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Ruffed grouse brood habitat use in a mixed hardwood forest: Implications for forest management in the Appalachians

Benjamin C. Jones [a,b,*], Jennifer L. Kleitch [a,c], Craig A. Harper [a], David A. Buehler [a]

[a] *University of Tennessee, Department of Wildlife and Fisheries, 2431 Joe Johnson Drive, Room 274, Knoxville, TN 37996-4563, USA*
[b] *Pennsylvania Game Commission, 2001 Elmerton Avenue, Harrisburg, PA 17110, USA*
[c] *Michigan Department of Natural Resources, Stevens T. Mason Building, P.O. Box 30444, Lansing, MI 48909, USA*

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Abstract

Brood habitat quality and availability may be a limiting factor for ruffed grouse (*Bonasa umbellus*) populations in the central and southern Appalachians. We measured brood habitat characteristics at forest stand and microhabitat scales in western North Carolina. From 2000 to 2004, we monitored radiotagged females with broods ($n = 36$) from hatch to 5 weeks post-hatch. We measured habitat characteristics and invertebrates at 186 brood locations and 186 paired, random locations. Brood sites had greater percent herbaceous ground cover, greater percent vertical cover 0–2 m, greater density of midstory stems <11.4 cm DBH, and greater invertebrate density compared with random sites. Seventeen broods survived the 5-week post-hatch period and were available for home range and second order habitat preference analysis. Mean 75% kernel home range was 24.3 ha (±4.0 S.E.). Top-ranked habitats for relative preference were mixed hardwoods in the 0–5, 6–20, and >80-year age classes, forest roads, and edges of maintained wildlife openings. Broods often were associated with managed stands. From this information, we recommend forest management prescriptions to enhance Appalachian ruffed grouse brood habitat.

Keywords: Appalachians; *Bonasa umbellus*; Broods; Forest management; Habitat use; Home range; Invertebrates; Ruffed grouse

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1. Introduction

Chick survival can be a limiting factor for Appalachian ruffed grouse populations (Devers, 2005). Female grouse promote chick survival by seeking areas that allow optimal foraging on invertebrates near the safety of protective cover (Bergerud and Gratson, 1988). Bump et al. (1947) realized the relationship between habitat and chick survival and suggested brood habitat quality ultimately determines an area's reproductive potential. Studies in the Appalachian region also highlight the importance of cover and invertebrates in managing ruffed grouse brood habitat (Kimmel and Samuel, 1984; Haulton et al., 2003; Tirpak et al., 2005).

Prompted by ruffed grouse population declines (Devers, 2005) and the popularity of grouse hunting, biologists in the central and southern Appalachians (CSA) are developing strategies to address ruffed grouse habitat needs. Provision of brooding areas may be a cornerstone of such plans, as fulfilling specific brood requirements also improves conditions for adults throughout the year. The reverse, however, may not be true, as broods are less adaptable to unfavorable conditions (Berner and Gysel, 1969).

Characteristics of brood habitat during the first few weeks after hatch are well documented from the north central United States, the core of ruffed grouse range. Requirements include ample invertebrates, a diversity of moderately dense, herbaceous groundcover and a high density of midstory shrubs and woody stems (Berner and Gysel, 1969; Porath and Vohs, 1972; Godfrey, 1975; Gullion, 1977; Kubisiak, 1978; Maxson, 1978). The diversity of forest stands exhibiting these conditions included lowland speckled alder (*Alnus rugosa*, Godfrey, 1975), mature alder-aspen (*Populus tremuloides*, *P. grandidentata*, Kubisiak, 1978), and various combinations of forest openings and edge habitats (Berner and Gysel, 1969; Porath and Vohs, 1972; Maxson, 1978).

Several studies have examined brood habitat in the CSA (Stewart, 1956; Scott et al., 1998; Haulton et al., 2003);

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* Corresponding author at: Pennsylvania Game Commission, Bureau of Habitat Management, 2001 Elmerton Avenue, Harrisburg, PA 17110, USA. Tel.: +1 717 787 9613.
E-mail address: benjjones@state.pa.us (B.C. Jones).

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however, conflicting reports exist regarding forest types preferred by broods in the region. The range of forest types reportedly used, from closed canopy, mature stands to young clearcuts, may complicate decision making for managers choosing among silvicultural options.

Most forest management plans are implemented at stand and compartment scales. Within forest stands, vegetation characteristics (i.e., microhabitat) are a function of site quality and disturbances and management activities including timber harvest. Within compartments, or multiple stands, habitat is influenced by these activities albeit at a coarser resolution. Habitat selection can occur at one or both of these scales (Johnson, 1980); therefore, a comprehensive understanding of forest management effects on wildlife can only be gained through investigations at multiple spatial scales. We initiated such a study in the Appalachian Mountains of North Carolina to provide information pertinent to forest management for ruffed grouse in the southern Appalachians. Our objectives were to (1) compare habitat use versus availability at the forest stand scale; (2) examine vegetation structure of brood habitat; (3) investigate invertebrate availability in brood habitats; and (4) identify forest management options for creating, maintaining, and improving ruffed grouse brood habitat in the southern Appalachians.

