A test of 3 models of Kirtland's warbler habitat suitability

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Abstract We tested 3 models of Kirtland's warbler (*Dendroica kirtlandii*) habitat suitability during a period when we believe there was a surplus of good quality breeding habitat. A jack pine canopy-cover model was superior to 2 jack pine stem-density models in predicting Kirtland's warbler habitat use and non-use. Estimated density of birds in high- and medium-class habitat was higher for the canopy-cover model (4.4 birds/100 ha in high class, 2.9 birds/100 ha in medium class) than for either stem-density model (2.2–2.5 birds/100 ha in high class, 1.2–1.7 birds/100 ha in medium class). Lower bird density was estimated in low- class habitat for the canopy-cover model (0.3 birds/100 ha) than for the stem-density models (0.7 birds/100 ha). Overall estimated density of male Kirtland's warblers on the Mack Lake wildfire area was 1.3–1.5 birds/100 ha. For all 3 models, Kirtland's warblers selected territories that contained 16–27% low-, 23–49% medium-, and 32–50% high-class suitability habitat. There was no correlation between territory size and proportion of territory in each habitat class. Even though many male Kirtland's warblers included low-class habitat in their territories, >97% of those birds also included medium- or high-class habitat. This study confirmed the importance of high stem density and high canopy cover to Kirtland's warbler habitat occupancy of young jack pine habitat regenerated from wildfire. However, low-class stem-density or low-class canopy-cover habitat also was included in territories, even though additional high- and medium-class habitat was available and apparently unoccupied. Therefore, habitat managed for Kirtland's warblers should contain medium- and low- as well as high-class habitat patches in juxtaposition.

Key words *Dendroica kirtlandii*, habitat models, habitat suitability, Kirtland's warbler.

Kirtland's warbler (*Dendroica kirtlandii*) is an endangered migratory songbird that breeds only in northern Lower Michigan (Probst 1986). State and federal agencies actively manage breeding habitat for this species based on an understanding of its breeding habitat requirements. Nelson (1992) summarized essential elements of these requirements from the literature: (1) large stand size, preferably >40 ha, (2) naturally regenerated or planted jack pine (*Pinus banksiana*) tree stratum, (3) tree age 7-21 years, (4) tree height 1.7-5.0 m, (5) oak and other hardwood stems numbering fewer than those of jack pine, and (6) average jack pine density (≥2500 stems/ha). These breeding habitat requirements have not been empirically tested with *a priori* predictions of habitat suitability and occupancy. Thus, habitat managers must base their decisions on an untested understanding of the breeding habitat requirements of Kirtland's warblers.

A study of habitat requirements can be complex. For example, choice of habitat by individuals may depend on the magnitude of intraspecific competition. For this reason, Fretwell (1972) suggested that habitat quality should be studied when a species is rare and a surplus of good habitat is present. In this regard, the Kirtland's warbler population decreased by >50% from 1961 to 1971 and subsequently remained fairly stable through 1989 (Trauger and Bocetti

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Kirtland's warbler (*Dendroica kirtlandii*). Photo by John R. Probst.

1993). In the late 1980's, availability of breeding habitat increased substantially following regeneration and growth of jack pine in the 10,000-ha Mack Lake wildfire area, which burned in 1980. Thus, by 1989, the carrying capacity had increased greatly while the Kirtland's warbler population remained stable (Probst and Weinrich 1993). This created an opportunity to study the breeding habitat requirements of Kirtland's warblers when there was a surplus of breeding habitat.

We studied patterns of Kirtland's warbler use on the Mack Lake wildfire area in 1989, the third year after initial use (9 years after it burned). In 1989, this wildfire area met the first 5 of 6 habitat conditions listed above. In addition, fire and other factors created heterogeneous conditions leading to variation in jack pine density. This produced an opportunity to examine the response of Kirtland's warblers to the sixth habitat factor.

Probst (1988) suggested that the specific habitat requirements of Kirtland's warblers can be explained by their foraging ecology, i.e., a minimum foliage volume is necessary to meet their foraging requirements. The hypothesis we examined was that, within limits, Kirtland's warbler abundance is positively related to jack pine foliage volume. We constructed 3 models of Kirtland's warbler habitat suitability using 2 proximate measures of jack pine foliage volume: stem density and canopy cover. We assumed that there was a surplus of good breeding habitat and that Kirtland's warblers in the Mack Lake wildfire area would first select the highest quality breeding habitat available. Under these assumptions, we expected to observe all Kirtland's warblers occupying only the best habitat available. We then determined the efficacy of 3 models of Kirtland's warbler breeding habitat suitability by comparing for each model the classifications of habitat occupied by Kirtland's warblers to the classifications of habitat not occupied by them.

