LANDSCAPE AND LOCAL INFLUENCES OF FOREST MANAGEMENT ON CERULEAN WARBLERS IN PENNSYLVANIA

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ABSTRACT.— Populations of cerulean warblers (*Dendroica cerulea*) have declined rangewide, and conservation of this mature-forest species is poised to become a major forest management issue in central hardwood forests. Although cerulean warblers are associated with large trees in mature forest, cerulean warblers also use edges of timber harvests, roads, and ridgetops within heavily forested areas – all habitats with heterogeneous canopy structure. Thus, certain types of forest management may be compatible with conservation of this declining species and may even create habitat by creating canopy gaps. In this paper, I examined data from the forested landscapes of Pennsylvania (1997-1999) and asked how local and landscape-level characteristics influenced the occurrence of cerulean warblers. More specifically, I examined the extent to which amount of forest cover within 1 km, distance from recent harvests (<5 years old), and habitat structure were associated with presence of cerulean warblers. Occurrence of cerulean warblers on 17 mature oak-hickory forest stands was best explained by distance to the nearest timber harvest. Within forested landscapes of Pennsylvania, cerulean warlbers were more likely to occur closer to, rather than farther from recent silvicultural activity. However, this model was closely ranked to other univariate models containing forest cover, canopy cover, large trees, and snags. Results suggest that cerulean warblers respond to a suite of local and landscape-level factors.

Conservation of cerulean warblers (*Dendroica cerulea*) is poised to become a major forest management issue in eastern deciduous forests. Cerulean warblers were once fairly common birds in Appalachian hardwood forests, but populations of this mature-forest warbler have declined rangewide since 1966, with annual declines of –4.4 percent (Sauer et al. 2003). The Ohio Hills and Northern Cumberland Plateau Physiographic Provinces still hold the greatest breeding concentrations of this warbler (Rosenberg et al. 2000). Even in these areas, though, steep declines are evident (Sauer et al. 2003), making population trends especially alarming. Cerulean warbler is listed as a species of concern by U.S. Fish and Wildlife Service, a high priority species by Partners-In-Flight, and a WatchList species by the National Audubon Society. Cerulean warbler also was petitioned for federal protection (threatened status) in 2002. If this species is federally protected under the Endangered Species Act (ESA), forest management in eastern deciduous forests will be dramatically impacted. Even if the bird is not formally protected under ESA, conservation of cerulean warblers will remain an important goal of agencies and conservation organizations.

Anthropogenic land use changes are probably the primary cause of population declines for cerulean warblers. In particular, fragmentation of mature, deciduous forest on breeding grounds is cited as an important contributing factor (Hamel 2000). Indeed, cerulean warblers are usually considered area-sensitive, and minimum patch sizes range from 10->8,000 ha (Hamel 2000). Such variation in area requirements is likely a consequence of different amounts of regional forest cover. The species also may be sensitive to land uses within landscapes. For example, cerulean warblers were more likely to occur in forested landscapes disturbed by silviculture than forested landscapes disturbed by agriculture (Rodewald and Yahner 2001).

Paradoxically, forest harvesting has the potential to be an important tool for the conservation of cerulean warblers, as it may improve habitat conditions by creating canopy gaps and heterogenous forest structure. Cerulean warblers often are associated with well-spaced large trees with high canopies

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(Jones and Robertson 2001). They also use edges of timber harvests, roads, and ridgetops within heavily forested areas. For example, cerulean warblers were detected in and adjacent to variable retention stands containing ca. 100 trees/ha in central Pennsylvania, (Rodewald and Yahner 2000). Similarly, these birds frequently sang in trees adjacent to clearcuts (4-20 ha) and forest roads in the forested landscapes of southern Ohio (A.C. Vitz, pers. obs). Due to their apparent preference for tall, uneven forest canopies, shorter rotation periods and even-aged silvicultural methods may negatively affect cerulean warblers because fewer stands reach maturity (Hamel 2000).

Presently, efforts to manage many forest wildlife species are constrained by inadequate knowledge about responses to silvicultural activities (Thompson et al. 2000), and this is especially true for cerulean warblers. Forest managers lack a thorough understanding of how this sensitive species responds to forest management at both local and landscape scales. I used data from the forested landscapes of Pennsylvania (1997-1999) to determine how local and landscape-level forest management activities influenced the occurrence of cerulean warblers. More specifically, I examined the extent to which amount of forest cover within 1 km, distance from recent harvests (<5 years old), and habitat structure were associated with presence of cerulean warblers.

Study Area

This study was conducted in Rothrock and Bald Eagle State Forests in central Pennsylvania. These state forestlands were primarily comprised of mature forest with scattered even-aged harvests (7-38 ha, 1-5 years old) and intermittently occupied residences. Thus, the landscape matrix was forested, and silvicultural disturbances occurred as patches within the forest matrix. Most roads in the study area were unpaved, narrow (<20 m wide) roads covered by a relatively unbroken forest canopy. Sites had little slope, were 250-500 m in elevation, and did not occur along ridgetops. Tree species common in the study area included white oak (*Quercus alba*), northern red oak (*Q. rubra*), chestnut oak (*Q. prinus*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), black gum (*Nyssa sylvatica*), black cherry (*Prunus serotina*), and hickories (*Carya* spp).

