IN PRESS. EXPECTED DEC. '10

rich5/fon-njaf/fon-njaf/fon00310/fon2298d10a | phillipa | S=7 | 6/4/10 | 14:38 | 4/Color Figure(s): 2 | Art: NF-09-025 | Input-elr

Snag Longevity and Decay Class Development in a Recent Jack Pine Clearcut in Michigan

R. Gregory Corace III, Nancy E. Seefelt, P. Charles Goebel, and Heather L. Shaw

ABSTRACT

To better understand the factors that influence the longevity and decay class development of natural and girdled snags in jack pine (*Pinus banksiana* Lamb.) plantations managed for Kirtland's warbler (*Dendroica kirtlandii* Baird) breeding habitat in the northern Lower Peninsula of Michigan, we followed the fate of 335 jack pine and oak (*Quercus* spp.) snags. After 2.5 years, 41% of snags snapped or uprooted, with most snapping or uprooting occurring within the first year. Jack pine snags experienced higher rates of snapping or uprooting than oak or all snags combined, regardless of whether natural or girdled. Girdling by itself or as an interaction term had no significant effect on snapping or uprooting for either jack pine or oak, but both diameter ($P = 0.03$) and height ($P = 0.01$) influenced snapping and uprooting in oak. Thirty months after treatment, the percentage of snags among decay classes differed between species of snag and snag types (natural-girdled), with snag height inversely related to snag decay class development. These results suggest that snag development will occur rapidly in recently clearcut jack pine stands and that higher densities of snags may need to be retained if management goals are to emulate more natural conditions.

Keywords: ecological forestry, forest wildlife habitat, jack pine, Kirtland's warbler, snags

In many regions of northern Lake States, changes in land-use practices and altered fire regimes have produced pine (*Pinus* spp.)-dominated forests that are structurally simplified relative to stands that developed following wildfire (Schulte et al. 2007, Drobyshev et al. 2008). Biological legacies such as residual live trees, dead standing trees (snags), and downed coarse woody debris (CWD) are either absent or are found in low abundance (Spaulding 2008). In some instances, the homogenization of pine-dominated stands is exacerbated by single-species habitat management that prioritizes actions on the basis of highly specific species needs and not necessarily on emulating structural patterns that result from natural disturbances. Such is the case in the northern Lower Peninsula of Michigan, where forest managers with the US Forest Service, the Michigan Department of Natural Resources, and the US Fish and Wildlife Service intensively manage approximately 52,600 ha with the primary goal of producing young (5–23-year-old) jack pine (*Pinus banksiana* Lamb.) plantations as breeding habitat for the Kirtland's warbler (*Dendroica kirtlandii* Baird).

The Kirtland's warbler is an endangered, neotropical migratory bird that evolved to breed in young, dense stands of jack pine produced by wildfire (Hutto et al. 2008). However, the loss of large-scale, stand-replacing wildfire across the regional landscape has led to the need for intensive habitat management to produce the desired breeding conditions (Probst 1986, 1988). Contemporary habitat management now involves clearcutting mature (>40 year) jack pine and then trenching and planting these sites with 2-year jack pine seedlings in an "opposing wave" pattern whereby the pattern of densely (>2,500 stems ha^{-1}) planted seedlings changes in a scheduled way and produces small openings in the plantation in which birds forage (Probst 1986, 1988, Huber et al. 2001).

Although intensive jack pine plantation management as described above has led to an increased population of warblers and has aided in breeding range expansion into the Upper Peninsula of Michigan, Wisconsin, and Ontario (Probst et al. 2003), plantation management has also had the unintended consequence of producing conditions that poorly emulate the structure and function of wildfire-generated jack pine stands. These plantations are often characterized by altered ecosystem patterns (Houseman and Anderson 2002) and processes (LeDuc and Rothstein 2007), in part because of the lack of biological legacies. In particular, because snags are not a breeding requirement for Kirtland's warbler, the abundance of snags in many of these plantations differs dramatically from wildfire-generated stands. According to Spaulding (2008), the abundance of snags in jack pine stands regenerated by wildfire differed by stand age (younger stands averaged 252 snags ha^{-1}, and older stands had up to 700 snags ha^{-1}) but were consistently much greater than in plantations.

Fortunately, snags can be a focus of management, and past studies have investigated the importance of snag management elsewhere (Franklin et al. 1987, Hutto 2006) and have described management techniques for enhancing snag abundance (Bull and Partridge 1986). Consideration of snags is even mentioned in the most recent multiagency guidelines for Kirtland's warbler habitat management: "All dead trees should be left in the sale area. An overall objective of

Manuscript received July 8, 2009, accepted March 16, 2010.

