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Brown Creeper (*Certhia americana*) Demographic Response to Hardwood Forests Managed Under the Selection System

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Manuscripts

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2 Forests Managed Under the Selection System

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Abstract: The Brown Creeper (*Certhia americana*) has been identified as one of the most sensitive passerines to partial forest harvest in North America. The effect of selection logging on Brown Creeper density, nest timing, nest survival, and nest/foraging site selection was examined in 5 silviculture treatments (intensive group-selection, typical group-selection, old single-tree selection, recent single-tree selection and control forests) of Algonquin Provincial Park, Canada. As Brown Creeper nests under the bark of large, decaying trees, we hypothesized that Brown Creeper density, timing of breeding, nest survival, and nest/foraging site selection would be negatively affected by silviculture through the removal of large, decaying trees as part of providing safe conditions for loggers. We monitored 101 nests of Brown Creeper during the 2010 and 2011 breeding seasons, mapped territories to estimate density, and conducted foraging surveys. Brown Creeper density was reduced by about 42% in logged stands compared to densities in control stands. Despite that, silviculture did not significantly alter timing of breeding or nest survival. Nest trees were significantly closer to small forested wetlands than randomly selected trees in all stands. However, the loss of large trees through partial harvesting meant that Brown Creeper nested closer to adjacent, small forested wetlands, and often in Balsam Fir in treated stands. In control stands, Brown Creeper nested further from forested wetlands, disproportionately in greater numbers in upland hardwoods, and preferentially in the bark of snags of Yellow Birch. The change in the species of tree used for nesting and the general forest type as a result of logging also resulted in consequences for the selection of foraging substrates. To maintain higher densities of Brown Creeper in logged stands in Algonquin Park, we recommend retaining

uncut blocks roughly the size of a Brown Creeper territory (10 ha) containing large diameter Yellow Birch snags.

Introduction

Logging can negatively affect North American breeding bird populations (Vitz and Rodewald 2006). Management concerns for birds that breed in mature forests occur because logging can fragment and reduce the amount of available mature forest breeding habitat, and increase the amount of edge and negative edge effects (Hartley and Hunter 1998, Flaspohler et al. 2001, Purcell et al. 2012). Selection or shelterwood silvicultural systems are designed to emulate small-scale natural disturbances that create conditions for regenerating these forests and also minimize impacts on mature forest breeding birds (Lindenmayer et al. 2006).

Forest managers have developed guidelines to preserve cavity trees because cavities provide a wide array of habitat to many species (Holloway et al. 2007). In stands managed under the selection system in Ontario, Canada, this recommendation entails retaining 10 living cavity trees > 25 cm diameter at breast height (DBH) per hectare (Ontario Ministry of Natural Resources 2010). However, for reasons related to worker safety, there are no guidelines in Ontario on the quantity or quality of standing dead trees to be retained in logged stands even though standing dead trees also play an important role in providing forests with essential habitat structures for some species of birds and other wildlife (Angelstam et al. 2003). Effective silviculture should encompass wildlife

61 habitat needs and plan for a continual supply of standing dead wood to provide long-term
62 structural habitat for many species (Ontario Ministry of Natural Resources 2000, 2004).

63 Standing dead trees are crucial to the Brown Creeper (*Certhia americana*), whose
64 hammock-like nests are placed in flaking bark (Poulin et al. 2013). Brown Creepers also
65 forage for insects on large live trees with deep bark fissures (Adams and Morrison 1993).
66 Brown Creeper responds negatively to forest edges as nests located farther from edges
67 are more likely to fledge young (Poulin and Villard 2011, Purcell et al. 2012). Thus,
68 Brown Creeper may be affected by increases in the amount of edge habitat and
69 fragmentation created by logging. These relatively strict habitat requirements confine
70 them to areas with mature forest with a high density of standing dead or declining trees
71 for nesting and large trees for foraging (Wiggins 2005).

72 The Brown Creeper was recently identified as one of the most sensitive passerine
73 species to partial logging in North America (Vanderwel et al. 2007). Brown Creeper
74 habitat in North America is limited to protected old growth forests and mature forests
75 where management maintains suitable conditions (Poulin et al. 2013). In Ontario, under
76 the *Occupational Health and Safety Act* (2010), standing dead trees must be cut or
77 lowered to the ground if in the vicinity of forestry workers felling trees (Ontario Ministry
78 of Labour 2010), although the Stand and Site Guide (OMNR 2010) does suggest leaving
79 these trees when safe to do so. Studies investigating the effect of modern silvicultural
80 practices on forest bird communities show that the Brown Creeper is significantly less
81 abundant in logged areas, attributing this decline mainly to the loss of snags and foraging
82 trees (Mahon et al. 2008, Poulin et al. 2010). Thus, current wildlife habitat
83 recommendations may not be providing adequate habitat for Brown Creepers and

silviculture, in general, may play an important role in determining future Brown Creeper population trends (Wintle et al. 2005).

Single-tree selection is the most common silvicultural system used in the tolerant hardwood forests of Algonquin Provincial Park (Algonquin Forestry Authority 2010). On a 20 to 30 year rotational cycle, single-tree selection harvests remove individual trees to release young shade tolerant tree seedlings. The technique often removes trees with declining health and attempts to emulate small-scale natural disturbances such as a single-tree fall gaps or the mortality of small groups of trees (OMNR 2004). The removal of individual trees creates relatively small gaps in the canopy that quickly become filled and create shaded growing conditions, therefore, promoting the growth of shade-tolerant species like sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), and eastern hemlock (*Tsuga canadensis*).

