Management and Conservation Article

Supplemental Feeding of Northern Bobwhite Affects Red-Tailed Hawk Spatial Distribution

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ABSTRACT Supplemental feeding is a widely used management practice in areas managed for northern bobwhite (*Colinus virginianus*; hereafter quail). Although food provisioning is intended to benefit quail directly, it may also indirectly affect predators by allowing them to focus on the increased concentration of prey. We studied the effects of food supplementation for northern bobwhite on red-tailed hawk (*Buteo jamaicensis*) space use in a longleaf pine (*Pinus palustris*) ecosystem in southwestern Georgia. We used radiotelemetry to determine whether hawks were attracted to areas where supplemental feeding occurred. We found hawks almost 3 times closer to feeding sites (224 ± 96 m; $\bar{x}$ ± SE) than expected (638 ± 96 m). Our data provide an example of a common game management practice having an unintended influence on a top predator. (JOURNAL OF WILDLIFE MANAGEMENT 72(2):428–432; 2008)

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As a wildlife management practice, supplemental feeding aims to maximize the yield of target species, which traditionally are game animals such as northern bobwhite (*Colinus virginianus*, hereafter quail). Food provisioning can benefit quail populations by increasing overwinter survival rates, physical condition, and reproduction (Cookingham 1964, Robel 1969, Townsend et al. 1999, Thackston and Whitney 2001). However, supplemental feeding also may spread disease and increase predators at feeding sites (Landers and Mueller 1997, Townsend et al. 1999). Several studies have documented changes in carnivore habitat use as a result of direct food supplementation (Crabtree and Wolfe 1988, Vander Lee et al. 1999, Jones et al. 2002); however, studies that provide supplemental food directly to raptors are rare (Ward and Kennedy 1994, Ward et al. 1997).

Supplemental feeding of quail increases density of other animals, such as rodents, that also benefit from enhanced food supply (Boutin 1990, Doonan and Slade 1995, Landers and Mueller 1997). Because rodents are the primary prey of red-tailed hawks (*Buteo jamaicensis*; Fitch et al. 1946, Petersen 1979, Preston and Beane 1993), increased concentration of rodents in areas that receive supplemental food results in an indirect supplementation of hawk food supply. Such indirect food supplementation of avian predators has not been studied; however, studies examining direct food supplementation of raptors have reported the possibility of earlier laying dates and larger clutch sizes (Newton and Marquiss 1981, Dijkstra et al. 1982), higher nestling survival rates (Ward and Kennedy 1996, Wiehn and Korpimaki 1997, Dewey and Kennedy 2001), later dispersal (Kenward et al. 1993), and improved nestling and female condition (Wiehn and Korpimaki 1997, Dewey and Kennedy 2001).

Supplemental feeding of quail on our study area presented a unique opportunity to conduct an experimental study to determine influence of food supplementation of prey on predator space use. Rodent populations on the study site increased up to 550% in areas of supplemental feeding (L. M. Conner, Joseph W. Jones Ecological Research Center [JWJERC], unpublished data). A recent study on bobcats (*Lynx rufus*) on the study site documented the effect of this indirect supplementation, or the supplementation of prey, on predators, as bobcats were found approximately 10 times closer than expected to feeding sites (Godbois et al. 2004). No studies have considered the response of avian predators to such indirect food supplementation. Therefore, we examined effects of indirect food supplementation on red-tailed hawk space use in an area managed for quail in southwestern Georgia. We expected red-tailed hawks to be located closer to supplemental feeding sites than expected, where an increased density of small mammal prey items would presumably increase hunting efficiency.