AQ: H *R. Gregory Corace III (greg_corace@fws.gov), US Fish and Wildlife Service, Seney National Wildlife Refuge, 1674 Refuge Entrance Road, Seney, MI 49883. Nancy E. Seefelt and Heather L. Shaw, Department of Biology, Central Michigan University. P. Charles Goebel, Ohio State University.* *The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the US Fish and Wildlife Service. Funding for this work was provided by Seney National Wildlife Refuge, the Central Michigan University (CMU) Office of Research and Sponsored Programs, and the CMU Department of Biology. Special thanks to Christopher Finch (CMU) for field assistance and Laural Tansy (Seney National Wildlife Refuge) for administrative assistance. This article was greatly improved by the editorial comments of an associate editor and three anonymous reviewers.*

This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; kilometers (km): 1 km = 0.6 mi; hectares (ha): 1 ha = 2.47 ac.

15–25 dead trees per acre (37–62 ha^{-1}) is desirable. In those cases where fewer than 10 standing dead trees per acre (25 ha^{-1}) are present, live trees greater than 6 inches (15 cm) dbh may be used to recruit snags" (Huber et al. 2001, p. 15). However, as far as we are aware, no studies have examined the longevity of snags left in jack pine clearcuts or the efficacy of mechanical treatments to produce snags by girdling trees with commonly used logging equipment in Michigan. Although several studies have examined snag dynamics in older wildfire-generated jack pine stands in Canada (Brais et al. 2005, Metsaranta et al. 2008), most snag research has been com-
AQ: A pleted in the western part of the United States. These studies have either focused on natural snags within the context of postfire salvage logging or investigated snag management techniques on western species of pine (Bull and Partridge 1986, Shea et al. 2002, Hutto 2006). However, autoecological differences among pine species and geographic variation in the disturbance regimes that maintain pine-dominated forest ecosystems and produce snags warrant more regionally appropriate snag management studies.

To foster a more ecological and multispecies approach to jack pine plantation management of Kirtland's warbler breeding habitat in Michigan, we conducted a retrospective analysis of 335 natural and girdled snags in a recent jack pine clearcut. Specific research questions were as follows: (1) What is the longevity of natural and girdled snags of different tree species 2.5 years after silvicultural treatment (clearcut)? (2) How does decay class development compare between snag species in the two snag types (natural and girdled)? (3) What physical snag characteristics are related to observed patterns in the above?

Figure 1. Northern Lower Peninsula of Michigan counties (shaded) with Kirtland's Warbler Wildlife Management Area tracts (scattered blocks). The actual study site was in northwest Clare County.

Study Area

This study was conducted on the US Fish and Wildlife Service Kirtland's Warbler Wildlife Management Area (WMA). The WMA comprises 125 tracts in eight counties of the northern Lower Peninsula of Michigan and covers 2,705 ha. The majority (94%) of the WMA stands are in the Highplains Landtype Association, with sand-dominated soil types well suited for the growth of jack pine and the production of Kirtland's warbler habitat (US Fish and Wildlife Service 2009). The WMA is also characterized by a relatively severe climate. The growing season ranges from 70 to 130 days, with frequent spring freezes. Mean annual precipitation is relatively uniform across the area (71–81 cm) (Albert 1995). In terms of soil and forest types, the specific study parcel (located in the northwest corner of Clare County, Michigan) was representative of the WMA
F1 overall (Figure 1).

Methods

As part of the typical initial treatment to produce Kirtland's warbler habitat, 35 ha of mature (>40 year old), monotypic, even-age jack pine were clearcut during September and October 2006. Approximately 95% of the basal area/volume was removed from the site during harvest. After harvest, the remaining 5% was composed of snags and scattered residual live trees (mostly red pine [*Pinus resinosa* Sol.]). To create snags, one logger was assigned to use a
F2 Ponsse harvester to girdle live trees (Figure 2). All girdled live trees were >18 cm dbh, the approximate mean dbh of the jack pine-dominated stand before harvest. Individuals of all overstory tree species were girdled: jack pine, red pine, white pine (*Pinus strobus* L.), black cherry (*Prunus serotina* Ehrh.), and oak (*Quercus* spp.).

Between September and December 2007 (on average, 12 months after treatment) a total of 335 snags (those that developed through natural processes prior to harvesting and those that were produced by girdling during the harvest) were inventoried. A total of 165 were natural snags (86 jack pine, 78 oak, and 1 black cherry), and 170 were girdled snags (85 jack pine, 75 oak, 9 red pine, and 1 white pine). For each snag, we recorded (1) snag species, (2) snag size (dbh), (3) snag height, (4) snag decay class (Holloway et al. 2007, Table 1), and (5) direction of fall, if snag had reached decay class 5 T1/AQ:B
(DC5; i.e., uprooted or snapped to <6 m in height). During four subsequent visits in April 2008 (approximately 17 months after treatment), July 2008 (approximately 20 months after treatment), October to November 2008 (approximately 24 months after treatment), and April 2009 (approximately 30 months, or 2.5 years, after treatment), each snag was reinventoried to determine longevity (i.e., time to DC5). Because this plantation and others of the WMA are managed primarily for the benefit of wildlife species and the fact that standing snags (especially larger snags) are an important structural variable in habitat selection of many associated bird species (Corace et al., in press) our main interest was in the longevity of snags (natural and girdled) in the stand. In addition, we also investigated differences in decay class development between natural and girdled snags and between tree species comprising both snag types.