Methods

I selected 17 25-ha forest sites within contiguous mature forest (approximately 80-110 years old) and delineated 1-km radius landscapes centered on each study site. Because cerulean warbler territories average 1 ha (range = 0.38-2.4 ha; Oliarnyk and Robertson 1996), a 314-ha area was thought to represent a landscape in that it could contain multiple conspecific territories and multiple land cover types. I calculated forest cover from classified thematic mapper imagery using ARC/INFO geographic information system software (ERSI 1997). Even-aged harvests, such as clearcuts less than 15 years old, were classified as non-forest. Older sapling or pole-stage forests could not be distinguished from mature forest by thematic mapper imagery. Uneven-aged techniques had not been widely applied in the study area. Recent harvests were digitized manually using ARC/VIEW geographic information system software. Because most (>80 percent) non-forest cover within the landscape consisted of recent (<15 years) even-aged harvests, percent forest cover was used as an inverse indicator of the amount of silvicultural activity within the landscape. I also calculated distance (m) to nearest recent harvest (<5 years old) directly from maps. This measure indicated the proximity of intense silvicultural activity to the study site, which is relevant to short-term displacement and disturbance. Sites averaged 76 percent ± 13.7 forest cover within 1 km (range = 49-95 percent) and 550 m from a recent harvest ± 348 m (range = 150-1000 m).

Cerulean warblers were sampled at 3 points located at 150-m intervals along a transect bisecting each study site from 30 May-25 June 1997-1999. Points were at least 150 m from habitat edges (e.g., road or clearcut), and all were located in mature forest. Twice per year, 10-minute, 50-m radius point counts were conducted between 0545-1045 on days without strong wind (> 20 mph) or rain. To minimize temporal effects, I surveyed sites in reverse order on the day of the second visit. Abundance data for cerulean warblers were summed over the three point counts per site and averaged over the two visits in each year (to produce one measure of abundance for each site per year). I later converted these data to simple presence-absence (1,0) for each site (over all 3 years combined).

Habitat characteristics were measured in a 0.04-ha (11.4-m radius) circular plot centered on each of the three bird-sampling points in late June 1997. Numbers of live trees by species in three dbh (diameter breast height) classes (8-23 cm, 23-38 cm, and > 38 cm dbh) and number of snags (standing dead trees $\geq$ 15 cm dbh) were recorded. I also established two 20-m perpendicular transects through the center of each sampling point in north-south and east-west directions. The forest canopy was measured at 2-m intervals along these transects using an ocular tube (hit, no-hit) and used to calculate percent canopy cover (total number of hits/20 points).

Because use of traditional hypothesis-testing in observational studies has been criticized recently, I used an information-theoretic approach, which is considered to be more robust than traditional hypothesis-testing for many ecological studies because it emphasizes fitting and ranking explanatory models as opposed to using *P*-values (Burnham and Anderson 1998, Johnson 1999). Due to my limited sample size (n=17 sites), I could examine only a small set of explanatory models. Therefore, I developed a set of 9 *a priori* candidate models based on the known ecology of the cerulean warblers, which are known to prefer large trees (variable = number of trees >38 cm dbh), heterogeneous canopy with gaps (variables = canopy cover and numbers of snags), high amounts of forest cover (variables = percent forest cover within 1 km and distance to nearest harvest) (Table 1).

I used PROC GENMOD (SAS Institute, Inc. 2001) to test candidate models using a binary distribution with a logit link. From the log-likelihood values generated by the GENMOD procedure, I calculated a bias-corrected version of Akaike's information criteria (AIC_c), differences among models (ΔAICc), and Akaike weights (ω_i) to rank and select the model (s) best supported by the data (Burnham and Anderson 1998). The model with lowest AIC_c value and ΔAICc = 0.00 was considered the best explanatory model (Burham and Anderson 1998). Confidence intervals also were considered when judging the relative importance of variables.

Results

Cerulean warblers were detected on 6 of the 17 sites. A model containing distance to nearest harvest best explained variation in the occurrence of cerulean warblers, and the weight of evidence for this model was 1.5x greater than the next model (Table 1). Occurrence of cerulean warblers was negatively related to distance to harvest, meaning that birds were more likely to occur closer to, rather than farther from, harvests (parameter estimate = -0.0021 ± 0.0017). However, 4 univariate models were closely ranked to the top model ($\Delta AIC_c < 2.0$), which means that they are also plausible given the data. These models included the following variables: forest cover (0.038 ± 0.043), canopy cover (0.036 ± 0.067), snags (-0.10 ± 0.25), and large trees (-0.46 ± 0.38) (Table 1). However, Wald 95% confidence intervals for each of these variables included zero, suggesting that even the best models were not strongly related to occurrence of cerulean warblers.

Discussion

Occurrence of cerulean warblers in the managed forests of Pennsylvania was not strongly related to the local and landscape variables examined here, which may reflect the relatively small sample size used in this study. Nevertheless, the patterns identified can prove useful in filling some of the knowledge gaps regarding the ecology of the species and its response to forest management.

