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LANDSCAPE CHARACTERISTICS ASSOCIATED WITH ACTIVE AND ABANDONED RED-COCKADED WOODPECKER CLUSTERS IN EAST TEXAS

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ABSTRACT.—I investigated spatial characteristics of Red-cockaded Woodpecker (*Picoides borealis*) cluster sites in the Raven Ranger District of the Sam Houston National Forest, Texas. Active cluster sites were larger and closer to other active clusters than inactive ones and had larger gravity interaction values. Inactive sites were significantly more isolated than were active clusters, they were more likely to be surrounded by inimical land uses, and they were less likely to be connected by corridors of mature timber to active cluster sites. This research indicates that spatial landscape parameters influence Red-cockaded Woodpecker cluster status and they should be considered in management plans for the species. *Received 24 Oct. 1994, accepted 16 May 1995.*

The Red-cockaded Woodpecker (*Picoides borealis*) is a cooperative breeder with highly specific habitat requirements. Nesting and roosting cavities are excavated in living pine trees that are typically infected with heart-rot fungus (*Phellinus pini*) and that tend to be the older trees in a forest (Jackson 1977, Conner and Locke 1982, Hooper 1988, Hooper et al. 1991b, Conner et al. 1994). Cavity trees occur in clusters, and the woodpeckers are intolerant of hardwood midstory development in the cluster sites (Loeb et al. 1992, Kelly et al. 1993). Red-cockaded Woodpeckers have declined throughout their range because of a shortage of potential cavity trees (Hooper 1988) and infrequent fire regimes to control midstory development (Conner and Rudolph 1989). Where these problems are absent, populations have been stable or have increased (Hooper et al. 1991a, USFS 1993, Conner et al. 1995). In three of the National Forests in Texas, the Angelina, Davy Crockett, and Sabine, past declines had been precipitous, amounting to a decrease in active clusters of 10% per year between 1983 and 1988 (Conner and Rudolph 1989). However, populations in all National Forests in Texas have stabilized or increased in recent years (Conner et al. 1995). The timber characteristics required for a forest stand to be used by Red-cockaded Woodpeckers are known (Boone 1980, Hooper et al. 1980, USFWS 1985, Walters 1991), but landscape requirements of usable patches have been studied little. Conservation of species requires that adequate areas of habitat are maintained, with the size and configuration of "adequate" habitat differing from spe-

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cies to species and from situation to situation. Bird species richness and abundance may be related more to landscape structure than to habitat physiognomy (McCollin 1993), and birds with restrictive habitat structure needs, such as Kirtland's Warbler (*Dendroica kirtlandii*) and the Northern Spotted Owl (*Strix occidentalis caurina*), are also dependent on patch size and configuration (Jakubauskas 1992, Lamberson et al. 1992). To maintain biodiversity, whether in the general sense or the case of an individual species, requires a landscape approach (Harris 1984, Hansson and Angelstam 1991, Franklin 1993).

The U.S. Forest Service (USFS) is managing southern pine forests to improve and maintain Red-cockaded Woodpecker habitat (USFS 1985, Hooper et al. 1990, Walters 1991, USFS 1991), primarily by thinning, midstory reduction, and prescribed burns (Conner 1989, Conner and Rudolph 1991b, Conner et al. 1995) in active cluster sites and by creation of replacement and recruitment stands of suitable habitat. Management on all National Forests in Texas during the past three years has included the use of artificial cavity inserts and translocation of woodpeckers to increase the number of breeding pairs in each forest (Conner et al. 1995).

Dispersal of birds into new territories seems to be a limiting factor on populations: Ligon et al. (1986) reported that establishment of new clusters was virtually unknown. More recently, it has been demonstrated that populations can expand when suitable habitat is present (Hooper et al. 1991a). In addition, Copeyon et al. (1991) and Walters et al. (1992) have demonstrated the success of new cluster formation when artificial cavities were provided. This emphasizes the need for preservation of existing habitat and creation of new habitat by management. Furthermore, particularly in the absence of translocation, individuals must be able to disperse from existing clusters into suitable habitat: connectivity among existing patches, and between existing and newly-created patches, must be adequate (Ligon et al. 1986). The objectives of this study were to determine whether landscape characteristics, particularly measures of isolation, were different between active and inactive Red-cockaded Woodpecker cluster sites and how to use knowledge of any differences in habitat management.