A benefit of single-tree selection for most forest dwelling birds is the stand remains forested at all times (Medin and Booth 1989) and tree markers can be provided with the direction to maintain certain habitat features. Since European settlement, species like black cherry (*Prunus serotina*) and yellow birch (*Betula alleghaniensis*) that require ample sunlight have become less common because of their inability to survive and maintain growth in conditions where the canopies close before the next thinning phase (Quinn 2004). Group-selection silviculture is also based on periodic harvests but removes trees within small gaps (size range 20m-40m across) and may include single-tree selection removals in the areas between the gaps. In Algonquin Park two forms of group-selection silviculture have been employed: intensive, where the matrix is not logged, and typical, where the matrix is also treated with single-tree selection (Falk et al. 2010). The

patches allow more sunlight through the canopy to promote the growth of valuable tree species of mid shade tolerance (Moorman and Guynn 2001). A point count survey indicated Brown Creepers population numbers were not reduced in stands cut through group-selection silviculture in Algonquin Park (Tozer et al. 2010), but that study did not address whether Brown Creepers continued to nest in logged areas after harvest or whether they were displaced to unlogged portions within auditory limits of the surveyed stands.

Our goal was to determine whether five forms of silvicultural prescription in Algonquin Provincial Park negatively impacted Brown Creeper nest density and survival, and whether particular nest site characteristics were correlated with higher nest survival. We hypothesized that treatments with less disturbance in the matrix (intensive group selection and old single tree selection), would have higher Brown Creeper densities because they would have more declining or dead trees for nesting than recent single-tree selection or typical group selection where declining trees in the stand are harvested or removed for logger safety. Studies in the same sites on other bird species have not found reductions in nest success in response to silvicultural treatments, suggesting that the predator communities may not be affected by silviculture at the current intensity in the Algonquin landscape (Falk et al. 2011, Leblanc et al. 2011). Therefore we did not predict a change in nest success of Brown Creeper between our logging treatments.

We also investigated nest and foraging tree selection by Brown Creeper in stands with different logging prescriptions to determine whether nesting trees with appropriate characteristics (e.g., flaking bark) or foraging trees might be limiting in logged stands, and thus help to explain potential declines in density. We analyzed selection of foraging

and nest tree species and their DBH at the site level and the broader stand level by remotely distinguishing forest types and distances of nests to forested wetlands. We predicted that Brown Creeper in logged treatments would be nesting and foraging on different tree species, and of smaller size than in reference stands. We also predicted that those silvicultural treatments with more intact matrix (intensive group selection) would contain the majority of Brown Creeper nests in the intact matrix areas (i.e., upland hardwoods) compared to treatments with more matrix disturbance where Brown Creeper nests would be closer to unlogged forested refuges. Finally, we examined the effects of silvicultural treatment on Brown Creeper timing of nest initiation, clutch size and length of the nestling period. As Brown Creepers forage on bark, we predicted that, if silviculture reduced foraging substrates, we would see later breeding, lower clutch sizes or longer nestling periods in logged than in control stands.

Methods and Materials

Study area

The research was conducted in the southern pan handle region of Algonquin Provincial Park (centered on 45°53'N, 78°60'W - 45°37'N, 78°21'W), Ontario, Canada. The study area consists of rolling hills and many lakes, rivers and bogs (Martin 1960). The majority of the forest in the study sites was classified in GIS as upland tolerant hardwood forest (75%) and the remainder as mixed forest with the odd imbedded or adjacent coniferous lowland (2%). To be classified as mixed forest, the species composition had to contain at least 20% coniferous species. Tree species consisted largely of sugar maple (68%), while the remainder was comprised of American beech (9%), eastern hemlock (9%), yellow birch (6%) and black cherry (1%). The lowland

areas that contained vernal pools (i.e. “forested wetlands” hereafter) were surrounded by balsam fir (*Abies balsamea*) (1%) and black spruce (*Picea mariana*) (1%). These forested wetlands could be quite small ($<100\text{m}^2$). Within study sites, silviculture prescriptions were restricted to the upland tolerant hardwood forest so that the lowland conifer patches containing forested wetlands had not been logged in many decades (at least 40+ years). The study sites were part of a continuous forested landscape in Algonquin Provincial Park, which is 7653 km^2 .