We used chi-square tests to test for differences in the cumulative percentage of snags (between snag types of the same species) that experienced DC5 within each of five sampling periods over 2.5 years. We used analysis of variance to test whether differences existed between the average initial snag size (dbh) and height of those snags that developed to DC5 and those that did not. We used binary logistic regression to determine how the additions of an indicator variable (girdled, yes/no) and interaction terms (dbh_girdle and height_girdle) influenced a binary categorical response variable (DC5 yes/no) after 2.5 years. We used linear regression to examine

COLOR

Figure 2. Jack pine snags days after girdling by mechanized logging equipment (September to October 2007, Kirtland's Warbler Wildlife Management Area).

Table 1. Snag decay classes, where uncertainty existed between assigning a decay class to a given snag during a given sampling period, a midpoint value (e.g., 1.5, 2.5, 3.5, or 4.5) was used.

Decay class	Snag characteristics
1	Recently dead tree with intact tops and the majority of fine branching present
2	Trees with loose bark, intact tops, and most of the fine branches
3	Trees with <50% of coarse branches and <50% bark
4	Trees with broken tops and few or no coarse branches, >6 m in height
5	Trees with broken tops and no coarse branches, <6 m in height

Adapted from Holloway et al. (2007)

the relationship of decay class development after 2.5 years using snag dbh and height as predictor variables and decay classes (DC1–DC5) as response variables. Because this study was retrospective, and because our initial measurements of dbh and height were made up to 12 months after snags were created and during this time many snags had already snapped or uprooted, analyses using dbh and height as predictors were based on a reduced sample size (n = 219) that included snags <DC4. Significance for all analyses was established at $\alpha = 0.10$. Finally, we used wind speed and direction data collected from the National Oceanic and Atmospheric Administration AQ: C (NOAA) Leota weather station (NOAA 2009), located approximately 3 km east-southeast of the study site, to try to correlate specific wind events with the snapping or uprooting (i.e., DC5) that we observed over 2.5 years.

Results

After 2.5 years, 137 of the 335 snags (41%) that we studied snapped or uprooted (i.e., developed to DC5). Of all snags that reached DC5 during the entire sampling period, 6% uprooted and 94% snapped. Natural oak snags were the only species group that experienced a rate of uprooting >5%. Regardless of snag species or type, most snags developed DC5 conditions within the first year. Little change in the number (or percentage) of snags reaching DC5 occurred thereafter (Figure 3). Thirty months after treatment, 50% F3 of all natural snags and 32% of all girdled snags were at DC5. We observed no significant difference in the snag longevity (time to DC5) between natural and girdled jack pine ($P > 0.10$), but all jack pine snags experienced higher rates of DC5 development than oak or all snags combined, regardless of whether natural or girdled or when sampled over 2.5 years (Figure 3). Overall, 63% of the natural jack pine either snapped or uprooted, compared with 36% of the natural oak snags. Conversely, 57% of the girdled jack pine developed to DC5, compared with 8% of the girdled oak.

Of those snags (n = 219) that had not snapped or uprooted by the time we did our initial measurements, relatively little difference existed between natural snags and girdled snags of any of the three species groups (Table 2). No clear relationships existed be- T2 tween snags that developed to DC5 and those that did not based on dbh and height alone (Figure 4). On average, neither dbh (degrees of F4 freedom [df] = 36, F = 2.06, P = 0.16) nor height (df = 36, F = AQ: D 1.69, P = 0.20) differed between natural jack pine snags that developed to DC5 and those that had not snapped or uprooted. For natural oak snags, however, snapped or uprooted snags were on average shorter (df = 56, F = 7.77, P = 0.01), whereas the average dbh of DC5 snags did not differ with those snags <DC5 (df = 56, F = 0.20, P = 0.65). For girdled jack pine snags, neither dbh (df = 42, F = 0.40, P = 0.53) nor height (df = 42, F = 2.37, P = 0.13) differed between snapped or uprooted snags and those still standing. The same held true for girdled oak (dbh: df = 70, F = 0.01, P = 0.93; height: df = 70, F = 1.44, P = 2.34)

Results of binary logistic regression suggested that jack pine and oak responded differently to girdling. For jack pine, none of the five variables (i.e., dbh, height, girdle [yes/no], dbh_girdle, height_girdle) was significant ($P < 0.10$). For oak, dbh (P = 0.03) and height (P = 0.01) each influenced development to DC5, with a positive relationship for dbh and a negative relationship for height. In other words, for each centimeter of dbh increase, there was a 26% increased likelihood of an oak reaching DC5. Conversely, for each meter of height increase, the chance of an oak reaching DC5 decreased by 57%. There was no effect of girdling as an interaction term or as a stand-alone input variable.

