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Evaluating the Potential for Ruffed Grouse Restoration in East-central Missouri by Linking Habitat Suitability and Population Viability

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TABLE OF CONTENTS:

LIST OF TABLES:

LIST OF FIGURES:

ABSTRACT

Ruffed grouse *Bonasa umbellus* (hereafter, grouse) are early-successional forest habitat (ESFH) specialists that prefer regenerating deciduous forests < 25 years-of-age for cover. Despite being historically present throughout much of Missouri, USA, grouse numbers declined rapidly during the early 1900s due to habitat loss and over-harvest. Although populations of grouse were reestablished in Missouri through translocations which began in the 1950s, grouse numbers have since declined precipitously, as they have throughout much of their southern range, due to the loss of ESFH. In response to declining grouse numbers, efforts to create ESFH were increased in the River Hills region of east-central Missouri during the early 2000s. Despite these efforts, grouse numbers have continued to decline, prompting the Missouri Department of Conservation to consider a restocking effort. Our objectives were to determine the amount of ESFH within a portion of the River Hills region and to use population viability analysis to evaluate the potential for establishing a self-sustaining grouse population through restocking. We used land use land cover and light detection and ranging (LiDAR) data to assess ESFH availability at three spatial scales within the River Hills region: a 319,100 ha study area, a 23,300 ha focal area, and Daniel Boone (DBCA; 1,424 ha) and Little Lost Creek (LLCCA; 1,173 ha) Conservation Areas. We conducted a population viability analysis to evaluate the potential for grouse population establishment given varying amounts of ESFH. Habitat analyses indicated 3.4% of the study area and 5.2% of the focal area consisted of ESFH < 7.62 m tall (approximately ≤ 25 years-of-age); 4.4% and 9.9% of DBCA and LLCCA consisted of ESFH, respectively. Population simulations under current habitat conditions in the focal area indicated a restocked grouse population would decline to zero by about year 20 post-release, and there was a 0.99 probability of extinction by year 50 post-release. When 25% of DBCA and LLCCA consisted of ESFH, the simulated grouse population grew slowly over 50 years and the probability of extinction decreased to 0.26. We suggest it is highly unlikely that a self-sustaining grouse population could be established under current habitat conditions, but with increased habitat management, a grouse population could be sustained in the region.

INTRODUCTION

The Ruffed Grouse *Bonasa umbellus* (hereafter, grouse) is North America's most widely distributed gallinaceous bird (Johnsgard 1973) with a geographic range extending from Alaska, south to the central Rocky and Appalachian Mountains, and portions of the Central Hardwood Region. Grouse are early-successional forest habitat (ESFH) specialists (Thompson and Dessecker 1997) that prefer even-aged deciduous forests generally supporting about 20,000 woody stems per hectare (Kubisiak 1985; Stoll et al. 1999) although stem densities exceeding about 10,000 stems per hectare (>1 m tall) appear suitable in their southern range (Hunyadi 1978; Kurzejeski 1979; Wiggers et al. 1992). Although the highest quality grouse habitat occurs in regenerating stands 5–15 years-of-age, areas of forest regeneration serve as habitat for up to 25 years post-disturbance (Whitaker 2003). These young, dense, stands protect grouse from predators (Dessecker and McAuley 2001) and provide particularly important cover for drumming males during spring (Stoll et al. 1979).

In contrast to grouse populations in their northern range, which exhibit predictable fluctuations in abundance (Gullion 1984), surveys conducted in portions of their southern range indicate long-term population declines over the last three decades (Sauer et al. 2012). Habitat loss and degradation are the predominant factors affecting grouse populations in their southern range (Thompson and Dessecker 1997) as declines in young forest habitats and isolation of habitat patches may be limiting recruitment and population densities (Dessecker and McAuley 2001). Although timber harvests and proactive habitat management are needed to ensure a continuous supply of grouse habitat, societal attitudes toward timber harvest may continue to limit efforts to provide these critical habitats (Dessecker and McAuley 2001).

Missouri is located at the southwestern edge of the historical range of grouse (Bump et al. 1947) and although present throughout most of the state, grouse populations were perhaps never as high nor as uniformly distributed as in states farther north and east (Lewis et al. 1968). By the early 1900s, habitat loss and market hunting had dramatically reduced grouse numbers throughout much of Missouri (McKinley 1960; Lewis 1971). The earliest grouse restoration efforts in Missouri involving translocation of wild birds occurred during the late 1950s and early 1960s when grouse were released on the Daniel Boone Conservation Area (DBCA) and the Thomas S. Baskett Wildlife Research and Education Center (TBWC) in the River Hills region of east-central Missouri. Based on the success of these early efforts (Lewis et al. 1968), a large-scale grouse restoration program occurred from 1978–1996 (Kurzejeski and Thompson 1999) with a goal of restoring the species to all parts of its native range where suitable forest habitat existed (Hunyadi 1984).

Initial evaluations of most early grouse releases in Missouri were favorable (Lewis et al. 1968; Hunyadi 1984). Just several years following the conclusion of the restoration efforts, however, the long-term ability of grouse populations to persist was questionable in all but a few cases (Kurzejeski and Thompson 1999). Whereas populations remained in some scattered locations throughout portions of the state, the only populations that persisted and expanded their ranges were those associated with the original release sites on DBCA and TBWC (Kurzejeski and Thompson 1999). Despite persisting for more than 35 years and expanding to a range encompassing 19,425 km^2, grouse numbers within the River Hills region have since declined precipitously (Forbes 2009).

In response to declining grouse numbers in the River Hills region, state and federal agencies, nongovernmental organizations, and private landowners formed the River Hills Forest Habitat Partnership in 2002 with a goal of increasing the amount of ESFH in the River Hills region to benefit grouse and other wildlife species that depend on this habitat type. Habitat management resulting from the partnership occurred on private lands to complement work being conducted on public lands managed by the Missouri Department of Conservation (MDC), and to expand the amount and connectivity of ESFH regionally. Despite these efforts grouse numbers have not rebounded within the region (Forbes 2009).

To effectively manage grouse, managers would benefit from knowing the potential for the region to support a viable population, and if restocking grouse to the region would result in a greater and more viable population. Therefore, the objectives of our study were to: (1) determine the amount of ESFH within a portion of the River Hills region, and (2) use population viability analysis to evaluate the potential for establishing a self-sustaining grouse population in the River Hills through a restocking effort.

