overall Conclusion

My data on production, nest success, nest habitat, brood habitat use, chick growth and survival, and movements in both restoration and unmanaged areas allow a direct assessment of how habitat management efforts undertaken in Searcy County, and to a lesser extent, Fulton County, influenced productivity of Northern Bobwhite. My findings suggest that management efforts in Searcy County did not produce habitat suitable for nesting quail. Although quail in Searcy County used restoration areas during winter, they tended to leave those areas at the beginning of the breeding season and seldom returned. I seldom heard or encountered quail on restoration areas in Searcy County during the breeding season even though I intensively searched for quail to trap in those areas. Transmitter-equipped quail located adjacent to restoration areas were rarely observed in restoration areas. Brood tending adults adjacent to restoration areas rarely used restoration areas except in one instance in which the adjacent field was mowed and in that instance the quail were depredated soon after moving into the restoration area. Further, arthropod biomass was significantly lower in restoration areas than in unmanaged fields and chicks captured in restoration areas in Fulton County grew more slowly than did chicks in unmanaged areas in both Searcy and Fulton Counties. Broods in restoration areas also moved further and faster than broods in unmanaged areas and arthropod biomass seemed to be causing the differences in those movements.

Quail need a mixture of habitat patches with distinct attributes for foraging, roosting, and nesting. I suspect that in Searcy County, management efforts have not produced the correct mix and distribution of habitat patches. Restoration activities did not produce consistent results; some activities produced habitat structurally similar to habitats used by broods but some activities produced habitats that were not. These inconsistencies in management outcomes probably occurred because of differences in management prescriptions as well as the timing of implementation by individual landowners. The timing of implementation by landowners may possibly be improved with follow up by the biologists who prescribe the habitat plan. I suspect that some areas have developed into either good brood rearing habitat or good nesting habitat or both. As the areas mature, perhaps the correct mix and distribution of brood rearing and nesting habitat will develop to the point that bobwhite begin to use these areas during the breeding season.

My results indicate that fescue fields can provide suitable nesting and brood rearing habitat. Quail nested successfully and were able to rear their broods to independence in fescue fields. Parameters of nesting success, clutch size, and proportion of nesting hens either exceeded or were close to estimates from other studies. However, not all fescue fields are equal in habitat suitability for northern bobwhites. I found and trapped many of my bobwhite adults within fescue fields that were lightly to moderately grazed. Conversely, I did not find bobwhites in undisturbed fescue or in fescue that was grazed heavily. I suspect that suitable management schemes such as using cattle at low stocking to provide a slight to moderate disturbance regime could be developed to support quail within fescue dominated fields.

Low adult survival in my study area reduced production and survival of chicks. Mortality of tending adults was the main cause of nest failure, low number of nests per hen, and chick mortality. I speculate that if habitat restoration increases adult survival then bobwhite production and chick survival would also increase. The relationship between restoration practices and adult survival should be investigated further.

Habitat restoration in Fulton County produced habitat that was used by quail for nesting and brood rearing. Although survival of chicks in restoration areas was higher than in unmanaged areas, arthropod abundance and growth rates of chicks tended to be lower than in the unmanaged habitats and movements were faster and quail moved farther in restoration than unmanaged sites. These behaviors and attributes indicate either a trade off (increased brood survival versus poor body condition). I conclude, based upon my findings on adult habitat use, production, chick growth, brood movements, and arthropod abundance that restoration practices in the focal areas have not produced habitat necessary to increase bobwhite quail populations because they lack either suitable nesting habitat for nesting bobwhites or they lack one or more habitat components. I recommend adjusting management practices to produce a matrix of mostly brood rearing habitat with interspersed patches of nesting habitat. In addition, promoting diversity of grasses and forbs, while avoiding monocultures of any one grass species (regardless of origin or season that they grow), should increase the brood rearing potential of fields and pastures.

My results indicate that fescue fields can support breeding populations of northern bobwhite. Therefore, I recommend that some efforts be placed on managing fescue fields for nesting bobwhites. Finally, I recommend that managers promote vegetation diversity in restoration areas so that arthropod populations will be diverse and abundant.

Table 1 The percentage of samples classified by the discriminant function model as brood rearing and nesting habitats in each restoration area and the associated management prescription. The percent of samples classified as brood rearing and nesting habitat represents the type of habitat available in each restoration area.

Area	Brood habitat	Nesting Habitat	Habitat Management Practice
Ashley Top	67%	7%	Land clearing and fire lanes 10/1/2003, burning 4/2/2004, native grass planting 5/20/2005.
David Treat	40%	7%	Burning 2/8/2006
Holstead Switch	27%	20%	Land clearing 9/8/2003, burning 4/8/2004, switch grass planting 6/3/2004, strip mowing 9/7/2004
Lower Shannon 2007	7%	60%	Burning 2/23/2005
Milikan	73%	7%	Land clearing and fire lanes 9/29/2004, burn 2/18/2005, native grass planting (little bluestem) 4/11/2005, disk 8/7/2006.
S. W. Treat	27%	20%	Fescue eradication 11/17/2004, disking 1/24/2006, burn 1/30/2006, native grass and legume planting 5/26/2006.
Shannon Cemetery	40%	7%	Burning 10/15/2005
Ashley Lower 2	73%	0%	Fescue eradication 11/2005, burning 4/2006, native grass planting (little bluestem, switch grass, big bluestem) 5/2006.
Holstead Borders	73%	0%	Land clearing 9/8/2003, burning 2/1/2006, native grass planting (switch grass, little bluestem) 6/3/2004, strip mowing 9/7/2004
Milikan Borders	89%	0%	Land clearing and fire lanes 9/29/2004, burn 2/18/2005, native grass planting (little bluestem) 4/11/2005, disk 8/7/2006.
Parks Borders	50%	7%	Disking 3/26/2006, native grass planting 5/11/2006, disking 10/1/2006.
Ratchford Borders '06	67%	0%	Land clearing and fire lane 1/26/2004, fertilizer and lime 3/11/2004, burning and disking 4/9/2004, Fescue eradication 8/10/2006
Ratchford Borders '07	67%	13%	Land clearing and fire lane 1/26/2004, fertilizer and lime 3/11/2004, burning and disking 4/9/2004, Fescue eradication 8/10/2006
Treat Borders	47%	0%	Land clearing 10/29/2005, burning 1/30/2007, native grass planting 4/11/2005, disking 8/8/2006

Table 2 Kruskal-Wallace comparisons of habitat variables. Groups that differ significantly are indicated by different letters. All comparisons were significant at $p = 0.05$.