Harvest treatments

Fifteen study sites or stands, of five treatment types with three replicates ranged in size from 14 – 72 ha depending on the prescription area. Reference stands, hereafter “control” sites, had not been logged in at least 60 years and are representative of the region’s older growth forests and the natural gap-phase replacement process. Two treatments identified from historical single-tree selection areas were used to provide a space-for-time substitution of impacts of the most common form of silviculture used in tolerant hardwood forests in this area over the past 40 years. Old single-tree selection sites were logged 20-25 years prior to the study (1980-1985) and represent some of the early adaptation to single-tree selection. Recent single-tree selection sites were logged 1-5 years prior to the study and represent the current technology and direction from revised recommendations. Recent single-tree selection silviculture in Algonquin includes leaving residual stand basal areas of 17 to $20\text{ m}^2/\text{ha}$, improving stand health, balancing diameter classes and maintaining wildlife habitat including cavity trees. The stands in the two group selection treatments came from an experiment designed to investigate the potential benefits of creating larger gaps for regenerating species of trees that require more

sunlight and may be declining under successive single-tree selection treatments (Falk et al., 2010). The stands were logged using chainsaws and cable skidders. All 6 group-selection stands were previously harvested using single-tree selection sometime between 1976 and 1984 and current treatments represent the first harvests under the group-selection silvicultural system. Typical and intensive group-selection sites were logged in the winter of 2006-2007, 3-5 years prior to our fieldwork. The typical group-selection prescription was intended to represent the typical application of group-selection silviculture that is currently being used occasionally in Ontario. This method consists of conducting normal single-tree selection across the stand while installing approximately 1 to 2 group selection gaps per hectare in ecologically appropriate locations that would provide the best opportunity to establish lesser shade-tolerant species such as yellow birch and black cherry. The circular gap diameters (tree crown to tree crown) were 20-25m (approx. 0.03 ha) for yellow birch and 25-30m (approx. 0.07 ha) for black cherry.

The intensive group-selection prescription, by contrast, restricted all harvesting to the gaps only and used a medium-sized circular gap of 25m in diameter (0.05 ha) gaps in a systematic grid pattern that removed 20% of the stand's basal area. (see Falk et al. 2010 for aerial photo of these treatments). Intensive group-selection increases harvest efficiency while creating patches of early successional forest adjacent to mature unaltered forest. By design, group-selection increases forest structure heterogeneity and creates a variety of habitats that could increase biodiversity (Campbell et al. 2007).

Territory mapping

Brown Creepers were located by sight and sound while walking at a speed of 1-3 km/h through the sites. Searching was carried out on rainless days between 5:30am and

2:00pm. The birds were followed for usually 30-45 minutes to establish the boundaries of their territory. The sex of the bird was recorded, based on the call type. Females often respond instantly to the male's song with a short "zee" call (pers. obs.). We searched each site as a function of Brown Creeper detections. Locations of each bird were marked using a Global Positioning System (GPS) unit. After 6-10 visits to the same sites, and mapping the pair's movements throughout the entire breeding season, territory boundaries could be estimated. Nest locations, counter-singing, and territorial disputes led to more defined boundaries. As first nests were lost to predation and the pair re-nested there was the potential for territory boundaries to shift but they could typically be re-estimated relative to the other territories and in all cases these territories fell at least partially within the boundaries of the old territories.

Nest monitoring

Most nests were found during the nest building stage, in late April or early May in both years of the study (2010, 2011). Initially, equal effort was spent searching for Brown Creepers in each of the sites. However, as some sites consistently contained more Brown Creeper activity, we focused on finding all the nests by concentrating our effort in those stands. We are confident, as a result of time spent monitoring the densities of Brown Creepers in the sites, that very few nests were missed on any sites. Brown Creeper nests were also located while mapping territories. Nests located ≤ 4 m above ground were checked with a fiber optic video camera ($n = 65$), that was equipped with a light on the tip of a rigid 60 cm arm that transmitted live colour video to a small monitor, to allow recording of nest contents and accurate age of the nest. Nests were revisited every 4-6 days throughout laying, incubation and the nestling stage until 2-3 days prior to fledging,

when they were checked every 2-3 days to determine the outcome. Nests > 4 m above ground were given age approximations (in days) based on parental behavior (e.g., brooding, size of food, frequency of feedings) and if young were audible ($n = 36$). The nest outcome was considered successful when ≥ 1 young could be seen out of the nest, or the nest was intact and young were capable of fledging on the previous visit, or when parents were seen carrying food near the nest.

Foraging trees

Brown Creepers were followed while foraging [hereafter “foraging observation”]. After first detected, we waited until the bird flew to a new tree to begin the foraging observation. Once it landed on the new tree, the time spent on each tree, the species of tree, percent moss cover, and DBH of the tree were recorded. If we were unable to follow the bird for ≥ 15 seconds then the foraging observation was discontinued. Additionally, if the bird was observed preening, perching, or acting defensively, the foraging observation was discontinued. Trees randomly selected ($n=585$) within the boundaries of each site, were evaluated along a transect that ran through the center of each site, ranging from 500-1500 meters, depending on the size of the site. The number of random trees assessed in each site was proportionate to the total number of foraging observations in that site. Random numbers were generated to correspond with the distance from the transect starting point. The closest tree ≥ 10.3 cm DBH to the random generated number along the transect was assessed as that size was the smallest DBH foraging tree that we observed a Brown Creeper use. We used the characteristics of these trees to compare to used trees, and assumed that they represented available foraging habitat (Jones 2001).

