VARIATION IN AVIAN ABUNDANCE AND COMMUNITY DIVERSITY THROUGHOUT A SINGLE-TREE SELECTION TIMBERLAND IN NEW HAMPSHIRE

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ABSTRACT

Sound land management practices can provide economic and recreational benefits to humans while maintaining quality wildlife habitat. The Bear Paw Timberlands in Conway, New Hampshire are managed with single-tree selection harvests, a relatively low-disturbance technique used to develop uneven-aged forest stands. We conducted breeding season point counts and vegetation surveys to assess changes in bird populations and associations between birds and vegetation characteristics following a series of harvests in the Bear Paw Timberlands. We detected increases in populations of multiple species and foraging guilds, which also differed significantly between different timber harvests. Post-harvest development of the understory, including saplings and shrubs, likely diversifies habitat and supports a wider range of bird species than unharvested areas that lack understory structure.

INTRODUCTION

Birds, particularly forest-dwelling species, rely heavily on privately owned lands during the breeding and non-breeding seasons. More than half of forests in the United States are located on private land (The State of the Birds 2013). In the eastern United States, an estimated 84% of forests are privately owned (The State of the Birds 2013). Responsible and conscientious private land management is therefore essential to the conservation of avian communities and other wildlife. With best practice management techniques, forests may be used for a variety of commercial and recreational purposes while still maintaining suitable wildlife habitat. However, in 2013, only 13% of private owners nationwide had formal forest management plans (Butler et al. 2016). Similarly, in 2006, only 4% of private owners had conservation easements, voluntary but legally binding agreements that permanently protect land from development (Butler 2006).

Tin Mountain Conservation Center (TMCC), a nonprofit environmental education organization, owns 1,181 acres of timberland under a conservation easement in Conway, New Hampshire. TMCC purchased the timberlands with funds from a donor that stipulated future management using leading sustainable forestry practices (Tin Mountain Timberlands 2014). Since acquisition in 2006, TMCC has been managing various portions of the timberlands using single-tree selection. Single-tree selection is a method of harvesting individual trees in order to create uneven-aged stands with both mature trees and gaps, allowing recruitment and regeneration (Introduction to Silvicultural Systems 2017). In 2012, to assess the ecological impacts of these management practices, TMCC initiated a study of avian communities on a portion of their managed timberlands using weekly breeding season point counts and annual vegetation surveys.

Birds are commonly studied as indicators of environmental health. Point counts serve as reasonable proxies for bird density and abundance (Dawson 1981). Provided that population changes are relatively unbiased by sampling methods or observers and that observed changes in abundance relate to actual changes in abundance, bird populations can be linked to specific environmental conditions (Temple and Wiens 1989). According to DeGraaf et al. (1998), forest structural characteristics were the best predictors of bird abundance in the White Mountains Region of New Hampshire, more so than cover-type or size-class. As such, we expect that bird abundance on our managed sites will change in accordance with harvest-related changes in forest structure. We expect the most influential habitat characteristics to be attributable to harvest activities, including a regenerating understory (marked by greater abundance of shrubs and saplings) and a diminished upper canopy layer (as indicated by lower basal area and canopy cover).

Specifically, we expect that early-successional bird species will increase while mature forest species will decline in harvested areas, although we expect these changes to occur in moderation. Unlike clearcutting, which removes entire tracts of trees, selection harvests create only small canopy gaps, maintaining much of the existing habitat. Accordingly, selection harvests can retain mature forest bird species while creating habitat for some early-successional species as well (Thompson et al. 1996, Costello et al. 2000). However, avian population changes in TMCC's managed timberlands are likely to be short-lived. In a study of avian response to a group-selection timber harvest in Maine, avian populations returned to pre-harvest levels within 15 years (Campbell 2007). While 15 years currently exceeds the time-since-harvest in TMCC timberlands, forest management plans recommend subsequent single-tree selection harvests at 15 to 20 year intervals (Cline and Stepanauskas 2016b).

This study examines avian abundance and diversity over the first five years of data collection with regard to each breeding season, several distinct single-tree selection timber harvests, and various vegetation characteristics in the timberlands owned by TMCC. We aimed to determine whether variations in avian populations are linked to particular vegetation characteristics associated with recent timber harvests. We also attempted to assess whether commercial single-tree selection harvests will diminish, maintain, or increase bird diversity and abundance of a wide range of species.

METHODS

Site Description

The Bear Paw Timberlands are located in Conway, New Hampshire. In sum, the property is 1,181 acres, divided into five management units. Management Units 2 and 3 (466 acres) are contiguous parcels with similar land use histories. Hereafter, we will collectively refer to Units 2 and 3 as "Bear Paw."

Bear Paw forests are semi-mature, containing a mixture of deciduous and coniferous species. Although continuous forests surround Bear Paw as well, much of the land has been cut heavily, making TMCC-managed properties "unique" to the immediate area (Cline and Stepanauskas 2016b). Bear Paw also includes small wetlands and several major streams in the Saco River watershed, all of which have 100-foot buffer zones in which no recent timber harvests have occurred. The land is under a conservation easement that requires management activities to maintain good water quality and wildlife habitat and to provide opportunities for low-impact public recreation (Cline and Stepanauskas 2016b).

The entirety of Bear Paw purportedly has a similar land use history. The presence of stone walls indicates that the area was once open farmland. Stand maps from 2002 and 2003 indicate that most of the property's canopy trees were roughly 80 to 90 years old at time of survey (Forest Stewardship Plan 2002, Forest Stewardship Plan 2003). However, between 1975 and 1979, Bear Paw Timber owned and harvested portions of the area for milling products (Cline and Stepanauskas 2016b). Subsequent owners allowed the forest to regenerate without further management until 2006, when TMCC acquired the property. TMCC has since administered three separate but adjoining timber harvests on Bear Paw, which occurred in the winters of 2008 (57 acres), 2010 (48 acres), and 2011 (51 acres). All three cuts were single-tree selection harvests. Adjacent "transitional habitat" plots were left uncut (Figure 1).

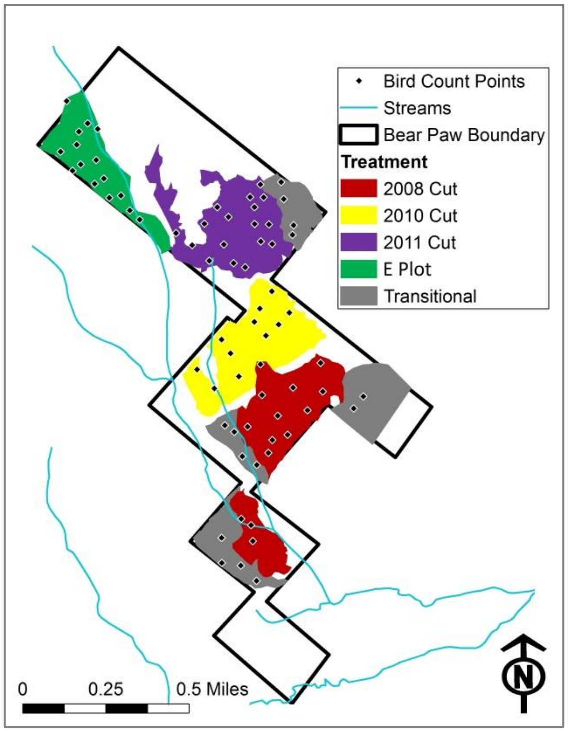


Figure 1. Map of Bear Paw treatment types and bird count points.