	Brood Unmanaged	Brood Restored	Nest	Random Unmanaged	Random Restored
Variable	x	x	x	x	x
Overhead	33.66 A	26.21 A	76.7 B	48.13 A	47.38 A
Shrub	7.34 A	7.86 A	11.3 A	12.53 A	11.75 A
Forb	32.68 A	20.07 AB	9.4 B	8.75 B	23.5 AB
Grass	35.9 A	24.8 A	65.5 CB	70.3 B	45.9 AC
Litter	10.37 A	13.15 A	35.3 B	18.88 AB	20.62 AB
Bare	32.51 A	42.78 A	2.7 B	12.38 BC	28.08 C
Open Space 0-5 cm	68.15 A	70 A	24.5 B	44.06 BC	55.54 AC
Open Space 5-15 cm	73.46 A	68.36 AC	29 B	53.25 BC	57.97 AC
Height	42.3 A	32.8 A	67.14 B	32.19 A	36.12 A
# forb species/m^2	5.43 A	5.57 AB	2.7 B	4.19 AB	5.12 AB
# grass species/m^2	4.89 A	3.86 AB	3.8 AB	4.38 AB	3.69 B
Arthropod Biomass	2.684 B	0.414 A	-	1.875 AB	1.226 A

Table 3 Arthropod biomass associated with restoration practices. For comparison, the median arthropod biomass collected from brood used habitats in restored and unmanaged areas are shown in the last two rows.

Restoration Area	Biomass (g)/sample	Restoration Practice
Ashley Lower	4.882	Fall fescue eradication (herbicide), spring burn, planting native grass (switch grass, little bluestem, big blue stem).
Ashley Lower 2	1.261	Fescue eradication 11/2005, burning 4/2006, native grass planting (little bluestem, switch grass, big bluestem) 5/2006.
ashley top 2006	0.707	Land clearing and fire lanes 10/1/2003, burning 4/2/2004, native grass planting 5/20/2005
ashley top 2007	1.075	Land clearing and fire lanes 10/1/2003, burning 4/2/2004, planting a variety of native grass species 5/20/2006
caldwell	4.238	Disking spring 2005, a variety of planted of grass species established before 2005
david treat 2006	0.7	Burning 2/8/2006
david treat 2007	0.684	Burning 2/8/2007
Haringer	0.169	Burning periodically since 2001, burn spring 2005, disking spring 2005.
Holstead switch 06	0.041	Land clearing 9/8/2003, burning 4/8/2004, switch grass planting 6/3/2004, strip mowing 9/7/2004
Holstead switch 07	0.445	Land clearing 9/8/2003, burning 4/8/2004, switch grass planting 6/3/2004, strip mowing 9/7/2005
lindsey parks	0.555	Disking 3/26/2006, native grass planting 5/11/2006, disking 10/1/2006.
Lower Shannon 06	0.682	Burning 2/23/2005
Lower Shannon 07	0.247	Burning 2/23/2006
milikan 06	1.1	Land clearing and fire lanes 9/29/2004, burn 2/18/2005, native grass planting (little bluestem) 4/11/2005, disk 8/7/2006.
milikan 07	1.397	Land clearing and fire lanes 9/29/2004, burn 2/18/2005, native grass planting (little bluestem) 4/11/2005, disk 8/7/2006.
ratchford 06	0.609	Land clearing and fire lane 1/26/2004, fertilizer and lime 3/11/2004, burning and disking 4/9/2004, Fescue eradication 8/10/2006
ratchford 07	1.522	Land clearing and fire lane 1/26/2004, fertilizer and lime 3/11/2004, burning and disking 4/9/2004, Fescue eradication 8/10/2007
S.W. Treat 06	0.48	Fescue eradication 11/17/2004, disking 1/24/2006, burn 1/30/2006, native grass and legume planting 5/26/2006.
S.W. Treat 07	1.024	Fescue eradication 11/17/2004, disking 1/24/2006, burn 1/30/2006, native grass and legume planting 5/26/2006.
Shannon Cemetery 06	3.238	Burning 10/15/2005
Shannon Cemetery 07	0.709	Burning 10/15/2005
Brood restored	0.411	-
Brood unmanaged	2.53	-

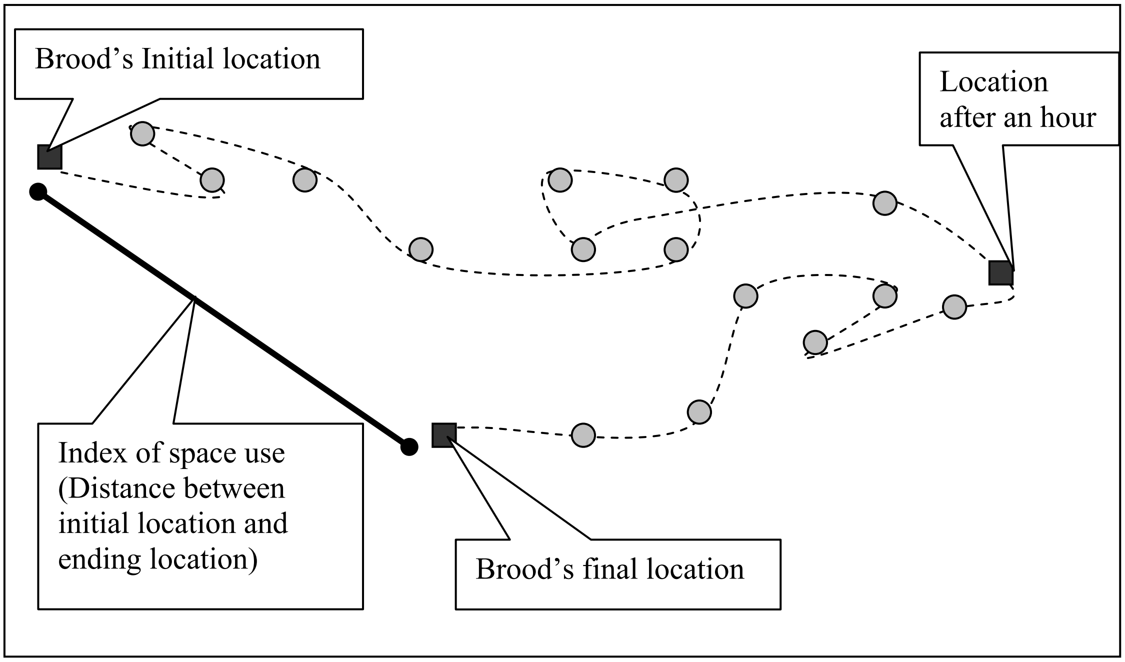

Figure 1 A hypothetical example of a course of travel by a bobwhite brood during monitoring. The black squares represent locations of broods established from less than ten meters away at the beginning of tracking, after an hour of tracking, and at the end of tracking. The grey circles represent the location of the brood taken at 5 minute intervals from approximately 50 meters away. The path that the brood traveled is represented by a dotted line. The index of space use is the distance between the brood's initial location and their ending location at the end of tracking and is represented by a solid black line.