Nest vegetation assessment

Nests were revisited after the breeding season to measure vegetation characteristics, so that active nests were not disturbed. The following measurements were taken on each of the trees: DBH, percent bark cover, species, nest height, and health (live or dead). Habitat features within 5 m of the nest tree were also recorded including the percent cover of regeneration (0.5 m -1.3 m), sapling (>1.3 cm, <2.5 cm DBH), understory layers (>2.5 cm, <9.9 cm DBH), and forest canopy cover. Other measurements, describing the immediate habitat around the nest and placement in the landscape, taken at both nest and randomly selected trees were: basal area, distance to nearest edge (i.e., soft edges: maintained road, lake, large skidder trail, and harvested gaps), distance to canopy gap, and distance to nearest forested wetland. Random nest trees were chosen in the same manner as random foraging trees. The distance from nests and random points to the nearest edge was measured using a GPS unit. We classified a forested wetland as an area that contained standing water or wet soil in spring although it could dry over the course of summer (i.e., vernal pools). A nest was considered to be located in a forested wetland if it was 10 m or closer to the water's edge. Basal area was measured with a factor-2 prism. Canopy cover was estimated visually at a height of 10 m and 20 m and the two estimates were averaged for analyses. Tree height was measured with a clinometer or VertexTM laser. Nest concealment was measured by estimating the percentage of the nest hidden when viewed from 5m away in the cardinal directions and 1m above and below the nest using a mirror on an extendable pole. These measures were averaged.

To determine the proportion of the upland hardwood and mixed forest in each site, ArcMAP 10 (ESRI 2011) was used. The area of each habitat type (upland hardwood and mixed) was determined by clipping the polygons to each site boundary (Ontario Ministry of Natural Resources 2009, digital forest resource inventory layer, Accessed: 2012).

Statistical Analyses

Nest survival by treatment

Program MARK (White and Burnham 1999) models nest survival with daily survival rates (DSR) varying for each day between nest visits. We tested the hypothesized effect of treatment on nest survival to determine its importance compared to time-dependent variables (e.g., date and year), the latter thought to be important nuisance variables in explaining variation in nest success (Dinsmore et al. 2002, Rotella 2011). . Subsequently, we used a second set of models containing nest tree characteristics, placement of nest in the landscape, and nest characteristics in addition to the top time-treatment model to determine which one was the most important in determining Brown Creeper nest survival. We used the information-theoretic approach to evaluate competing models (Burnham and Anderson 1998) and used model averaging, across all candidate models to incorporate model uncertainty (Buckland et al. 1997, White et al. 2001).

Nest survival was generated from program MARK's DSR for each treatment raised to the nest period of 37 days (based on our observation of nests), including 6 days for laying, 15 for incubation and 16 for nestlings. Too few nests were found in any individual silviculture treatment to warrant analysis so nest success was compared between logged and control stands only.

289

290 **Site selection**

291 We used the Manly selectivity measure to investigate selection of nesting and
292 foraging tree species. We applied this measure to data from control and logged stands
293 separately (Manly et al. 2002), using package ‘adehabitat’ in R (R development core
294 team 2011) following the work of Calenge (2006). This method compares the available
295 trees to the trees used for nesting and foraging. The proportion of available tree species
296 was gathered from the random tree transects. For these analyses habitat use and
297 availability were measured at the population level (design I type of analyses) (Manly et
298 al. 2002). We also ran a one-way ANOVA to compare DBH of the nest tree as the
299 dependent variable and tree type (dead coniferous, dead deciduous, live deciduous) as the
300 predictor variables and we ran a t-test to compare DBH in control and logged stands.

301 We used ArcMap 10 (ESRI 2011) to quantify the amount of each forest type (i.e.,
302 upland hardwood and mixed forest) in the sites based on classifications from Ontario
303 Ministry of Natural Resource’s Ontario Geospatial Data Exchange forest resource
304 inventory (Ontario Ministry of Natural Resources 2009). We performed a MANOVA to
305 determine if the area occupied by each forest type based on those classifications, was
306 significantly different between the treatments. We performed a chi-square test to
307 determine if Brown Creepers showed a preference for forest types at the stand level using
308 proportions of nests in the two forest types among control and logged treatments. We also
309 compared the differences in the number of nests located in forested wetlands, number of
310 nests in snags vs. live trees, and number of nests in conifer vs deciduous trees using chi-

square tests between control and logged treatments. We also ran a chi-square test to determine the difference in snag availability between control and logged treatments.

For foraging trees, we used a general linear model to compare the foraging tree characteristics, DBH, tree height and percent moss cover, with the predictor variables: tree type (random or forage tree), treatment and site nested within treatment, the latter term included to account for the nested structure of the data. We used the 'site nested within treatment' mean square error to calculate the significance of the other main effects to account for the random effect of sites. The three response variables were run separately, all of which were considered, a priori, to be characteristics that helped to define foraging trees of the Brown Creeper (Franzreb 1985).

Densities

We calculated the number of territories and partial territories by territory mapping. If a territory was partially within the site boundary, we estimated the portion of its territory in the site to the nearest 25%. We did not calculate the actual size of the territories because territories in the logged sites straddled the adjacent forested wetland areas and we did not spend as much time determining the outlines of the territory outside our stand boundaries. As a consequence, in logged stands, mostly partial territories of Brown Creeper were present and we totaled up these partial territories to estimate densities. In the unlogged territories the full territory was often contained within the upland hardwood portion of the stand. Density was calculated as the number of pairs per ha. We performed a one-way ANOVA to compare densities between treatments. We also used a one-way ANOVA to compare densities between logged and control treatments.