2. Methods

2.1. Study area

We conducted research on Wine Spring Creek Ecosystem Management Area (WSC; 3230 ha), within Nantahala National Forest in western Macon County, North Carolina. The area lies within the Blue Ridge Physiographic Province and is part of the southern Nantahala Mountain Range. Elevation ranges from 915 to 1644 m. Terrain is characterized by long, steep ridges with perpendicular secondary ridges connecting upper elevations to narrow valley floors (Whittaker, 1956). The area was predominantly forested with <1% coverage in small openings. The U.S. Forest Service purchased WSC in 1912 after extensive logging representative of the period. Since then, forest management practices included salvage harvest of blight-killed American chestnut (*Castanea dentata*), thinning, clearcutting, and diameter-limit cutting (McNab and Browning, 1993). Beginning in 1995, two-aged shelterwood, shelterwood, and group selection harvests were implemented as part of a study to examine effects of these practices on various ecosystem aspects (Elliott and Knoepp, 2005).

We classified habitats by vegetative community type and stand age. Communities were stratified into three land classes (i.e., XERIC, SUBXERIC, and MESIC) defined by elevation, landform, soil moisture, and soil thickness (McNab and Browning, 1993). Within communities, plant species variation occurred along a moisture continuum, similar to that described by Whittaker (1956). Xeric communities were on high elevation, steep, south and west aspects characterized by shallow, dry soils. Overstory tree species included scarlet oak (*Quercus coccinea*), black oak (*Q. velutina*), pitch pine (*Pinus rigida*) and chestnut oak (*Q. prinus*). Subxeric communities were at middle elevations and upper elevations on less exposed aspects. Overstory was dominated by chestnut oak, white oak (*Q. alba*), hickory (*Carya* spp.), northern red oak (*Q. rubra*), red maple (*Acer rubrum*), and yellow poplar (*Liriodendron tulipifera*). Mesic communities occurred on north and east aspects, on lower slopes, and in sheltered coves. Stands were comprised of yellow poplar, eastern hemlock (*Tsuga canadensis*), northern hardwoods including sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*) and birch (*Betula* spp.), and mixed mesophytic obligates including American basswood (*Tilia americana*) and yellow buckeye (*Aesculus octandra*). Sites with 75–100% cover in rhododendron (*Rhododendron maximum*) were placed in a separate habitat classification (RHODO).

Additional habitat classes included gated forest roads (ROAD) and wildlife openings (WLO). Roads were defined by a buffer width of 5 m from road center on each side that included the road and adjacent berm. Wildlife openings were small, permanent clearings (0.50 ± 0.12 ha S.E.). Opening and road management included an initial planting of orchardgrass (*Dactylis glomerata*), tall fescue (*Festuca arundinacea*) and white-dutch clover (*Trifolium repens*) maintained by annual or biennial mowing.

Stand ages were determined by years since harvest or stand establishment in categories deemed important to ruffed grouse (0–5, 6–20, 21–39, 40–80, >80 years).Grouse begin use of regenerating mixed hardwood and oak stands approximately 6 years after harvest when dominated by regenerating woody saplings (Kubisiak, 1987; Thompson and Dessecker, 1997). At approximately 20 years of age, habitat quality decreases as the upper canopy closes and woody stem density and herbaceous ground cover decrease (Kubisiak, 1987; Storm et al., 2003). Mixed hardwoods remain in this ‘‘pole stage’’ until 40 years of age. By 80–120 years, oaks have reached reproductive maturity and are capable of producing significant acorn crops (Guyette et al., 2004). Acorns are an important fall and winter food for ruffed grouse in the Appalachians (Norman and Kirkpatrick, 1983; Servello and Kirkpatrick, 1987). Oaks stands in the 80–120-year age class are also considered full rotation age on many sites (U.S. Forest Service, 1994). Beyond 120 years, natural mortality of upland oaks increases (Guyette et al., 2004), resulting in canopy gaps with localized sapling cover. Wildlife openings, forest roads and rhododendron-dominated understory were not assigned age categories because they are in a state of arrested succession and their structural characteristics do not change appreciably over time (Phillips and Murdy, 1985).