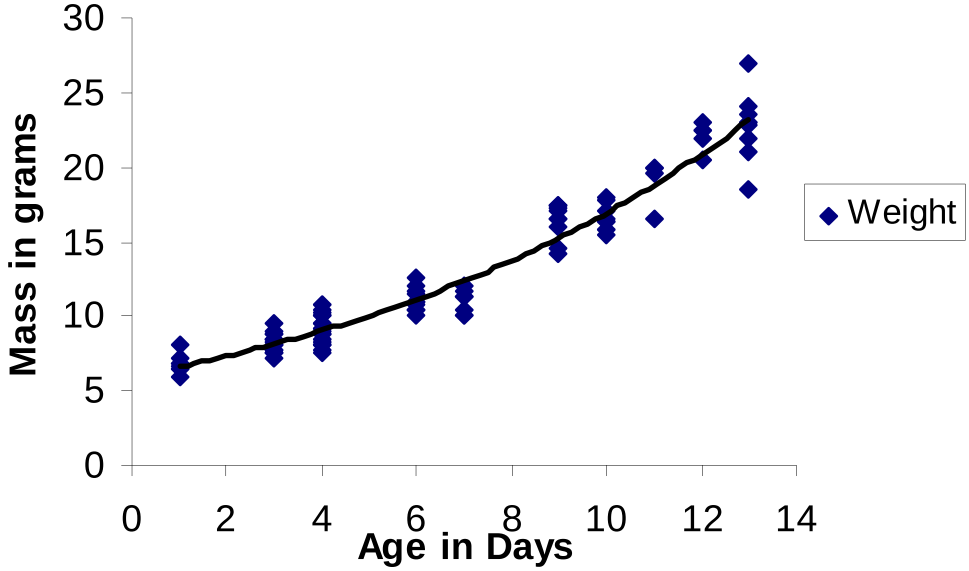

Figure 2 Growth of bobwhite chicks from age 1 day post hatch to 13 days post hatch (n = 127 observations, 89 chicks on first captures, and 37 chicks from second captures). The equation for the growth curve is Mass = (174.0283)/(1+(28.40927)*EXP{-(.1140282)*(age)}). The R^2 value for the line is 0.95.

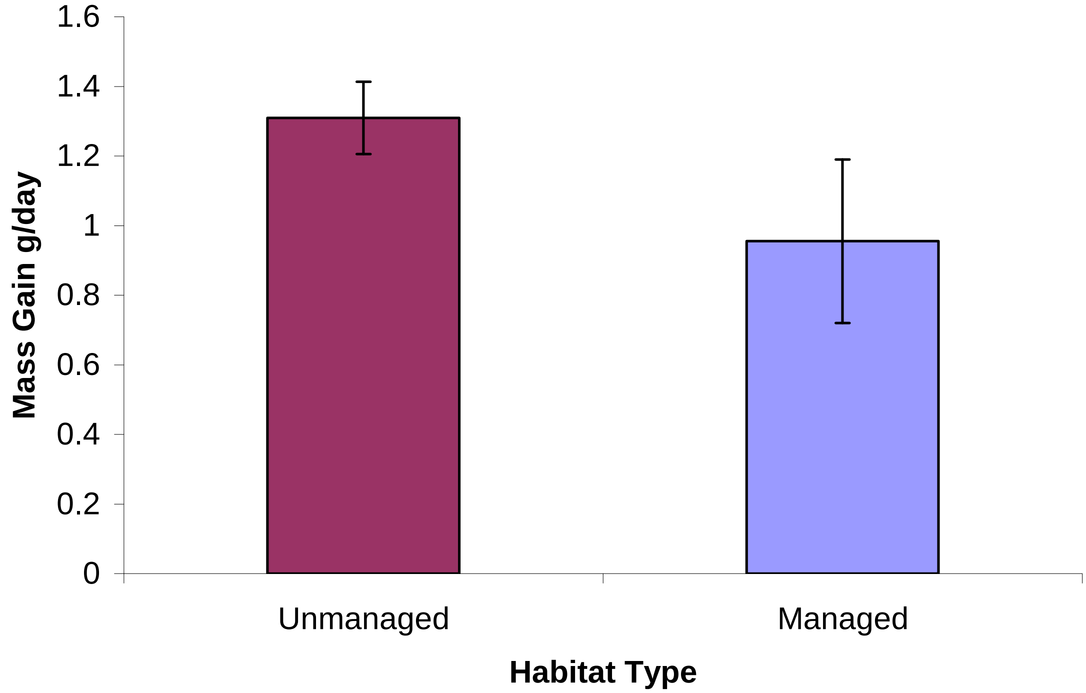

Figure 3 Average mass gain per day by five broods in restoration areas and two broods in unmanaged areas from 2005-2006. Broods gained 0.35 g more mass per day in unmanaged areas than in restoration areas.