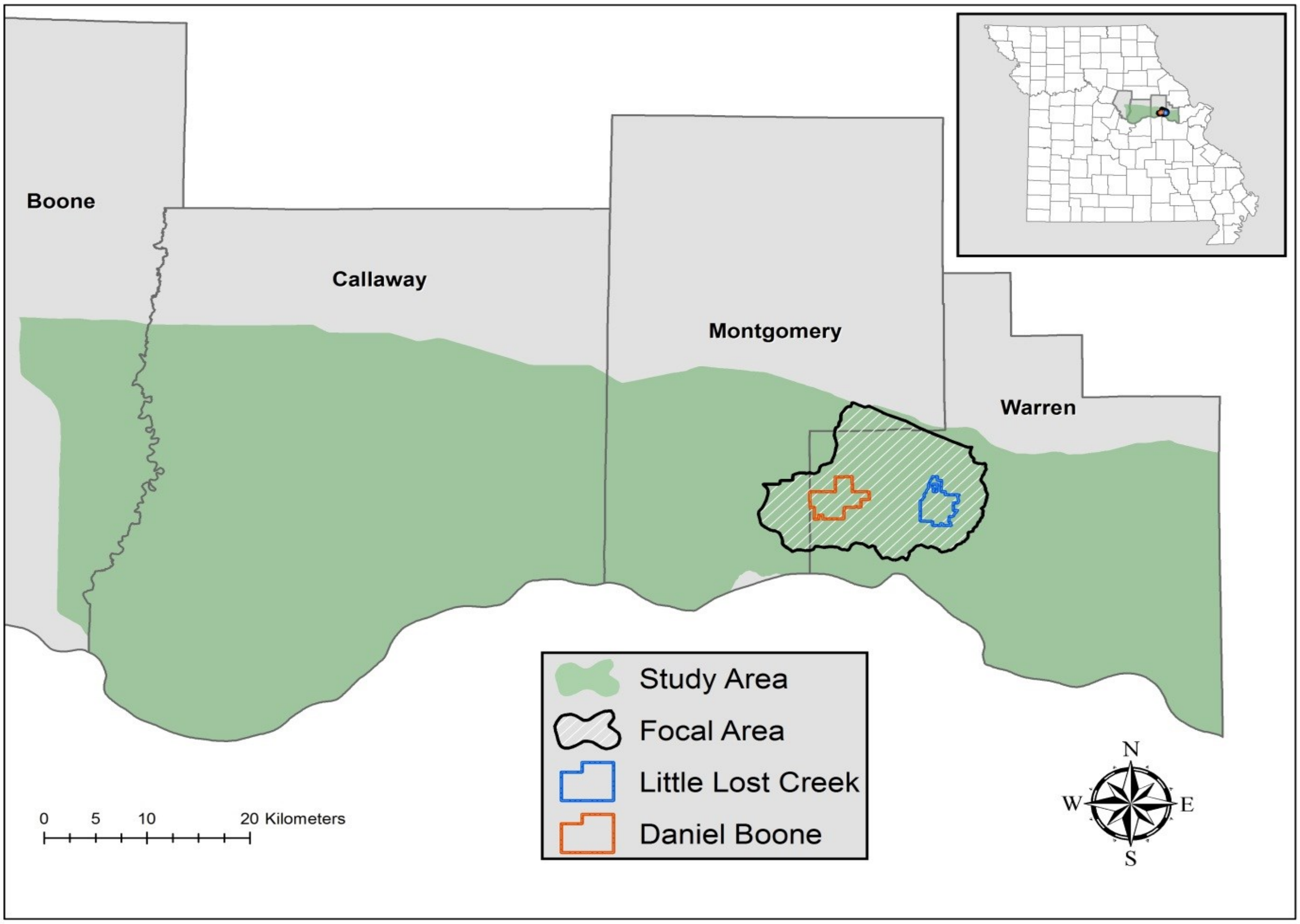

Figure 1. Study area, focal area, Daniel Boone and Little Lost Creek Conservation Areas, and portions of Boone, Callaway, Montgomery, and Warren Counties used in a study of ruffed grouse population viability in Missouri, 2014.

STUDY AREA

We determined the amount of ESFH at three spatial scales: 1) study area (319,100 ha) located in the River Hills region of east-central Missouri in portions of Boone, Callaway, Montgomery, and Warren Counties, 2) focal area (23,000 ha) located within the study area in portions of Montgomery and Warren Counties, and 3) DBCA (1,424 ha) and Little Lost Creek Conservation Area (LLCA; 1,173 ha) located within the focal area in Warren County (Figure 1).

The study area was located almost entirely within the Outer Ozark Border subsection of the Ozark Highlands (Nigh and Schroeder 2002). This heavily forested region is dominated by rugged terrain consisting of highly dissected hills and streamside breaks. Regional relief is mostly 61–107 m (Nigh and Schroeder 2002). The ecoregion historically consisted of oak *Quercus* spp. savanna and woodland, oak and mixed-hardwood forests, and occasional prairie and glades. The current landscape remains heavily forested but includes some row crop agriculture and pastureland. Daniel Boone Conservation Area and LLCCA are managed by the MDC with a focus of restoring and maintaining natural communities. The areas consist mostly of oak-hickory *Carya* spp. forests, woodlands, and glades, and are open to a variety of public uses.

After determining the amount of ESFH, we assessed population viability at the focal area scale because it contained DBCA and LLCCA, where ESFH management had been ongoing. This was also one of the most heavily-forested portions of the study area, offering what we believed was the greatest potential to support a grouse population.

METHODS

Habitat Analysis

Land use land cover analysis.–The Missouri Resource Assessment Partnership (MoRAP; Columbia, Missouri) created a land use land cover (LULC) map of the study area generated from a 15-class 30-m spatial resolution dataset current as of October 2011. A classification and regression tree (CART) modeling approach, using a boosted regression tree in See5 software (RuleQuest Research Pty Ltd, St Ives NSW 2075, Australia), was used to classify 15 LULC classes based on > 2,000 spatially explicit photo-interpreted ground samples. Natural and false color aerial imagery were used to determine to which of the 15 LULC classes each of the ground samples belonged. Leaf-on and leaf-off imagery were used to ensure that cover types were viewed from two distinct points in time to exploit phenological differences. Twenty-five layers of information were used for data classification including spring, summer, and fall Landsat Thematic Mapper data and digital elevation model (DEM) derived variables (aspect, slope, solar insolation, and landscape position). The layers included six bands from each of the Landsat 5 satellite scenes (18 total), alluvium, aspect, slope, solar, insolation, landscape position, National Land Cover Database (NLCD; Multi-Resolution Land Characteristics Consortium) forest canopy, and NLCD impervious surface.