Nest parameters

We compared date of first egg, clutch size, length of nestling period, and date of fledging between control and logged areas using t-tests for each year. There were too few nests found in the logged treatments to compare between the different forms of selection silviculture. First nesting attempts were recognizable from second attempts because the first attempt was found after conducting an initial survey of the territory in which pairs had just established and were engaged in courtship activities. These surveys were early in the breeding season, and subsequent visits to the territory were followed with locating the pair during the nest building stage. Second nest attempts were identified when pairs of Brown Creeper were found building a new nest within the same territory as a failed first attempt. We assessed chick age using chicks with known hatching dates as a guide. We used backdating where necessary to provide additional information. The latest date of first egg attributed to a first nest was May 19th. We compared nest survival of early (before and including May 19th) (75 nests) and late nests (after May 20th) (13 nests).

We used the statistical programs R version 2.13.1 (R development core team 2011), SPSS version 20 (SPSS 2010), and MARK (White and Burnham 1999) for all analyses.

Results

In the two years of the study, 101 active Brown Creeper nests were found and used in subsequent habitat selection analyses. Among those nests, 88 were within the treatment boundaries and had confirmed nest contents of ≥ 1 egg (2010 n=36, 2011 n=52) and were used in analyses evaluating the effects of silvicultural treatment on nest success. There were 61 (69.3%) first nesting attempts and 27 (30.7%) renests. In both years we

found more than a third of all nests (33/88) in the control stands, despite that control areas comprised only 22% of the total area where we searched ($\chi^2 = 12.3$, $P < 0.0005$). Apparent nest success (successful nests/all nests) was 63.6% across all treatments and predation accounted for 87.5% of all nest failures with nest contents. Four nests with eggs failed due to parental abandonment, and one nest tree fell down.

Densities

There was no significant difference in Brown Creeper densities among the five silvicultural treatments, although all treatments contained lower average densities than control stands ($F_{4,10}=1.8$, $P = 0.419$) (Fig. 1). When all logged stands were combined into a single logging category, there was a significantly higher density of Brown Creepers ($F_{1,13}= 5.0$, $P < 0.05$), in control than logged stands (control: 0.124 ± 0.02 pairs/ha, logged: 0.0720 ± 0.01 pairs/ ha).

Nest survival by treatment and time

There was little support for the model that included the effect of treatment (control vs. logged) on nest survival and treatment was the least important of the variables included in the models explaining variation in nest survival (Table 1). The variables in the top model and with the greatest weights were date, year, and nest age². Nests initiated earlier had a higher probability of survival. Nest survival of early nests, whose first eggs were laid on or before May 19th (latest date of all first nest attempts) was 0.617 ± 0.0026 (n=75) whereas nests whose first egg date was after May 19th had a nest survival of 0.433 ± 0.0091 (n=13). Nest success was slightly higher in 2011 than 2010.

Nest survival by tree characteristics and placement

The models with nest tree characteristics (% bark cover, tree species, DBH, and dead vs. alive), placement in the landscape (distance to edge, distance to forested wetland, basal area, and canopy cover), and nest characteristics (height and concealment) did not predict Brown Creeper nest survival better than the top model from the treatment-time (Table 1) nest survival model (Table 2).

Nest tree selection

In control stands we found 26 nests (78.8%) in deciduous tree species and only 7 in conifer species while in logged stands 19 (34.5%) were in deciduous tree species and 36 in conifer species ($\chi^2 = 16.2$, $P < 0.0001$) (Table 3). All nests in coniferous trees were located in dead trees, while 10 of the nests in deciduous trees were in living (including declining) trees. The average DBH of coniferous nest trees, dead deciduous and live deciduous nest trees were 35.7 ± 2.2 cm, 49.2 ± 3.2 cm and 53 ± 5.7 cm, respectively ($F_{7,100} = 9.31$, $P < 0.01$). Nest trees in control sites had significantly larger DBH than nest trees in logged sites ($t = 2.2$, d.f.=86 $P < 0.05$).

Patterns of preference varied between control and logged stands. In control stands, Brown Creeper preferred to nest in yellow birch trees while sugar maple trees were under-utilized. In logged stands balsam fir trees were the most frequently selected nest trees while sugar maple was under-utilized (Fig. 2.a).

There were no significant differences in the proportions of the remotely assessed forest types (e.g., upland hardwood vs. mixed forest) among treatments (MANOVA, $F_{8,18} = 0.730$, $P = 0.665$, Wilk's $\lambda = 0.570$). However, in control sites nests were located significantly more often in upland hardwood forests compared to logged sites ($\chi^2 = 6.07$,

d.f.= 2, $P < 0.02$, Table 3). Snags made up 12% of randomly selected trees in control sites and only 2% in logged sites ($\chi^2 = 21.3$, d.f.= 2, $P < 0.001$) (Table 3). In comparison to site level characteristics Brown Creeper also nested in areas within the stand with higher basal area (Table 3).

Foraging tree selection

We collected 305 foraging observations of Brown Creeper that were on average 34.8 ± 1.2 sec duration. Brown Creeper were recorded foraging on sugar maple trees 51.8% of total foraging time observed. Sugar maple was by far the most dominant tree species and accounted for 68% of all trees randomly surveyed. Brown Creeper used similar proportions of foraging tree species through the breeding season. From the Manly selectivity measure, no tree species was preferred for foraging in control stands, and most species were used in proportion to their availability on the landscape. In the logged stands, Brown Creeper preferred to forage on: balsam fir, black spruce, yellow birch, and eastern hemlock, all tree species that occupy the forested wetlands. Tree species proportionately under-utilized were sugar maple, which predominately occupy the drier uplands (Fig. 2.b).