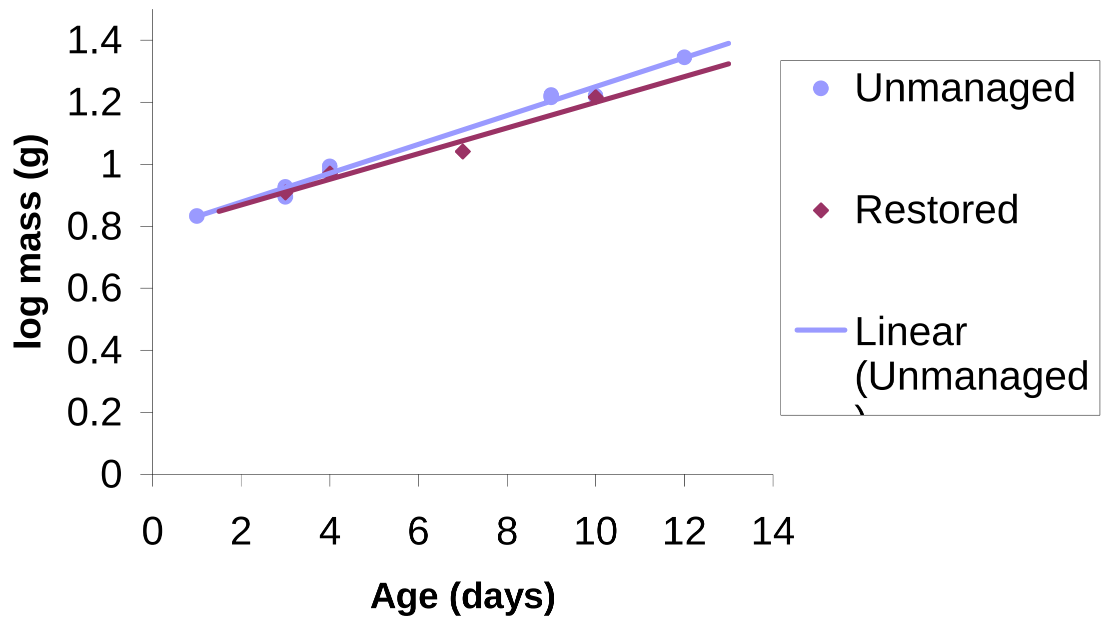

Figure 4 Log transformed mass (averaged within broods) of all bobwhite chicks in restoration and unmanaged areas as a function of age. The slopes of the lines for growth in restored and unmanaged areas are significantly different (n = 14, t = 2.269, p = 0.0509, df = 13, restored R2 value = 0.98, unmanaged R2 = 0.9836).

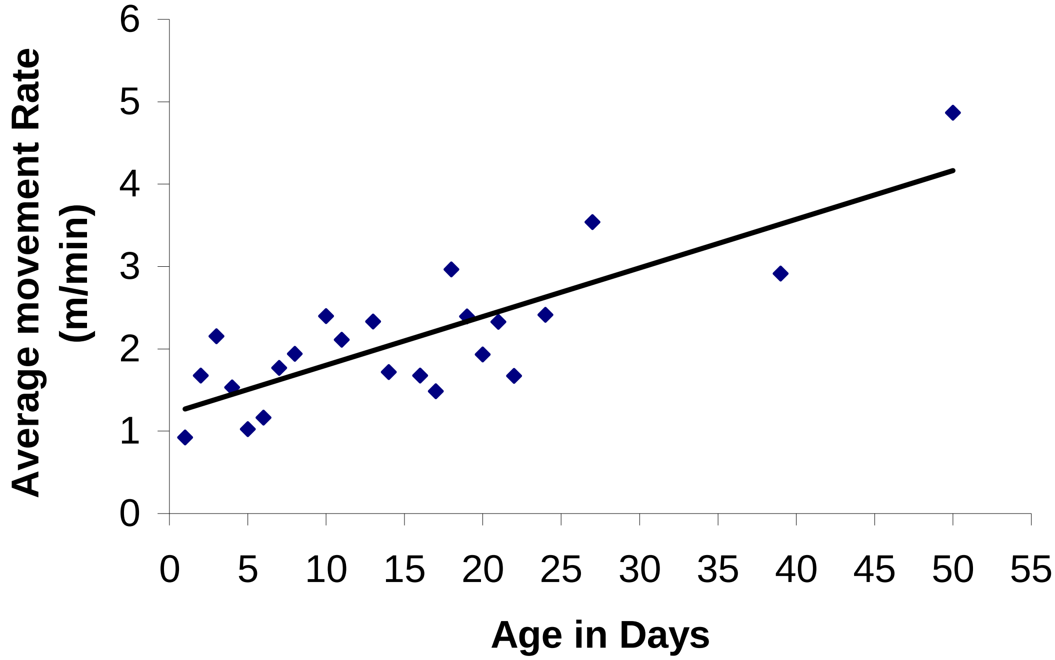

Figure 5 Movement rates of chicks averaged by age from zero to 50 days post hatch. Nonmovements (i.e., loafing periods) and non-foraging movements were removed. Broods increased their rate of movement while foraging as they aged according to the equation: Rate (m/min) = (1.2117) + (.059) (age in days). The R-squared value for regression line is 0.6616.

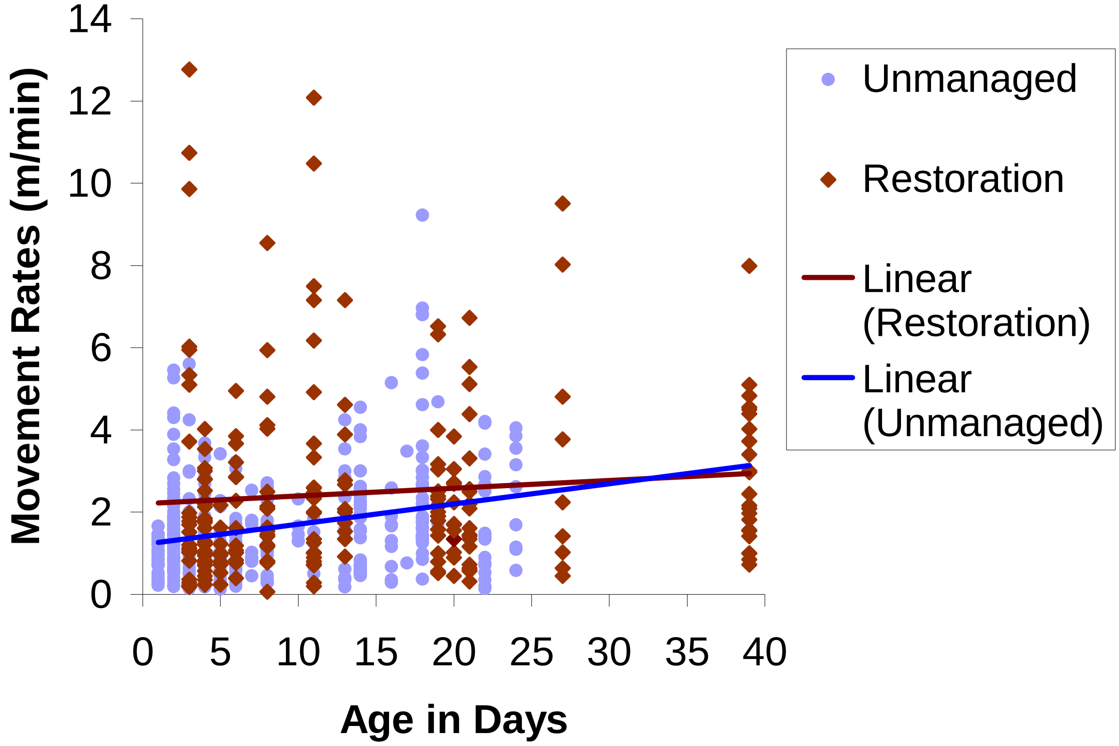

Figure 6 Movement rates of broods from hatching up to 39 days post hatch in restoration and unmanaged areas. The line with the lower intercept represents the movement rates of broods in unmanaged areas and the upper line represents the movement rates of broods in restoration areas. The slopes of the lines are significantly different ($n = 564$, $F = 15.253$, $p = 0.0001$).