At the landscape scale, presence of cerulean warblers was negatively related to distance to nearest harvest and positively related to forest cover within 1 km. The positive relationship with forest cover is consistent with the species' reported preference for forested landscapes. The affinity of cerulean warblers for forests near recent harvests is less readily explained, but it may result from increased canopy gaps adjacent to harvests and the unimproved forest roads that access them. Indeed, anecdotal observations indicate that, in many parts of their range, cerulean warblers commonly sing adjacent to clearcuts and along forest roads. Other accounts report that the species can tolerate disturbances, such as hurricanes or ice storms (Hamel 2000). For example, Jones et al. (2001) reported that, after initial declines, populations of cerulean warblers were relatively resilient to a large-scale natural disturbance (ice storm) in southern Ontario.

Table 1.—Results from the information-theoretic approach applied to 9 *a priori* models to explain variation in the occurrence of cerulean warblers at 17 forest sites in central Pennsylvania, 1997-1999. Log-likelihood ratios were calculated by Proc GENMOD (SAS Institute Inc., 2001). The number of parameters (k) includes estimates for main factors listed and an intercept value.

Candidate Models	Log-likelihood	K	AICc	ΔAICc	w_i
Distance to harvest	-10.18	2	25.06	0.00	0.282
Forest cover	-10.61	2	25.92	0.86	0.183
Canopy cover	-10.89	2	26.49	1.43	0.138
Snags	-10.95	2	26.61	1.55	0.130
Large trees	-11.03	2	26.77	1.71	0.120
Forest cover, distance to harvest	-10.13	3	27.76	2.70	0.073
Snags, canopy cover	-10.84	3	29.18	4.12	0.036
Snags, large trees	-10.94	3	29.38	4.32	0.033
Full model (including all variables)	-7.32	6	33.10	8.04	0.005

Table 2.—Correlations among local and landscape variables for 17 forest stands in central Pennsylvania, 1997-1999. Pearson correlation coefficient (r) followed by P-values are listed; n = 17 in all cases.

	Distance to harvest (m)	Percent forest cover
Number of snags (≥ 15 cm dbh)	-0.515, 0.035	0.480, 0.051
Number of small trees (8-24 cm dbh)	-0.344, 0.176	0.887, <0.001
Number of medium trees (24.1-38 cm dbh)	-0.467, 0.059	0.765, 0.003
Number of large trees (>38 cm dbh)	-0.420, 0.093	0.289, 0.260
Number of understory stems (< 8 cm)	-0.414, 0.098	0.230, 0.375
Number of logs	-0.443, 0.075	0.351, 0.168
Percent grass cover	0.197, 0.448	-0.504, 0.039
Percent bare ground cover	-0.177, 0.496	0.654, 0.004
Percent canopy cover	0.036, 0.892	0.303, 0.238

Despite the controversy that sometimes accompanies timber operations, ecologists have often suggested that forest management and maintenance of multiple seral stages within forests may benefit bird communities. For example, Thompson et al. (1992) showed that compared to unmanaged mature forests (i.e., without timber harvests), managed-forest landscapes containing multiple seral stages as the result of clear-cutting (i.e., 10 percent regeneration, 10 percent sapling, 80 percent pole-timber within 200 ha) contained equal or greater densities of most forest interior migrants, greater densities of shrubland birds, and no differences in avian nest predators and brood parasites.

At local scales, occurrence of cerulean warblers was positively associated with stands containing greater canopy cover, fewer snags, and fewer large trees than other stands. As a whole, these associations are less intuitive than ones at the landscape scale, and the patterns seem to contradict what is known of habitat selection by cerulean warblers (Hamel 2000). The apparent mismatch between findings at local and landscape scales may be, in part, explained by correlations among variables (Table 2). For example, distance to harvest was weakly correlated with numbers of snags and medium-sized trees, while percent forest cover was correlated with numbers of snags, small and medium trees, grass and bare ground cover. Thus, it is possible that cerulean warblers were selecting for landscape features that were simply correlated with local ones (or vice versa).

One important caveat of my study is that occurrence in a stand does not necessarily indicate that quality habitat for that species. For example, cerulean warblers may prefer to nest near harvests because

Another consideration is that the forested landscape context of my study system may have dampened negative effects of silviculture, and relationships could dramatically change if the extent of forest cover was reduced. Regional forest cover is known to mediate the effects of edge and area, and can profoundly affect the influence of landscape-scale factors on forest birds (e.g., Robinson et al. 1995, Donovan et al. 1997). Maintenance of a mature forest matrix may be a key factor governing use of silviculture in conservation efforts for cerulean warblers.

As populations of cerulean warbler continue to decline, natural resource managers and biologists must carefully consider forest management activities in the context of conserving cerulean warblers and their mature-forest allies. Unfortunately, inadequate knowledge of species' basic habitat and landscape requirements and demographic responses to habitat alterations impede effective conservation. Hopefully, additional investigations by researchers conducted throughout the range of cerulean warblers will elucidate these relationships in the near future.

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