Trees used for foraging had greater DBH in control stands than in stands of any other treatment (treatment effect: $F_{4,10} = 4.96$, $P = 0.006$). Forage trees also had significantly greater DBH than random trees in all treatments (tree type effect: $F_{1,10} = 12.04$, $P = 0.0005$; no sig. interaction, Table 4). There was no treatment effect for tree height or proportion of moss cover (treatment effect, Height: $F_{4,10} = 0.26$, n.s.; Moss cover: $F_{4,10} = 0.26$, n.s.: Table 4, no significant interactions between treatment and tree type).

Randomly selected trees were shorter than forage trees (tree type effect, Height: $F_{1,10} =$

22.3, $P < 0.001$, Table 4) but tree types did not vary significantly in moss cover (moss:
 $F_{1,10} = 0.18$, n.s.)

Nest parameters

First eggs were laid nearly eight days later in 2011 than in 2010, presumably owing to the later spring in 2011 (mean April temperatures, 2010: 6.9 ± 0.62 °C; 2011: 3.25 ± 0.68 °C (Environment Canada, Algonquin East Gate weather station), but first egg dates did not vary significantly among control and logged areas in either year. Clutch sizes were largely invariant both between control and logged areas, as were the lengths of the nestling periods, although sample sizes were very small for the latter variable. As expected, the date that young fledged was also later in 2011, but this date did not vary significantly between control and logged treatments (Table 5).

Discussion

Silviculture in tolerant hardwoods of Algonquin Provincial Park, Ontario resulted in a significant reduction in the number of Brown Creeper territories, as compared to unlogged stands, a reduction that was consistent across all forms of silviculture that we studied. The 42% reduction in densities of Brown Creeper in logged stands in the park paralleled the significantly fewer nests that were found in those stands. By contrast, Brown Creeper nest survival was not affected by logging, nor were other characteristics associated with Brown Creeper nests including nest initiation dates, clutch size or the length of the nestling periods. We also documented a change in the species of nesting trees selected by Brown Creeper in logged stands, and a reduction in the sizes of nest trees. These changes occurred because in the logged stands significantly more nests were

located in the mixed forest and forested wetland portions of the study sites compared to the unlogged stands. We attribute the reductions in densities that we observed in harvested stands due to the reductions in the availability of Yellow Birch for nesting in the upland portions of the stand. Finally, there were significant changes in the preference of particular tree species used for foraging, albeit with only slight differences in the characteristics of those trees, as a result of logging.

Our results of logging impacts on densities of Brown Creepers are very similar to those reported by Poulin et al (2010) who studied this species in hardwood forests under partial harvest in New Brunswick, Canada. In that study, nest density was twice as high in control plots than in treatments. In New Brunswick, Brown Creeper nested in the bark of Balsam Fir even in control stands and there was no significant reduction in Balsam Fir after harvesting. In our study site, Yellow birch is probably preferred as a nesting tree because it can grow very large (> 60 cm DBH) and has a thick flexible bark that can conceal nests. Once the upland areas were logged, Brown Creeper did preferentially nest in balsam fir snags, as in New Brunswick, despite the much smaller DBH of that species. Like yellow birch, this tree species provides large plates of bark to conceal nests. The availability of yellow birch in the New Brunswick study is unknown although it is considered a dominant species there (Poulin et al. 2010). Why Brown Creeper prefer different species for nesting in the two different regions is not known.

Due to the lack of difference in the preferred nesting tree for Brown Creeper in control and harvested stands in New Brunswick, the authors suggested that foraging trees were limited after partial harvest and this reduction caused the decline in densities. In our study, in control stands, Brown Creeper foraged on trees in the upland hardwoods

whereas in harvested stands, they foraged on trees associated with the forested wetlands. Brown Creeper are, like most territorial breeding passerines, central place foragers during the nesting season (Orians and Pearson 1979). This response in the selection of forage trees as a result of relocation of nests to the forested wetlands did not appear to result in a reduction in the ability of Brown Creepers to provision young, as we did not observe any decline in variables associated with food supply that might impact nest performance (e.g., date of first clutch, clutch size). While Brown Creeper showed strong selectivity for taller and larger trees for foraging, we also documented only moderate treatment effects (on DBH only) on these characteristics. Thus, all of our harvest treatments appeared to continue to provide large trees for foraging. Therefore, we do not have evidence to suggest that foraging trees are limiting in the Algonquin study area.

We expected that nest tree characteristics would be associated with variation in nest survival and that favourable characteristics could then be incorporated into a recommendation for new guidelines on wildlife tree characteristics. However, Brown Creeper nest survival was not affected by nest tree characteristics or placement in the landscape. Quiet vocalizations, small size and very inconspicuous nests may help to protect Brown Creeper from nest predation in their highly specialized nesting sites as nest success was relatively high in this study in comparison to that described for other passerines nesting in the same landscape (Falk et al. 2011). Similar to our result, Brown Creeper nest success in New Brunswick was not impacted by partial harvest, although in that study the number of territories that produced at least 1 young was significantly higher in the control stands (Poulin et al. 2010). The difference in methodology between our studies may explain the difference in our results.