Stands in the 6–20-year age class were regenerating following clearcut harvest (1.3–24.6 ha, $n = 44$) in the late 1980s and early 1990s. Alternative regeneration harvests (i.e., shelterwood, two-aged shelterwood, group selection) were cut 1996–1997; therefore, they were included in the 0–5-year age class during study years 2000–2001 and subsequently moved into the 6–20 year age class for study years 2002–2004. Target residual basal area was 9.0 m^2/ha for shelterwood. Ruffed grouse data were collected prior to residual overstory removal in these stands. Mean shelterwood size was (5.56 ± 0.42 ha

S.E., $n = 3$). For two-aged shelterwood, target residual basal area was 5.0 m^2/ha. Residuals in two-aged shelterwood were to be retained through the next rotation, resulting in two-aged stands. Mean size of two-aged stands was (4.68 ± 0.18 ha S.E., $n = 3$). Group selection was implemented in three stands with 4–9 groups/stand. Mean group size was 0.36 ha (±0.05 S.E.). For habitat analysis, each group opening was treated as a separate stand (i.e., digitized in the GIS similar to small clearcuts). All shelterwood, two-aged shelterwood, and group selection harvests were implemented on subxeric sites that were intermediate in soil moisture.

Stand grouping by years since harvest was necessary to minimize number of habitat types, despite use of various silvicultural systems. At a stand scale, most even-aged stands (i.e., clearcut and shelterwood), two-aged stands, and individual group cuts were similar relative to key habitat features, including stem density and herbaceous cover (Elliott and Knoepp, 2005). Although grouping occurred for analysis, grouse use of stands under different silvicultural systems was separated for discussion purposes. Further, microhabitat features were measured at brood use locations to identify fine-grained habitat features.

Subxeric oak and mixed oak-hickory in the >80-year age class (SUBXER5) made up the greatest proportion of the study site (31.5%) and wildlife openings (WLO) made up the least (<1.0%; Table 1). Early successional habitats in the 6–20-year age class (XERIC2 and SUBXER2) occupied 9.3% of the area. The 6–20-year, and 21–39-year age classes were not represented on mesic sites. There were 52.6 km of gated forest roads (1.1% of total area).

Table 1
Land class, stand age (years), resultant ruffed grouse habitat delineations, number of stands, mean stand size (ha) and study area coverage (%) of Wine Spring Creek Ecosystem Management Area, Macon County, North Carolina, 1999–2004

Land class	Age	Habitat	n	Mean ± S.E.	Coverage
Mesic	40–80	MESIC4	23	21 ± 5.3	9.7
Mesic	>80	MESIC5	12	37 ± 8.7	9.1
Mesic	NA	RHODO	18	53 ± 20.3	19.6
Subxeric	0–5	SUBXER1[a]	30	2 ± 0.4	0.8
Subxeric	6–20	SUBXER2	40	10 ± 0.6	8.1
Subxeric	21–39	SUBXER3	7	11 ± 1.7	1.6
Subxeric	40–80	SUBXER4	8	16 ± 3.9	2.7
Subxeric	>80	SUBXER5	43	36 ± 4.3	31.5
Xeric	6–20	XERIC2	4	15 ± 4.4	1.2
Xeric	40–80	XERIC4	6	20 ± 3.4	2.4
Xeric	>80	XERIC5	15	39 ± 11.2	11.9
Roads	NA	ROAD	NA	NA	1.1
Openings	NA	WLO	24	0.5 ± 0.1	0.2

[a] Represented alternative regeneration treatments (i.e., shelterwood, two-aged shelterwood, and group selection).

2.2. Field methods

We captured grouse using intercept traps (Gullion, 1965) during two annual periods, late August to early November and early March to early April, 1999–2003. Gender and age (juvenile or adult) were assessed by feather characteristics and molt patterns (Kalla and Dimmick, 1995). Grouse were weighed, leg-banded, fitted with a 12-g necklace-style radio-transmitter (Advanced Telemetry Systems, Isanti, Minnesota, USA) and released after processing.

We monitored females with broods from hatch to 5 weeks post-hatch, a critical period when chick mortality is greatest and survival may depend on habitat (Bump et al., 1947; Haulton, 1999; Larson et al., 2001). Brood females were located 1–2 times daily by triangulation and 2–3 times weekly by homing. Homing provided visual locations necessary to confirm brood survival and identify sites for vegetation and invertebrate sampling. Triangulated locations were recorded from permanent telemetry stations. To adequately represent diurnal time periods, an equal number of locations were recorded during morning (0700–1100), mid-day (1101–1500), and evening (1501–1900). Stations were geo-referenced using a Trimble Global Positioning System (Trimble Navigation Limited Inc., Sunnyvale, CA, USA). Transmitter signals were received using Telonics TR-2 receivers (Telonics Inc., Mesa, AZ, USA), Clark model H7050 headphones (David Clark Company Inc., Worcester, MA, USA), and hand-held 3-element yagi antennas. For each grouse location, we recorded time, azimuths ($n = 3$–5) to nearest degree, grouse activity (moving or still), and a relative measure of signal strength (1 = weakest and 5 = strongest). A maximum of 20 min was allotted between first and last azimuths to minimize error from animal movement. While in the field, locations were plotted on paper maps to check precision. Telemetry data were entered in Microsoft Excel and converted to x and y UTM coordinates using program LOCATE II (Nams, 2000). Error was assessed by mean error ellipse of grouse locations and from test beacons ($n = 10$) placed at central points (Jennrich and Turner, 1969) in randomly selected grouse home ranges. Telemetry bearing error on beacons was ±6.53°. Grouse locations with error ellipses >7 ha were culled from the data set. Intensive monitoring continued as long as a female had ≥1 surviving chick or until 5 weeks post-hatch. Beyond 5 weeks, broods reportedly shift habitats as their diet changes from predominantly invertebrates to plant material (Stewart, 1956; Godfrey, 1975).