METHODS

The study area comprised Compartments 1 through 54 of the Raven Ranger District of the Sam Houston National Forest (SHNF), Texas (Fig. 1). The SHNF is 80 km north of Houston, in the area known as the Pineywoods. It covers an area of 193,622 ha, of which 65,217 ha are National Forest lands; the remainder are private inholdings which were not considered for this study.

The primary source of data for this study was the USFS stand-map database for the Raven District. Line data of the district stand maps were imported to ARC/INFO, version 5.1 (Environmental Systems Research Institute 1989). The line data, which were in preliminary

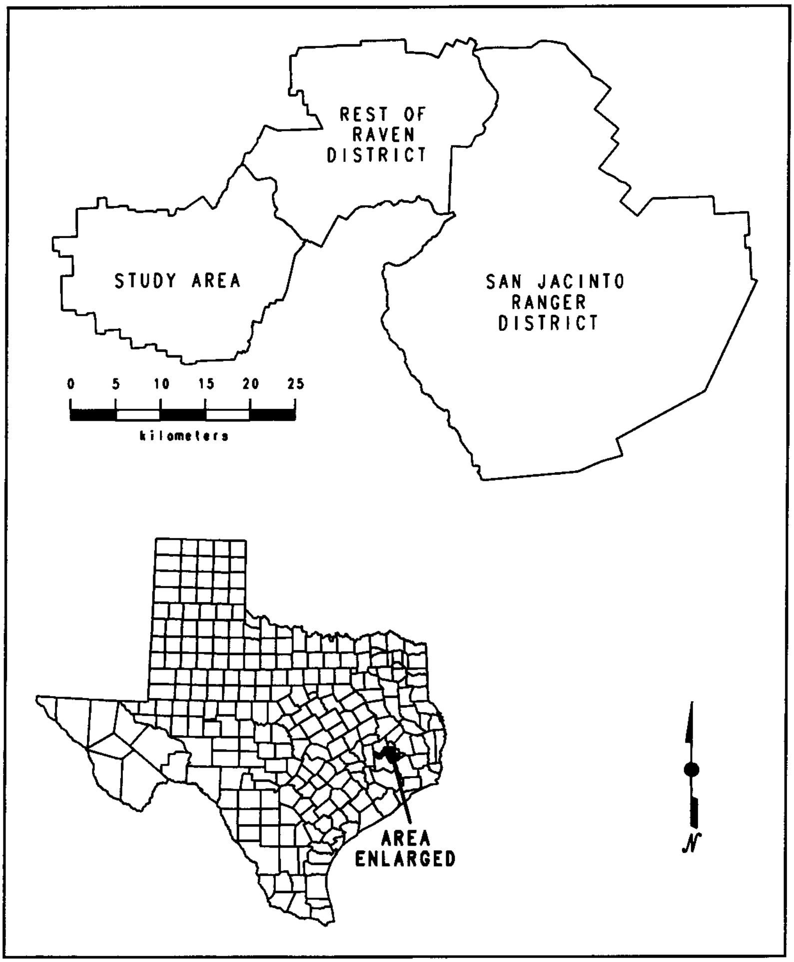

FIG. 1. Study area location map, Raven Ranger District, Sam Houston National Forest, Texas.

form, were compared to the hard-copy stand maps obtained from the Raven District, and errors were corrected using a visual display terminal. Attribute data on the stands were read from the USFS Continuous Inventory of Stand Conditions-II (CISCII) computerized database and attached to the appropriate stand polygons.

Many polygons were drawn on the stand maps, and subsequently digitized, that corresponded either to cut areas in stands of mature trees (inclusions) or stands of relict trees in young plantations. The nature of the inclusions and relict stands was ascertained by visually interpreting stereopairs of 1:24,000 false-color infrared aerial photographs of the study area, taken in 1988 through 1991.

For statistical analyses of the data SAS-STAT version 6.07 (SAS Institute 1989) was used. General comparisons of parameters between different active and inactive clusters were conducted with the Wilcoxon-Mann-Whitney signed-ranks test with tied-ranks correction and large-sample normal approximation with continuity correction (Wilcoxon test: Zar 1984). In each comparison, the null hypothesis was that there was no difference in parameter value between active and inactive cluster stands. A significance level of 0.05 was used.

The proximity of clusters to one another was assessed in three ways: as direct distance measurements, by a gravity model, and by determining the isolation coefficient for each cluster. The distance measurements were straight-line, edge-to-edge distances from each cluster, active or inactive, to the next nearest active cluster. The distances (DISTANCE) for active and inactive sites were compared.

