# IMPACTS OF PREDATION ON QUAIL

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***Abstract***: Northern bobwhite (*Colinus virginianus*) and scaled quail (*Callipepla squamata*) populations have declined throughout most of their distribution, and these declines have become more dramatic in recent years. In this review, we examine the role of predation in quail management. Predation is the major source of nest loss and of mortality for young and adult quail. Mean nest success across studies reviewed was 28%. Mammalian predators most often implicated in nest predation include striped skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), opossums (*Didelphis virginianus*), foxes (*Urocyon cinereoargenteus* and *Vulpes vulpes*), coyotes (*Canis latrans*), and feral hogs (*Sus scrofa*). Accipiters *(Accipiter* spp.) and northern harriers *(Circus cyaneus*) are the most common avian predators of quail. Less information is available for assessing the impact of predation on scaled quail, but observations from areas where bobwhites and scaled quail are sympatric suggested that scaled quail are less vulnerable to predation than bobwhites. Although quail have adaptations for coping with high predation rates (e.g., renesting, large clutches), populations in some areas may be suppressed by predation. Changes in land use, management practices, and predator communities interact to depress quail populations over much of the bobwhite's range.

Because of their relatively small size, and the fact that they spend their entire lives on the ground, various species of quail are extremely vulnerable to predation. However, prevailing paradigms in quail management suggest that predators are rarely a management concern, and that predation should be managed only indirectly (i.e., habitat management) (Errington 1934). Rollins and Carroll (2001) reviewed the evidence relative to the impacts of predation on northern bobwhite (*Colinus virginianus*; hereafter bobwhite) and scaled quail (*Callipepla squamata*) as models for North American species. This paper is an abridged summary of that review.

## CURRENT STATUS OF BOBWHITE AND SCALED QUAIL

### Bobwhites

The decline of the bobwhite in the Southeastern U. S. is well documented (reviewed by Brennan 1999; Figure 1). The decline of bobwhites is generally correlated with dramatic changes in land use throughout the region over the last 80 years. The shift away from a landscape dominated by rather diverse and low-impact agriculture in the early 20th century to landscapes dominated by hardwood forests and intensive pine silviculture in the latter 20th century reduced habitability for bobwhites.

In more recent times, dramatic changes in agricultural practices (e.g., clean farming, increased use of pesticides) may also have contributed to poorer quality or quantity of remaining habitats. In any event, what was a landscape that supported large and widespread populations of quail is now gone.

Although bobwhite densities are generally higher at the western periphery of their range (e.g., Texas), their abundance there has declined at a rate of -4.7% per year since 1981 (Sauer et al. 2000). The Texas population's trend is essentially parallel to that of populations in the Southeast (Figure 1). Bobwhites occur over most of Texas, but quail trends vary among ecoregions (Peterson and Perez 2000). Bobwhite populations in the Rolling Plains and South Texas Plains ecoregions have remained relatively stable, but roadside counts in 2000 were the lowest since counts began for the Gulf Prairies and Marshes, Cross Timbers and Prairies, and Edwards Plateau ecoregions (Texas Parks and Wildlife 2000).

**Scaled quail**

Scaled quail range over most of the Chihuahuan desert including portions of Arizona, Colorado, Kansas, New Mexico, Oklahoma, and Texas. Scaled quail populations have declined significantly (from -3.8% to -8.2% per year from 1966-91 throughout their range, especially during the last 15 years (Schemnitz 1993, 1994, Rollins 2000, Sauer et al. 2000). Scaled quail populations experienced a drastic, inexplicable decline about 1989 over much of their range in Oklahoma and north Texas (Rollins 2000). Populations in the Oklahoma panhandle declined 50% from 1956 to 1991 (Schemnitz 1993) and scaled quail essentially disappeared along the eastern periphery of its range where they were common to abundant in 1987 (Rollins 2000). Data from both the Breeding Bird Survey (Sauer et al. 2000) and the Texas Parks and Wildlife Department (2000) documented this demise (Figure 2). Relative to the Southeast, land use changes have been less dramatic in scaled quail range, which is dominated largely by livestock grazing.

**Factors contributing to quail population declines**

Aside from the possible impacts of predation and land use changes, other factors may be involved in the decline of bobwhite and scaled quail populations. Other factors believed to be contributing to the decline of quail in the Southeast range from fire ants (*Solenopsis* spp.) to acid rain (Brennan 1999). In these areas suitable landscapes have been maintained and quail are managed intensively (Burger et al. 1998).