Forest canopy height analysis.–A vegetation height map of the study area was created by MoRAP using light detection and ranging (LiDAR). Light detection and ranging is an active remote-sensing technique that uses discrete light pulses and measured time intervals to collect dense and accurate elevation values, which are used to generate a three-dimensional representation of the earth's surface (NOAA 2008; Vierling et al. 2008). Light detection and ranging data are typically collected from aircraft, enabling rapid point collection over large areas (NOAA 2008). Although LiDAR is a relatively recent tool for ecological researchers, it has already demonstrated its ability to accurately measure topography, vegetation height, and cover in addition to more complex canopy structure and function attributes (Lefsky et al. 2002). Because early-successional forests provide habitat for grouse (Kurzejeski et al. 1987; Stoll et al. 1999), identification of these areas was critical to quantifying grouse habitat availability on the study area. Because a high degree of correlation exists between forest canopy height and forest age (Johnson et al. 2009), use of LiDAR to map forest canopy height represented a means of quantifying grouse habitat.

Light detection and ranging data were available for the portion of the study area located in Warren, Boone, and Callaway Counties (Missouri Spatial Data Information Service, Columbia, Missouri). These data were flown in 2008, 2009, and 2010 for each respective county. Quick Terrain Modeler software (Applied Imagery, Chevy Chase, Maryland) was used to generate a DEM representing the elevation of bare ground and a digital surface model (DSM) to represent canopy elevation. Each raster was output at 10-m spatial resolution to match the resolution of the multispectral Spot5 satellite imagery and other ancillary data used to model vegetation height in the portion of the study area located in Montgomery County where LiDAR data were unavailable. The DEM raster was subtracted from the DSM using the raster calculator to generate a relative height raster.

Light detection and ranging data were not available for a 37,800 ha (11.8%) portion of the study area located in Montgomery County; therefore, MoRAP modeled vegetation height based on the spectral relationship with LiDAR vegetation height (Pascual et al. 2010; Stojanova et al. 2010). Fifty-two independent variables were used to inform the classification including 10-m spatial resolution spring and summer 2010 Spot5 imagery (no suitable fall data were available for the study area), Spot5 spectral statistics for each band, Spot5 based vegetation indices, DEM variables, and soils. Where LiDAR data were available, 1,400 training sample points, stratified by 3-m height classes, were taken within the study area. These samples were input into See5 CART modeling software (RuleQuest Research Pty Ltd, St Ives NSW 2075, Australia) to produce vegetation height models. Image objects were created using eCognition software (Trimble Navigation Ltd., Westminster, Colorado) based on leaf-on and leaf-off spring and summer 2010 Spot5 imagery to extract spectral values for each band over the study area to be used in modeling. Stojanova et al. (2010) used a similar approach with Landsat Thematic Mapper imagery. Based on Spot5 imagery, 1.7 million objects were generated. For each object, the maximum, minimum, mean, and standard deviation of Spot5 spectral values were calculated for each band of spring and summer dates of imagery and then applied to the objects. Each of the four spectral statistics was converted to a raster for each band, resulting in 36 rasters of Spot5 statistics to be used as independent variables for modeling.

The stratified random sample points were used to determine a statistical relationship between vegetation height and the spectral and environmental independent variables. Two products were generated that modeled vegetation height in a different manner. Both were output at 10-m resolution. The first product was a thematic classification based on seven height classes in 3-m increments. A boosted regression tree was generated to predict the classification with a 10-fold cross-validated accuracy of 52%. This 7-class vegetation height dataset was used to fill the LiDAR gap for the 7-class vegetation height raster ranging from 0–3 m to ≥ 18.3 m. The second product was a continuous vegetation height surface modeled using Cubist (RuleQuest Research Pty Ltd, St Ives NSW 2075, Australia) data mining software to build a rule-based predictive model. The sample points used in the thematic classification were used in this modeling effort, however, to inform the model, the absolute height value at each point was used rather than the height class value. The resulting Cubist model produced a continuous height surface with a 10-fold cross-validated correlation coefficient of 0.79 and a RMS of 2.9 m. This dataset was used to populate the portion of the study area in which LiDAR data were unavailable.

Light detection and ranging data were used to determine the amount of ESFH within the study area, focal area, and on DBCA and LLCCA. Although the highest quality habitat occurs from 5–15 years post-disturbance, regenerating forest stands are used by grouse for up to 25 years (Whitaker 2003); therefore, we classified all forested land cover types < 7.62m tall (approximately ≤ 25 years-of-age; Johnson et al. 2009) as ESFH. We acknowledge that the length of time a regenerating forest provides habitat for early-successional species such as grouse is also dependent on site quality and cause of disturbance (Thompson and DeGraaf 2001). However, given the relationship between woody stem density and forest age (Thompson and DeGraaf 2001), and the large spatial scale of our study area, we believe our approach represents a reasonable way of identifying ESFH.

Population Modeling

We modeled grouse populations using a stage matrix model approach similar to that used by Tirpak et al. (2006) and Devers et al. (2007). Because young forest habitats protect grouse from predators throughout the year (Dessecker and McAuley 2001), we linked survival rates to habitat availability, measured as the percentage of ESFH. We parameterized fecundities and survivals in the stage matrix using data from Tirpak et al. (2006) and Devers et al. (2007). We used data from the three study sites from Tirpak et al. (2006) that were most similar to Missouri in forest composition (i.e., Virginia 2, West Virginia 2, North Carolina 1) because grouse demographics differ between oak-hickory and mixed-mesophytic forests

(Tirpak et al. 2006; Devers et al. 2007). We implemented population simulations using RAMAS GIS software (Applied Biomathematics, Setauket, New York).