A non-adjacent uncut plot (E Plot) was originally established as a control. However, past management plans indicate that this portion of the property had noticeably less hemlock than other portions of Bear Paw prior to the TMCC harvests (Forest Stewardship Plan 2002), which suggests a different soil type and higher site index than the rest of Bear Paw (D. Stepanauskas, personal communication, 2017 March 20). Much of E Plot is also relatively devoid of a developed shrub layer (C. Ballantic, personal communication, 2017 March 20). E Plot is therefore a valuable point of comparison, but it is not a control plot representative of Bear Paw's pre-harvest conditions.

Bird Counts

TMCC began studying Bear Paw's bird populations in 2012. From 2012 to 2016, trained observers conducted standardized breeding season point counts along permanent transects (Figure 1). Points are located in each of the cuts (2008 cut n=13, 2010 cut n=12, 2011 cut n=17 in all years), in adjacent uncut transitional areas (n=14 from 2012 to 2014, n=12 from 2015 to 2016), and in the non-adjacent uncut E Plot (n=15).

Point count protocols are in accordance with the guidelines of Ralph (1993) with the exception of distance between points. Although Ralph (1993) recommends that points should be spaced at a minimum of 250 meters (820 feet), Bear Paw points were located approximately 300 feet apart in order to obtain a reasonable sample size within the relatively small study area. However, observers attempted to avoid double-counting individual birds at neighboring points, typically recording birds only if they were within 200 feet of the count point.

In each year, observers conducted point counts once weekly. Point counts began in late May in 2012 and in late April in subsequent years, always extending through mid-July.
Counts started between 0600 and 0700 and concluded by 1000. A single trained observer visited each point for five minutes, remaining stationary while recording all individual birds seen or heard from that point during the five-minute span. We excluded birds recorded as "unknown" species from analyses.

Vegetation Plots

A permanent vegetation plot is located approximately 100 feet to the northeast, northwest, and south of each bird count point. Observers surveyed each vegetation plot once per summer. Measurements and assessments are described in Table 1.

Table 1. Key vegetation characteristics and methods of assessment.

Vegetation Characteristic	How Determined	Plot Size	Years Assessed	Notes
Basal area (ft^2/ acre)	10-factor basal area prism	Variable radius	2012-2016	Reported as an average of all years to eliminate fluctuations in basal area between years
Percent canopy cover	Densiometer	NA	2012-2014, 2016	Reported as an average densitometer measurement taken each of the four cardinal directions
Number of saplings	Counted	1/100 acre	2012-2016	
Percent groundcover of two major shrubs	Estimated visually	1/100 acre	2013-2016	Two major shrub types were hobblebush (*Viburnum lantanoides*) and *Rubus* species
Percent groundcover of coarse woody debris	Estimated visually	100 foot transect	2012, 2013	Reported as an average of 2012 and 2013
Percent coniferous trees	Calculated from identification of all trees to species level	Variable radius	2012	Includes all trees in variable radius basal area prism plot

Foraging Guild Groupings

We grouped bird species into foraging guilds, described by DeGraaf et al. (1984) and Robinson and Holmes (1982). We assigned birds to guilds based on their breeding season or year-round feeding habits, disregarding non-breeding feeding habits. For species that forage in multiple ways, we assigned a primary foraging guild based on life history descriptions from Guide to North American Birds (2016).

Biodiversity Metrics and Statistical Analyses

We excluded 2012 from analyses of observations per point (here used as a proxy for bird abundance) due to the lack of data collection between late April and late May, the period during which the most birds are likely to be singing and in courtship. However, we still considered 2012 in analyses of effective species and effective guilds, which are based on relative rather than absolute abundance.

We calculated diversity (H) of both bird species and foraging guilds according to the Shannon-Weiner index (Shannon 1948). We then calculated the number of effective species and effective guilds for each point as exp(H), which indicates the number of equally common species or guilds that would generate the given Shannon diversity index (Jost 2006). All of our results refer to diversity in terms of effective species and effective guilds. We compared abundance and diversity measures between years and treatment types using linear regressions, one-way analysis of variance (ANOVA), two-tailed Student's t-tests (t-tests), and Tukey's post-hoc tests.

We also used ANOVA and t-tests to assess whether interannual variation was the result of different observers. We compared the results of three experienced observers that conducted counts over the course of multiple full breeding seasons (CMB, 2014 and 2016; MLC, 2014 and 2015; SEA, 2014 and 2015). All had conducted point counts in Bear Paw prior to 2014 as well.

We compared each observer's mean number of observations per point per day to the observations of all other observers within each treatment type. As some sample sizes were too small to conduct statistically valid comparisons, we only examined instances in which an observer had completed counts over the course of four or more weeks in a given year and treatment. However, observers conducted counts at different sets of points and on different numbers of days, so these comparisons should be treated only as general indicators.

We also correlated observations of the focal bird species with each of the key vegetation characteristics described above using linear regressions for each year of data collection. Focal bird species were all those species observed at least fifty times in each year, which provided a reasonable sample size for regressions and comparisons between treatments (Balantic 2014). In regressions between focal species and vegetation characteristics, we excluded points with no observations of the given focal species. Regressions were therefore driven primarily by bird presence, not skewed by a large number of points where the focal species may have been absent (Balantic 2014).

All statistical tests were performed using JMP 13 (JMP 2016).

RESULTS

Variation in Abundance and Diversity between Years

Number of observations per point and number of effective species increased significantly over time in all treatments, generally peaking in 2015 (Table 2, Figure 2). Effective guilds increased significantly in the 2011 cut, transitional areas, and E Plot and slightly but not significantly in the 2008 and 2010 cuts.

Table 2. P-values for linear regressions of number of observations per point (2013 to 2016), effective species (2012 to 2016) and effective guilds (2012 to 2016). The slope of each linear regression is in parentheses below the p-value. Significant values are shaded.

Treatment	Observations per Point	Effective Species	Effective Guilds
2008 Cut	<0.0001 (+10.21)	<0.0001 (+0.86)	0.1224 (+0.10)
2010 Cut	<0.0001 (+13.78)	0.0024 (+0.75)	0.0597 (+0.14)
2011 Cut	<0.0001 (+14.49)	<0.0001 (+1.80)	0.0083 (+0.20)
Transitional	<0.0001 (+9.47)	<0.0001 (+1.81)	<0.0001 (+0.55)
E Plot	<0.0001 (+9.40)	<0.0001 (+1.22)	<0.0001 (+0.46)

Observations per point also increased significantly between certain years in all treatment types (ANOVA p-values <0.0001 for all treatments, Figure 2a, see Appendix Table 1). The greatest overall increase occurred between 2014 and 2015, when the mean number of observations per point increased by at least 22% over the previous year in each treatment type (2008 cut: 27.3%, 2010 cut: 37.3%, 2011 cut: 22.6%, transitional: 36.7%, E Plot: 42.0%). In the 2011 cut, the increase was larger in 2014 (42.6% increase over 2013). There were no significant differences between 2015 and 2016, when abundance remained high.