Study area and methods

This study was conducted on the east-central portion of the historical Kirtland's warbler breeding range on the Mack Lake wildfire area, Huron National Forest, northern Lower Michigan (Fig. 1). On 5 May 1980, a prescribed fire was ignited on an 80-ha site west of Mack Lake to remove woody debris after logging. The fire escaped containment and was controlled only after burning nearly 10,000 ha in 30 hours (Simard et al. 1983). Forest habitats burned in the fire included jack pine (42%), red pine (*Pinus resinosa*, 16%), oak (*Quercus* sp.) mixed with pines and hardwoods (20%), aspen (*Populus* sp., 14%), and miscellaneous types (8%, Simard et al. 1983). Common understory species included blueberry (*Vaccinium angustifolium*), sedge (*Carex* sp.), and bracken fern (*Pteridium aquilinum*).

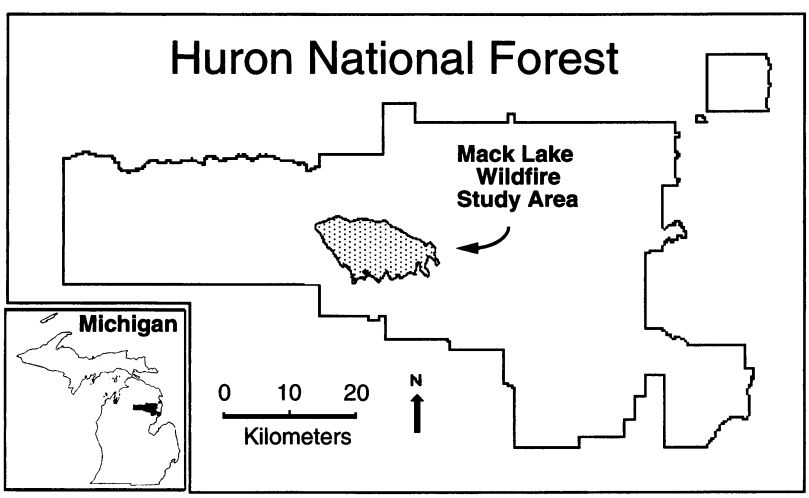

Fig. 1. Mack Lake Wildfire Area, Huron National Forest, northern Lower Michigan, 1989.

Much of the Mack Lake wildfire area regenerated naturally to jack pine.

Predictive models

Three sets of predictions about occupancy of Kirtland's warbler habitat were made using 3 models of breeding habitat suitability. The 3 models were: Huron National Forest jack pine stem density (Huron stem-density model), North Central Forest Experiment Station jack pine stem density (North Central stem-density model), and jack pine canopy cover (canopy-cover model). Each of the 3 models contained 3 classes of Kirtland's warbler breeding habitat suitability: low, medium, and high.

Predictions of habitat suitability were made before birds were censused in the study area. Singing male Kirtland's warblers were predicted to have a higher density in habitat classified as high than in habitat classified as medium for all 3 models. Singing male Kirtland's warblers were predicted to not occupy habitat classified as low by the models.

Jack pine stem density. Jack pine stem-density data were collected on 7,734 census plots within 6,260 ha of the Mack Lake wildfire area during summer 1985. Stems ≤5 cm diameter at breast height (1.4 m) were tallied within 1.6-m-radius circular plots on an 80 x 100-m grid. Jack pine stem counts were recorded up to 20 stems, after which "20+" was recorded. The stem-density grid was truncated at private property boundaries and at habitat types not regenerating naturally following the Mack Lake wildfire (e.g., unburned forest, pine plantations, wetlands, lakes, etc.).

Tree stem count data and geographic coordinates of sample plot locations were entered into a geographic information system (GIS). Each sample plot was assumed to represent a 0.8-ha rectangular area surrounding the sample plot. The Huron stem-density model used existing jack pine forest-type classes of low, medium, and high that were defined by the Huron National Forest as <2000, 2000-8000, and >8000 jack pine stems/ha, respectively. The North Central stem-density model was a modification of the Huron forest-type classes that better approximated our understanding of Kirtland's warbler breeding-habitat suitability. In the North Central stem-density model, jack pine stem densities of <2000, 2000-5000, and >5000 stems/ha represented low-, medium-, and high-class, respectively.