While our sample size for any particular selection system was too small to evaluate each method individually, average Brown creeper density was consistently lower in each logged treatment than in the controls. While we are unable to make a strong inference about which specific treatments are the least harmful to Brown Creeper densities, we found fewer nests in stands affected by intensive group-selection than we anticipated given that the uncut areas between gaps were not logged using this experimental methodology. This method of silviculture also created the most amount of fragmented forest because it contained more gaps. In addition, Brown Creeper nests were closer on average, to forested wetlands in intensive group-selection stands than in other treatment types (Geleynse 2012 M.Sc. thesis). These observations suggest that even though some snags may have been retained in the upland hardwood matrices, there were insufficient snags for breeding. Thus, this method appears to have the strongest negative impacts on Brown Creeper.

As current wildlife tree provisions focusing on cavity dependent wildlife state that the tree to be retained must be alive (OMNR 2010), lower density of Brown Creeper in logged sites is, as indicated above, probably the result of inadequate provision of critical nesting habitat features under these guidelines. Selection silviculture over the entire landscape will not likely maintain optimal Brown Creeper nesting and foraging habitat. Although lowland conifer forests adjacent to and often surrounding the upland stands may provide nesting and foraging refuge areas for Brown Creeper following logging, our findings of loss of Brown Creeper territories especially in the dominant land cover of the upland forest is a significant concern on a landscape level because of the lower productivity per hectare that this represents. Recommendations to keep large snags of

preferred species in harvested areas are not compatible with current silvicultural practices because they are in direct conflict with the Ontario's Occupational Health and Safety Act (Ontario Ministry of Labour 2010). Revising the wildlife tree guidelines to retain a portion of uncut area in the upland hardwood area that is roughly the size of a Brown Creeper territory (10 ha) (Poulin et al. 2008, 10.4 ha) or larger that contain snags as well as large living trees (especially yellow birch) may be more beneficial to Brown Creeper than saving a particular number of live cavity trees (10) dispersed throughout the cutblock. We suggest that this size of area be retained at a minimum because anything less might be too small if the adjacent forest is unsuitable. However, this size may be efficiently used by possibly more than one nesting Brown Creeper territory since the area adjacent to the retained block could be used as supplemental foraging habitat. On a landscape scale these uncut patches could make up a target percentage of the entire prescribed area. It may be possible to maintain Brown Creeper densities by retaining more (up to 50%) upland hardwoods since the forested wetlands will already be retained. These areas would also be beneficial to other old growth forest specialists.

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Table 1. Model selection results with 25 models examining age/date/treatment effects on Daily Survival Rate (DSR) for Brown Creepers in Algonquin Provincial Park, Ontario. The variables examined were Date (Julian date), treatment (Control vs. Logged), nest age, and year (2010-2011). A superscript (e.g., Nest age²) indicates a quadratic effect. The model Nest age² + Date + Year had the lowest AICc of 195.997.

Model	Delta AICc	Model Likelihood
Nest Age ² + Year + Date	0	1
Date + Year	0.038	0.9812
Date	0.1397	0.9325
Nest Age ² + Date	0.755	0.6856
Date + Year + Nest Age	1.0792	0.5829
Date + Nest Age	1.3434	0.5109
Date + Treatment	1.421	0.4914
Date + Treatment + Year	1.44	0.4867
Nest Age ² + Year + Date + Treatment	1.7367	0.4196
Year + Nest Age	2.1369	0.3435
Nest Age	2.3218	0.3132
Nest Age ² + Date + Treatment	2.3299	0.3119
Date + Treatment	2.7419	0.2539
Date + Treatment + Nest Age	2.8703	0.2381
Year	3.4612	0.1772
Treatment + Year + Nest Age	3.5421	0.1701
Treatment + Nest Age	3.5815	0.1668
Nest Age ² + Year	3.8206	0.1481
Nest Age ²	4.0348	0.133
Constant	4.2186	0.1213
Treatment + Year	5.3763	0.068
Nest Age ² + Year + Treatment	5.432	0.0661
Nest Age ² + Treatment	5.4847	0.0644
Treatment	6.0602	0.0483

Table 2. Model selection results with 10 variables evaluating the importance of nest tree characteristics (% bark cover, tree species, diameter at breast height (DBH), health (snag vs. alive), placement in the landscape (distance to edge, distance to forested wetland, basal area, canopy cover), and nest characteristics (height and concealment) on DSR of Brown Creeper nests (2010-2011, Algonquin Provincial Park, Ontario). All models contain top age/date/treatment model (Nest age² + Year + Date), which also had the lowest AICc of 195.997.

Model	Delta AICc	Model Likelihood
Nest Age ² + Year + Date	0	1
Health	0.6645	0.7173
DBH	1.2602	0.5325
Canopy cover	1.4824	0.4766
Nest height	1.6753	0.4327
Basal area	1.7181	0.4236
Concealment	1.8152	0.4035
Bark cover	1.8699	0.3926
Dist. to forested wetland	1.9705	0.3733
Tree species	1.9742	0.3727
Dist. to edge	2.0078	0.3664
Constant	4.2186	0.1213

Table 3. Site (obtained from randomly selected trees) and nest tree characteristics for Brown Creeper in each silvicultural treatment in Algonquin Provincial Park, Ontario.