Thirty months after treatment, the percentage of snags among the five decay classes differed between snag species and snag types. The percentage of snags in different decay classes for natural jack pine and oak were relatively similar, whereas girdled jack pine snags had developed much more quickly into later decay classes (>DC3) than girdled oak (Figure 5). Logistic regression found that snag dbh F5 and height together explained only 20%, 3%, 17%, and 7% of the variation in decay class development after 2.5 years in natural jack pine, girdled jack pine, natural oak, and girdled oak, respectively. In all four models, snag height was inversely related to decay class development, but it significantly affected >DC3 status in only three models (Table 3). T3

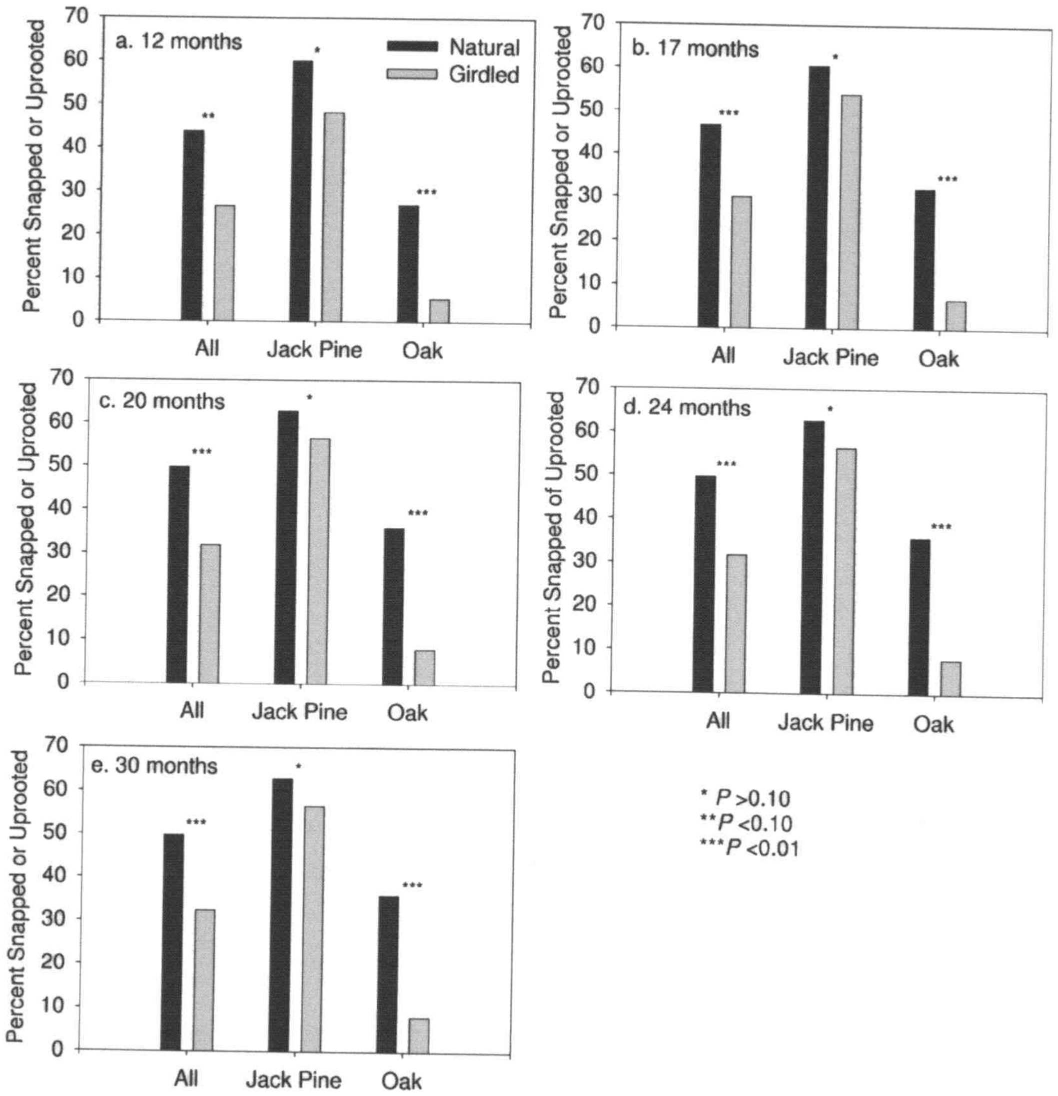

Figure 3. Cumulative percentage of snags (jack pine and oak, natural and girdled) that developed to decay class 5 (DC5; i.e., snapped or uprooted) during five sampling periods over 2.5 years.