We modeled the female portion of the population in a stage matrix model that included juvenile and adult stages

$$\begin{bmatrix} f_j & f_a \\ s_j & s_a \end{bmatrix},$$

where f_j and f_a are stage-specific fecundity and s_j and s_a are stage-specific annual survival. We used annual time steps in which nesting occurred each spring, juveniles became adults immediately after the breeding season, and a post-breeding census occurred (Caswell 2001). Reported population sizes represent adults and juveniles on approximately September 1 (Tirpak et al. 2006). Fecundities for juveniles and adults represent recruitment and are productivity (female chicks per hen) multiplied by survival for juveniles and adults, respectively (Caswell 2001). All elements of the stage matrix were subject to stochastic variation to approximate environmental variation and effects on vital rates. Standard deviations were 0.128, 0.148, 0.138, and 0.167 for juvenile and adult fecundities and survivals, respectively, and were representative of the range of values reported by Tirpak et al. (2006). Because the model was stochastic, we present population projections that are the mean and standard deviations for 1,000 simulations of each scenario.

Devers et al. (2007) estimated annual productivity multiple ways, but the estimate that performed best in population models was 0.91 female chicks per female, which was based on the number of female chicks alive 35 days post-hatch per female alive on April 1. Because this estimate incorporated productivity (number of female chicks produced) and breeding season survival of females, juvenile and adult fecundities were 0.91 × juvenile non-breeding season survival and 0.91 × adult non-breeding season survival, respectively.

We linked survival to habitat quality by making it a function of the percentage of early-successional forest. To obtain these functions, we regressed juvenile and adult breeding season and non-breeding season survival rates on the percentage of early-successional forest on the three previously mentioned study sites from Tirpak et al (2006). We then estimated these four survival rates as a function of the percentage of early-successional forest in the scenario being considered using the regression equation and annual survivals as the breeding season survival × non-breeding season survival.

In the first scenario, we modeled a single grouse population with a starting abundance of 1,000 females to simulate population growth at varying levels of ESFH (5.2%, 10%, 15%, 20%, and 25%). In a second scenario, we constructed a model with separate populations for DBCA and LLCCA and the rest of the focal area to simulate a possible grouse release scenario. In this scenario, we used current percentages of early-successional forest on DBCA (4.4%; Table 1) and LLCCA (9.9%; Table 1). In a third scenario, we simulated population growth with 25% ESFH on both DBCA and LLCCA. We selected 25% ESFH for DBCA and LLCCA because that level resulted in population growth under the first modeling scenario and we wanted to determine population trends when DBCA and LLCCA were managed under this ideal scenario. For the second and third modeling scenarios, we assumed the remainder of the focal area (excluding DBCA and LLCCA) had its current percentage of ESFH (5.2%; Table 1). Survivals and fecundities for the second and third scenarios were established as in the single population model, based on the percent of ESFH; however, for the first year of the simulations, we calculated survivals and fecundities on DBCA and LLCCA based on a non-breeding season survival of 25% because this represents the approximate pooled survival rate for released grouse in Missouri (Kurzejeski and Root 1988) and because there is

Table 1. Percentages of early-successional forest (<7.62 m tall; 2008-2010) in the study area, focal area, and Daniel Boone and Little Lost Creek Conservation Areas in a study of ruffed grouse population viability in portions of Boone, Callaway, Montgomery, and Warren Counties, Missouri, 2014.

Spatial scale	Total area (ha)	% Area < 7.62 m tall
Study area	319,616	3.4
Focal area	23,290	5.2
Daniel Boone Conservation Area	1,424	4.4
Little Lost Creek Conservation Area	1,173	9.9

often elevated mortality following animal translocations (Dickens et al. 2010).

For the second and third scenarios, we set starting populations on DBCA and LLCCA at 30 female grouse each to represent releases of 60 grouse (Hunyadi 1984; assumes 50:50 sex ratio) at each area in the fall, and arbitrarily set the number of females in the rest of the focal area at 25 to represent a small established population. Populations were linked by dispersal such that each received 5% of the juveniles produced in each of the other two populations annually. Because DBCA and LLCCA had positive growth rates, they acted as population sources whereas the focal area had a negative growth rate, therefore, acting as a sink. We selected 5% dispersal because it allowed some growth in the sources while keeping them below any reasonable carrying capacity and supported persistence of the sink. We believe this is a reasonable approximation of how grouse would select habitat (Thompson et al. 1987) and disperse in this landscape.

RESULTS

Habitat Analysis

Land use land cover analysis.–Deciduous forest was the most abundant cover type (38%) in the study area. Grassland, cropland, mixed forest, and urban areas represented 31%, 12%, 4%, and 4% of the study area, respectively (Figure 2). Deciduous forest represented 66% of the focal area and grassland was the only other land cover type that comprised > 10% of the area (Figure 2). Ninety-five percent and 90% of DBCA and LLCCA, respectively, were deciduous forest and all other cover types represented < 10% of the land area.

Forest canopy height analysis.–Early successional forest (<7.62m tall) was 3.4% and 5.2% of the study area and focal area, respectively, and 4.4% and 9.9% of DBCA and LLCCA, respectively (Figures 3–5, Table 1).