Jack pine canopy cover. Jack pine canopy-cover data was obtained from 1:6,000-scale false-color infrared aerial photographs of the Mack Lake wildfire area, taken in September 1987. Standard stereoscopy photo interpretation methods were used to classify 7,130 ha into habitat types. Of this total, 5,986 ha of regenerating jack pine habitat type were classified using percent jack pine canopy cover. The canopy-cover model defined low-, medium-, and high-class habitat as <15, 15-35, and >35% jack pine canopy cover, respectively. Type lines for these habitats were transferred to paper base-maps and digitized into a GIS. The habitat-type lines delineated polygons with a minimum size of 0.1 ha.

Bird locations. All suitably aged habitat (burned in 1980 and including jack pine natural regeneration) within the Mack Lake wildfire area was surveyed for singing male Kirtland's warblers 4 times during 1989: on or before 23 May, 24 May-6 June, 7-20 June, and on or after 21 June. A spot-mapping technique, modified from the international mapping method (Int. Bird Census Comm. 1970, Franzreb 1977), was used to record locations of each singing male. Bird locations were transferred to U.S. Geological Survey 7.5 minute quad maps and digitized as points in a GIS.

We observed singing male Kirtland's warblers on 102 territories within the Mack Lake wildfire area during May and June 1989. We assumed equal observability of males among habitat classes. If observability did differ, it is likely that it was best in low-quality (sparser) habitat and worst in high-quality (denser) habitat. So, any bias would have produced a conservative result.

Overlay analysis

Locations of singing male Kirtland's warblers were overlaid on each of the 3 habitat layers in a GIS to determine habitat occupancy of suitability classes. Habitat occupancy was measured with a minimum polygon territory for each bird. One habitat class was assigned to each territory—the class that comprised the greatest proportion within each territory.

We used a chi-square goodness-of-fit test to compare choice of habitat among habitat classes for each of the 3 habitat models (1-way array with 3 cells) and between pairs of stem-density classes (1-way array with 2 cells). Choice of habitat (bird density) is the number of observed territories in each habitat class relative to the area of available habitat in each habitat class.

Comparisons within models were made by visually interpreting x-y plots of habitat availability to habitat occupancy. Proportion of habitat available in low, medium, and high classes were plotted on x-y plots for each model. In addition, we plotted a 99% confidence interval ellipse about the centroid of habitat occupancy and overlaid it on each habitat availability plot. Habitat availability points were compared to confidence interval ellipses of habitat occupancy.

Habitat occupancy differed among classes within a model when a habitat-availability point fell outside the bounds of a habitat occupancy 99% confidence interval ellipse, i.e, habitat was not occupied in proportion to its availability.

We compared models by visually interpreting a triangular plot of habitat-availability points and 99% confidence interval ellipses about habitat-occupancy centroids for all 3 models. Habitat occupancy differed among models when a centroid of 1 model fell outside the bounds of a confidence interval ellipse of another model.

Results

Habitat classification

Of 6,260 ha in each of the 2 stem-density models, 3,127 ha (50%) were comprised of jack pine <2,000 stems/ha (low class). In the Huron stem-density model, habitat of 2,000–8,000 (medium class) and >8,000 (high class) stems/ha comprised 1,553 ha (25%) and 1,580 ha (25%), respectively. In the North Central stem-density model, 1,144 ha (18%) and 1,989 ha (32%) of habitat were classified as 2,000–5,000 (medium class) stems/ha and >5,000 (high class) stems/ha, respectively.

Of 5,986 ha in the canopy-cover model, habitat of <15% canopy cover (low class) comprised 3,495 ha (58%), habitat of 15–35% canopy cover (medium class) comprised 1,782 ha (30%), and habitat of >35% canopy cover (high class) comprised 709 ha (12%; Fig. 2).

Bird census results

We recorded bird locations (n = 1,075) during 237 observation bouts (15- to 30-minute observations of an individual bird). We calculated a mean of 2.6 (SD = 1.1) observation bouts/bird. Mean number of location points/observation bout was 4.5. Mean number of discrete location points recorded/territory was 11.9 (SD = 6.5).

Habitat use analysis

Locations of 90 singing male Kirtland's warblers (n = 1,075 individual location points) were overlaid on the GIS habitat layer for jack pine canopy cover. Locations from 84 of those territories (n = 1,022 points) were overlaid on the Huron and North Central jack pine stem-density GIS habitat layers.

Choice of habitat differed from random (number of territories/unit area of available habitat is equal among 3 habitat classes) with the Huron stem-density (χ^2 = 18.8, 2 df, $P < 0.001$), North Central stem-density (χ^2 = 29.2, 2 df, $P < 0.001$), and canopy-cover (χ^2 = 93.1, 2 df, $P < 0.001$) models (Fig. 3). Thus, choice of habitat was disproportional to habitat availability for all 3 habitat models.