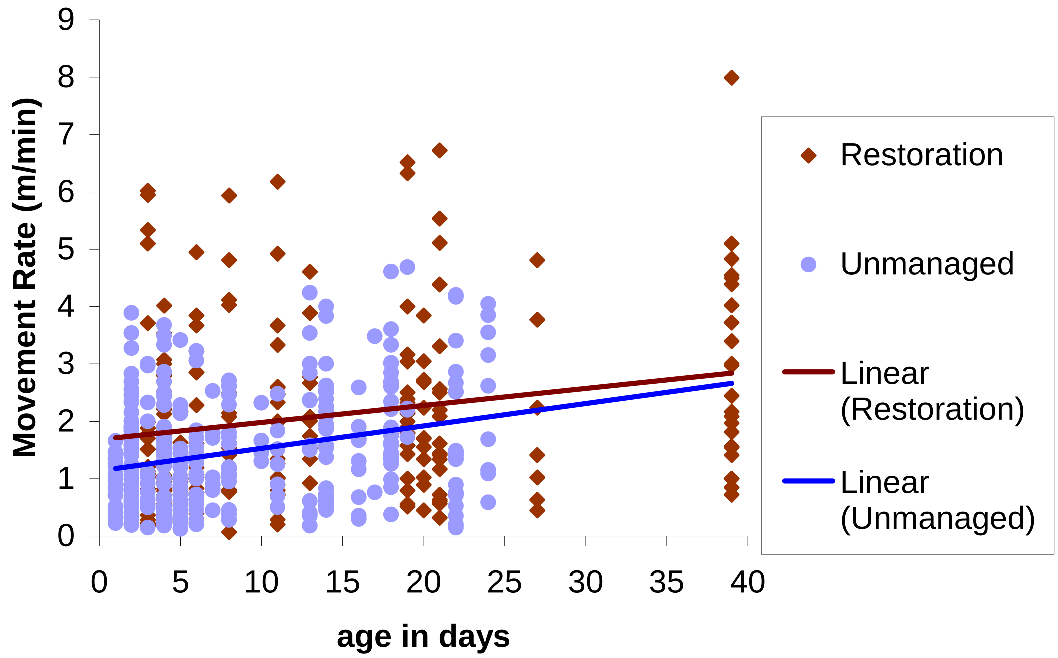

Figure 7 Movement rates of broods after non-foraging movements were removed from the data. Broods moved faster in restoration (upper line) than in unmanaged areas (lower line) ($n = 483$, $t = 4.071$, $p = 0.0001$).

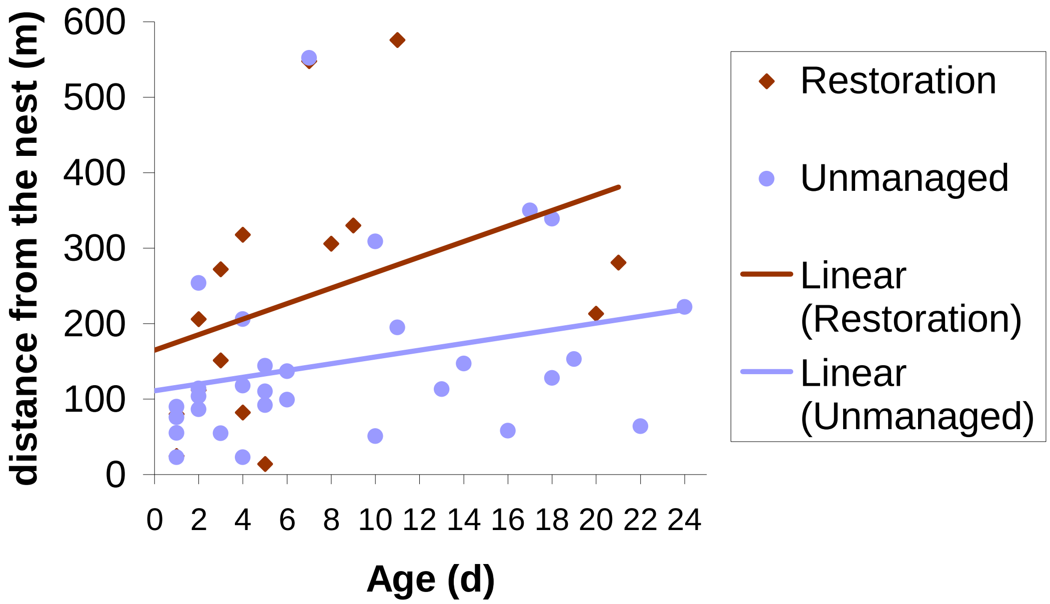

Figure 8 The distance from the nest that bobwhite broods were found as a function of age in restoration and unmanaged areas. The slopes of the lines are significantly different (n = 45, p = 0.026, df = 44).

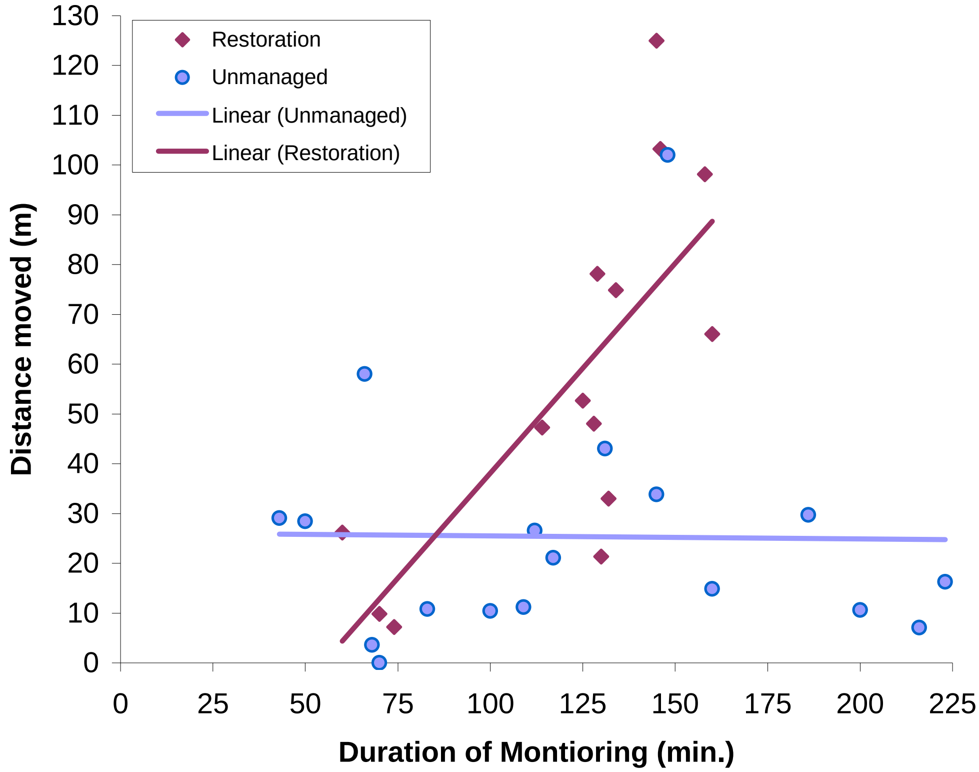

Figure 9 Index of area use (straight line distance between a broods' initial location and its ending locations) as a function of monitoring duration (minutes) in restoration verses unmanaged areas. The duration of time that broods were tracked was not different between restored and unmanaged areas.