Presently there is much speculation about the role predators play in the long-term declines of quail populations at a local scale, despite habitat management (Hurst et al. 1996). There is little evidence to suggest that predators are suppressing bobwhite populations at a regional level. However, anecdotal observations of predator removal where habitat management is being practiced suggest that some predators may be suppressing local quail populations.

How predators interact with quail populations may be affected not only by the way landscape changes have impacted habitat, but likewise predator populations, communities, and search efficiencies. For example, recent changes in land use may have made quail more vulnerable to predation (Hurst et al. 1996, Rollins 1999*a*).

The causes of the scaled quail decline are unknown. Schemnitz (1993) speculated that land use changes (e.g., Conservation Reserve Program) were responsible in the Oklahoma panhandle. Rollins (2000) provided anecdotal information suggesting that disease was the initial factor involved and that high nest depredation rates (> 80%) may have kept populations suppressed. Bobwhites, which are sympatric with scaled quail over much of the Rolling Plains ecoregion, declined in about the same time period (1989-90), but have since rebounded and exhibited irruptive population changes typical of the species in this area (Jackson 1962, Peterson and Perez 2000, Sauer et al. 2000). Scaled quail remained absent or occurred at only remnant levels over much of their former range in Texas from 1989-99, but began to show signs of a resurgence in 2000, especially in the Permian Basin region of Texas.

## PREDATORS OF BOBWHITES

Predation is the primary source of mortality for bobwhites at all life stages. There are numerous studies dating back to Stoddard (1931) documenting the impacts of predators on bobwhites, especially in the southeastern U.S.

### Nest depredation

Rollins (1999*a*) estimated that only about 4 of 100 eggs results in a bobwhite eventually added to the breeding population in Texas. Estimates of predation rates on quail nests are typically high, and hatch success rates vary from 12-45% (weighted = 28%; Table 1). Hatch rates in Texas ranged from 12-46% (Jackson 1947, Lehmann 1984, Hernandez 1999). Peoples et al. (1996) recorded a 50% hatch rate in western Oklahoma with predators accounting for 81% of the losses.

Bobwhites are persistent renesters, resulting in much higher percentages of hens actually producing chicks than would be suggested by low hatch rates (Guthery 1995, Burger et al. 1995*b*, Brennan 1999). Rollins (1999*a*) estimated that given a hatch rate of 30%, no hen mortality, and 2 renesting attempts, 66% of hens would eventually hatch a clutch of eggs. However, the number of successful clutches decreased to 49 and 33% when hen mortality was 20 and 40%, respectively.

Mesomammals are the most important group of nest predators. In Virginia, Fies and Puckett (2000) using simulated ground nests containing quail eggs, found that 41% of nest predators photographed by motion-sensing cameras were striped skunk (*Mephitis mephitis*), 37% were opossums (*Didelphis virginianus*), 8% were gray fox (*Urocyon cinereoargenteus*), and 4% were raccoons (*Procyon lotor*). Hernandez et al. 1997 used similar equipment to study nest depredation in west Texas and reported that raccoons (82% of all nests destroyed) were the primary predator of simulated quail nests. Less common predators included striped skunks, bobcats (*Lynx rufus*), gray foxes, nine-banded armadillos (*Dasypus novemcinctus*), and opossums.

Often snakes are diagnosed as the cause of nest depredation when no eggshells are found. For example, Peoples et al. (1996) implicated snakes in 55% of the nest losses recorded in western Oklahoma. However, Hernandez et al. (1997) cautioned that snakes may be overly maligned as an egg predator when diagnoses are based on lack of eggshell evidence. Aside from depredating nests, rat snakes (*Elaphus* sp.) and rattlesnakes (*Crotalus* spp.) have been documented preying upon bobwhites in Florida and bobwhite and scaled quail in Texas (Stoddard 1931, Carter 1995; D. Rollins, unpublished data).

**Brood survival**

Chick survival is the least understood aspect of quail mortality (DeVos and Mueller 1993, Hurst et al. 1996). Researchers have attempted to assess mortality of chicks after hatching, but logistical constraints have complicated such attempts (Carver et al. 1999). DeMaso et al. (1997) reported a survival rate of 36% from hatching to 39 days post-hatch in western Oklahoma. DeVos and Mueller (1993) estimated 29% survival to 1 month post-hatch. Roseberry and Klimstra (1984) reported chick survival rates of 25-47% in southern Illinois. In Iowa, Suchy and Munkel (2000) reported survival rates of 81% for chicks 21-56 days post-hatch.