STUDY AREA

Our research took place on Ichauway, the 12,000-ha outdoor research facility of the JWJERC in Baker County, Georgia, USA. Diverse ecological communities characterized the land at the study site, which was surrounded almost exclusively by center-pivot irrigated agricultural land. The site included approximately 7,250 ha of longleaf pine stands (*Pinus palustris*; Boring 2001, JWJERC 2001). Other forest types included slash (*P. elliottii*) and loblolly pine (*P. taeda*) forests, mixed pine and hardwood forests, lowland hardwood hammocks, oak barrens, and cypress–gum (*Taxodium ascendens*–*Nyssa biflora*) limesink ponds (Boring 2001, JWJERC 2001). Wetland features included isolated depressional wetlands, swamps, creeks, and a river. Human-influenced land types were agricultural fields and residential zones (JWJERC 2001). Broadly characterized, the study site

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comprised approximately 32% mature pine, 24% mixed pine–hardwood, 19% agriculture–food plots, 10% hardwood, 6% pine regeneration, 5% wetland, 2% scrub-shrub, and 2% urban, which included residential areas.

Forest management practices at Ichauway included prescribed burning, hardwood removal, exotic species control, and planting food plots. Wildlife management at Ichauway focused on a variety of game, nongame, and special concern species, with quail being a game species of primary importance. Quail management practices included the establishment of agricultural fields and food plots, supplemental feeding, and some mammalian predator removal (JWJERC 2001). There were 1,477 agricultural fields and food plots scattered throughout the site, which ranged in size from <0.1 ha to >10 ha, with an average plot size of 2 ha. Plantings within these agricultural sites consisted of a variety of agricultural grains including grain sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), cowpea (*Vigna* sp.), corn (*Zea mays*), winter wheat (*Triticum* sp.), sunflower (*Helianthus* sp.), and chufa (*Cyperus esculentus*). Supplemental feeding occurred on 2-week to 6-week intervals from 26 October 2004 to 10 May 2005.

METHODS

Red-Tailed Hawk Trapping and Tracking

We captured red-tailed hawks with bal-chatri traps containing 2 live rock doves (*Columba livia*) as lures (Berger and Mueller 1959). We banded hawks with a United States Geological Survey aluminum leg band and measured and aged them according to plumage. We collected blood samples to determine sex (Zoogen Services, Davis, CA). We used the weight measurement to verify ability of each hawk to carry the radiotransmitter package (American Wildlife Enterprises, Monticello, FL), which we attached via a backpack type harness constructed of 6.06-mm-wide tubular Teflon ribbon (Bally Ribbon Mills, Bally, PA; R. E. Kenward, Centre for Ecology and Hydrology, Winfrith Technology Centre, personal communication). The mass of the transmitter package (18–22 g) was <3% of each hawk's total body weight (Kenward 2001), and had no apparent effect on hawk behavior, because each resumed normal activities upon release. We released all hawks within 2 hours after capture.

Hawk monitoring began on 8 July 2004 and continued until 20 June 2005. We used visual sightings and triangulation with a handheld, 3-element yagi antenna (AF Antronics, Urbana, IL) and a handheld receiver (Wildlife Materials, Carbondale, IL) to determine hawk locations. We obtained 2 to 3 bearings from known reference points to estimate bird location using a Geographic Information System. Accuracy tests suggested that our bearings were unbiased (i.e., mean bearing error was zero) with a standard error of ±7°. Because of the vast road network available on our study area, we were generally able to get within 0.5 km of hawks when triangulating; thus, we assumed that our estimated locations were within approximately 100 m of true location (i.e., 95% CI using SE of 7° provides a radius of approx. 100 m at 0.5 km). We allowed ≤10 minutes ($\bar{x} = 2.2$ min) between bearings to minimize the effect of hawk movements on accuracy of triangulation (Cochran 1980, Kenward 1987, White and Garrott 1990). We obtained visual observations whenever possible, and we obtained 23% of our locations this way.

We located hawks ≥3 times per week to ensure ≥30 locations for each bird during each calendar season (Kenward 2001). We obtained hawk locations throughout the daytime activity period during each season. To ensure independence of locations, we maintained ≥6 hours between location times (White and Garrott 1990). All hawk trapping and monitoring procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (IACUC no. A2005-10025-0).