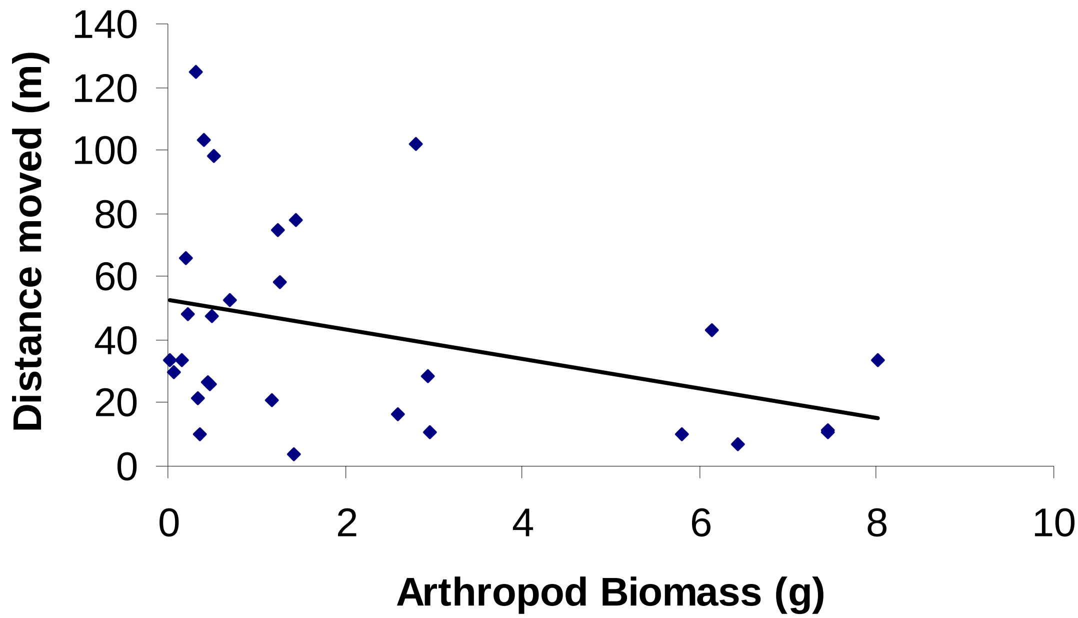

Figure 10 Index of space use (straight line distance between broods' initial locations and ending locations during monitoring) as a function of arthropod biomass collected along the course that broods traveled. The slope of the line is significant (n = 29, t = 2.0619, p = 0.049, df = 29). The equation of the line is distance = (52.831)+(-4.712)*(arthropod biomass) and the R^2 value = 0.1360.

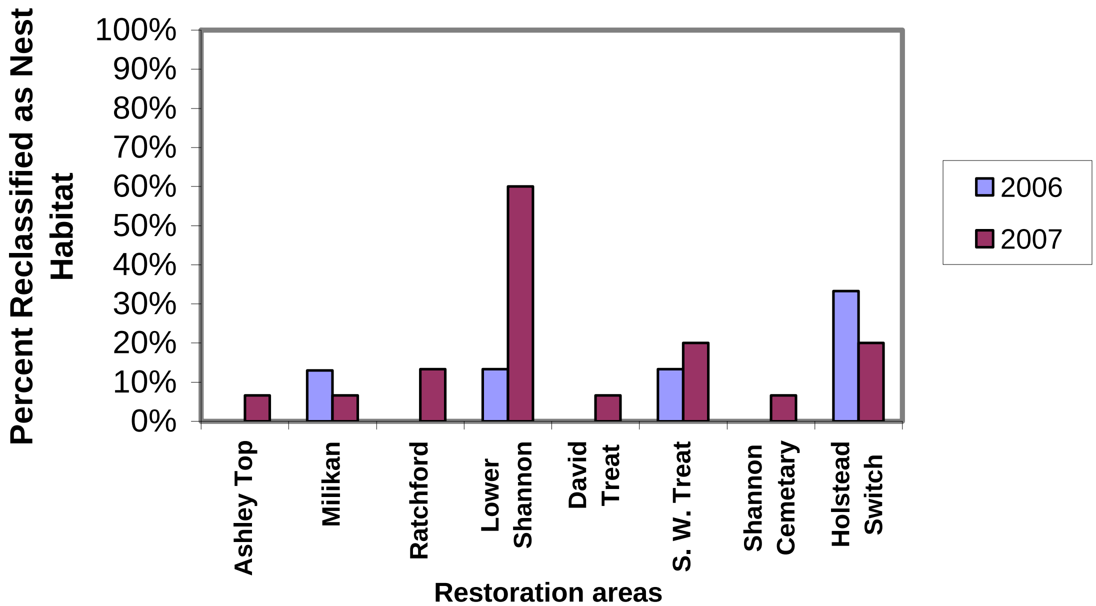

Figure 11 The percentage of randomly located samples in restoration areas classified as nesting habitat in the discriminant function analysis.