Choice of habitat between that with <2,000 stems/ha and that with 2,000–5,000 stems/ha did not differ (χ^2 = 3.12, 1 df, $P < 0.10$). Choice of habitat differed (χ^2 = 5.55, 1 df, $P < 0.05$) between that with 2,000–5,000 stems/ha and that with >5,000 stems/ha. There was a difference (χ^2 = 6.63, 1 df, $P < 0.05$) in choice between habitat with 2,000–5,000 stems/ha and that with 5,000–8,000 stems/ha. Habitat with 5,000–8,000 stems/ha differentiates the 2 stem-density models: it is within medium class for the Huron stem-density model and is within high class for the North Central stem-density model. There was no difference (χ^2 = 1.25, 1 df, $P > 0.10$) in choice between habitat with 5,000–8,000 stems/ha and that with >8,000 stems/ha.

Estimated density of male Kirtland's warblers in all habitat-suitability classes combined was 1.3 birds/100 ha (84 birds/6,260 ha) for the 2 stem-density models and 1.5 birds/100 ha (90 birds/5,986 ha) for the canopy-cover model. Estimated density increased from low- to high- class habitat suitability for all 3 models (Fig. 4). Areas of high-class habitat suitability were occupied at an estimated density of 4.4 birds/100 ha using the canopy-cover model, 2.2 birds/100 ha using the Huron stem-density model, and 2.5 birds/100 ha using the North Central stem-density model. Estimated density of birds in medium-class habitat was higher using the canopy-cover model (2.9 birds/100 ha) than using either the Huron (1.7 birds/100 ha) or the North Central (1.2 birds/100 ha) stem-density models.

For all 3 models, birds used medium- and high-class habitat more than low-class habitat. Plotted distances between habitat-use and habitat-availability centroids appeared similar between the 2 stem-density models (Fig. 5). Plotted distance between habitat-use and habitat-availability centroids were greater using the canopy-cover model than with either of the 2 stem-density models (Fig. 5). Although a smaller proportion of habitat was classified as having medium and high suitability with the canopy-cover model, use of these combined classes was higher under the canopy-cover model than under either of the 2 stem-density models.

Habitat selection (orientation of plotted use to plotted availability) appeared to be directed more toward high-class habitat with the canopy-cover model than with either of the 2 stem-density models. When distance and orientation factors are combined, the