Data Analysis

Analyses focused on adults that remained in the study area (6 F, 5 M). We excluded one adult male because it never established a home range and we deemed it a floater (Bloom et al. 1993, Leary et al. 1998). We converted all hawk locations to Universal Transverse Mercator coordinates with the FORTRAN program EPOLY (L. M. Conner, unpublished data).

Tractor-mounted spreaders broadcasted grain sorghum during the deer hunting season, and a mixture of sorghum and corn at other times, on established feed trails in thickets and along field edges. We used ArcGIS to create a data layer of feeding trails from Global Positioning System (GPS) data obtained from tractor-mounted GPS units. We divided the 6 months of supplemental feeding data into 4-week intervals to create 24 data layers of feed-trail data. After we established the first 4-week interval of feeding data, each subsequent interval began on the second week of the previous interval. We then combined each feed-trail data layer with hawk location data for the following 1-week interval. For example, we combined feeding data from the 4-week interval beginning at the start of the first week of November and ending at the end of the last week of November with hawk location data from the first week in December. The next feeding interval began at the beginning of the second week of November and concluded at the end of the first week of December, and we combined it with feeding data from the second week of December. The delay between feeding initiation and hawk location data allowed time for small mammals and hawks to locate areas of supplemental feeding.

We created a coverage of random points using Hawth's Tools such that all random points fell on the study area within a 100% minimum convex polygon bounding all hawk locations (Mohr 1947, Beyer 2004). Further, we used site-wide random points as opposed to random points within hawk home ranges because prior analyses suggested that hawks selected habitat when establishing home range but not within home ranges (Sexton 2005); thus, our analysis of effects of supplemental food on hawk locations took place at the spatial scale suggested by Neu et al. (1974)

Table 1. Mean distances (m) between red-tailed hawk telemetry locations and supplemental food provided for northern bobwhite relative to mean distance from random locations to supplemental food in southwestern Georgia, USA, during 2004–2005.

Hawk no.	Sex	Locations[a]	Hawk[b]	Random[c]
4	M	78	99.9	859.6
5	M	79	74.1	774.8
8	F	79	111.4	705.0
12	M	77	380.4	706.2
15	F	88	110.1	846.7
16	F	80	160.9	695.7
17	F	82	96.0	664.6
18	M	63	42.7	674.5
20	F	69	113.0	875.0
21	F	38	66.2	563.6
$\bar{x}$[d]		73.3	125.5	736.6
SE			30.1	31.7

[a] No. of hawk locations = no. of random locations.
[b] Mean distance from locations to supplemental food.
[c] Mean distance from random locations to supplemental food.
[d] Overall $\bar{x} \pm$ SE differ from that reported in text because means in text represent least squared means.

and used by Godbois et al. (2004) in a study of effects of supplemental feeding on spatial distribution of bobcats.

Because feeding took place in both time and space, we paired random locations with hawk locations to obtain a date for each random location that corresponded to dates of hawk locations, which ensured that the random point could be referenced to the nearest feeding trail on the day we located hawk and ensured that the number of random points used in analysis was equal to the number of hawk radiolocations. Moreover, we assigned a hawk number to each random location so that we could treat random locations as subsamples in subsequent analyses in a similar manner as actual hawk locations. However, this pairing was arbitrary and we only used it to create a random hawk as an experimental unit; thus, there was no justification for using hawk number as a mechanism for partitioning variance (i.e., treating a real and a random hawk as a blocked pair) in our analysis.

We used the NEAR function in ArcGIS to calculate 4 sets of distances: hawk locations to feed trails, hawk locations to food plots, random locations to feed trails, and random locations to food plots. We included distances to wildlife food plots in the analysis to control for effect of food plots, because feed trails tended to be located near food plots and hawks were known to be closer to this habitat type than expected (Sexton 2005).