Fire ants may also impact chick survival (Allen et al. 1995, Mueller et al. 1999). Allen et al. (1995) found that bobwhite declines in southeastern Texas were correlated with a particular county's invasion by red imported fire ants (*S. invicta*). Mueller et al. (1999) reported that 38% of all chick mortality up to 21 days post-hatch was attributable to fire ants.

**Post-brood survival**

Adult survival also varies widely by season and causes. Taylor et al. (2000) found that breeding season survival over 4 years in Mississippi ranged from 17-51%. Predators accounted for most of the mortality. Carter (1995) monitored the fate of 131 radio-marked bobwhites in west Texas during 1994-95 and reported a February-July survival rate of 13%. Mammals were responsible for 56% of the kills while raptors caused 25%. Burger et al. (1998) also suggested that non-breeding season mortality of adults was mainly attributed to predation from mammals (25%) and avian predators (16%); overall adult survival averaged 49%.

## PREDATORS OF SCALED QUAIL

**Nest depredation**

Nest success for scaled quail is typically low (< 25%) (Wallmo 1957) and depredation has been cited as a major, if not primary, cause of nest failure. Nest predators common in scaled quail range include coyotes, striped skunks, gray foxes, corvids (Slater 1996), various snakes, and increasingly feral hogs (Tolleson et al. 1998). Jackson (1942) reported 10 of 13 scaled quail nests failed in the Texas panhandle. In a more detailed report from the same area, Jackson (1947) reported that 30 of 34 bobwhite nests (88%) failed. He attributed the losses to coyotes (11 nests), snakes (6 nests) and small mammals (5 nests). Schemnitz (1961) reported only 6 of 42 nests (14%) hatched. The primary cause of nest failure was human disturbance (e.g., farming practices and mowing) and predators were implicated in only 19% of the nest losses. Recent studies (Hernandez et al. 1997, Fies and Puckett 2000) suggested that the accuracy of assigning species-specific causes of quail nest depredation is tenuous at best.

**Brood survival**

No published reports on chick or

brood survival could be found on scaled quail. As scaled quail population "busts" are characterized by poor recruitment, information on chick survival and brood ecology are sorely needed.

**Post-brood survival**

None of the 3 major autecological studies on scaled quail (Wallmo 1957, Schemnitz 1961, Campbell et al. 1973) cited predation as management concern; in fact predation was hardly mentioned as a source of mortality.

## RELATIVE VULNERABILITY OF SYMPATRIC BOBWHITE AND SCALED QUAIL

Bobwhite and scaled quail occur sympatrically in portions of Texas, and some studies have mentioned the relative vulnerability of these species to predators. Jackson (1947) suggested that predation was the proximate cause of a catastrophic decline in bobwhites in northwest Texas during the winter of 1943. Bobwhites and scaled quail were sympatric on Jackson's study site, and scaled quail accounted for about 65% of the total quail during 1941-43. Jackson detailed how bobwhite populations on his study area crashed "with explosive suddenness and all but remnants were lost to predation" between 7 - 15 January 1943. He conducted transects to estimate the amount of mortality that had occurred and concluded "everywhere the ground was littered with evidence that predation had been recent and terrific." Northern harriers (*Circus cyaneus*), red-tailed hawks (*Buteo jamaicensis*), and Cooper's hawks (*Accipiter cooperii*) were the raptors involved, but Jackson concluded that northern harriers were the only raptor species abundant enough in that area to have killed so many quail.

P. S. Carter (Angelo State University, unpublished data) radio-marked 27 scaled quail in west-central Texas (Irion County) and reported higher survival (70%) from February - July than for sympatric bobwhites (18%, $n$ = 54). Sixty percent of the mortalities in Carter's study (across both species of quail) were attributed to mammalian predators. A total of 9 scaled quail mortalities were documented; 5 from mammals and 2 from unknown raptors. One scaled quail each was killed by a great horned owl (*Bubo virginiana*) and 1 by a western diamondback rattlesnake (*C. atrox*).

These data support Jackson's (1947) observation that scaled quail may be less vulnerable to predation than bobwhites and Lehmann's (1984:225) opinion that "blue (i.e., scaled) quail seem somewhat more intelligent than bobwhites" in sympatric ranges.