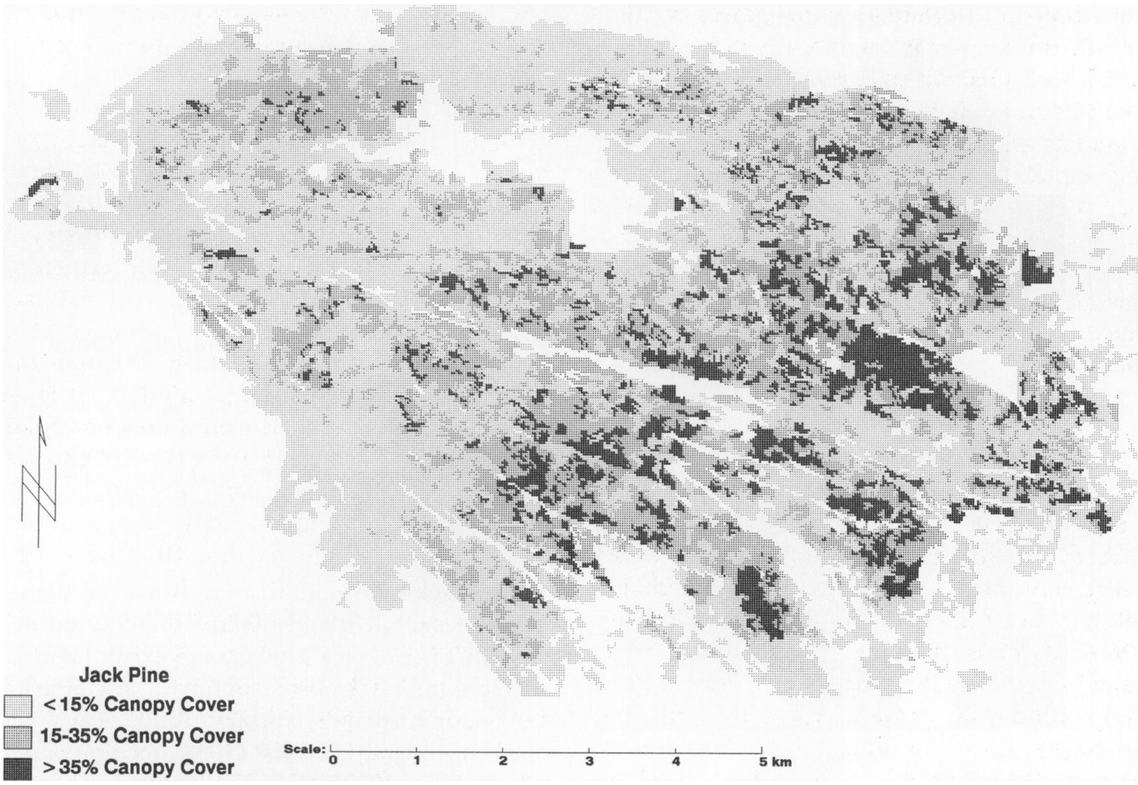

Fig. 2. Jack pine canopy-cover classes derived from photo interpretation of 1:6,000-scale false-color infrared aerial photographs (from 1987) on the Mack Lake Wildfire Area, Huron National Forest, northern Lower Michigan. Minimum mapping unit = 0.1 ha.

canopy-cover model appears to be a better predictor of habitat use and non-use than either of the 2 stem-density models.

Kirtland's warblers occupied territories that contained a combination of habitat classes. For all three models, mean proportions of habitat classes contained in territories were: 0.16–0.27 low class, 0.23–0.49 medium class, and 0.32–0.50 high class. Proportions of territories in low-, medium-, and high-class habitat territories were not correlated (Pearson correlation coefficient) with area (ha) of territories with the 2 stem-density ($P > 0.10$, $n = 84$) or the canopy-cover ($P > 0.10$, $n = 90$) models.

Habitat of low stem density or low cover was occupied under all 3 models. Under the 2 stem-density models, >85% of bird territories that included low-class habitat also contained some medium- or high-class habitat. With 1 exception, all territories recorded as including low-class habitat also contained medium- or high- class habitat under the canopy-cover model. Of all territories that included high-class habitat, 61–62% also included low-class habitat under the 2 stem-density models, and 52% also included low-class habitat under the canopy-cover model.

Discussion

Buech (1980) suggested that stem densities of 6,000 stems/ha provide good habitat in 10-year-old jack pine stands. In the 9-year-old jack pine habitat of the Mack Lake wildfire area, we detected no difference in Kirtland's warbler choice between habitat of 5,000–8,000 stems/ha and habitat of >8,000 stems/ha. These results suggest that Kirtland's warbler habitat use (in their fourth year of occupancy) of Mack Lake wildfire area increased with increasing stem densities up to 5,000–8,000 stems/ha. This class contains Buech's suggested stem density for good habitat.

Although Probst and Hayes (1987) classified marginal habitat as <2,500 stems/ha, we observed Kirtland's warblers in habitat of <2,000 stems/ha. This contradicts our assumption that the highest quality habitat available in the Mack Lake wildfire area would be occupied during 1989 and our prediction that habitat <2,000 stems/ha would not be occupied. However, habitat use was significantly higher in habitat of ≥2,000 stems/ha than in habitat of <2,000 stems/ha, and very few birds that occupied low class habitat used it exclusively. Kirtland's warbler territo-