The gravity model, derived from Newton's Law of Gravitation, is commonly used in urban geography (Hartshorn 1980), where population of a city is substituted for mass. Rudis and Ek (1981) applied the model to forest islands, and I substituted area of the cluster site for population. The model was also modified to use edge-to-edge distance, rather than center-to-center, since the woodpeckers are highly mobile within a cavity-tree cluster, and any deterrent to dispersal would be between the edge of one cluster and the edge of another. The gravity interaction (GRAVITY) between each cluster and the next nearest active cluster was calculated for all cluster sites, active and inactive, and the two classes were compared.

The isolation coefficient (II) of each cluster, a modification of the gravity model, is defined as follows (after Whitcomb et al. 1981): $II = 1 / \Sigma(A_i/d_i^2)$, where A_i = the area of each cluster site, i, within a given radius (d_o) from the study cluster, and d_i = the distance between cluster i and the study cluster. Three values of maximum distance (d_o) were investigated. The first was 4000 m (II4000), which exceeded the largest minimum centroid-to-centroid distance in the study area (ensuring that no stands would have an isolation coefficient of infinity) and approximated the known distance flown by individual birds reported by Boone (1980). The second maximum distance used was 1130 m (II1130), which corresponded to the effective radius of the largest home range of Red-cockaded Woodpeckers (400 ha) reported by Conner and Rudolph (1989). The third distance was 390 m, corresponding to the smallest home range (50 ha) that Conner and Rudolph (1989) listed. There are reports of birds covering greater distances (Hooper et al. 1980, Walters 1991), but these three values were the only ones considered here. For each of the three maximum distances, active cluster sites were compared to inactive ones; recruitment and replacement stands were compared to active cluster sites only in the 4000-m maximum distance case.

To determine the relationships between Red-cockaded Woodpecker clusters and surrounding landcover types, a neighbor analysis was performed. The percentage of cluster stand border shared with different landcover classes was compared for active and inactive sites. The neighboring landcover classes considered were sawtimber (ST), poletimber (PT), forest in regeneration (REG), seedling/sapling (SS), pasture (PAS), and open water (OW). A number of derived neighbor categories were created: ST + PT, ST + PT + REG, ST + PT + REG + SS, PAS + OW, and PAS + OW + SS.

To assess the impact of corridors on cluster status, the nature of the path from each cluster site to its next nearest active cluster was classified into one of four categories (1) direct (line-of-sight) path through pine sawtimber and/or poletimber; (2) indirect path through pine sawtimber and/or poletimber (deviation from line-of-sight to go around open country); (3) circuitous path that would require flying away from the target to stay within timber; and (4) no timber corridor adjacent to the cluster site (any area of land cover other than pine poletimber or sawtimber greater than 50 m wide completely surrounding the cluster). The frequencies of each class for active and inactive cluster sites were compared using a contingency-table log-likelihood test.

TABLE 1
SPATIAL STAND PARAMETERS IN ACTIVE AND INACTIVE CLUSTERS IN THE RAVEN RANGER DISTRICT, SAM HOUSTON NATIONAL FOREST, TEXAS

	Minimum		Maximum		Median		
Parameter	Active	Inactive	Active	Inactive	Active	Inactive	
Cluster site area, ha (AREA)	0.6	0.3	27.9	17.6	6.2	2.7	*
Distance from cluster site to nearest active cluster site, m (DISTANCE)	0	0	3320	3500	300	373	*
Gravity interaction between cluster site and nearest active cluster site (GRAVITY)	245	63	8×10^6	1×10^6	20×10^3	6×10^3	*
Isolation coefficient, d_2 = 4000 m (II4000)	0.4	0.5	119	45	2.1	3.8	*
Isolation coefficient, d_2 = 1130 m (II1130)	0.5	0.6	∞	∞	4.3	6.7	*

* Statistical significance between active and inactive cluster sites, Wilcoxon test, $\alpha = 0.05$.