Habitat Perimeter		Silvicultural Treatment				
Site	Control	Intensive group selection	Typical group selection	Old single tree selection	Recent single tree selection	L
Basal area (m ² /ha) 2 factor prism	20.6 ± 1.1	16.2 ± 2.5	14.4 ± 1.3	20.6 ± 1.6	16.4 ± 1.2	1
% snag	12 (21/179)	2 (2/105)	2 (3/162)	2 (1/41)	5 (4/86)	2
% declining trees	36 (64/179)	40 (42/105)	43 (69/162)	29 (12/41)	42 (36/86)	3
% live trees	52 (94/179)	58 (61/105)	55 (90/162)	69 (28/41)	53 (46/86)	5
% upland hardwood forest	72 ± 14	77 ± 12	65 ± 15	94 ± 2	74 ± 14	7
% mixed forest	23 ± 15	23 ± 10	35 ± 14	6 ± 2	26 ± 11	2
Nest tree						
Basal area (m ² /ha) 2 factor prism	23.8 ± 0.9	23.3 ± 2.1	19.5 ± 1.4	22.4 ± 1.8	21.4 ± 2	2
% in forested wetland	21 (7/33)	60 (6/10)	42 (8/19)	30 (3/10)	50 (8/16)	4
% in upland hardwood forest	58 (19/33)	40 (4/10)	16 (3/19)	56 (5/9)	29 (5/17)	3
% in snag	94 (31/33)	90 (9/10)	84 (16/19)	80 (8/10)	88 (14/16)	8
% in conifer tree species	21 (7/33)	70 (7/10)	63 (12/19)	50 (5/10)	75 (12/16)	6

Table 4. Least-squared means from general linear models testing whether DBH, height and moss cover varied between treatments and between those used for foraging by Brown Creepers and those randomly selected. Letters indicate cell that has a parameter estimate is significantly different than others.

Character	Forage or random	Silvicultural treatment				
		Control	Intensive Group-selection	Typical group-selection	Old single tree selection	Recent Single Tree Selection
DBH (cm)	Forage	40.2 1.70 ^a	30.9 2.27	33.4 1.91	36.5 3.19	32.3 2.03
	Random	32.8 1.16	29.4 1.49	29.6 1.20	31.2 3.23	30.2 1.53
Height (m)	Forage	23.2 0.6	21.0 0.8	22.4 0.7	24.6 1.1	21.2 0.7
	Random	17.2 0.4	17.9 0.5	16.7 0.4	18.4 1.1	19.3 0.5
Moss (% cover)	Forage	39.4 3.2	37.5 4.12	49.5 3.6	31.5 5.8	33.6 4.2
	Random	35.4 2.12	35.1 2.7	36.2 2.19	33.9 5.89	39.2 2.8

Table 5. Brown Creeper nest parameters (Julian date of first egg, clutch size, length of nestling period, and Julian fledge date) mean $\pm$ SE (n) estimates in 2010 (n=24) and 2011 (37) for control and logged silvicultural treatments.

	<u>2010</u>			<u>2011</u>		
	<u>Control</u>	<u>Logged</u>	<i>P</i>	<u>Control</u>	<u>Logged</u>	<i>P</i>
First egg date	May 5 $\pm$ 1.4 (11)	May 5 $\pm$ 1.2 (13)	0.89	May 13 $\pm$ 1.4 (12)	May 13 $\pm$ 0.7 (25)	0.83
Clutch size	5.7 $\pm$ 0.4 (6)	5.9 $\pm$ 0.1 (7)	0.66	6.1 $\pm$ 0.2 (9)	6.16.1 $\pm$ 0.1 (18)	0.81
Nestling stage	16 $\pm$ 0 (5)	15.3 $\pm$ 0.7 (3)	0.22	16 $\pm$ 0.4 (4)	16.1 $\pm$ 0.1 (14)	0.82
Fledge date	Jun 10 $\pm$ 1.8 (8)	Jun 10 $\pm$ 1.3 (11)	1.00	Jun 19 $\pm$ 1.1 (10)	Jun18 $\pm$ 0.7 (21)	0.50

Figure 1. Breeding density (pairs/ha) of Brown Creeper in each silvicultural treatment and a category with all logged stands. The top of the box represents the 75th percentile, the centerline in the box represents the 50th percentile and the bottom of the box represents the 25th percentile. The whiskers extending from the top and bottom of the box represent the highest and lowest values.

Figure 2.a Manly Selectivity ratio $\pm$ CI for Brown Creeper nest tree species in control and logged sites. The dot shows the mean selectivity of each tree species used as nesting substrate. The tree species is considered preferred when the mean is above 1 and the CI does not include 1. The tree species is considered proportionately under-utilized if the mean is below one and the CI is located from 0-1. If the CI includes 1 the tree species is selected proportionately to its availability. Nest sample size (n) is included.

Figure 2.b Manly Selectivity ratio $\pm$ CI for Brown Creeper foraging tree species in control and logged sites.

Fig. 1

Fig. 2.b

Fig. 2.a