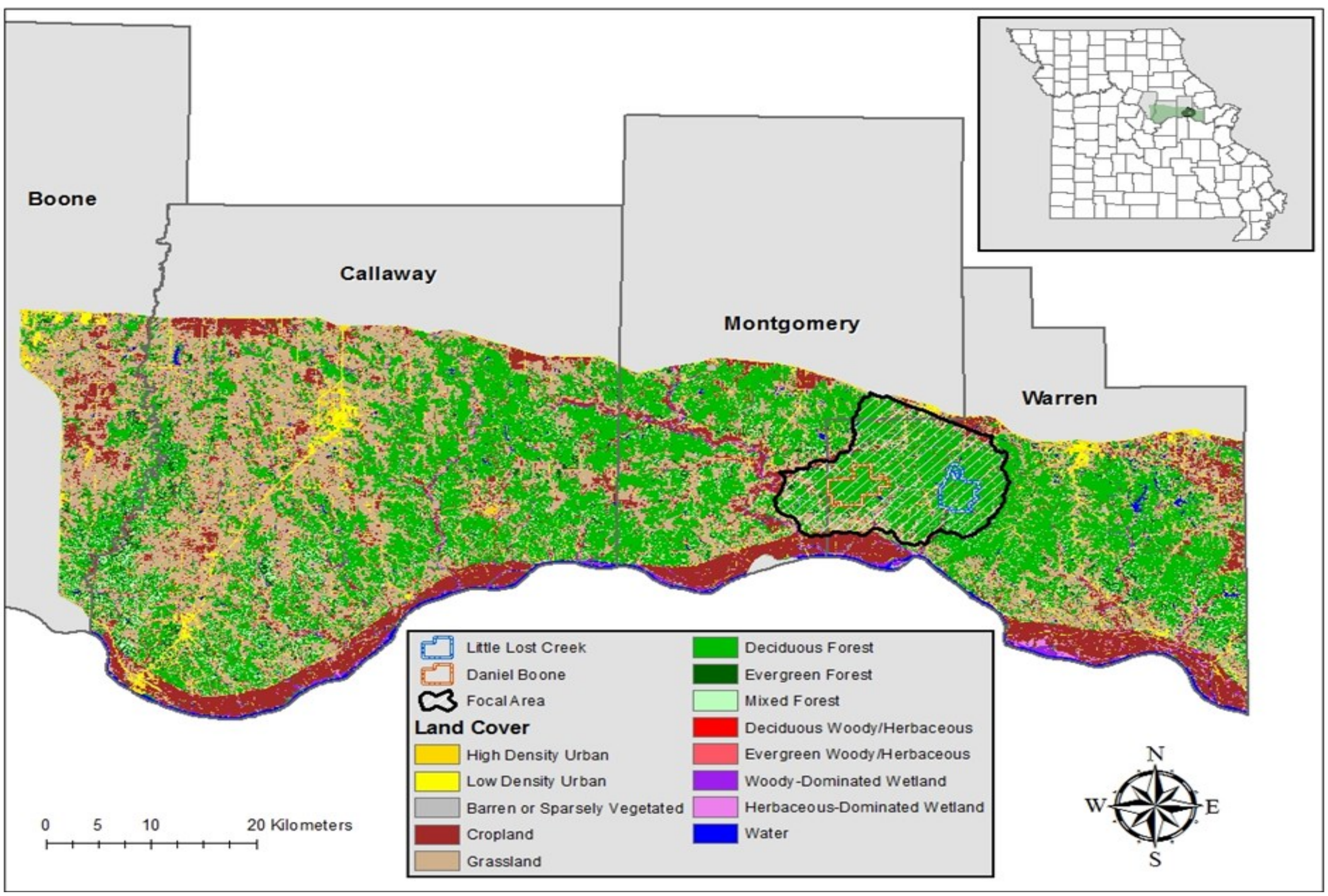

Figure 2. Land cover in 2011 in the study area, focal area, and Daniel Boone and Little Lost Creek Conservation Areas used in a study of ruffed grouse population viability in portions of Boone, Callaway, Montgomery, and Warren Counties, Missouri, 2014.

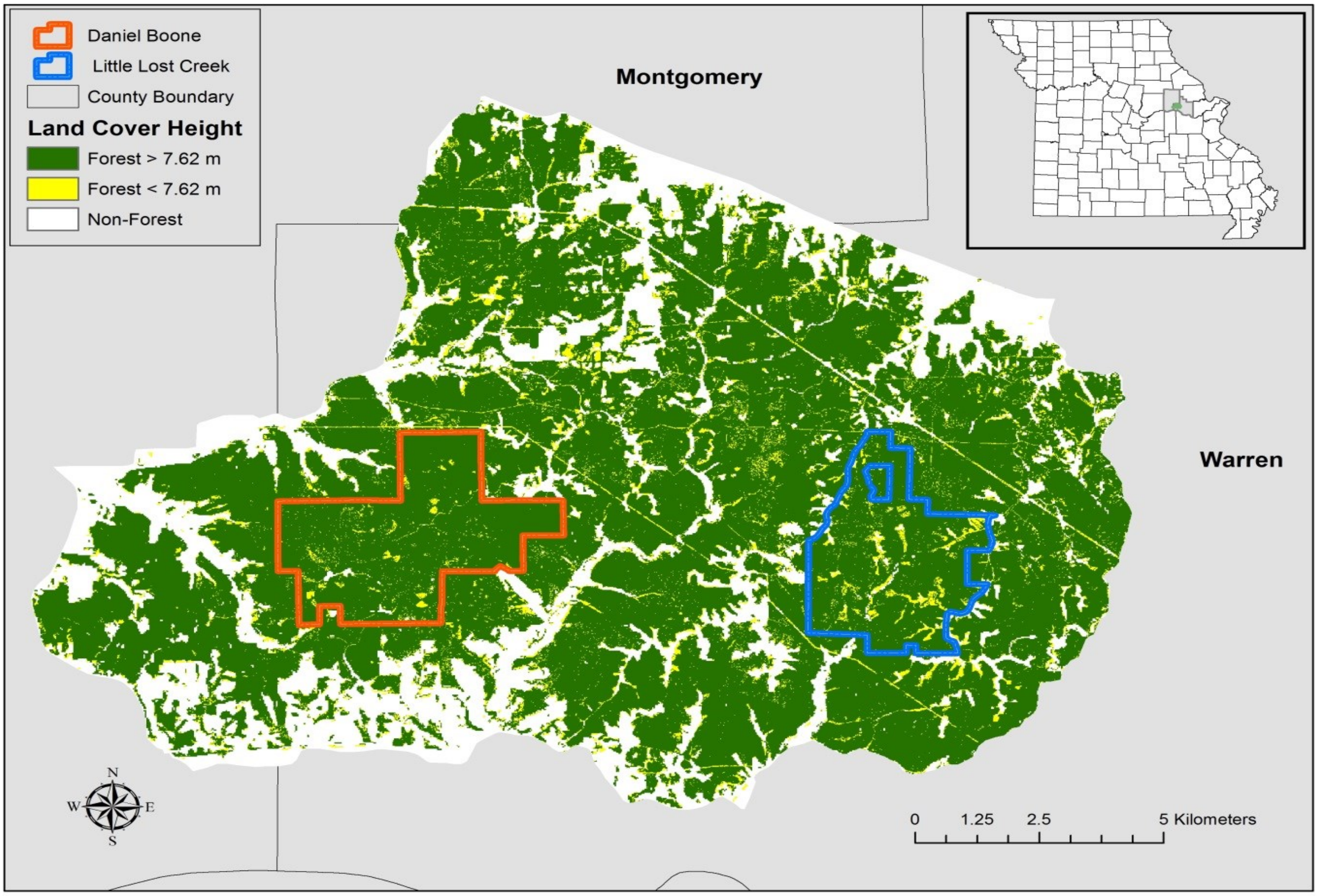

Figure 3. Forest canopy height and non-forest cover types in 2008 on Daniel Boone and Little Lost Creek Conservation Areas in the focal area used to study ruffed grouse population viability in portions of Montgomery and Warren Counties, Missouri, 2014.