It seems plausible that earlier investigations of scaled quail (Wallmo 1957, Schemnitz 1961, Campbell et al. 1973) were either unaware of, or dismissed, the incidence of predation because they lacked the technology to study it (i.e., radio telemetry). Rollins (2000) divided the knowledge about scaled quail ecology into 2 distinct eras: "before telemetry" and "after telemetry". More comprehensive studies involving radio-marked scaled quail are needed to assess cause-specific mortality patterns.

## ROLE OF PREDATION IN QUAIL IRRUPTIONS

Bobwhite and scaled quail exhibit irruptive (i.e., "boom and bust) population growth in Texas (Jackson 1962, Lehmann

1984). Population "busts" are believed to be a result of normal attrition, but below normal reproduction (Wallmo 1957). Irruptions appear to be related indirectly to rainfall, possibly through some plant-related stimulus (e.g., nutrition). Various investigators have proposed vitamin A deficiencies (Nestler 1946, Lehman 1953), phytoestrogens (Cain et al. 1987), and water deprivation (Koerth and Guthery 1991) as possible explanations for reproductive failures in quail in the southwestern U.S.

An alternate hypothesis is that precipitation increases nesting cover across the landscape, i.e., "usable space" (Guthery 1997), and subsequently increases nesting success by complicating the predators' search efficiency (Rollins 1999*a*). Quail irruptions in the Rolling Plains ecoregion of Texas are characterized by landscapes dominated by common broomweed (*Xanthocephalum dracunculoides*) (Jackson 1962, Rollins 1999*b*). Dense canopies of common broomweed effectively "insulate" quail from predators (avian and mammalian) and hence increase "usable space."

Predator search efficiency may decline as abundance of suitable nest sites or habitat heterogeneity increases across the landscape (Bowman and Harris 1980). It is more difficult for predators to locate ground nests in areas supporting an abundance of bunchgrasses compared to areas with few bunchgrasses (Jackson 1947). Lehmann (1984) noted higher nest survival in areas where the nest was situated in cover that was uniform with the surroundings.

Because quail population "busts" are usually associated with drought conditions in the southwestern U.S., and often confounded by overgrazing, suitable nesting cover is often limited in dry years. Slater et al. (2001) found that nest success of simulated quail nests in 8 counties in west Texas was higher on sites that provided > 306 potential nests sites per acre, a number similar to Guthery's (1986) recommendation of > 250 suitable nest clumps per acre for bobwhites in Texas. Carter (1995) found that sympatric bobwhites and scaled quail frequently used prickly pear (*Opuntia* spp.) for nesting sites. Subsequently, Slater et al. (2001) documented that nests situated in prickly pear survived at about twice the rate of more conventional nest sites (i.e., bunchgrasses). Thus prickly pear appears to provide some measure of protection against nest predators especially when traditional nest sites are limited by overgrazing or drought (Hernandez 1999).

## TEMPORAL CHANGES IN PREDATOR POPULATIONS AND COMMUNITIES

Our review of published research suggests bobwhite and scaled quail populations have changed at both local and regional scales. What about their predators? Comparing earlier studies (e.g., Stoddard 1931) to more contemporary studies suggests that changes have occurred within populations and communities of various predators that are often implicated in the decline of quail populations. Such temporal changes in predator populations may be important, especially in light of landscape changes that may make quail more vulnerable to predation (Rollins 1999*a*).

### Mesomammal trends

There is general consensus that mesomammal populations (e.g. raccoons) have increased over the last 20 years in the

Southeast. Rollins (1999*a*) identified a number of mechanisms that may be contributing to higher mesomammal populations or otherwise accentuating predation on quail and their nests. These mechanisms include 1) demise of the fur market in the mid-1980s, 2) increased supplemental feeding of deer (*Odocoileus* spp.), 3) increasingly fragmented habitats, and 4) a proliferation of farm ponds on the landscape.

Another example of temporal changes in a predator community is suggested by comparing 2 studies conducted in north-central Texas (Wise and Parker counties). Jackson (1952) removed potential quail predators (*n* = 574) from a 3,000-acre study site in Wise County, Texas over a 13-month period (1948-49) but dismissed the predator removal as having no impact on quail abundance. Of particular note, only 11 raccoons (2.0% of the predators removed) were trapped during his study. Fifty years later, E. Lyons (Angelo State University, unpublished data) removed 21-40 raccoons from 2 study sites (640 acres) during only 30-day trapping efforts in an adjacent county (Parker County) during 1999 and 2000, respectively. In other words, Lyons removed about 3 times more raccoons than Jackson did on study sites only 20% the size of Jackson's sites and with only 10% of the trapping effort.