Effective species changed significantly between certain years in all treatment types (ANOVA p-values=0.0002 for the 2008 cut, <0.0001 for all other treatments; Figure 2b; see Appendix Table 2). However, few differences between consecutive years were significant. From 2013 to 2014, significant increases occurred in the 2011 cut (32.6%) and in E Plot (28.5%). Effective species also increased in the 2011 cut between 2012 and 2013 (27.0%)

Effective guilds changed significantly between certain years in the 2011 cut, transitional area, and E Plot (ANOVA p-values<0.0001, Figure 2c, see Appendix Table 3). However, only one significant increase occurred in consecutive years (14.2% increase in transitional areas between 2013 and 2014). Although birds from 25 different guilds were observed over the course of five years, only seven of those guilds comprised at least 5% of all observations within at least one year and treatment (see Appendix Table 4).

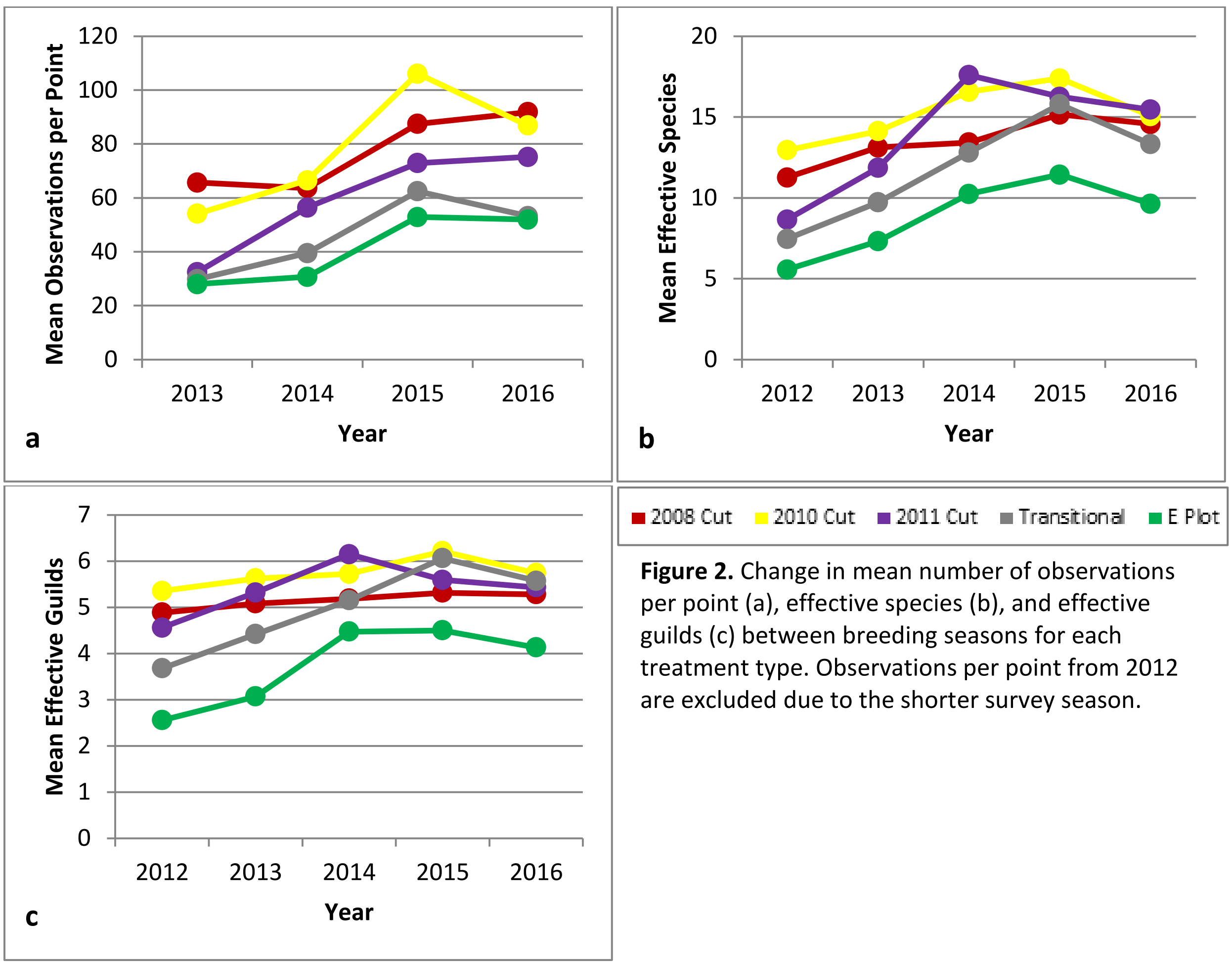
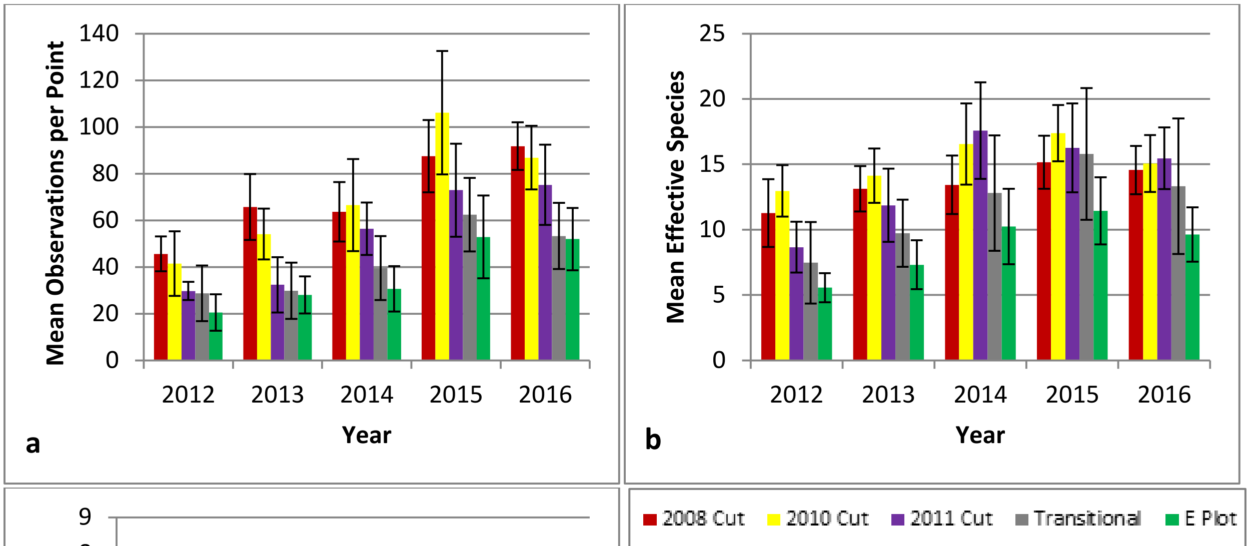


Figure 2. Change in mean number of observations per point (a), effective species (b), and effective guilds (c) between breeding seasons for each treatment type. Observations per point from 2012 are excluded due to the shorter survey season.