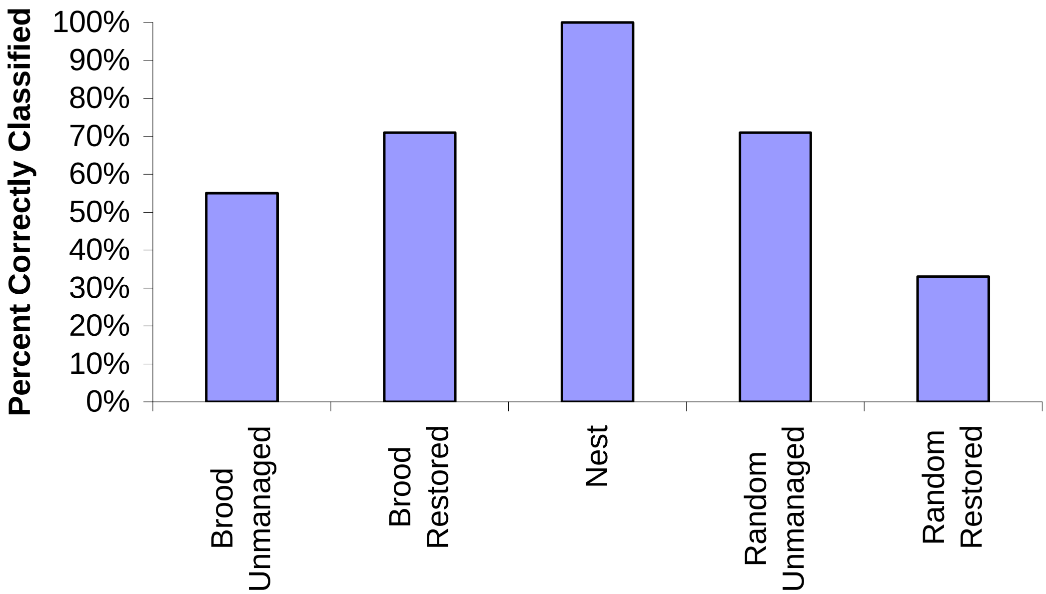

Figure 12 Percentage of samples correctly classified by the discriminant function. Samples represent averaged values within a transect.

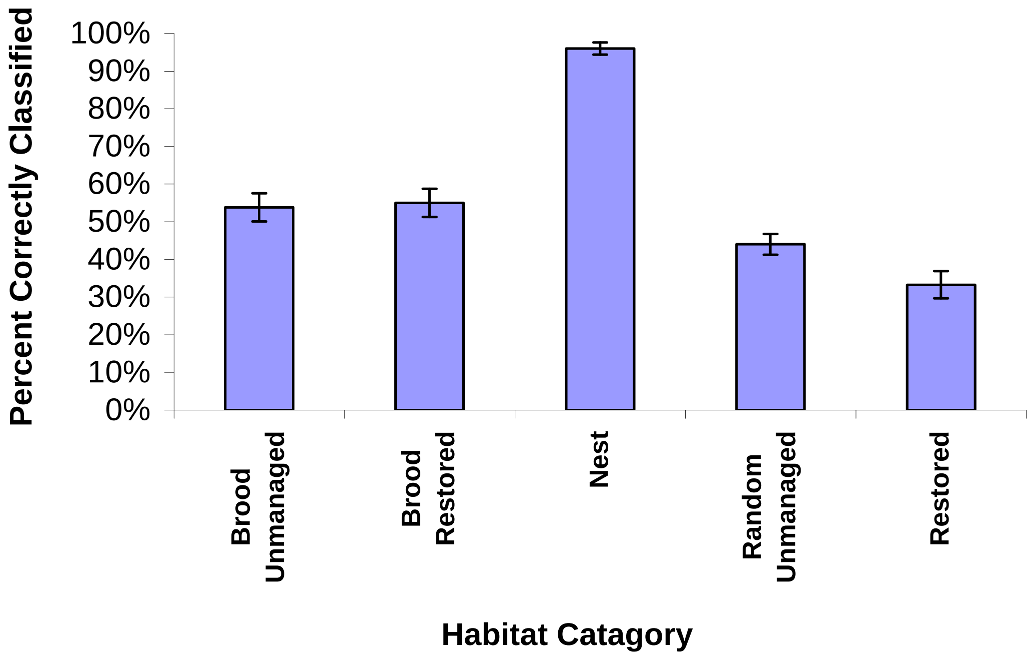

Figure 13 The average percentage of samples correctly classified by the discriminant function. The procedure was conducted multiple times on different independent samples from each transect. The error bars represent the standard errors of the correctly classified categories.

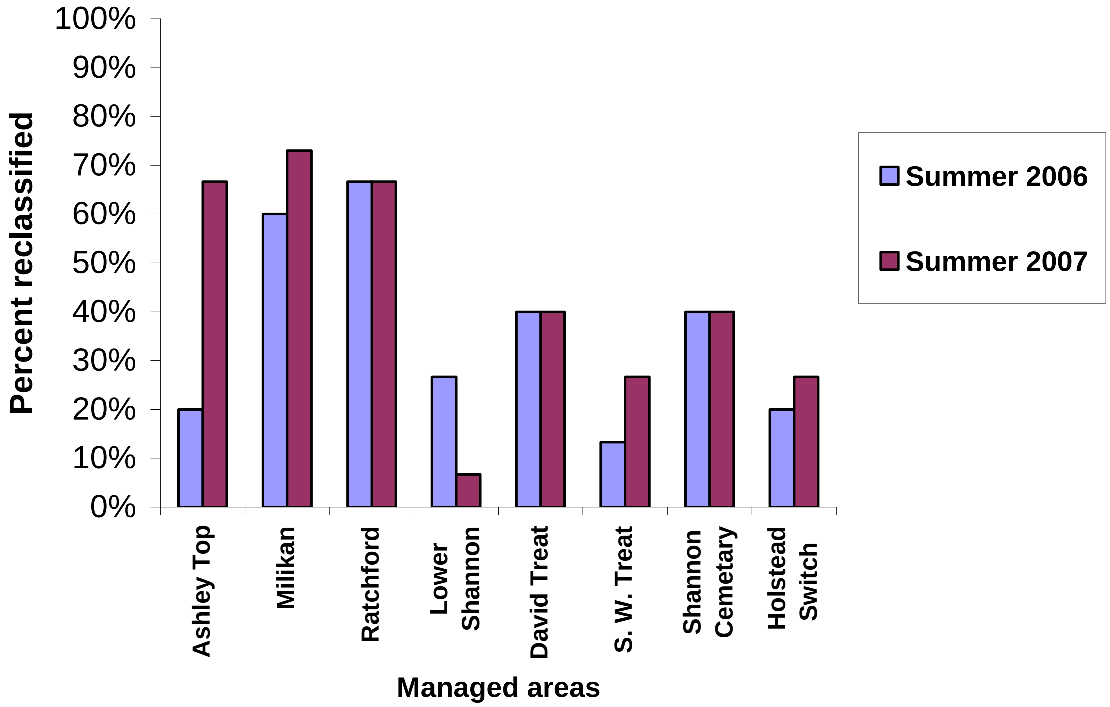

Figure 14 The Percentage of randomly located samples in restoration areas classified as brood-rearing habitat in the discriminant function analysis.