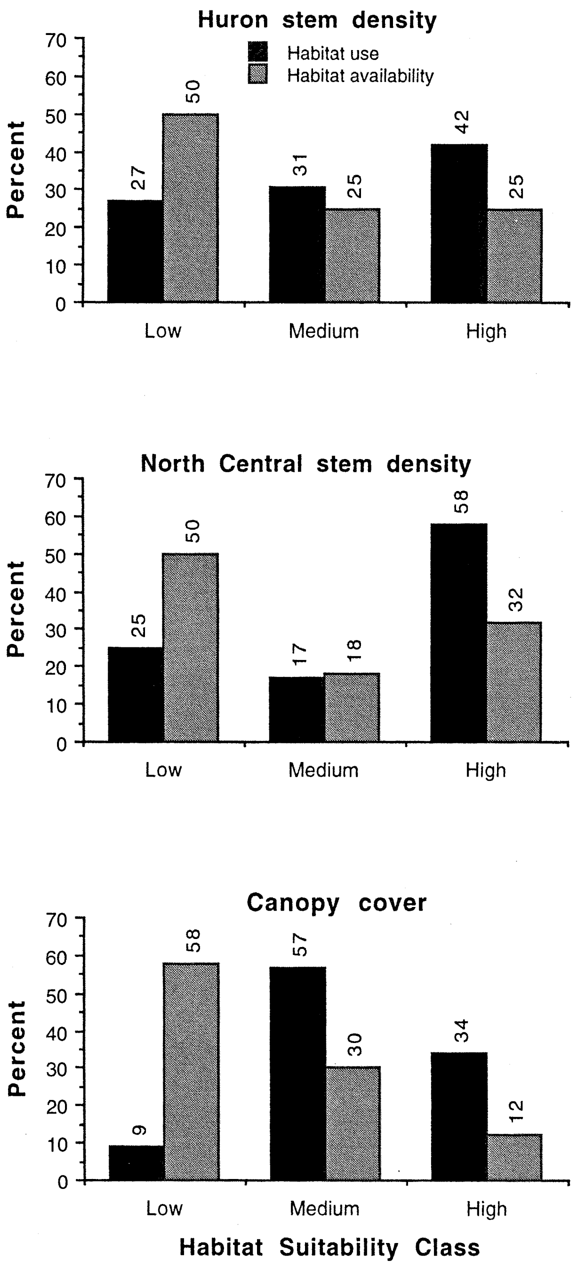

Fig. 3. Distribution (percent) of singing male Kirtland's warbler habitat use (solid bars) versus habitat availability (stippled bars) with the Huron stem- density model, North Central stem-density model, and canopy-cover model on the Mack Lake wildfire area, Huron National Forest, northern Lower Michigan during 1989. Habitat use was defined from territories.

ries almost always contained habitat of ≥2,000 stems/ha. Thus, our results approximate the classification of marginal habitat proposed by Probst and Hayes (1987).

Probst (1988) suggested that "optimal" Kirtland's warbler habitat is comprised of 35-65% jack pine canopy cover. We observed more singing males in 15-35% than in >35% jack pine canopy-cover habitat

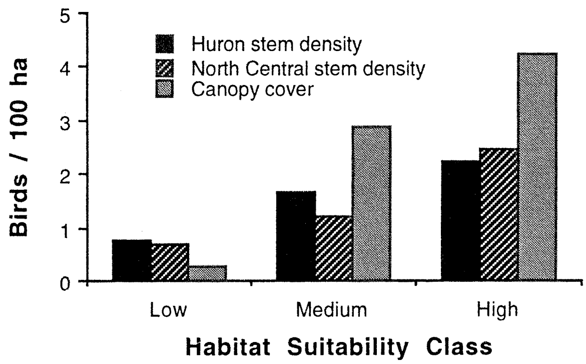

Fig. 4. Estimated density of Kirtland's warblers in low-, medium-, and high-habitat suitability classes with the Huron stem-density, North Central stem-density, and canopy-cover models. Density is birds/100 ha for territories on the Mack Lake wildfire area, Huron National Forest, northern Lower Michigan during 1989.

in the Mack Lake wildfire area. However, higher densities of male Kirtland's warblers occurred in >35% than in 15-35% jack pine canopy-cover habitat. This result supports Probst's "optimal" jack pine canopy cover for Kirtland's warblers during early years of stand occupancy. Probst (1988) recommended that stands have 20-25% tree cover for successful Kirtland's warbler colonization. Probst and Weinrich (1993) reported that pine stands (n = 10) recently colonized by Kirtland's warblers had 15-20% canopy cover. We observed a small proportion of birds oc-

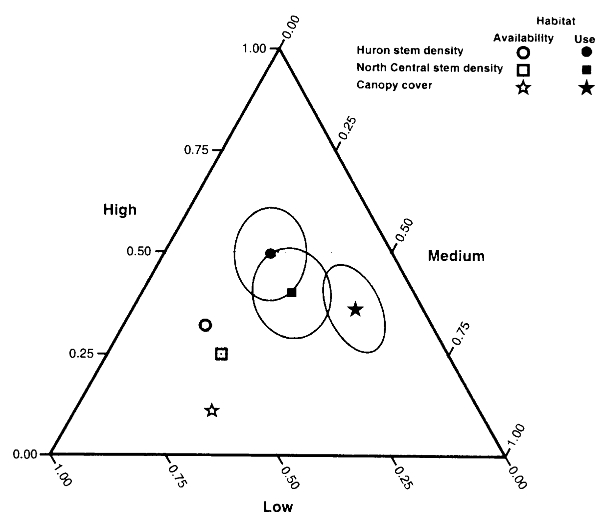

Fig. 5. Triangular plot of habitat use (solid symbol) and habitat availability (open symbol) in habitat classed low, medium, and high with the Huron stem-density model, North Central stem-density model, and canopy-cover model on the Mack Lake wildfire area, Huron National Forest, northern Lower Michigan during 1989. Habitat use is displayed as a centroid for proportion of territories within each habitat class. Centroids of habitat use are surrounded by 99% confidence interval ellipses.

cupying habitat of <15% jack pine canopy cover, but habitat of ≥15% was included in almost every territory. Thus, our results do not contradict the minimum jack pine canopy-cover limit suggested by Probst (1988) or observed by Probst and Weinrich (1993).