We collected microhabitat data in nested circular plots centered on brood homing locations. Corresponding random locations were sampled at a random distance (200–400 m) and azimuth (0–359°) from a brood location recorded the previous day. This allowed availability to differ among observations as broods moved within the study area (i.e., habitats available to a brood on any given day depended on its location the previous day; Arthur et al., 1996). The 200–400 m distance was chosen because it represented a range of daily distances typically covered by grouse chicks (Godfrey, 1975; Fettinger, 2002). We estimated basal area from plot center with a 2.5 m^2/ha prism. We recorded number of midstory saplings and shrubs <11.4 cm DBH and ≥1.4 m height within 0.01 ha plots. We estimated mean percent herbaceous groundcover by measuring the proportion of 3, 3.6-m tape transects that were intersected by vegetation. The transects were arranged at 0°, 120°, and 240°. Groundcover was expressed both as a total and within the categories fern, forb, grass, and briar. Briar included blackberry, raspberry (*Rubus* spp.), and greenbriar (*Smilax* spp.). We estimated vertical vegetation density using a 2.0 m vegetation profile board divided into 0.2-m sections (Nudds, 1977). Mean percent vertical coverage of vegetation was estimated 10 m from plot center at four sample points, one for each cardinal direction. During 2002–2004, mean percent overstory canopy also was estimated from these points using a densiometer. Standard deviation of the four canopy measurements was calculated to assess canopy continuity.

We sampled invertebrates within a 15 m radius of plot center using a 0.10-m^2 bottomless box and a terrestrial vacuum sampler (Harper and Guynn, 1998). During 2000–2001, five subsamples were collected at each plot. After 2001, power analysis revealed four subsamples were adequate to estimate mean invertebrate density within plots (Fettinger, 2002). Invertebrate samples were frozen pending sorting in the laboratory. Arthropods were sorted from leaf litter and detritus and identified to order according to Borror et al. (1989). After sorting, arthropods were placed in glass vials, oven-dried for 48 h at 60 °C (Murkin et al., 1996), and weighed by order. Orders frequently consumed by ruffed grouse chicks, including Araneae, Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, and Orthoptera, were grouped in a unique category (Bump et al., 1947; Stewart, 1956; Kimmel and Samuel, 1984).

2.3. Data analysis

We assessed habitat at two spatial scales: (1) habitat use versus availability across the study area (i.e., second-order selection; Johnson, 1980) and (2) microhabitat use within brood ranges. For analysis at the study area scale, use was represented by the proportion of habitats within brood home ranges. Availability was defined by 1200 m circular buffers around successful nest sites. Grouse chicks are capable of moving up to 1200 m during the first 5 weeks following hatch (Godfrey, 1975; Fettinger, 2002); therefore, this distance represented habitats available to broods based on their movement potential. The Animal Movement Extension to ArcView GIS 3.2 (Environmental Systems Research Institute Inc., Redlands, CA; Hooge and Eichenlaub, 1997) was used to calculate fixed kernel home ranges (Worton, 1989). Estimates were based on 75 percent kernel contours to define central portions of a home range and exclude ‘‘occasional sallies’’ (Burt, 1943; Seaman et al., 1999). To determine adequate sampling (minimum locations), home range area was plotted against number of locations to determine sampling level at which area variation decreased and became asymptotic. We determined 18 locations was the minimum required for home ranges; therefore, only broods with ≥1 chick surviving at 5 weeks post-hatch and ≥18 locations were used for analysis. Home range estimates were based on telemetry and homing locations combined.

We overlaid home ranges on a Geographic Information System (GIS) created for the area using color infrared aerial photographs, 1:24,000 U.S. Geologic Survey 7.5-min quadrangles, U.S. Forest Service Continuous Inventory of Stand Condition (CISCS), and ground truthing. We clipped home ranges from the GIS layers to determine proportional use of each habitat type. Use was compared with availability using compositional analysis (Aebischer et al., 1993). Relative ranks of habitat use were assigned by calculating pair-wise differences in use versus availability for corresponding habitat log-ratios. To control Type I error, we examined the data for 0% observations in any available habitat (Bingham and Brennan, 2004). We used the Shapiro–Wilk’s test to assess normality in log-ratio differences and randomization tests to determine differences in use versus availability for non-normal data. Significance tests ($\alpha = 0.05$) were used to examine differences in relative preference among ranked habitats (Aebischer et al., 1993).