When comparing individual observers within treatments and between years, t-tests on eight pairs of data indicated four significant increases between years (see Appendix Table 5). The remaining pairings all showed increases between years, although they were not statistically significant. T-tests on 20 pairs of data indicated seven significant differences within years (See Appendix Table 6). CMB once had less observations than the average of other observers, and MLC had less observations than other observers on four occasions. SEA twice had more observations than other observers.

Variation in Abundance and Diversity between Treatments

Within each year, number of observations per point (ANOVA p-values<0.0001, disregarding 2012), effective species (ANOVA p-values<0.0001), and effective guilds (ANOVA p-values<0.0001 in 2012, 2013, and 2016; 0.0007 in 2014; 0.0002 in 2015) varied significantly between treatment types (Figure 3; see Appendix Tables 7, 8, and 9). The 2008 and 2010 cuts had more observations per point than the transitional areas and E Plot in all years. From 2014 to 2016, the 2011 cut also had more observations per point than E Plot. The 2008 and 2010 cuts had more observations per point than the 2011 cut in 2012. In 2013, 2015, and 2016, all three cuts had more effective species than E Plot. In 2012 and 2013, the 2008 and 2010 cuts had more effective species than the transitional areas, as did the 2010 and 2011 cuts in 2014. In all years, the 2010 and 2011 cuts had more effective guilds than E Plot, as did the 2008 cut in 2012, 2013, and 2016 and the transitional areas in all but 2014. The 2008 cut had more effective guilds than the transitional areas in 2012 and 2013, and the 2010 cut had more effective guilds than the transitional areas in 2012.



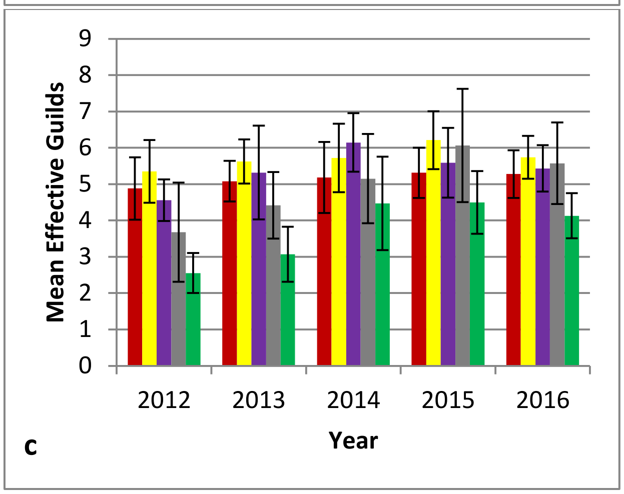


Figure 3. Comparison of mean number of observations (a), effective species (b), and effective guilds (c) between treatment types within each breeding season. Error bars are one standard deviation.

Relative Foraging Guild Abundance

In all years, the most common foraging guilds were ground gleaner insectivores (IGG), lower-canopy gleaner insectivores (ILG), and upper-canopy gleaner insectivores (IUG) in the 2008 cut, 2010 cut, transitional areas, and E Plot (see Appendix Table 4). Although the 2011 cut exhibited the same pattern in 2014 and 2015, insectivore air salliers (IASA) were among the most common guilds in 2012 and 2013, and insectivore bark gleaners were among the most common guilds in 2012 and 2016.

In 2012, IUG were the most common foraging guild in all treatment types. In 2013, ILG became the most predominant guild in the 2008 cut. Thereafter, the proportion of ILG observations increased markedly in the 2010 and 2011 cuts (Figure 4). In 2014, 2015, and 2016, ILG were the most common guild in the 2008 and 2011 cuts, and IUG remained the most prevalent guild in the 2010 cut, transitional areas, and E Plot.

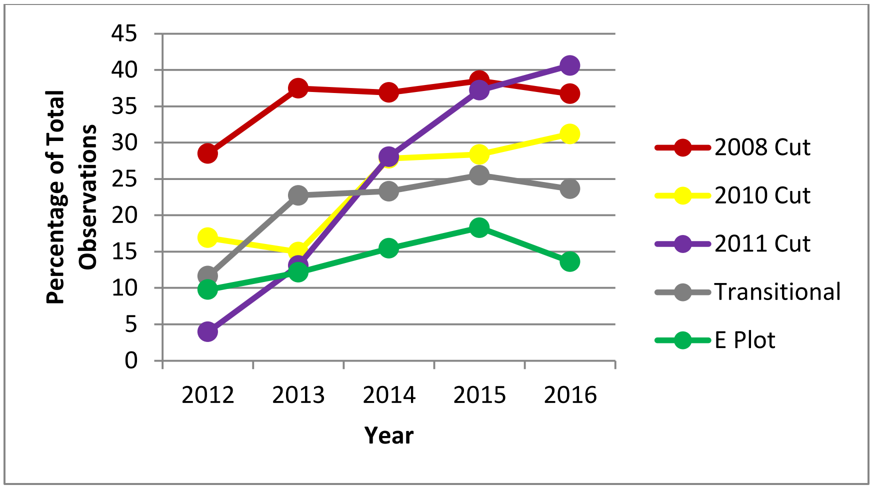


Figure 4. Insectivore lower canopy gleaners (ILG) as a percentage of all observations in each treatment type within each breeding season.

Individual Species

Twelve species were observed at least 50 times in each year (see Appendix Table 10). Of these, several species are habitat generalists, while others have specific preferences of vegetation type and structure, including both mature and second-growth forests (Guide to North American Birds 2016). They represent five different foraging guilds (DeGraaf 1984, Guide to North American Birds 2016).

We examined trends in the number of observations of individual species using linear regressions (from 2013 to 2016, Table 3). Of the twelve focal species, only the eastern wood-pewee showed no significant increases or decreases in any treatment type. Only one focal species showed any significant declines; hermit thrushes decreased in the 2010 cut and E Plot while remaining stable in the other treatments. All other focal species increased significantly in at least one treatment. Only chestnut-sided warblers increased in all treatment types. Ovenbirds increased in all but the 2011 cut, and black-throated blue warblers increased in all but E Plot.

Table 3. P-values for linear regressions of individual bird species in each treatment type in terms of number of observations per point (2013 to 2016). The slope of each linear regression is in parentheses below the p-value. Significant values are shaded.