Table 2. Characteristics of 219 snags (by species group) that had not developed to decay class 4 or 5 (i.e., snapped or uprooted) before the first sampling period.

Metric	Jack pine (n = 80)		Oak (n = 128)		Other (n = 11)	
	Natural	Girdled	Natural	Girdled	Natural	Girdled
Number	37	43	57	71	1	10
Mean dbh, cm (±1 SD)	26.29 (6.82)	27.81 (5.29)	31.05 (9.83)	31.64 (8.27)		35.08 (7.59)
Mean height, m (±1 SD)	8.52 (2.93)	12.38 (3.29)	10.97 (3.13)	12.36 (2.39)		17.31 (3.68)

We were able to determine the direction of fall for 85 snags that developed to DC5. On the basis of the direction of fall, we determined that winds coming from the west and north accounted for 84% and 62% of the snapping or uprooting, respectively. Moreover, the modal (31%) wind direction that potentially influenced these responses in snags was between 301° and 330°, or northwest winds, which are common winter winds. There were 186 days over the 2.5-year study with wind events exceeding 32 kph, and 8 days on which wind speeds were >48 kph. Sixty-three (34%) of these days had predominantly southwest winds, 18% had north winds, 17% had south winds, 13% had northwest winds, and 12% had west winds. Maximum wind speed recorded was 64 kph, with all three days with this wind speed being >12 months after treatment. A total of 98 days with wind events exceeding 32 kph were recorded during the first 12 months of the study, when most DC5 development occurred. This average of approximately 8.2 days/months of wind ≥32 kph was greater than the average for the other time periods of study (range, 2.8–4.8 days month^{-1}).

Discussion

In many jack pine-dominated ecoregions of the northern Lower Peninsula of Michigan, habitat management for Kirtland's warbler

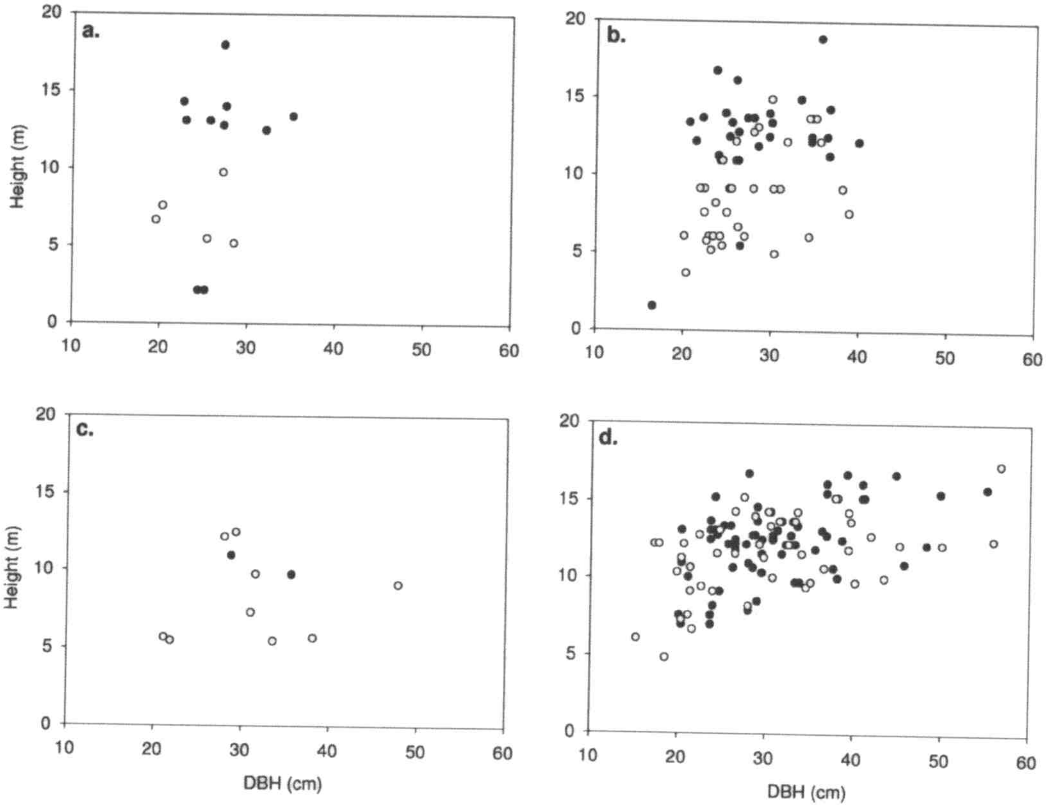

Figure 4. Relationship between dbh and height for jack pine at decay class 5 (DC5; i.e., snapped or uprooted) (a), jack pine <DC5 (b), oak at DC5 (c), and oak <DC5 (d) after 2.5 years. Open circles denote natural snags, and filled circles denote girdled snags.