In Mississippi, hunter harvest data from 1980-96 suggested that red fox *(Vulpes vulpes)*, gray fox, and bobcat remained stable, but that coyote (*Canis latrans*) populations increased 7-fold (Lovell et al. 1998). The relationship between coyotes and quail is unclear. Lehmann (1984) identified coyotes as perhaps the most common mammalian predator of bobwhites in south Texas, but Guthery (1995) concluded that controlling coyotes likely would not increase quail productivity given the quail's ability to renest. Interestingly, the highest bobwhite populations are typically found in the Rolling Plains and Rio Grande Plains ecoregions, and these are the same areas of Texas that typically harbor the highest densities of coyotes. Similarly, the Edwards Plateau ecoregion, which is located between the Rolling and Rio Grande Plains typically has the lowest quail abundance of these 3 ecoregions. The fact that the Edwards Plateau has the lowest coyote densities in Texas (because of a history of sheep and goat ranching in this area [Nunley 1985]) suggests that coyote suppression may "release" mesomammals like raccoons, gray fox, and feral cats. Additional studies are needed in order to document this relationship however, as edaphic factors also differ among these 3 ecoregions.

**Other mammals**

When Stoddard (1931) undertook his studies on plantations in southern Georgia, striped and spotted skunks (*Spirogale putorius*) were important predators of quail nests. However, recent video data from several hundred nests on plantations in the same region found no evidence of predation by either species (E. Staller, C. Sisson, W. Palmer, and J. Carroll, University of Georgia, Auburn University, and Tall Timbers Research Station, unpublished data). This video surveillance of nests also confirmed armadillos as a predator of bobwhite nests, substantiating the findings of Hernandez et al. (1997) in Texas. During Stoddard's era, there were no armadillos in that region, but today they are ubiquitous.

Finally, the distribution and abundance of feral hogs (*Sus scrofa*) has increased over much of the Southeast and Texas (Tolleson et al. 1993). Feral hogs were implicated in 9 and 24% of the simulated nest losses in Shackelford and Foard counties (respectively) in Texas. The impact of feral swine depredation on quail nests is unclear however. Similar to coyotes, those areas of Texas with the highest feral hog abundance (e.g., Rolling Plains, Rio Grande Plains) also support the highest quail populations.

### Status of avian predators

Among common avian predators of bobwhites, population increases of >2.0% per year have been observed using the Breeding Bird Survey (1966-99) over large areas of the U.S. (Sauer et al. 2000). Trends for accipiters, e.g., the Cooper's hawk (6.7% year) and sharp-shinned hawk *(A. striatus)* (2.8% year) have increased steadily over the last 30 years (Figure 3). Factors responsible for the increase of various avian predators of quail are unknown, but could include the dissipation of organochlorine insecticides, increased law enforcement, and educational efforts on raptor conservation. Accipiters are generally considered the most efficient predator of quail and Stoddard (1931:212) characterized Cooper's hawks as "the outstanding natural enemy of the bobwhite."

Greater roadrunners *(Geococcyx californianus*) are often implicated as a serious predator of quail nests and chicks in Texas. However, recent research in south Texas (C. Ruthven, Texas Parks and Wildlife Department, personal communication) found quail remains (2 chicks) in only 1 of 120 roadrunner stomachs. Nevertheless, roadrunner abundance in the Chihuahuan Desert has increased 3.6% per year over the last 30 years (Figure 4).

## EFFECTS OF PREDATOR REDUCTION ON QUAIL POPULATIONS

Empirical evidence of the impact (or lack thereof) of predator removal on quail abundance is limited. Beasom (1974) studied the effects of intensive predator control on bobwhites and wild turkeys (*Meleagris gallopavo*) in the eastern Rio Grande Plains of Texas. He removed 188 coyotes, 120 bobcats, 65 raccoons, 46 striped skunks, and 38 other mammalian predators from a 9 square mile study area over a 2-year period. He observed moderate gains in bobwhite abundance and strong increases in turkey production. Guthery and Beasom (1977) conducted a similar study of intensive removal of mammalian predators (e.g., coyotes, striped skunks) from a 6 square mile study area in the western Rio Grande Plains of Texas, but could not demonstrate a treatment effect on either bobwhite or scaled quail populations. Their conclusion was that, if predator removal was effective at all, the effect would be demonstrated by allowing quail populations on "poorer" areas to be similar to better habitats.