	Treatment				
Species	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
Black-capped chickadee	0.1284 (+0.43)	0.3177 (+0.24)	0.0083 (+0.38)	0.1383 (+0.35)	0.0030 (+0.79)
Blue-headed vireo	<0.0001 (+1.19)	0.0022 (+0.94)	0.0343 (+0.35)	0.0932 (+0.39)	0.5584 (+0.11)
Blackburnian warbler	0.0004 (+1.12)	0.0445 (+0.61)	0.1118 (+0.41)	0.4423 (+0.16)	0.0001 (+0.87)
Black-throated blue warbler	0.0482 (+1.08)	<0.0001 (+2.07)	<0.0001 (+2.51)	0.0080 (+0.82)	0.0672 (+0.27)
Black-throated green warbler	0.0105 (+1.28)	0.0123 (+1.33)	0.1326 (+0.36)	0.1462 (+0.66)	0.0030 (+1.35)
Chestnut-sided warbler	0.0072 (+1.23)	<0.0001 (+3.11)	<0.0001 (+4.93)	0.0055 (+0.63)	0.0107 (+0.19)
Eastern wood-pewee	0.4154 (-0.16)	0.5240 (-0.18)	0.6490 (-0.09)	0.5172 (+0.09)	0.3116 (+0.13)
Hermit thrush	0.5300 (-0.11)	0.0135 (-0.56)	0.2234 (-0.16)	0.4461 (+0.12)	0.0354 (-0.21)
Ovenbird	<0.0001 (+2.25)	0.0013 (+1.53)	0.0859 (+0.42)	0.0007 (+1.69)	<0.0001 (+3.15)
Red-eyed vireo	0.5443 (+0.19)	0.0743 (+0.91)	0.0371 (+0.69)	0.2432 (+0.41)	0.7782 (+0.11)
Scarlet tanager	0.1682 (-0.30)	0.6537 (+0.10)	0.4286 (-0.14)	0.9004 (-0.02)	0.0024 (+0.45)
Yellow-bellied sapsucker	0.4200 (+0.20)	0.0111 (+0.68)	0.0116 (+0.49)	0.0006 (+0.68)	0.9120 (-0.01)

We also compared the incidence of individual species between treatments based on the number of observations per point in each year using ANOVA and Tukey's post-hoc tests (Table 4, Figure 5, see Appendix Table 11). In all years, black-throated blue warblers were observed more frequently in the 2008 cut than in any other treatment. From 2014 to 2016, they were also observed more frequently in the 2010 cut than in the transitional areas or E Plot, as were eastern wood-pewees. Chestnut-sided warblers were more common in the 2008 cut than in transitional areas or E Plot in all years, and they were more common in the 2010 and 2011 cuts than transitional areas or E Plot from 2014 to 2016. Yellow-bellied sapsuckers were always more common in the 2008 cut than in E Plot. In 2015 and 2016, ovenbirds were least prevalent in the 2011 cut.

One additional species did not meet the fifty-observation-per-year threshold, but they are still noteworthy due to significant differences in abundance between treatment types: least flycatchers (Table 4, Figure 5, see Appendix Tables 10 and 11). In all years, least flycatchers were more common in the 2010 cut than the 2011 cut, transitional areas, and E Plot.

Table 4. Significant differences in individual bird species between treatment types in terms of number of observations per point within each year. Differences are according to Tukey's post-hoc tests at a significance level of p≤0.05. Significant differences that occurred in all years are in bold. Table continues on following page.

	Year				
Species	2012	2013	2014	2015	2016
Black-capped chickadee	10 Cut>08 Cut 10 Cut>11 Cut 10 Cut>Transition 10 Cut>E Plot				
Blue-headed vireo	10 Cut>08 Cut 10 Cut>11 Cut 10 Cut>Transition 10 Cut>E Plot		10 Cut>08 Cut 10 Cut>11 Cut 10 Cut>Transition 10 Cut>E Plot	08 Cut>Transition 10 Cut>Transition	08 Cut>11 Cut 08 Cut>E Plot 10 Cut>E Plot
Black-throated blue warbler	**08 Cut>10 Cut** **08 Cut>11 Cut** **08 Cut>Transition** **08 Cut>E Plot**	**08 Cut>10 Cut** **08 Cut>11 Cut** **08 Cut>Transition** **08 Cut>E Plot**	**08 Cut>10 Cut** **08 Cut>11 Cut** **08 Cut>Transition** **08 Cut>E Plot** 10 Cut>E Plot 11 Cut>Transition 11 Cut>E Plot	**08 Cut>10 Cut** **08 Cut>11 Cut** **08 Cut>Transition** **08 Cut>E Plot** 10 Cut>E Plot 11 Cut>Transition 11 Cut>E Plot Transition>E Plot	**08 Cut>10 Cut** **08 Cut>11 Cut** **08 Cut>Transition** **08 Cut>E Plot** 10 Cut>Transition 10 Cut>E Plot 11 Cut>Transition 11 Cut>E Plot
Black-throated green warbler	10 Cut>11 Cut Transition>11 Cut			08 Cut>11 Cut 10 Cut>11 Cut E Plot>11 Plot	08 Cut>11 Cut 10 Cut>11 Cut E Plot>11 Cut
Chestnut-sided warbler	08 Cut>10 Cut 08 Cut>11 Cut **08 Cut>Transition** **08 Cut>E Plot**	08 Cut>10 Cut 08 Cut>11 Cut **08 Cut>Transition** **08 Cut>E Plot**	08 Cut>11 Cut **08 Cut>Transition** **08 Cut>E Plot** 10 Cut>Transition 10 Cut>E Plot 11 Cut>Transition 11 Cut>E Plot	**08 Cut>Transition** **08 Cut>E Plot** 10 Cut>Transition 10 Cut>E Plot 11 Cut>Transition 11 Cut>E Plot	**08 Cut>Transition** **08 Cut>E Plot** 10 Cut>Transition 10 Cut>E Plot 11 Cut>08 Cut 11 Cut>10 Cut 11 Cut>Transition 11 Cut>E Plot
Eastern wood-pewee	08 Cut>Transition 08 Cut>E Plot **10 Cut>Transition** **10 Cut>E Plot** 11 Cut>10 Cut 11 Cut>Transition 11 Cut>E Plot	08 Cut>Transition 08 Cut>E Plot **10 Cut>Transition** **10 Cut>E Plot** 11 Cut>10 Cut 11 Cut>Transition 11 Cut>E Plot	**10 Cut>Transition** **10 Cut>E Plot** 11 Cut>Transition 11 Cut>E Plot	**10 Cut>Transition** **10 Cut>E Plot**	08 Cut>E Plot **10 Cut>Transition** **10 Cut>E Plot** 11 Cut>Transition 11 Cut>E Plot
Hermit thrush		10 Cut>Transition 10 Cut>E Plot	10 Cut>E Plot 11 Cut>E Plot		08 Cut>E Plot 11 Cut>E Plot
Least flycatcher	**10 Cut>11 Cut** **10 Cut>Transition** **10 Cut>E Plot**	**10 Cut>11 Cut** **10 Cut>Transition** **10 Cut>E Plot**	**10 Cut>11 Cut** **10 Cut>Transition** **10 Cut>E Plot**	10 Cut>08 Cut **10 Cut>11 Cut** **10 Cut>Transition** **10 Cut>E Plot**	10 Cut>08 Cut **10 Cut>11 Cut** **10 Cut>Transition** **10 Cut>E Plot**
Ovenbird	08 Cut>11 Cut Transition>11 Cut E Plot>11 Cut	10 Cut>11 Cut		08 Cut>11 Cut 10 Cut>11 Cut Transition>11 Cut E Plot>11 Cut	08 Cut>11 Cut 10 Cut>11 Cut Transition>11 Cut E Plot>11 Cut
Red-eyed vireo	08 Cut>10 Cut 11 Cut>08 Cut 11 Cut>10 Cut		08 Cut>E Plot		