To determine if hawks were attracted to supplemental feeding sites, we used an Analysis of Covariance within a general linear model to compare distances from hawk and random locations to feeding trails. We treated each hawk and each random set of locations as experimental units with the actual distances serving as subsamples. Thus, our sample consisted of 10 hawks and 10 sets of random locations. We used distance to food plots as a covariate in our analysis because hawks preferred food plots, and food plots frequently served as sites for supplemental feeding (Sexton 2005). However, supplemental feeding occurred throughout the site and in no way was food solely applied in association with food plots. Thus, treating distance to food plots as a covariate was warranted to remove variation associated with supplemental food location relative to food plots. We performed this analysis and calculation of least squared means and their standard errors using SAS software (SAS Institute, Cary, NC). We set statistical significance at $\alpha = 0.10$.

RESULTS

We radiotagged 22 red-tailed hawks (6 F juv, 2 M juv, 8 F ad, 6 M ad) between 8 July 2004 and 20 June 2005. We tracked hawks over varying time periods, because of different capture dates, migration, mortality, and unknown losses. Six hawks (5 juv, 1 ad) dispersed or were otherwise lost before we obtained $\geq$30 locations necessary to estimate seasonal home ranges. The number of hawks tracked seasonally ranged from 7 to 12 ($\bar{x} = 10$). We tracked 10 hawks during the period when supplemental food was provided (Table 1). After correcting for distance to wildlife food plots, our analysis indicated that hawks were located almost 3 times closer ($F_{1,17} = 4.92$, $P = 0.04$) to feeding areas (224 $\pm$ 96 m; $\bar{x} \pm$ SE; $n = 10$) than to random locations (638 $\pm$ 96 m; $n = 10$).

DISCUSSION

Supplemental feeding sites attracted red-tailed hawks, presumably due to the increased abundance of prey and subsequent increase in hawk foraging efficiency at these sites (Boutin 1990, Doonan and Slade 1995, Landers and Mueller 1997). Red-tailed hawks generally prey upon small- to medium-sized (15-g to 2-kg) mammals, birds, and reptiles (Preston and Beane 1993). In the eastern United States, red-tailed hawks hunt mostly voles, mice, and rats (Preston and Beane 1993). Research of hawk diets in other parts of their range also reported a strong preference for small mammals, which made up as much as 99% of their prey (McAtee 1935, Fitch et al. 1946, Luttich et al. 1970, Smith and Murphy 1973, Petersen 1979). Such prey items benefit immediately from the provision of energy-rich grains supplied for quail (Landers and Mueller 1997). Cotton rat (*Sigmodon hispidus*) densities increased $\geq$50% on supplementally fed sites and other studies have reported up to a 3-fold density increase in small-bodied herbivores in areas of food supplementation (Boutin 1990, Doonan and Slade 1995). Preliminary analyses of ongoing research suggest that supplemental feeding within longleaf pine stands increases abundance of cotton rats, house mice (*Mus musculus*), eastern harvest mice (*Reithrodontomys humulis*), and cotton mice (*Peromyscus gossypinus*) by 5.5, 3.2, 2.0, and 1.5 times, respectively (L. M. Conner, unpublished data), indicating that supplemental food intended for quail also increased densities of small mammals, providing an abundance of prey for hawks.

MANAGEMENT IMPLICATIONS

Quail management techniques, such as supplemental feeding and planting food plots, affect other organisms in the system in which quail live (Landers and Mueller 1997). Maintenance of small open patches as wildlife food plots provides sites that enable perch-hunting raptors such as red-tailed hawks to become concentrated (Fitch et al. 1946, Orde and Harrell 1977). The combination of an abundant supply of prey and enhanced foraging conditions would be expected to attract red-tailed hawks. Red-tailed hawks concentrate hunting efforts on small mammals and snakes and opportunistically prey on birds (Errington 1933, McAtee 1935, Bent 1937, Knight and Erickson 1976, Preston and Beane 1993). Because supplemental feeding of quail concentrates on red-tailed hawks, quail survival in fed areas may be negatively impacted; thus, further research should be conducted to determine if supplemental feeding increases predation rates on quail by attracting red-tailed hawks to the feed area. Future research should also examine red-tailed hawk diet in areas managed for quail, and how supplemental feeding might affect hawk reproduction.

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