If an effect is to be realized from reducing predators, it will most likely be by reducing potential mesomammals involved in nest depredation (Rollins 1999*a*). However, reducing the populations of mammalian nest predators is labor intensive, costly, and will not necessarily result in an increase in quail abundance. Frost (1999) removed approximately 1 mesomammal per 12 acres (mostly raccoons) from 600-acre study areas over a

30-day period just prior to the 1998 and 1999 nesting seasons in Tom Green county, Texas. Survival of radio-marked bobwhites and fate of simulated quail nests were similar on trapped and nontrapped sites. Scent stations indicated that, at this scale and level of trapping (180 trap nights per acre), mesomammal abundance was not reduced even in the short-term.

## DISCUSSION

Although predation is usually the primary source of mortality for quail at all stages of their life cycle, predator control has historically been dismissed as a management recommendation for quail. Errington's (1934) long-term studies of bobwhites and predators in the Upper Midwest suggested that habitat, not predators, limited bobwhites. His concept, i.e., manage habitat not predators, has been pervasive in the quail management literature since that time. We do not discount the current management paradigm of indirect predator control (i.e., habitat management), and especially as the "first line of defense." However, the issue of predation as it relates to quail must be evaluated in a more contemporary context of an increasingly fragmented landscape (Robel 1993) and temporal changes in predator populations. In light of these changes, and the current rate of declines observed in quail in some regions, we concur with Hurst et al. (1996) that the issue of predator control relative to avian recruitment in Galliformes should be revisited.

### Predator control or predation management?

As bobwhite populations continue to decline in the Southeast there is increasing pressure to implement predator control as a means of increasing bobwhite abundance. Some conservation organizations, e.g., Quail Unlimited, are increasingly questioning the "if you build it, they will come" habitat paradigm as the sole means of sustaining bobwhite populations. In calling for broad spectrum predator control, some in and out of the wildlife profession may be acting prematurely. As Leopold (1953:60) suggested "the urge to comprehend must precede the urge to reform." Waterfowl managers have done an admirable job in the quest to understand the ecological implications of predator control, and subsequently in predation management. Quail managers may be well advised to study such examples.

As in the northern plains, some predators might adversely impact those predator species which prey heavily upon nesting game birds. For example, coyotes at low densities will displace red foxes, thereby resulting in higher duck nest survival (Sovada et al. 1995). Similar correlations between coyote densities and bobwhite have been reported in Texas (Rollins 1999*a*). Coyotes may suppress smaller, more efficient nest predators (e.g., gray foxes, raccoons), or at least restrict their distribution on the landscape.

### An integrated approach to predation management

We suggest the development of an "Integrated Pest Management" (IPM) approach for managing predators of quail. The concept of IPM was developed to enhance strategic control of pests in crops (Pedigo 1989), and recognizes that a species of insect may be either a "pest" or "beneficial" depending on the situation involved. Further, IPM introduces the idea of economic thresholds, i.e., the level of pest damage that can be sustained before it becomes economical to provide a corrective treatment. Most IPM strategies include both nonlethal (e.g., crop rotations) and lethal (e.g., insecticides) control alternatives. The former is applied as the first line of defense with the latter being applied in the most "surgical" manner feasible to reduce treatment costs and minimize risks to the environment. Appropriate parallels relative to predator management for quail are numerous.

## CONCLUSION

Changes in land management over the last 30 years have resulted in conditions that make it more difficult to maintain high densities of quail (especially bobwhites) over much of their distribution. There is no doubt that land fragmentation will continue, and likely accelerate over the next 20 years in bobwhite and scaled quail ranges (e.g., Texas; Wilkins et al. 2000). At the same time, there is evidence that some predators of quail may have benefitted from these changes. How these landscape level changes in land use, and predator and prey populations, impact the interaction of quail and their predators are unclear at this time. But our challenge as quail managers is apparent: how to maintain (or restore) quail populations in an increasingly fragmented habitat. We suggest that appropriate predation management techniques should be one of the management tools considered in such restoration efforts.

The potential role of predation as a suppressing agent in quail populations needs additional study. It is crucial to understand how landscape level changes in land use might change relationships between quail and their predators, as well as change both predator and prey communities. What is needed is experimental research to define more clearly the relationships between quail and their predators within the context of current land use and habitat management. Leopold and Hurst (1994) outlined strategies for studying the impacts of predators on game bird management.