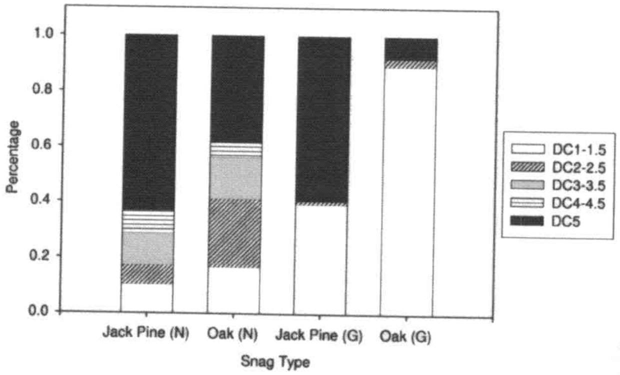

Figure 5. Percentage of jack pine and oak snags (N, natural; G, girdled) in different decay classes (DC1–DC5) after 2.5 years.

has produced structurally simplified forest patterns relative to the natural (or historical) disturbance regime, wildfire. Because forest structure in jack pine is important for other wildlife species (Corace et al., in press) as well as other ecosystem processes (LeDuc and Rothstein 2007, Spaulding and Rothstein 2009), more consideration must be made in enhancing postclearcut residual stand structure. This study attempted to start the process of understanding what techniques might best be used to enhance residual stand structure and produce plantations that at some level better emulate wildfire-generated stands. In doing so, we assessed both snag longevity and decay class development of natural and girdled snags. Because our study was conducted in a jack pine stand typical of stands managed by multiple agencies for Kirtland's warbler habitat and because we used girdling techniques that would be possible on most logging operations in the northern Lower Peninsula of Michigan, we believe our findings provide an initial framework for future attempts at producing more natural conditions in intensively managed Kirtland's warbler jack pine plantations. However, this study has a number of limitations, including not being replicated across space and a lack of initial natural snag assessment prior to harvest. This was a small case study, and our finding should not be unconditionally extrapolated beyond the study area.

Most snag development to DC5 (i.e., most snapping or uprooting) occurred within the first year (i.e., low snag longevity), and after 2.5 years, approximately 41% of the snags had snapped or uprooted. Although we believe that a few anomalous wind events may have factored into the low snag longevity we observed, this finding is consistent with other studies done in the western states (see Hutto 2006) that suggest that relative to the average longevity of the dominant tree species in a stand, most snags are maintained for only a short duration within a stand. For instance, working in a western landscape regulated by stand-replacing wildfire, Lehmkuhl et al. (2003) found that stands >20 years of age had only 30% of the snags they had after initial disturbance. If this pattern of low snag longevity holds true for most intensively managed jack pine stands, then the present guidelines for Kirtland's warbler jack pine plantations that suggest leaving 37–62 snags ha^{-1} would produce a stand with significantly fewer snags after 1 year. These recommendations would still be considerably less than the Spaulding (2008) value of 252 snags ha^{-1} for young jack pine stands produced by wildfire.

Our findings also indicated species-specific differences in the rates of snag longevity and decay class development, with jack pine

Table 3. Results of linear regression illustrating the influence that dbh and height have on decay class (DC) for jack pine and oak (girdled and natural) after 2.5 years.

	Predictor *P* value				
Snag species and type	dbh (cm)	Height (m)	Model	Model *P* value	Model R^2 (%)
Jack pine, natural	0.713	0.011	DC = 4.38 + 0.016 dbh − 0.1207 height	0.03	20
Jack pine, girdled	0.312	0.586	DC = 2.90 − 0.054 dbh − 0.046 height	0.58	3
Oak, natural	0.451	0.002	DC = 4.31 + 0.013 dbh − 0.174 height	0.01	17
Oak, girdled	0.401	0.029	DC = 1.93 + 0.009 dbh − 0.086 height	0.09	7

being less likely to remain as long in the stand as oak. Unfortunately, our review of the literature did not allow us to compare this finding with other geographically relevant papers that investigated snag longevity in young jack pine plantations, or, for that matter, any papers regarding girdled jack pine. Metsaranta et al. (2008) found that natural jack pine snag "fall rate" in mature stands to average 0.026 snags year^{-1}, but no value was given for postwildfire stands or postclearcut stands.

We were surprised to find that decay class development, including development to DC5, seemed to be greater for shorter snags. We had suspected that taller snags would be more prone to snapping and uprooting, but instead we believe that this finding was (at least for the girdled jack pine snags) due to the interaction of girdle length and snag height. Unfortunately, we were not able to consistently measure girdle length, nor were we able to quantify the depth at which girdling affected trees. Nonetheless, nearly all snaps occurred within the length of the girdle (Figure 2). In shorter snags, this girdle would have comprised a greater proportion of the overall height of these snags and thereby likely reduced structural integrity more severely in these snags. Snapping that occurred in natural jack pine (and less so in natural oak snags, as it was the only treatment group that experienced a rate of uprooting >5%) may have been a function of advanced decay class development, but we were unable to substantiate this claim because of the lack of pretreatment data. To maintain girdled snags longer and provide taller snapped snags, it may be advisable to limit the area of the girdle and to make the girdle as high in the tree as possible.