At the microhabitat scale, we used an information-theoretic approach (Burnham and Anderson, 1998) to evaluate differences in vegetation characteristics and invertebrate density between brood and random sites. We created a set of a-*priori* candidate models using combinations of microhabitat variables previously determined important to ruffed grouse broods. Variables included in models were percent total groundcover, percent vertical cover ≤2 m, midstory stems ≤11.4 cm DBH, and density of invertebrates in orders preferred by ruffed grouse chicks (Stewart, 1956; Berner and Gysel, 1969; Porath and Vohs, 1972; Godfrey, 1975; Kubisiak, 1978; Maxson, 1978; Kimmel and Samuel, 1984; Thompson et al., 1987; Scott et al., 1998; Fettinger, 2002; Haulton et al., 2003). We used bias-corrected Akaike’s information criterion (AIC_c) and weight of evidence (w_i) to rank and select the model(s) that most parsimoniously fit the data (Burnham and Anderson, 1998). We used logistic regression to calculate 2 log-likelihood values for each model with brood sites = 1 and random sites = 0 (Procedure GLM, SAS Institute, Cary, NC, USA.). Log-likelihoods were then used to calculate Akaike’s Information Criterion. Multicollinearity of explanatory variables was assessed for each model with variance inflation factor (VIF) output by the REG Procedure in SAS. Goodness of fit of the most parsimonious models was assessed with Hosmer and Lemeshow goodness of fit test (Hosmer and Lemeshow, 1989).

Means, standard errors and 95% confidence intervals were calculated for all microhabitat variables for simple comparisons between brood and random sites. Several additional variables including basal area, canopy cover and standard deviation of canopy cover were not included in information theoretic models because we believed they would lead to collinearity (e.g., a linear relationship between canopy cover and groundcover). Although not included in models, these variables may be important to grouse; therefore means, standard errors, and 95% confidence intervals were calculated for simple comparisons.

We explored the possibility of testing for microhabitat differences between broods that lost all chicks and broods that had ≥1 chick alive at 5 weeks. Trends were not apparent due to under sampling of unsuccessful broods. For second-order habitat, survival was inherent in our data because broods had to survive the entire 5-week period to be eligible for home range analysis.

3. Results

From 2000 to 2004, we monitored 36 brood females resulting in 372 microhabitat plots (186 brood, 186 random). Seventeen brood females had $\geq$1 chick alive at 5 weeks post-hatch. Mean home range size was 24.3 ha (±4.0 S.E.). At the second order selection scale, log-ratio differences were non-normal (Wilk's $\lambda = 0.90$). Randomization tests recommended for non-normal log-ratios ($n = 10{,}000$; Aebischer et al., 1993) indicated overall use differed from availability ($P < 0.001$). Top-ranked habitats for relative preference were SUBXER1, SUBXER2, SUBXER5, ROAD, and WLO (Table 2). Ranks were interchangeable among these five habitats.

For microhabitat, the most parsimonious model included an intercept term, percent total herbaceous groundcover, percent vertical cover, density of midstory stems <11.4 cm DBH, and preferred invertebrate density ($\text{AIC}_c = 482.36$, $\omega_i = 0.965$; Table 3).

Cross-validation revealed the model correctly classified 66.3 % of brood locations, and lack of fit was rejected by Hosmer and Lemeshow goodness of fit test ($\chi^2 = 6.02$, $P = 0.645$). Explanatory variables in the best model were not linearly related (VIF < 1.38).

Compared with random plots, brood sites had greater percent herbaceous groundcover, greater percent vertical cover, greater density of midstory stems/ha <11.4 cm DBH, greater number of invertebrates/m^2, and greater variability in canopy cover (Tables 4 and 5).

Herbaceous groundcover on both brood and random plots was evenly distributed between forb and fern with lesser amounts of grass and briar. Vertical vegetation coverage 0–2 m in height also was evenly distributed across 0.4 m sections. Invertebrate density differed among orders preferred by grouse (Table 5). Invertebrate biomass did not differ between brood and random plots.