RESULTS

The study site had a total area of 35,568 ha. Immature sawtimber covered 29% of the study area, followed by mature sawtimber with 25%. There were 107 active clusters with a total area of 699 ha, and 60 inactive clusters comprising 208 ha. All the active clusters and all but three of the inactive ones were in mature or immature sawtimber. There were 52 recruitment stands, managed to create attractive habitat for birds seeking new cluster sites, and 151 replacement stands, which are recruitment stands adjacent to existing active or inactive cluster sites. The dominant timber in the study area was loblolly pine, which covered 83% of the USFS lands. Shortleaf pine occupied another 9%, and hardwoods accounted for an additional 6%.

Active cluster stands were larger than cluster stands that had become inactive (Table 1; Wilcoxon test, $P = 0.0001$): median values were 6.2 ha compared to 2.7 ha. The distance from each active cluster to its next nearest active neighbor ranged from 0 m (in the case of contiguous clusters) to 3320 m (Table 1). The distance from each inactive site to the nearest active cluster had a similar range but somewhat higher median. The distributions of distances (Fig. 2) were significantly different, with inactive sites being further away from the closest active cluster than were active ones (Wilcoxon test, $P = 0.0151$). The majority of clusters, regardless of status, were close to their next nearest active cluster; 76% of

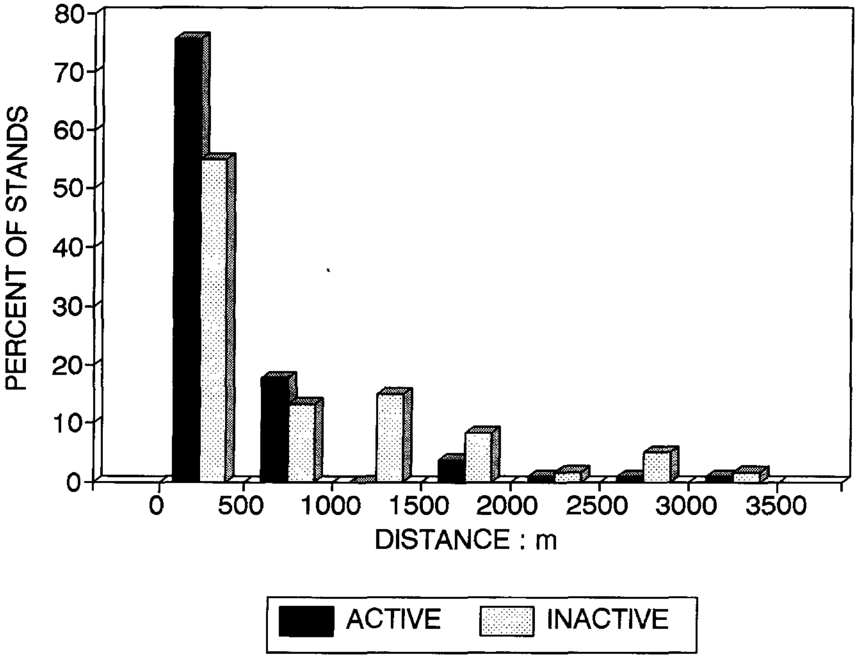

FIG. 2. Comparison of distance to nearest active cluster stand (DISTANCE) from active versus inactive clusters.

actives and 55% of inactives were within 500 m. However, 32% of inactive cluster sites were more than 1 km from the next nearest active cluster, compared to only 7% of active ones.

The gravity interactions between active clusters and their next nearest active neighbor had a much higher range and median than between inactive sites and their nearest active cluster (Table 1; Wilcoxon test $P = 0.0030$). While 62% of active clusters had gravity interactions greater than 10^4, only 42% of inactive cluster sites had values this high. Conversely, only 7% of active clusters had gravity interactions below 10^3, compared to 25% of inactive cluster sites (Fig. 3).

With a maximum search radius of 4000 m the isolation coefficients (II4000) of inactive sites were significantly higher than II4000 of active clusters (Table 1; Wilcoxon test, $P = 0.0207$). While 30% of inactive sites had II4000 values above eight, only 7% of active ones were this isolated (Fig. 4). Conversely, 82% of active sites were below four compared to 58% of inactive sites. Recruitment stand isolation coefficients (II4000) were significantly higher than active clusters (Wilcoxon test, P