Compared with natural snags, many girdled snags that had not snapped or uprooted had not yet developed the diversity of later (e.g., DC3–DC4.5) snag decay class characteristics. As loose bark and other later decay class characteristics are important for wildlife taxa such as bats (Chioptera, Jung et al. 2004), this finding supports the contention of Shea et al. (2002) that girdled snags do not provide the same habitats for wildlife at the same time as natural snags. Natural snags, of course, have had more time to develop characteristics such as loose bark. Future work should more thoroughly compare snag decay class development over time and compare and contrast girdled snags with those that develop by wildfire in jack pine stands in Michigan.

Emulating the structural patterns resulting from natural disturbances is a major aspect of contemporary ecological forestry (Hansen et al. 1991, Seymour and Hunter 1999, Franklin et al. 2007), but its full implementation in some stands is difficult because of other goals and objectives, including wildlife habitat management (Corace et al. 2009). Although more study is required before meaningful snag management guidelines can be provided to managers of Kirtland's warbler habitat, basic forest ecology principles suggest that the abundance of biological legacies (such as snags) created by density-dependent mortality is much lower than the abundance following stand-replacing disturbances (Oliver and Larson 1996, Frehlich 2002). If a stand is harvested either before it is disturbed or before it succeeds to another forest type, there will be a deficit in these biological legacies compared with the amount following a natural stand-replacing disturbance. If land managers wish to produce breeding habitat for Kirtland's warbler that better emulate conditions of wildfire-generated jack pine stands and are yet unable or unwilling to use prescribed fire or managed wildfire, we believe mechanical treatments should be used to enhance the number of snags left as residual structure. Although some of these snags may be retained for only a relatively short duration, their eventual use as CWD should not be discounted. Snag management should be viewed as an integral part of CWD management as well. Finally, more care should be given to the spatial arrangement of managed snags, as clustering snags may reduce snapping or uprooting and produce more natural spatial patterns of residual structure.

Literature Cited

ALBERT, D.A. 1995. *Regional landscape ecosystems of Michigan, Minnesota and Wisconsin: A working map and classification.* US For. Serv. Gen. Tech. Rep. NC-178. US For. Serv., St. Paul, MN. 250 p + map.

BRAIS, S., F. SADI, Y. BERGERON, AND Y. GRENIER. 2005. Coarse woody debris dynamics in a post-fire jack pine chronosequence and its relation with site productivity. *For. Ecol. Manag.* 220:216–226.

BULL, E.L., AND A.D. PARTRIDGE. 1986. Methods of killing trees for use by cavity nesters. *Wildlife Soc. B.* 14:142–146.

CORACE, R.G. III, P.C. GOEBEL, D.M. HIX, T. CASSELMAN, AND N.E. SEEFELT. 2009. Applying principles of ecological forestry at National Wildlife Refuges: Experiences from Seney National Wildlife Refuge and Kirtland's Warbler Wildlife Management Area, USA. *For. Chron.* 85:1–7.

CORACE, R.G. III, P.C. GOEBEL, AND D.L. MCCORMICK. In press. Kirtland's warbler habitat management and multi-species bird conservation: Considerations for planning and management across jack pine habitat types. *Nat. Area J.* AQ: E

DROBYSHEV, I., P.C. GOEBEL, D.M. HIX, R.G. CORACE III, AND M. SEMKO-DUNCAN. 2008. Interactions between forest composition, structure, fuel loadings and fire history: A case study of red pine-dominated forests of Seney National Wildlife Refuge. *For. Ecol. Manag.* 256:1723–1733.

FRANKLIN, J.F., H.H. SHUGART, AND M.E. HARMON. 1987. Tree death as an ecological process. *BioScience* 37:550–556.

FRANKLIN, J.F., R.J. MITCHELL, AND B.J. PALIK. 2007. *Natural disturbance and stand development principles for ecological forestry.* US For. Serv. Gen. Tech. Rep. NRS-GTR-19. 44 p.

FREHLICH, L.E. 2002. *Forest dynamics and disturbance regimes.* Cambridge University Press, Cambridge, U.K. 266 p.

HANSEN, A.J., S.J. SPIES, J.L. SWANSON, AND J.L. OHMANN. 1991. Conserving biodiversity in managed forests: Lessons from natural forests. *BioScience* 41: 382–392.

HOLLOWAY, G.L., J.P. CASPERSEN, M.C. VANDERWEL, AND B.J. NAYLOR. 2007. Cavity tree occurrence in hardwood forests of central Ontario. *For. Ecol. Manag.* 239:191–199.