Table 3
A-*priori* candidate models, number of parameters estimated (K), bias-corrected Akaike's information criterion (AIC_c), and model weights (w_i) used to evaluate ruffed grouse brood microhabitat on Wine Spring Creek Ecosystem Management Area, Macon County, North Carolina, 1999–2004

Model[a]	K	AICc	ΔAIC	w_i
Gcvr + lat + midstem + arthropods	4	482.358	0.000	0.965
Gcvr + lat	2	489.757	7.399	0.024
Gcvr + lat + midstem	3	491.246	8.888	0.011
Gcvr	1	502.026	19.668	0.000
Arthropods	1	502.212	19.854	0.000
Lat	1	502.935	20.577	0.000
Lat + midstem	2	504.821	22.463	0.000
Midstem	1	512.816	30.458	0.000

[a] Gcvr = percent herbaceous groundcover; lat = percent vertical vegetation cover 0.0–2.0 m in height; midstem = density of woody stems <11.4 cm dbh; arthropods = density of invertebrates in orders preferred by ruffed grouse chicks.

4. Discussion

With respect to forest types, broods surviving to 5 weeks post-hatch used mixed hardwood stands in the 0–5, 6–20, and >80-year age classes. Site conditions were neither xeric nor mesic but rather subxeric with northern red oak and red maple dominant in the overstory and flame azalea (*Rhododendron calendulaceum*), American chestnut sprouts, red maple, serviceberry (*Amalanchier arborea*), and northern red oak in the midstory. The 0–5-year class was represented by use of 3–4-year-old group selection cuts and two, two-aged shelterwood stands. Broods also utilized 6–

Table 2
Ranks of habitats used vs. availability at the study area scale for female ruffed grouse with broods on Wine Spring Creek Ecosystem Management Area, Macon County, North Carolina, 1999–2004

Habitat	Wlo	Subxer2	Subxer5	Subxer1	Road	Rhodo	Mescov4	Mescov5	Subxer3	Xeric2	Xeric4	Subxer4	Xeric5	Rank
Wlo		+	+	+	+	+++	+++	+++	+++	+++	+++	+++	+++	1
Subxer2			+	+	+	+++	+++	+++	+++	+++	+++	+++	+++	2
Subxer5				+	+	+++	+++	+++	+++	+++	+++	+++	+++	3
Subxer1					+	+++	+++	+++	+++	+++	+++	+++	+++	4
Road						+++	+++	+++	+++	+++	+++	+++	+++	5
Rhodo							+	+	+	+++	+	+++	+	6
Mescov4								+	+	+	+	+++	+	7
Mescov5									+	+	+	+	+	8
Subxer3										+	+	+	+	9
Xeric2											+	+	+	10
Xeric4												+	+	11
Subxer4													+	12
Xeric5														13

Statistical significance among habitat types is examined by following a habitat type across a row and comparing it to corresponding types in columns. A triple plus sign (+++) indicates significant relative preference at $\alpha = 0.05$.

Table 4
Microhabitat variables measured at sites used by ruffed grouse females with broods ($n = 36$) and corresponding random sites on Wine Spring Creek Ecosystem Management Area, Macon County, North Carolina, 1999–2004

Variable	Brood				Random			
	Mean	*n*	S.E.	95% CI	Mean	*n*	S.E.	95% CI
Basal area (m^2/ha)	17.0	186	0.7	15.5–18.5	17.9	186	0.8	16.4–19.4
Canopy cover (%)	76.3	90	2.0	72.4–80.3	82.0	90	1.8	78.5–85.5
Std. dev. (%)[a]	12.1	90	1.1	9.9–14.3	6.9	90	0.7	5.6–8.2
Stem density (ha^{-1})	6250	186	441	5380–7120	4963	186	355	4263–5662
Shrub (ha^{-1})	2947	186	379	2198–3695	2172	186	309	1562–2781
Hardwood (ha^{-1})	3303	186	217	2875–3732	2791	186	186	2424–3159
Lateral cover (%)								
0.00–2.00 m	52.3	186	2.0	48.4–56.3	41.5	186	2.0	37.6–45.3
0.00–0.40 m	77.1	186	1.8	73.6–80.6	65.3	186	2.0	61.4–69.2
0.41–0.80 m	57.0	186	2.3	52.5–61.5	45.7	186	2.2	41.4–49.9
0.81–1.20 m	47.6	186	2.3	43.0–52.1	36.6	186	2.3	32.0–41.1
1.21–1.60 m	41.7	186	2.4	36.9–46.4	32.6	186	2.3	28.0–37.2
1.61–2.00 m	38.4	186	2.5	33.4–43.3	27.1	186	2.3	22.7–31.6
Ground cover (%)								
Forb	23.5	186	1.6	20.3–26.7	21.1	186	1.6	17.8–24.3
Fern	23.3	186	1.9	19.6–27.0	17.6	186	1.5	14.7–20.5
Grass	5.6	186	0.8	4.0–7.2	4.3	186	0.8	2.6–5.9
Briar[b]	3.3	186	0.7	2.0–4.6	1.9	186	0.4	1.1–2.7
Total	55.7	186	2.0	51.8–59.7	44.8	186	2.0	40.8–48.7

[a] Standard deviation of four canopy measurements taken at each site.