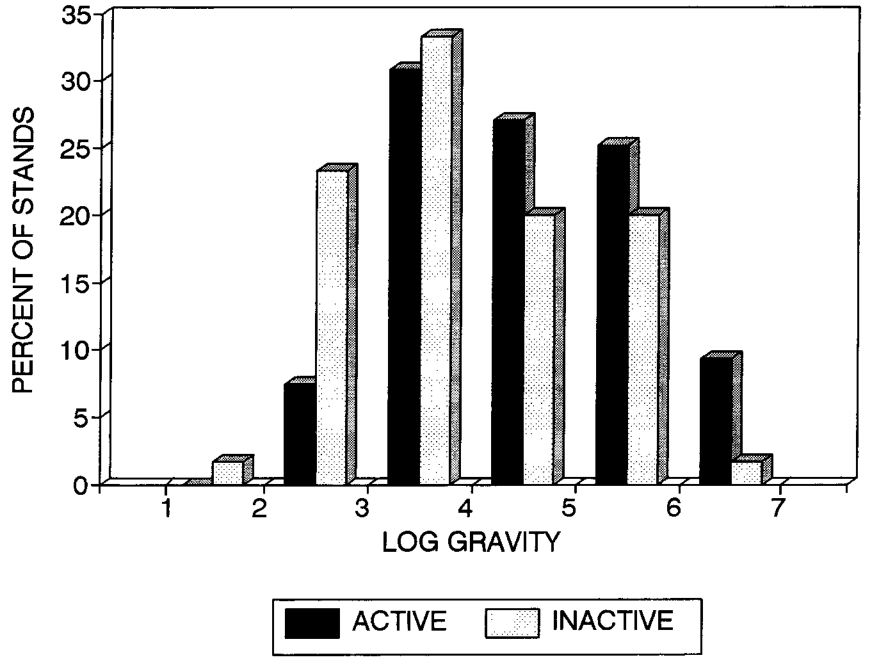

FIG. 3. Comparison of gravitational interaction with nearest active cluster stand (GRAVITY) for active versus inactive clusters. Note that the abscissa has a logarithmic scale.

= 0.0001). Replacement stand isolation coefficients, on the other hand, were significantly lower than active clusters (Wilcoxon test, $P = 0.0001$). When a maximum search radius of 1130 m was considered (Table 1), inactive sites still had significantly larger isolation coefficients (II1130) than did active clusters (Wilcoxon test, $P = 0.0234$). Nine of the active clusters (8%) had infinite isolation coefficients compared to 23 (38%) of the inactive ones. The maximum search radius of 390 m did not prove to be very instructive: only 14 of the active clusters (13%) and six of the inactive ones (10%) had finite isolation coefficients (II390).

There was no significant difference between active and inactive clusters in the percentage of cavity-tree cluster perimeter shared with any of the individual landcover classes or class groups except open country (PAS and PAS+OW). None of the active clusters shared their perimeter with pasture, compared to five of the inactive ones, a significant difference (Wilcoxon test, $P = 0.0016$). Three of the active clusters and six of the inactive ones shared part of their perimeters with the combined PAS+OW category (Wilcoxon test; $P = 0.0304$). Because there were only three active clusters and six inactive ones with any shared perimeter with

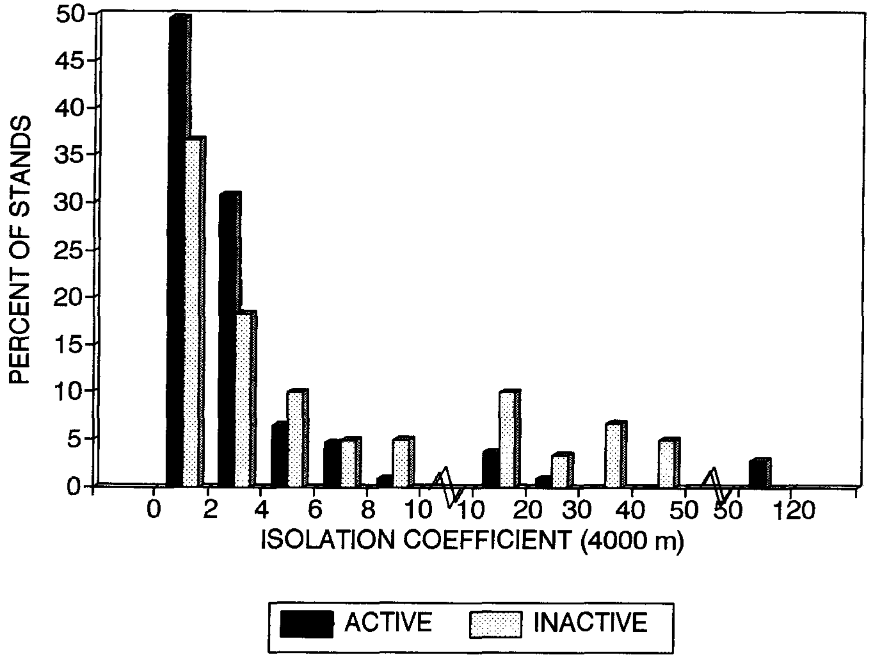

FIG. 4. Comparison of isolation coefficient, considering all active clusters within 4000 m (II4000), for active versus inactive clusters. Note the changes in abscissa scale at isolation coefficient values of 10 and 50.