Probst (1988) hypothesized that volume of jack pine foliage is the primary factor in Kirtland's warbler selection of breeding habitat. Based on his field observations of Kirtland's warbler foraging ecology, he surmised that initial occupancy of habitat is limited by a minimum foliage volume necessary to meet foraging requirements. In this regard, our results support Probst's (1988) suggestion that jack pine canopy cover is more useful than stem density in evaluating Kirtland's warbler habitat quality. We attained better predictions of Kirtland's warbler habitat use and nonuse with the canopy-cover model than with either of the jack pine stem-density models.

Probst and Weinrich (1993) suggested that a sudden increase in suitably stocked, regenerating pine forest would not be fully occupied by Kirtland's warblers immediately because survivorship and productivity of Kirtland's warblers would not be sufficient to fill all suitable habitat when it first becomes available. The density of male Kirtland's warblers suggested such an increase in habitat occurred following regeneration and maturation of jack pine (about 6,000 ha) in the Mack Lake wildfire area but probably did not occur in the smaller, 447-ha wildfire in Walkinshaw's (1983) study. Estimated density of male Kirtland's warblers was 1.3–1.5 birds/100 ha in Mack Lake wildfire area during 1989 (9-year-old habitat). In a similar study of 9-year-old jack pine habitat regenerating naturally from wildfire, Walkinshaw (1983) estimated density much higher: 16 males/100 ha (28 males/179 ha) in "favorable" habitat and 6.3 males/100 ha (28 males/447 ha) for all habitat within the Artillery Range North wildfire area (burned in 1967). We expected a surplus of habitat in the Mack Lake wildfire area. The low density of birds suggested that some suitable habitat was not occupied during 1989.

Mayfield (1960) and Walkinshaw (1983) noted that Kirtland's warblers tend to occur in colonies. Morse (1989) stated that within a local homogeneous pine stand, Kirtland's warbler breeding territories are clumped. But within this assembly, Mayfield (1960) observed that territories are rarely adjacent to one another on more than 1 or 2 sides. Mayfield (1960) suggested that this loose assembly is a result of a gregarious drive of Kirtland's warblers rather than selection of some attractive habitat feature. Morse (1989) concluded that social factors may influence the pattern of Kirtland's warbler occurrence within homogeneous pine stands. Mack Lake wildfire area was comprised of jack pine with heterogeneous stem density and canopy cover. Therefore, we could not determine whether social factors affected the distribution of Kirtland's warblers in this area.

If habitat is heterogeneous and patches are smaller than the size of a territory, then >1 patch of habitat likely would be included in a territory. This seems true in some portions of the study area (Fig. 2). For example, the northwest quarter contains high-class jack pine canopy-cover habitat only in patches smaller than the size of local Kirtland's warbler territories. In contrast, habitat of medium-class jack pine canopy cover occurs in patches much larger than the size of local territories. Territories in such areas contain primarily medium-class habitat but also include small patches of high- or low-class habitat. In east central portions of the Mack Lake wildfire area, habitat patches of medium and high class often are larger and habitat patches of low class are smaller than local territories. Even though Kirtland's warbler territories could be contained entirely within a single patch of high- or medium-class jack pine canopy-cover habitat, they usually include both classes and often contain low-class habitat.

A second explanation for heterogeneity of habitat within territories is that territorial competition partitions high class habitat patches among >1 bird territory. Under this explanation, a high-class patch would include portions of several territories, each of which extends into adjacent medium- or low-class habitat. However, this is true in only a few cases. Many territories within the study area are not adjacent to another territory. Often, there are unoccupied patches of high-class habitat (similar or greater in area than most territories) located between territories. When 2 or more territories are adjacent to one another and share a patch of high-class habitat, they usually are surrounded by unoccupied patches of high- and medium-class habitat larger in area than the occupied territories.

A third explanation for heterogeneity of habitat within territories is that Kirtland's warblers select territories to include habitat patches of more than 1 class. Smith (1979) noted that smaller Kirtland's warbler territories were correlated with increasing interspersion of cover and open spaces (e.g., high and low stem density or canopy cover classes). Barnes et al. (1989) observed a correlation between Kirtland's warbler occurrence and a patchy or 'contagious' pattern of jack pine regeneration (interspersed with openings). We observed a weak positive correlation between territory size and proportion of low-class habitat with the canopy-cover model, but only when the 2 largest territories were excluded from analysis.