An IPM-based approach to predator management for quail needs to be developed. Information is needed to develop economic thresholds and integrated predation management strategies that satisfy both biological and political facets of predation management. Recent technology (e.g., radio telemetry, continuous video surveillance) will continue to expand our knowledge on the relative management importance of various predators. If raptor populations (e.g., accipiters) continue to increase, the efficacy of nonlethal predation management strategies (i.e., habitat management) needs to be quantified. Additional, long-term experimental studies, designed appropriately (Leopold and Hurst 1994), are needed to clarify relationships between quail, their predators, and habitat dynamics. The decline of quail, especially bobwhites, underscores the urgency for such studies.

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**Table 1.** Nest success rates (%) and percentage of mortalities due to predators of bobwhite nests at various locations.

| Location | *n* | % Nest Success | Method of Monitoring | % lost to predators | Reference |
|---|---|---|---|---|---|
| Illinois | 863 | 34 | Nest Search | 37 | Roseberry and Klimstra (1975) |
| Florida | 601 | 36 | Nest Search | 64 | Stoddard (1931) |
| Florida | 51 | 45 | Telemetry | 89 | DeVos and Mueller (1993) |
| Georgia | 1,725 | 18 | Nest Search | - | Simpson (1976) |
| Missouri | 157 | 44 | Telemetry | 68 | Burger et al. (1995*b*) |
| North Carolina | 35 | 34 | Telemetry | 73 | Puckett et al. (1995) |
| Oklahoma | 161 | 50 | Telemetry | 76 | Peoples et al. (1996) |
| Tennessee | 766 | 23 | Nest Search | - | Dimmick (1974) |
| Texas (north) | 34 | 12 | Nest Search | 88 | Jackson (1947) |
| Texas (north) | 81 | 46 | Telemetry | 91 | Hernandez (1999) |
| Texas (south) | 532 | 45 | Nest Search | 84 | Lehmann (1984) |
| Weighted Mean | | 28 | | | |

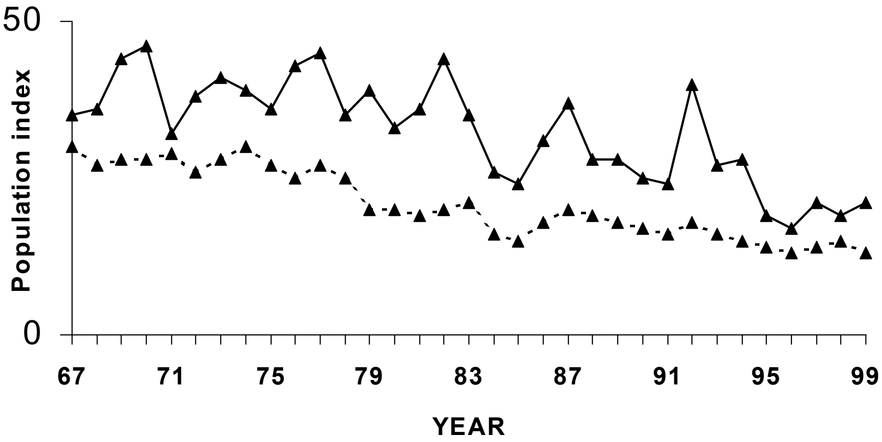


**Figure 1.** Northern bobwhite abundance in the Southeastern U.S. (dashed line) and Texas (solid line) according to Breeding Bird Survey data, 1967-96 (Sauer et al. 2000).

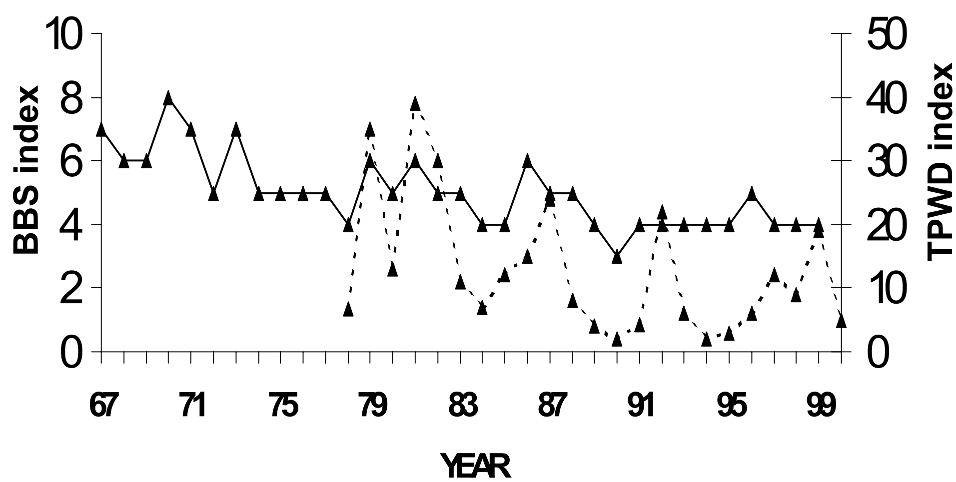


**Figure 2.** Scaled quail abundance in Texas according to Breeding Bird Survey data (solid line), 1967-99 (Sauer et al. 2000) and Texas Parks and Wildlife Department roadside counts (dashed line), 1968-2000 (Texas Parks and Wildlife Department 2000).