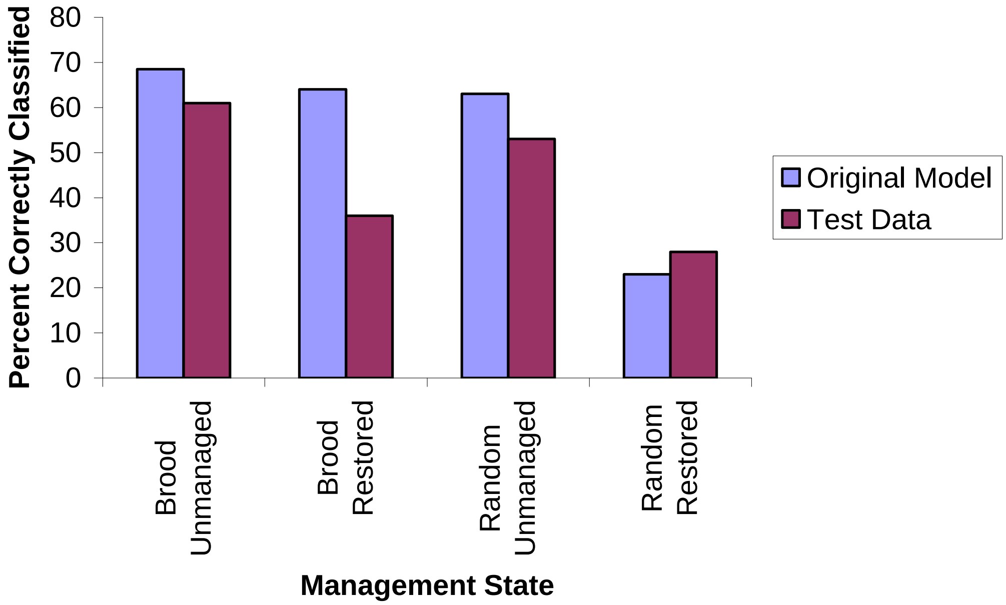

Figure 15 Performance of the discriminant function on a test data set.

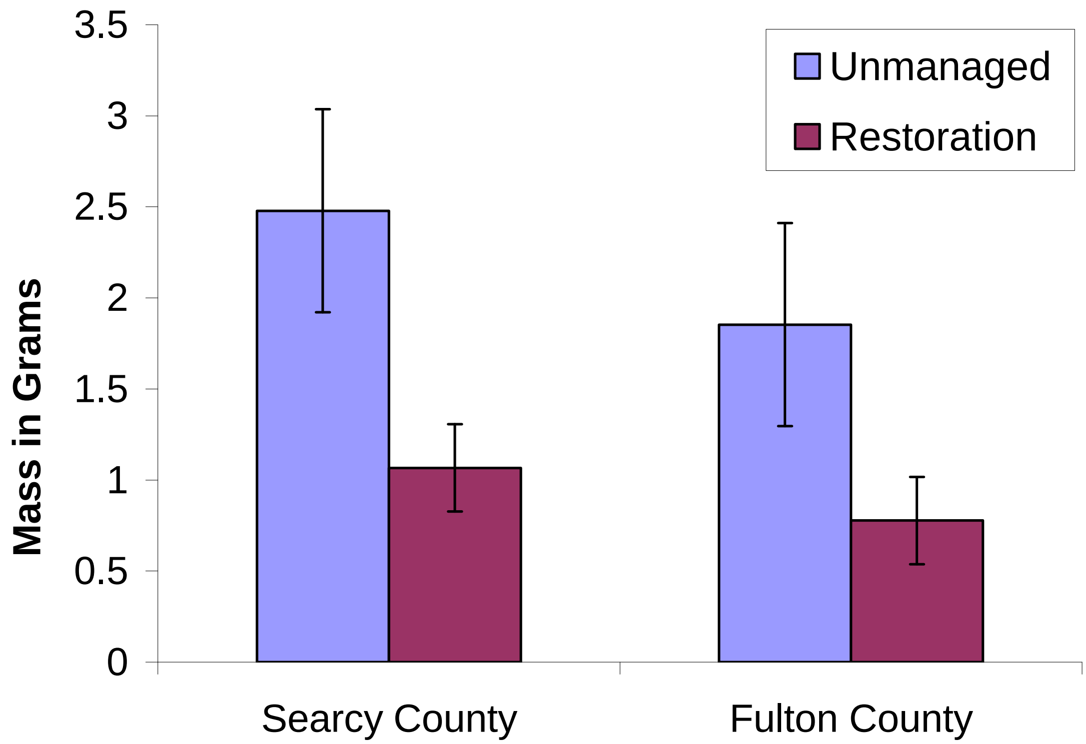

Figure 16 Invertebrate biomass in restoration and unmanaged areas in Fulton and Searcy Counties with associated standard errors. The differences are statistically significant (Mann-Whitney U test, n = 74, Z =0.002).

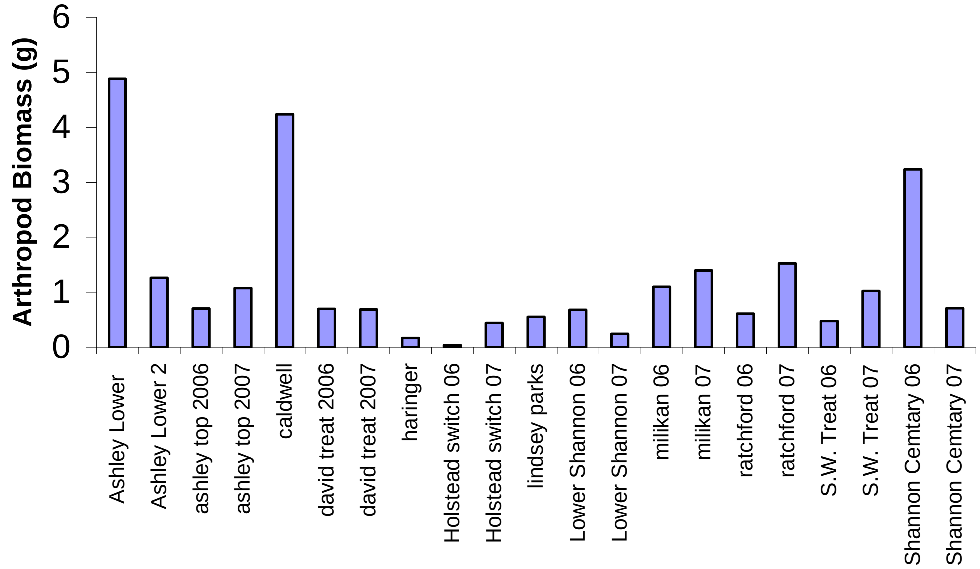

Figure 17 Arthropod biomass (g)/sample in each of the restoration areas. For comparison, average arthropod abundance in brood used habitats in unmanaged areas was 2.53 g and was 0.41 g in brood used habitats in restoration areas.

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