HOUSEMAN, G.R., AND R.C. ANDERSON. 2002. Effects of jack pine plantation management on barrens flora and potential Kirtland's warbler nest habitat. *Restor. Ecol.* 10:27–36.

HUBER, P., J.A. WEINRICH, AND E.S. CARLSON. 2001. *Strategy for Kirtland's warbler habitat management.* Michigan Department of Natural Resources, US For. Serv., US Fish and Wildlife Service. Unpublished guidelines.

HUTTO, R.L. 2006. Toward meaningful snag-management guidelines for post-fire salvage logging in North American conifer forests. *Conserv. Bio.* 20:984–993.

HUTTO, R.L., C.J. CONWAY, V.A. SAAB, AND J.R. WALTERS. 2008. What constitutes a natural fire regime? Insights from the ecology and distribution of coniferous forest birds of North America. *Fire Ecol.* 4:115–132.

JUNG, T.S., I.D. THOMPSON, AND R.D. TITMAN. 2004. Roost site selection by forest-dwelling male Myotis in central Ontario, Canada. *For. Ecol. Manag.* 202:325–335.

LEDUC, S.D., AND D.E. ROTHSTEIN. 2007. Initial recovery of soil carbon and nitrogen pools and dynamics following disturbance in jack pine forests: A comparison of wildfire and clearcut harvesting. *Soil Biol. Biochem.* 39:2865–2876.

LEHMKUHL, J.F., R.L. EVERETT, R. SCHELLHAAS, P. OHLSON, D. KEENUM, H. RIESTERER, AND D. SPURBECK. 2003. Cavities in snags along a wildfire chronosequence in eastern Washington. *J. Wildlife Manag.* 67:219–228.

METSARANTA, J.M., V.J. LIEFFERS, AND R.W. WEIN. 2008. Dendrochronological reconstruction of jack pine snag and downed log dynamics in Saskatchewan and Manitoba, Canada. *For. Ecol. Manag.* 255:1262–1270.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA). 2009. *Mesowest station interface.* Available online at raws.wrh.noaa.gov/cgi-bin/roman/meso_base.cgi?stn = LEOM4; last accessed ■■. AQ: F

OLIVER, C.D., AND B.C. LARSON. 1996. *Forest stand dynamics.* John Wiley and Sons, New York. 520 p.

PROBST, J.R. 1986. A review of factors limiting the Kirtland's warbler on its breeding grounds. *Am. Mid. Nat.* 116:87–100.

PROBST, J.R. 1988. Kirtland's warbler breeding biology and habitat management. P. 28–35 in *Integrating forest management for wildlife and fish*, Hoekstra, R., and J. Capp (eds.). US For. Serv. Gen. Tech. Rep. NC-122.

PROBST, J.R., D. DONNER, C.I. BOCETTI, AND S. SJOGREN. 2003. Population increase in Kirtland's warbler and summer range expansion to Wisconsin and Michigan's Upper Peninsula, USA. *Oryx* 37:365–373.

SALLABANKS, R., AND E.B. ARNETT. 2005. Accommodating birds in managed forests in North America: A review of bird-forestry relationships. P. 345–365 in *Bird conservation implementation and integration in the Americas: Proceedings of the third international Partners in Flight Conference*, Ralph, C.J., and T.D. Rich (eds.). US For. Serv. Gen. Tech. Rep. PSW-GTR-191. 643 p. AQ: G

SCHULTE, L.A., D.J. MLADENOFF, T.R. CROW, L.C. MERRICK, AND D.T. CLELAND. 2007. Homogenization of northern U.S. Great Lakes forests due to land use. *Landscape Ecol.* 22:1089–1103.

SEYMOUR, R.S., AND M.L. HUNTER, JR. 1999. Principles of ecological forestry. P. 22–61 in *Managing biodiversity in forest ecosystems*, Hunter, M.L., Jr. (ed.). Cambridge University Press, Cambridge, U.K. 714 p.

SHEA, P.J., W.F. LAUDENSLAYER, JR., G. FERRELL, AND R. BORYS. 2002. *Girdled versus bark beetle-created ponderosa pin snags: Utilization by cavity-dependent species and differences in decay rate and insect diversity.* US For. Serv. Gen. Tech. Rep. PSW-GTR-181. 9 p.

SPAULDING, S. 2008. *Does clearcut harvesting emulate the effects of natural disturbance on the development of stand structure in* Pinus banksiana *forests of northern Lower Michigan?* MSc thesis, Michigan State Univ., East Lansing, MI. 50 p.

SPAULDING, S.E., AND D.E. ROTHSTEIN. 2009. How well does Kirtland's warbler management emulate the effects of disturbance on stand structure in Michigan jack pine forests? *For. Ecol. Manag.* 258:2609–2618.

US FISH AND WILDLIFE SERVICE. 2009. *Kirtland's Warbler Wildlife Management Area Comprehensive Conservation Plan.* US Fish and Wildlife Service, Fort Snelling, MN. 114 p.