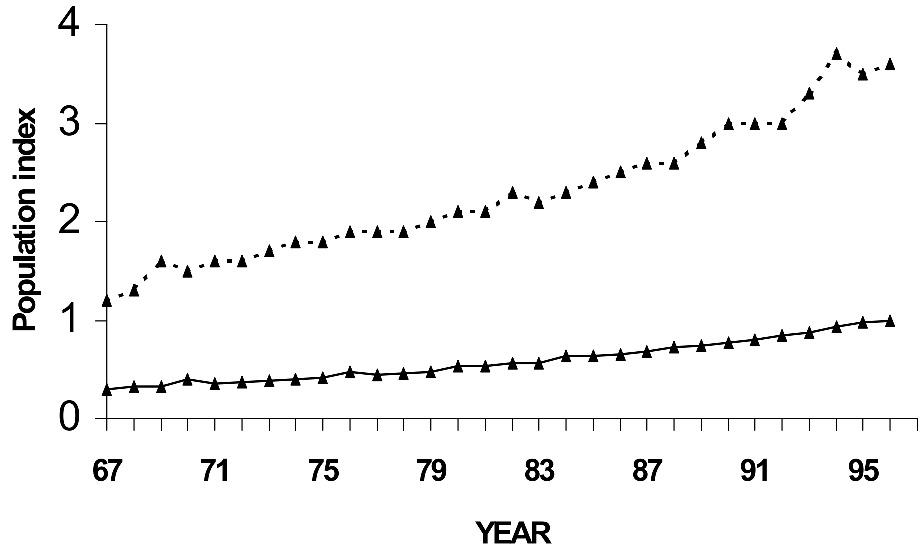


**Figure 3.** Sharp-shinned hawk (solid line) and Cooper's hawk (dashed line) abundance in the United States according to the Breeding Bird Survey data, 1967-96 (Sauer et al. 2000).

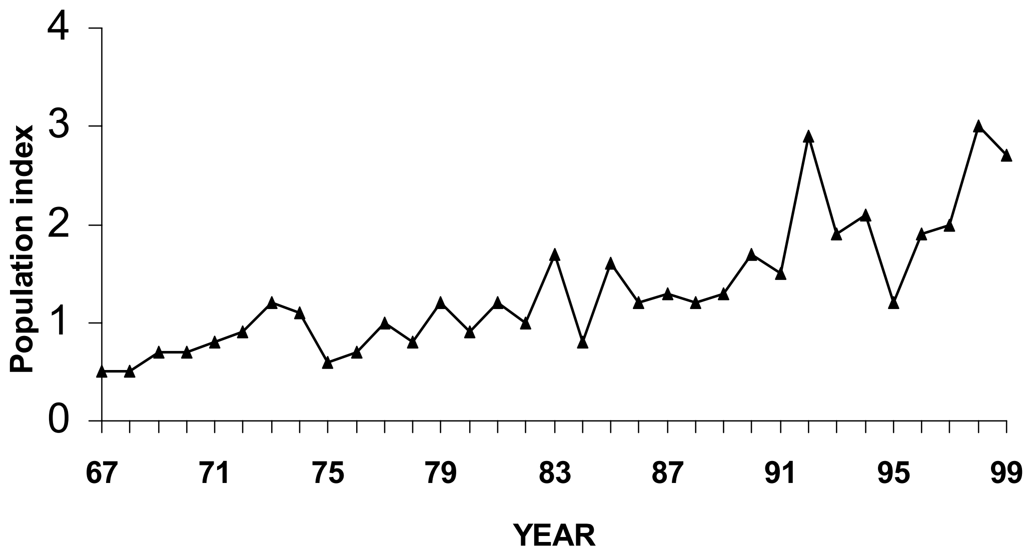


**Figure 4.** Roadrunner abundance in the Chihuahuan desert according to the Breeding Bird Survey data, 1967-99 (Sauer et al. 2000).