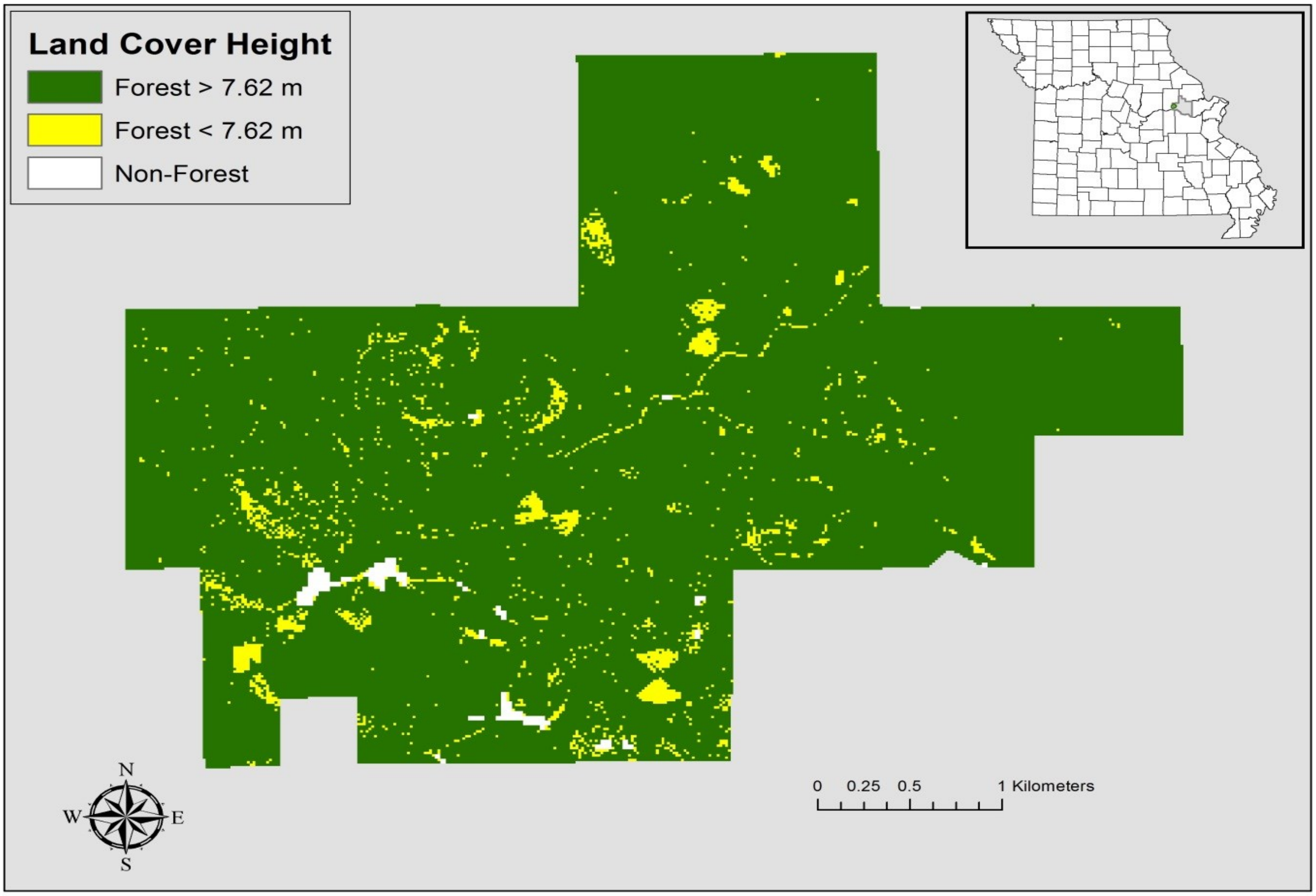

Figure 4. Forest canopy height and non-forest cover types in 2008 on Daniel Boone Conservation Area, Warren County, Missouri used in a study of ruffed grouse population viability in 2014.