[b] Included coverage in greenbriar (*Smilax* spp.), blackberry, and raspberry (*Rubus* spp.).

20-year-old mixed hardwood clearcuts. All brood locations within clearcut and shelterwood stands occurred within 50 m of the harvest boundary (i.e., along the stand's inner edge). This explains in part why mean BA at brood use sites was 17 m^2/ha when residual BA in shelterwood stands was 5–9 m^2/ha; trees from the adjacent, uncut stand were often counted in the prism plot when measuring brood use site vegetation.

There was apparent polarity between use of younger age classes and >80-year-old mixed hardwoods. During the mid-1980s an extensive drought in the southeastern United States resulted in overstory tree mortality and gap formation in late-rotation oak forests (Clinton et al., 1993). These canopy openings promoted localized patches of early successional structure similar to that found in younger stands. Broods often were associated with these small canopy openings as indicated by greater variability in canopy cover at brood locations compared to random. The drought did not have the gap-creating effect on mesic sites, resulting in more contiguous overstory canopy in mesic stands. Because timber harvests had not been conducted in mesic stands, the heterogeneous canopy and resultant midstory and understory sought by broods were not present. Most habitat studies in mixed hardwood forests have noted an association of ruffed grouse broods with canopy openings. In Missouri, Freiling (1985) found broods near canopy gaps in mature sawtimber stands. Porath and Vohs (1972) and Stewart (1956) gave similar reports from Iowa and

Table 5
Density of invertebrates (number/m^2) preferred by ruffed grouse chicks at sites used by females with broods ($n = 36$) and corresponding random sites on Wine Spring Creek Ecosystem Management Area, Macon County, North Carolina, 1999–2004

Class	Order	Brood ($n = 186$)			Random ($n = 186$)		
		Mean	SE	95% CI	Mean	SE	95% CI
Arachnida	Araneae	13.1	0.8	11.4–14.8	12.4	0.7	11.1–13.7
Hexapoda	Coleoptera	4.8	0.4	3.9–5.7	3.5	0.3	2.9–4.2
	Diptera	15.5	1.4	12.7–18.3	12.4	1.2	10.2–14.7
	Hemiptera	1.3	0.2	1.0–1.7	1.5	0.4	0.7–2.3
	Homoptera	8	1.2	5.7–10.3	5	0.5	4.0–6.1
	Hymenoptera	13.5	4.3	5.1–21.9	7.7	1.5	4.9–10.6
	Lepidoptera (Adult)	0.5	0.1	0.3–0.7	0.5	0.1	0.3–0.7
	Lepidoptera (Larval)	1.6	0.2	1.1–2.1	0.8	0.1	0.6–1.1
	Orthoptera	0.5	0.1	0.3–0.7	0.3	0.1	0.1–0.4
Total		58.9	5	49.0–68.7	44.3	2.4	39.5–49.0

Virginia, respectively. In New York, Bump et al. (1947:140) cited brood use of ‘‘spot-lumbered hardwoods’’, similar to today’s group selection harvests. A common theme across these studies was a broken overstory canopy that resulted in understory diversity.

On WSC, microhabitats selected by broods had greater vertical vegetation cover, herbaceous groundcover, and midstory stem density compared to available. Random plots were frequently within the same stand as use plots, suggesting broods selected within stand microsites based on vegetation structure. Similar to our study, others have emphasized the importance of vertical cover in the 0.0–2.0 m stratum and percent groundcover in the 50–60% range (Thompson et al., 1987; Scott et al., 1998; Haulton et al., 2003); however, there is disagreement in the literature regarding importance of midstory stem density. Supporting desirability of high stem density, Scott et al. (1998) found broods used 10-year-old clearcuts with 21,100 stems/ha in Pennsylvania. In Missouri, Thompson et al. (1987) reported moderate stem density of 5558 stems/ha at brood locations. Conversely, in Virginia and West Virginia, Haulton et al. (2003) found that broods used relatively open midstory conditions (i.e., 3581–3822 stems/ha) though more dense stands were available.

Variability in reported midstory stem density is likely a function of associated herbaceous cover. Broods appear to select sites based on herbaceous structure with midstory stems providing additional cover when available. On WSC, brood use was observed in areas where ample groundcover and moderate midstory stems (6250 stems/ha) coincided, most frequently along recent timber harvest edges and in canopy gaps. These disturbances occurred on intermediate moisture sites that supported diverse, herbaceous communities when sunlight was permitted to reach the forest floor (Elliott and Knoepp, 2005). Forty seven percent of midstory stems on brood use sites were flame azalea, which created a patchy, low shade-producing canopy. Kimmel and Samuel (1984) stressed the importance of shade from a diversity of shrubs and small trees to provide a desirable microclimate for grouse chicks and insects. In some oak forests, particularly more xeric oak-hickory types, intensive canopy disturbance and resultant desiccation may reduce herbaceous stratum cover. In southwestern Virginia and West Virginia, Hammond et al. (1998) reported herbaceous species richness decreased as canopy disturbance intensity increased. This may explain why Haulton et al. (2003), who studied grouse broods in the same general area, found broods in mature, closed canopy stands although openings created by pulpwood clearcuts were available. It may also explain why WSC broods that used shelterwood and clearcuts were located near the shading effect of the stand edge; the 5–9 m^2/ha of residuals within shelterwood stands did not provide the shading and microclimate that broods found under 75% canopy closure and 17 m^2/ha BA.