PAS+OW, it was not possible to test the hypothesis that larger cluster stands could remain active in the face of inimical land uses around their perimeters than could smaller ones. For this analysis and the next, five inactive sites in young replanted stands ($\leq$33 yr) were excluded.

There were direct corridors from 64% of the active clusters, compared to 67% of the inactive ones (Table 2). The primary difference between active and inactive cluster sites involved less-direct and absent corridors. Indirect or circuitous corridors formed a link to 34% of active clusters, compared to 18% of inactive ones, while corridors were absent around only 3% of active clusters versus 15% of inactive ones. A 4 × 2 contingency analysis of the data indicated that the frequency of different corridor classes was significantly different between active and inactive cluster sites (log-likelihood with small-sample adjustment $G = 10.11$, $0.01 \leq P \leq 0.025$).

DISCUSSION

Inactive cluster stands were smaller and more isolated from other woodpecker groups than were active cluster stands; all metrics for iso-

TABLE 2
NUMBER AND PERCENTAGE OF ACTIVE AND INACTIVE CLUSTERS WITH DIRECT, INDIRECT, CIRCUITOUS, AND ABSENT CORRIDORS

Cluster status	Corridor class				
	Direct	Indirect	Circuitous	Absent	Total
Active	68 (64)	26 (24)	10 (9)	3 (3)	107 (100)
Inactive	37 (67)	8 (15)	2 (4)	8 (15)	55 (100)
Total	105	34	12	11	162

Values in table are numbers (and percentages) of clusters of each status, active or inactive, in each corridor class. The differences were significant ($G = 10.11$, $0.01 \leq P \leq 0.025$).

lation, except II390, were significantly different between the two classes. In contrast, while Conner and Rudolph (1991a) found that forest fragmentation close to a cluster was associated with small group size, they found no difference in the number of active clusters within 2 km of a cluster between small and large groups. This indicates the value of using various different metrics to measure isolation. Gravity interaction and isolation coefficient, for example, which incorporate cluster area and distance between clusters, may give more insight into isolation than does the number of clusters within a given radius alone. Walters (1991) describes the population dynamics of cooperative breeders such as the Red-cockaded Woodpecker, and he points out that they are generally unsuccessful at long-range dispersal, instead relying on use of nearby habitat. Reoccupation of inactive territories was the most common mechanism of new group formation in one population (Doerr et al. 1989), but territories that had been inactive for two years were rarely recolonized. Dispersing birds may therefore not find and recolonize isolated sites as readily as sites closer to dispersal centers. Managed recruitment stands had a significantly higher isolation coefficient (II4000) than active clusters. If breeding pairs are translocated to these sites this may not be a problem, but reliance on natural dispersal for cluster formation and maintenance may not be successful when isolation coefficients are high.

Pasture and open water adjacent to a cluster negatively influenced its status. There were few cluster sites that had such apparently inimical neighboring land uses, but those that did were much more likely to be inactive than active. Thus, fragmentation of forest, and especially of forest ownership, can have this added negative impact on Red-cockaded Woodpecker status. In addition, the absence of a timber corridor from one cluster site to another was a negative factor on cluster status: active clusters were more likely to be connected to other clusters by corridors of pine sawtimber and/or poletimber, even circuitous ones, than inactive sites were. Red-cockaded Woodpeckers have been observed using seed trees or shelterwood in cutover areas for cavity construction (Conner et al. 1991), so it is not unreasonable to assume that such trees can also provide dispersal corridors.

The Red-cockaded Woodpecker will only recover to sustainable population levels if suitable habitat is available, and the suitability will depend on spatial, as well as timber, characteristics. When selecting stands for remedial work, those with the greatest potential for becoming and remaining active clusters should be considered first. The selection process should include determination of isolation measures, neighboring land uses, and connectivity among cluster sites.

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