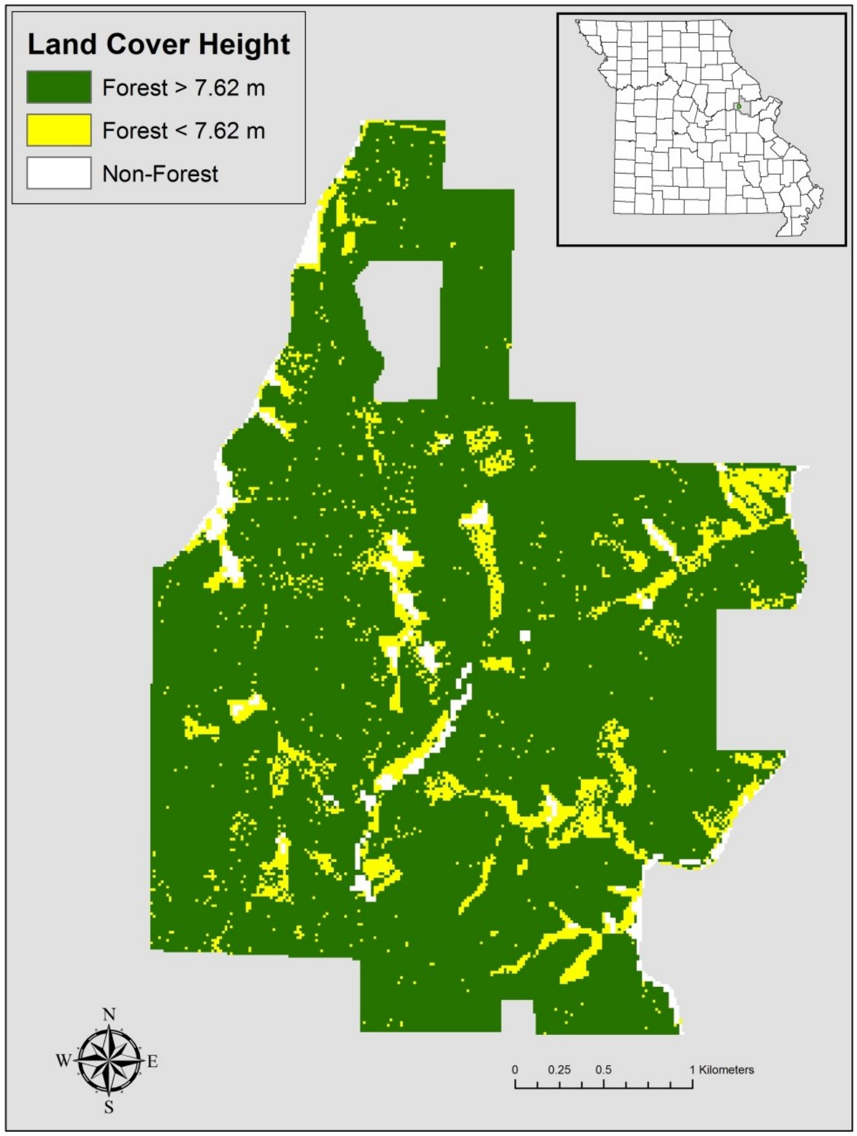

Figure 5. Forest canopy height and non-forest cover types in 2008 on Little Lost Creek Conservation Area, Warren County, Missouri used in a study of ruffed grouse population viability in 2014.

Population Modeling

Adult breeding season survival rates (from Tirpak et al. 2006) were highly correlated with the percentage of ESFH on the three study sites from Tirpak et al. (2006) ($R^2 = 0.969$; Figure 6, Table 2). This relationship was considerably weaker for juvenile breeding season survival (0.024), but stronger for both adult (0.571) and juvenile (0.536) non-breeding survival.

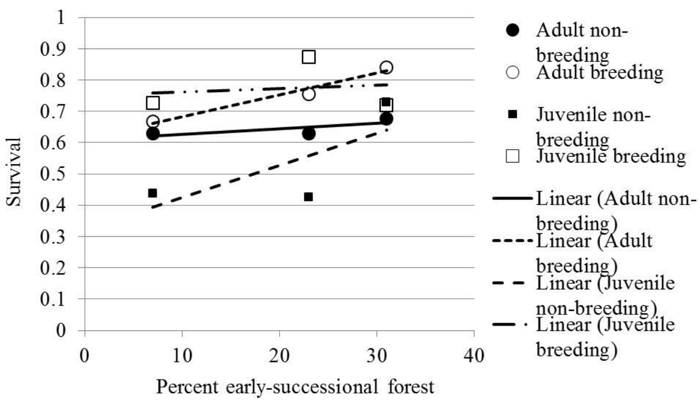

Figure 6. Breeding and non-breeding survival for juvenile and adult ruffed grouse as a function of percent early-successional forest. We fit simple linear regression models to survival estimates from the three sites (Tirpak et al. 2006) to estimate survival for a study of ruffed grouse

Table 2. Model parameters, standard errors (SE), and R^2 for regression models predicting ruffed grouse survival rates as a function of percent early-successional forest on three study sites from Tirpak et al. (2006) that we used in a study of ruffed grouse population viability in Missouri, 2014.

	Intercept		Percent early-successional forest		
Survival rate	Parameter	SE	Parameter	SE	R^2
Adult breeding	0.612	0.028	0.701	0.125	0.969
Adult non-breeding	0.61	0.034	0.171	0.148	0.571
Juvenile breeding	0.752	0.156	0.111	0.705	0.024
Juvenile non-breeding	0.324	0.212	1.007	0.937	0.536

We estimated fecundities and survivals for different levels of ESFH (5.2%, 10%, 15%, 20%, 25%, and 30%). Adult fecundities and survival rates were greater than those of juveniles (Table 3). Survival rates for adults (0.544) and juveniles (0.495) were greatest at 30% ESFH as were fecundities, which were 0.602 and 0.574, respectively (Table 3).

Table 3. Estimated fecundities and survivals as a function of percentage of early-successional forest used to simulate ruffed grouse populations in Missouri, 2014. Fecundities are based on an annual productivity of 0.91 female chicks per female (Devers et al. 2007) and survivals predicted from regression models fit to data from Tirpak et al. (2006).

	Percent early-successional forest					
Matrix element	5.2%	10%	15%	20%	25%	30%
Juvenile fecundity	0.341	0.386	0.433	0.48	0.527	0.574
Adult fecundity	0.563	0.571	0.579	0.586	0.594	0.602
Juvenile survival	0.284	0.324	0.366	0.408	0.451	0.495
Adult survival	0.402	0.428	0.456	0.485	0.514	0.544

The simulated single population of 1,000 female grouse declined rapidly with 5% and 10% ESFH and was extinct, on average, in less than 20 and 25 years, respectively (Figure 7). The population declined at slower rates with 15% and 20% ESFH, but was still nearly extinct in 30 years at 15% ESFH and had declined by > 50% with 20% ESFH. With 25% ESFH, the population had nearly exponential growth (Figure 7).

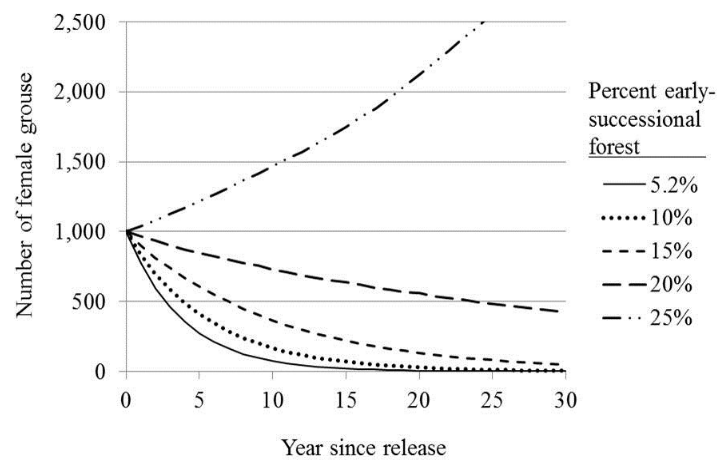

Figure 7. Simulated population trajectories for a ruffed grouse population with varying levels of early-successional forest in the focal area in Missouri, 2014; 5.2% was the current level of early-successional forest.

Population simulations of a grouse release on DBCA and LLCCA with current percentages of ESFH (Table 1) resulted in rapid population decline to zero within about 20 years of release and had a 0.96 and 0.99 probability of extinction at year 30 and 50, respectively (Figure 8).