Broods on WSC also used edges of managed herbaceous openings and forest roads; however, they did not venture into opening interiors dominated by perennial cool-season grasses such as orchardgrass and fescue. Perennial cool-season grasses can harbor high invertebrate densities (Hollifield and Dimmick, 1995); however, the arthropods are not available because dense, ground-level thatch inhibits chick movement (Harper et al., 2001). The periphery of managed openings had moderate forb cover and overstory shrubs that provided invertebrate prey and ease of mobility for grouse chicks. It was along these opening peripheries that brood use was observed.

Invertebrates are a primary food source for grouse chicks <5 weeks old (Bump et al., 1947; Stewart, 1956). On WSC, density of preferred orders including ants (Hymenoptera) and leafhoppers (Homoptera), was greater on brood plots compared to random. We realize that most managers cannot sample invertebrates to assess grouse habitat; however, habitat evaluations can focus on vegetation structure to improve invertebrate density and protective cover (Harper et al., 2001). Rather than selecting habitats based on food availability, birds use proximate cues related to prey abundance (Schoener, 1968; Smith and Shugart, 1987). Kimmel and Samuel (1984) noted a link between herbaceous cover and grouse chick feeding opportunities. For wild turkey (*Meleagris gallopavo*) poults, which consume similar prey, practices that encourage herbaceous communities and associated invertebrates have been recommended (Hurst, 1978; Pack et al., 1980; Rogers, 1985). Such activities can promote optimal foraging, thus reducing exposure and predation risk. Ultimately, this represents the manager’s greatest opportunity to improve ruffed grouse recruitment.

Prescribed burning has been cited as a technique to improve herbaceous structure and invertebrate availability for ruffed grouse. Fire can control competing woody stems, stimulate herbaceous plant growth from the seedbank, and stimulate insect emergence by facilitating soil warming (Euler and Thompson, 1978; Rogers, 1985). During 17 years of prescribed fire in an Illinois oak forest, cover and abundance of summer herbs increased (Bowles et al., 2007). These fires also decreased midstory shrub density from 7000 to 4340 stems/ha, similar to the shrub density preferred by broods in this study. On WSC, a prescribed fire conducted prior to our grouse research also increased herbaceous cover (Elliott et al., 1999), suggesting merit in improving brood range. Although fire can be a valuable tool to manage brood habitat in the central and southern Appalachians, burns should be conducted prior to the mean nest initiation date of 16 April (Devers, 2005) to minimize negative impacts on nesting females.

5. Conclusions

A comprehensive understanding of forest management effects on wildlife can be gained through habitat investigations at multiple spatial scales. Similar to other studies, herbaceous groundcover, invertebrates, and midstory stem density were important components of ruffed grouse brood habitat on WSC. These requirements were met where openings in the forest canopy encouraged herbaceous plant growth and moderate woody stem regeneration.

Seventy five percent canopy closure and 17 m^2/ha BA promoted these conditions on WSC. Timber management and prescribed fire can be used to create and maintain these conditions on other areas; however, variability in herbaceous stratum response among eastern forests precludes boilerplate recommendations (Gilliam and Roberts, 2003). Rather, managers should use available information to develop an image of desirable vegetation structure and implement site-specific practices known to reproduce these conditions on their management unit. With this approach, managers can assess and perpetuate ephemeral grouse habitats using adaptive resource management.

Interspersion of forest age classes creates diverse grouse cover in close proximity (Sharp, 1963; Berner and Gysel, 1969; Gullion, 1977; Kubisiak, 1978). Where mature, undisturbed forests have closed canopies, timber management including group selection, thinning, shelterwood, and two-aged shelterwood can improve conditions. The periphery of these managed stands can provide habitat for young broods in summer, while their interiors can provide habitat for juveniles in fall and for adults year-round (Sharp, 1963; Gullion, 1977). In maturing (>40 years), mixed hardwood stands with closed canopies, timber management and prescribed burning can allow sunlight to reach the forest floor, resulting in diverse understory communities favored by grouse broods. On forest roads and permanent clearings, eliminating perennial cool season grasses and maintaining forb communities through minimal maintenance should be a priority (Healy and Nenno, 1983; Harper et al., 2001).

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