	Year				
Species	2012	2013	2014	2015	2016
Red-eyed vireo (cont.)	11 Cut>E Plot Transition>10 Cut				
Scarlet tanager		08 Cut>E Plot	11 Cut>E Plot		
Yellow-bellied sapsucker	**08 Cut>E Plot** 10 Cut>E Plot 11 Cut>E Plot	08 Cut>11 Cut 08 Cut>Transition **08 Cut>E Plot** 10 Cut>11 Cut 10 Cut>Transition 10 Cut>E Plot	08 Cut>11 Cut 08 Cut>Transition **08 Cut>E Plot**	**08 Cut>E Plot** 10 Cut>11 Cut 10 Cut>E Plot 11 Cut>E Plot Transition>E Plot	**08 Cut>E Plot** 10 Cut>11 Cut 10 Cut>Transition 10 Cut>E Plot

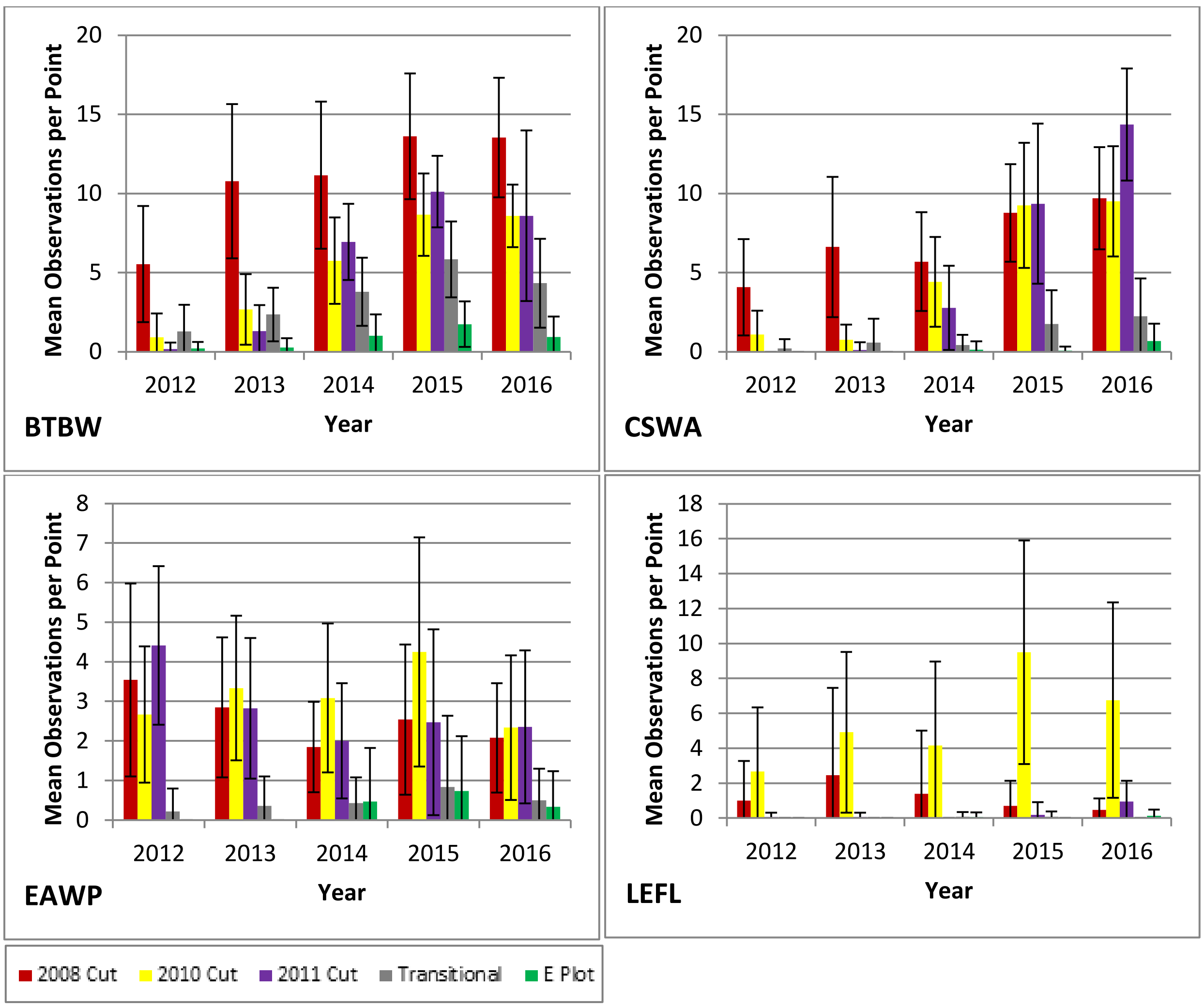


Figure 5. Comparison of mean number of observations of individual bird species (black-throated blue warbler [BTBW], chestnut-sided warbler [CSWA], eastern wood-pewee [EAWP], least flycatcher [LEFL]) between treatment types within each breeding season. Error bars represent one standard deviation.

Vegetation Characteristics

Although the entirety of Bear Paw is a mixture of deciduous and coniferous trees, proportions differ between treatments (ANOVA p-value<0.0001, see Appendix Table 12). The 2010 cut has the highest proportion of coniferous trees (average=56.1%, standard deviation=19.2), followed by the 2008 cut (average=48.3%, standard deviation=19.2) and E Plot (45.6%, standard deviation=13.8). Transitional areas are 29.4% conifers (standard deviation=17.6%), and the 2011 cut is 25.9% conifers (standard deviation=23.5).

A comparison of structural vegetation characteristics indicated predictable differences between treatments. E Plot had the greatest basal area of all of the treatments (ANOVA and Tukey's post-hoc p-values<0.0001, Figure 6). Correspondingly, all of the cuts had more coarse woody debris (ANOVA and Tukey's post-hoc p-values<0.0001, Figure 6), including slash left behind from the harvests, than transitional areas or E Plot. The number of saplings also differed significantly between treatment types in all years (ANOVA p-value=0.0011 in 2012, <0.0001 in all subsequent years), generally increasing in the cuts while remaining low in the transitional areas and E Plot (Figure 7). From 2013 to 2016, the 2008 cut had the greatest number of saplings (see Appendix Table 13). One major shrub species, hobblebush, was present in small amounts in E Plot but negligible in the cuts (see Appendix Table 14). Another major shrub type, *Rubus* sp., was present in the cuts but nearly absent from transitional areas and E Plot (see Appendix Table 15). Nearly all vegetation characteristics are correlated with each other (see Appendix Table 16).