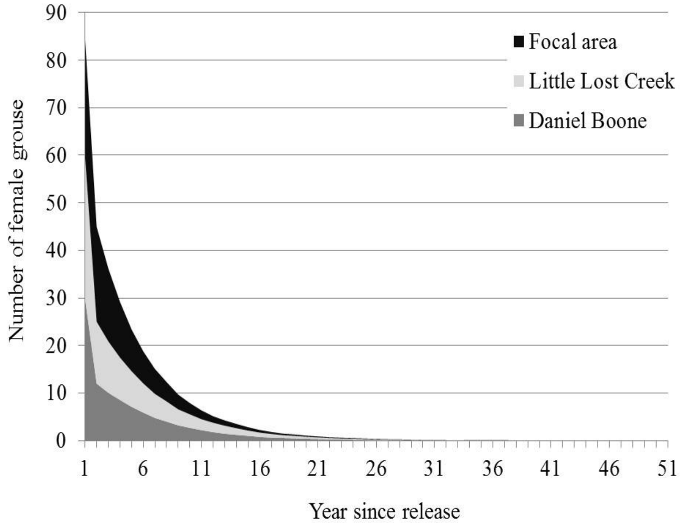

Figure 8. Mean population size based on a three population model simulating a reintroduced population of ruffed grouse on Daniel Boone (DBCA) and Little Lost Creek Conservation Areas (LLCCA), Warren County, Missouri, 2014. Simulation assumed 60 grouse (30 females) were released on each area, 25 female grouse were present in the remainder of the focal area, and current levels of early-successional forest (5.2%, 4.4%, and 9.9% on the focal area, DBCA, and LLCCA, respectively).

When we increased the percentage of ESFH on DBCA and LLCCA to 25%, population simulations resulted in an initial decline due to low first year survival following the release, then an increase to approximately 120 grouse (assuming 50:50 sex ratio) 50 years post-release and a 0.13 and 0.26 probability of extinction at year 30 and 50, respectively (Figure 9).

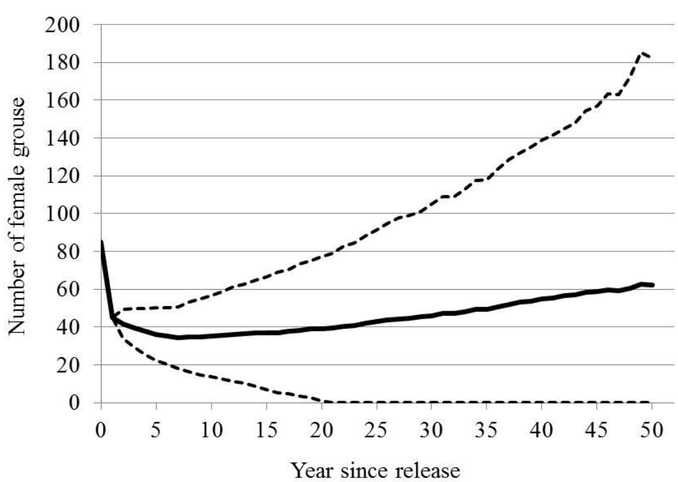

Figure 9. Mean population size (+ 1 S.D.) based on a three population model simulating a reintroduced population of ruffed grouse on Daniel Boone (DBCA) and Little Lost Creek Conservation Areas (LLCCA), Warren County, Missouri, 2014 if early-successional forest represented 25% of DBCA and LLCCA. Simulation assumed 60 grouse (30 females) were released on each area and there were 25 female grouse and current levels of early-successional forest (5.2%) in the remainder of the focal area.

DISCUSSION

Grouse are ESFH specialists (Thompson and Dessecker 1997) that are declining in abundance throughout their southern range (Sauer et al. 2012) primarily as a result of habitat loss due to succession (Thompson and Dessecker 1997; Dessecker and McAuley 2001). In Missouri, the proportion of hardwood timberland consisting of small-diameter stands declined by more than 50% from the 1980s to the 2000s (Franzreb et al. 2011). Similarly, results of our study indicate the amount of ESFH within our study and focal areas is very limited. Even on DBCA and LLCCA, where ESFH management has been ongoing, the percentage of ESFH remains considerably less than what modeling results suggest is needed to sustain a grouse population.

Given the low percentage of ESFH on the study area, focal area, and on DBCA and LLCCA, there is a high probability that a translocated grouse population would go extinct relatively quickly. Because habitat quality is probably the primary reason for unsuccessful grouse releases in Missouri (Hunyadi 1984), a restocking effort at this time given current habitat conditions, would be unlikely to result in the establishment of a self-sustaining population. We acknowledge there is uncertainty in the population parameters used in the models, however, we feel there is a high level of confidence in the general result that more ESFH is required to sustain a grouse population in the study area than is currently present.

Although we cannot state specifically what particular amount of ESFH is required to establish a grouse population, results of our study suggest that oak-hickory forests with 25% of the landscape < 25 years old are capable of sustaining grouse populations. Similarly, Kurzejeski et al. (1987), in the context of restoration criteria, believed grouse release sites in Missouri should contain 15–20% of the forest at < 20 years old and Whitaker (2003) recommended grouse habitat managers maintain 8–12% of the landscape in forests from 5–15 years old. Creating the amount of habitat that population modeling suggests is needed to sustain a grouse population would require increasing the amount of ESFH on DBCA and LLCCA by 5.7 times and 2.5 times current levels, respectively.

MANAGEMENT IMPLICATIONS

A grouse release in the River Hills would be unlikely to result in the establishment of a self-sustaining population under current habitat conditions. We believe there is a high probability that a grouse population could be self-sustaining within the region if DBCA and LLCCA were managed such that 25% of their area had forests < 25 years-of-age at any given time. Because even-aged silvicultural systems are the most appropriate for creating grouse habitat (Thompson and Dessecker 1997; Dessecker and McAuley 2001; Fearer and Staufer 2003; Whitaker 2003; Dessecker et al. 2006), forest management should involve regeneration or shelterwood harvests leaving residual basal areas < 4.6 m^2/ha (Thompson and Dessecker 1997). Although grouse will use forest stands for up to 25 years post-harvest, regenerating stands 5–15 years-of-age offer the highest quality habitat (Whitaker 2003). As such, presence and distribution of this age class would likely have considerable influence on population establishment and expansion following a release.

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