Apart from this, there was no correlation between territory size and proportion of territory in 3 habitat classes. These results suggest that Kirtland's warblers on the Mack Lake wildfire area selected territories with a combination of habitat classes. Present models of Kirtland's warbler breeding habitat suitability fail to predict distribution of territories within heterogeneous habitat.

Management recommendations

The canopy-cover model (derived from aerial photo interpretation) was better than either stem-density model (derived from ground sample plots) for predicting Kirtland's warbler habitat occupancy in the early years of occupancy. Photo interpretation produced continuous classification, including habitat within islands of private property which were not surveyed via the stem-density sample conducted on the ground. Both stem-density models also produced favorable results. Thus, both types of data are useful for predicting potential Kirtland's warbler habitat occupancy.

Stem-density data were collected before this study by the Huron National Forest for its management needs. The most practical means of predicting occupancy of Kirtland's warbler habitat may be to use such data, which are already available. Future stem-density-based habitat mapping of Kirtland's warbler management areas should be modified from current classes of <2,000, 2,000-8,000, and >8,000 stems/ha to classes of <2,000, 2,000-5,000, 5,001-8,000, and >8,000 stems/ha to more accurately reflect Kirtland's warbler habitat-suitability classes. Sample size should be considered when designing jack pine stem-density studies if the data will be used for Kirtland's warbler breeding habitat analysis. If sample sizes are large, chi-square goodness-of-fit test statistics can be used for analysis (Jelinski 1991).

This study confirmed the importance of high stem density or high canopy cover to Kirtland's warbler occupancy of young jack pine habitat regenerating from wildfire. Stocking density and canopy cover factors should be emphasized when managing jack pine stands for Kirtland's warbler breeding habitat. Specifically, young jack pine stands (≤10 years) should average >2000 stems/ha or >15% jack pine canopy cover. Jack pine patches of 5000-8000 stems/ha or 35-50% canopy cover should be included within stands of Kirtland's warbler breeding habitat. Habitat patches containing jack pine of <2000 stems/ha or <15% canopy cover are acceptable if these patches are adjacent to and in smaller proportion than higher density jack pine habitat.

Ideally, Kirtland's warbler breeding habitat should be heterogeneous in stem density or canopy cover. Dense areas within young stands are occupied first (Buech 1980), but territories usually contain a mixture of stem-density or canopy-cover classes. As young stands mature, stem density decreases (from mortality), canopy cover increases, and tree crowns broaden. Areas of sparse stem density can become more suitable with time as canopy cover increases. For these reasons, Buech (1980) estimated that good Kirtland's warbler habitat occurs at a density of 6,000 trees/ha when 10 years, 2,500 trees/ha when 15 years, and 1,500 trees/ha when 22 years of age. Probst and Weinrich (1993) observed tree canopy cover of 16-38% in young habitat recently occupied, 21-68% in middle-aged habitat with established populations, and 54-86% in older habitat with declining populations.

To provide heterogeneous habitat for Kirtland's warbler territories and to maximize the length of potential occupancy, new habitat should contain a mixture of jack pine stem density or jack pine canopy cover. This mixture should be juxtaposed so that Kirtland's warbler territories, 1-10 ha in area, may include all 3 classes. Examples of habitat management for heterogeneity can be adapted from Probst (1988). Although our recommendations are derived from young jack pine regenerated after fire, inferences may apply to young jack pine plantations of similar structure.

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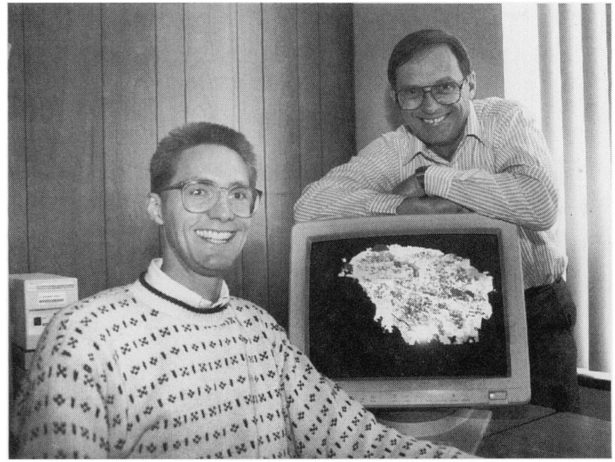

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