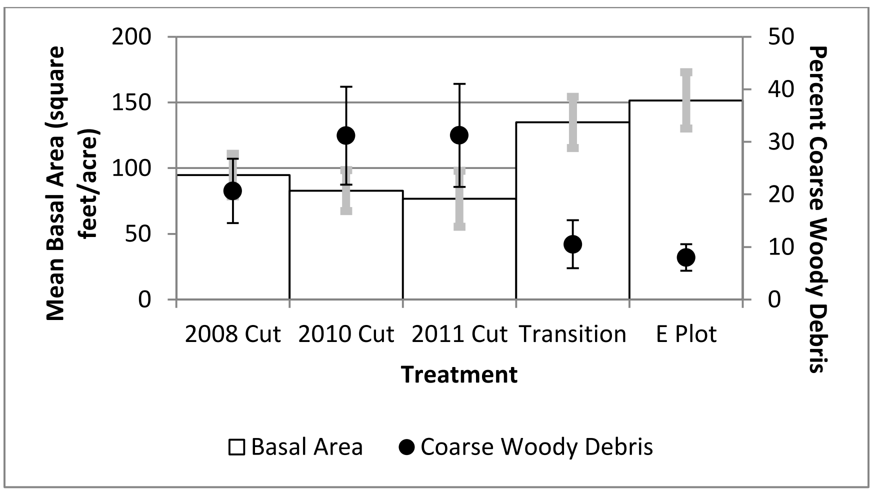


Figure 6. Mean basal area (average of all years) and percent of ground covered by coarse woody debris (average of 2012 and 2013). Error bars are one standard deviation.

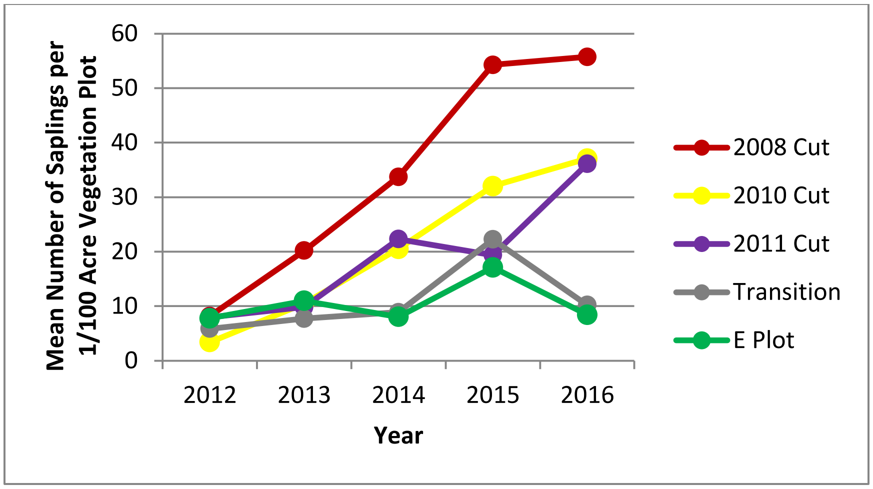


Figure 7. Mean number of saplings per 1/100 acre vegetation plot over time in each treatment.

Relationships between Birds and Vegetation Characteristics

In linear regressions between focal species and vegetation characteristics, we identified two instances of significant relationships across all years (Table 5). Black-throated green warblers always had a slight positive correlation with the percent of conifers, and chestnut-sided warblers always had a strong positive correlation with the number of saplings (Figure 8). We identified four additional trends that were significant in four of the five years of the study: black-throated blue warblers (Figure 9), red-eyed vireos, and yellow-bellied sapsuckers had positive correlations with the number of saplings, and red-eyed vireos had a negative correlation with basal area. Black-throated blue warblers and scarlet tanagers also had significant positive correlations with the percent *Rubus* cover in three of the four years that *Rubus* was assessed. Three other significant relationships occurred in three separate years: black-throated blue warblers had a negative correlation with mean basal area, while ovenbirds had a positive correlation with basal area and a negative correlation with coarse woody debris.

Table 5. Significant correlations between observations per point of individual species and vegetation characteristics in each year. Increases are in bold, and decreases are in italics. Changes are according to linear regressions at a significance level of p≤0.05. Significant differences that occurred in all years of sampling or in all but one year of sampling are shaded.

	Vegetation Characteristic						
Species	Basal area (ft^2/ acre)	Percent canopy cover	Number of saplings	Percent groundcover of hobblebush	Percent groundcover of *Rubus* sp.	Percent groundcover of coarse woody debris	Percent coniferous trees
Black-capped chickadee			*2012*			*2015*	**2012**
Blue-headed vireo			*2012* **2016**			**2014**	**2015** **2016**
Blackburnian warbler							**2015** **2016**
Black-throated blue warbler	*2014* *2015* *2016*	*2016*	**2013** **2014** **2015** **2016**	*2015* *2016*	**2013** **2014** **2015**	**2015** **2016**	
Black-throated green warbler	**2016**		*2012*				**2012** **2013** **2014** **2015** **2016**
Chestnut-sided warbler	*2015* *2016*	*2016*	**2012** **2013** **2014** **2015** **2016**		**2015** **2016**	*2013* **2015** **2016**	
Eastern wood-pewee		*2013* *2014*			**2015**		**2013**
Hermit thrush	*2015*				**2015**	**2013**	**2013** **2014**
Ovenbird	**2012** **2015** **2016**	**2012** **2016**				*2012* *2015* *2016*	**2015** **2016**
Red-eyed vireo	*2012* *2014* *2015* *2016*	*2012* *2014*	**2012** **2013** **2014** **2016**	*2014*			*2012* *2014*
Scarlet tanager		*2014*	**2013**	*2013*	**2013** **2014** **2016**	**2014**	
Yellow-bellied sapsucker			**2013** **2014** **2015** **2016**		**2013**		**2015**

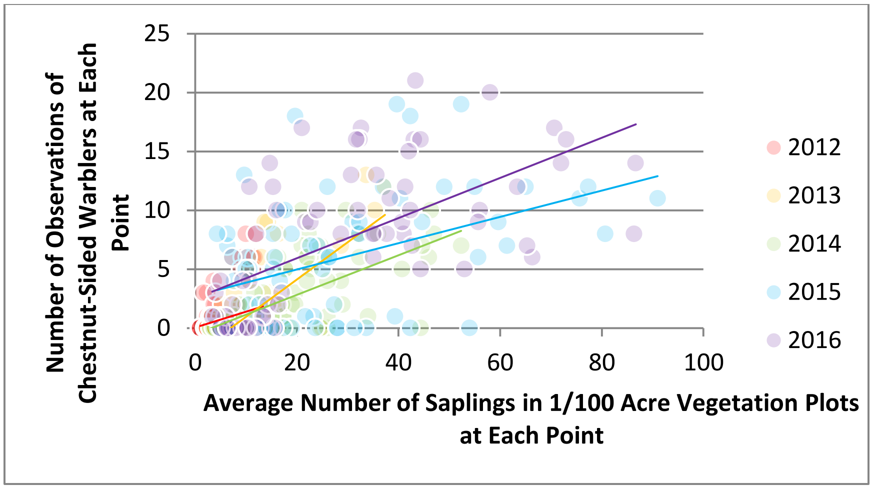


Figure 8. Correlation between the number of chestnut-sided warblers observed at each point and the mean number of saplings in 1/100 acre vegetation plots at each point in each year (2012 R^2=0.5235, prob>F 0.0010; 2013 R^2=0.6354, prob>F <0.0001; 2014 R^2=0.3656, prob>F <0.0001; 2015 R^2=0.1585, prob>F 0.0042; 2016 R^2=0.2413, prob>F 0.0001).

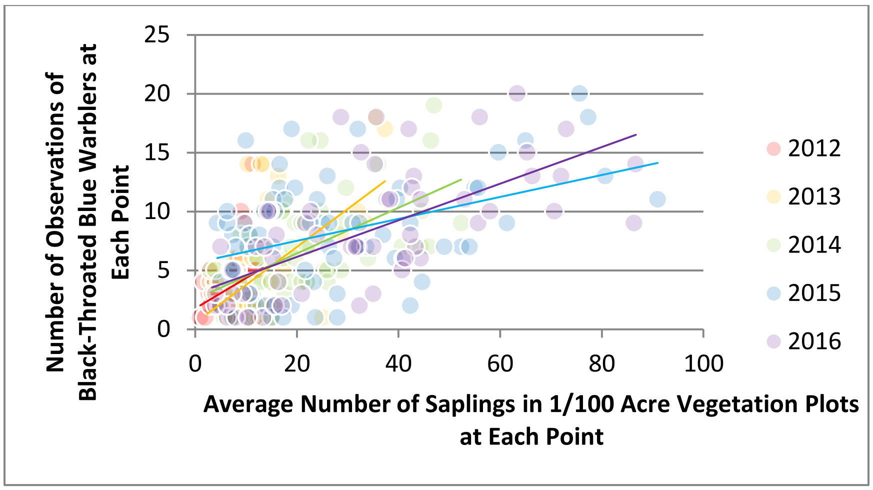


Figure 9. Correlation between the number of black-throated blue warblers observed at each point and the mean number of saplings in 1/100 acre vegetation plots at each point in each year (2012 R^2=0.0877, prob>F 0.1120; 2013 R^2=0.3184, prob>F <0.0001; 2014 R^2=0.3435, prob>F <0.0001; 2015 R^2=0.1734, prob>F 0.0005; 2016 R^2=0.4371, prob>F <0.0001).

DISCUSSION

We detected significant increases in bird abundance and species diversity on both managed and unmanaged New Hampshire forests between 2012 and 2015, followed by a slight but insignificant decrease in 2016. Anecdotally, New Hampshire breeding bird populations may have declined in 2016 in conjunction with a regional drought, but to date, no major statewide increases in bird populations have been noted during this time period (P. Hunt, personal communication, 2017 January 12). Similarly, over the past several years, bird abundance remained relatively stable in a long-term study plot at Hubbard Brook Experimental Forest in the White Mountains Region of New Hampshire (R. Holmes, personal communication, 2017 March 5). While Richard Holmes (personal communication, 2017 March 5) notes that overall abundance trends can obscure trends in individual species populations, most of Bear Paw's common bird species increased over this time period. Ten of twelve focal species—representing four different foraging guilds and a range of habitat requirements—increased in at least one of the five treatments (Table 3). If the increase in Bear Paw is a "real" effect, it may be directly related to local changes, including the Bear Paw timber management activities. Nearby management activities conducted by other landowners, including an adjacent patch cut, may also have affected Bear Paw's bird populations.

However, most Bear Paw observers differed between years, confounding the effects of years and observers. Observer differences may be related to experience (Sauer et al. 1994) as well as hearing loss, which is typically linked to observer age (Farmer et al. 2014). With the exception of MLC, who was middle-aged, all primary observers were young adults, and we therefore assume that their hearing ranges were comparable. We cannot directly assess observer abilities, which likely varied between years and may or may not have been greater in years with greater recorded bird abundance and diversity. An increase in observer quality can result in a greater number of bird detections, which can in turn create an "overly optimistic" assessment of population trends (Sauer et al. 1994). Such observer effects can be substantial. One study yielded counts representing a range of 19% to 65% of a simulated bird population, which depended on species, song characteristics, and observers (Alldredge et al. 2007). We should expect that observer-biased detection probabilities in Bear Paw had a similarly large spread.

Despite probable observer biases, comparisons of bird abundance as recorded by three experienced, multi-year Bear Paw observers suggest that the increases in numbers of observations between years are not strictly artifacts of bias. Specifically, in eight interannual, within-treatment comparisons of experienced observers, all eight showed increases in bird abundance between 2014 and subsequent years, four of which were statistically significant (Appendix Table 5). However, these observers counted different sets of points between years while often visiting the same points repeatedly within the same breeding season. The fact that few significant differences existed between observers (compared within the same year and treatment) reassuringly suggests that different sets of points within the same treatment type may not have had detectable differences in bird abundance (Appendix Table 6). Even so, in future years, rotation of observers between different sets of points may help to average out variable observer abilities.

We can more reliably assess differences in bird abundance and diversity between treatment types within the same year. Most cuts had significantly greater numbers of observations, species diversity, and guild diversity than the undisturbed E Plot in multiple years (Figure 3). In this respect, our analysis of Bear Paw agrees with other studies indicating that bird abundance and diversity are higher in recently harvested New England forests than in unharvested areas (Campbell 2007, Duguid et al. 2016). In order to assess changes in relative bird abundance and diversity between treatments, it may be valuable to think of the various treatments in terms of the number of years post-harvest, corresponding with various stages of response and recovery. Between 2012 and 2016, the 2008 cut was four to eight years post-harvest, the 2010 cut was two to six years post-harvest, and the 2011 cut was one to five years post-harvest.

Unfortunately, without pre-treatment data, we cannot determine whether cuts had greater bird abundance and diversity than other portions of Bear Paw prior to the harvests. Although the harvests occurred between 2008 and 2011, bird and vegetation surveys did not begin until 2012, so we lack data regarding pre-treatment conditions in the cut areas. While the transitional areas and E Plot are intended to be indicators of pre-treatment conditions, we cannot directly assess changes that occurred due to harvests. However, another Bear Paw Timberlands management unit, Unit 1 (153 acres), is non-adjacent but within a mile of Bear Paw. Although it has not been harvested since 1972, a portion of Unit 1 was harvested in early 2017, and another section is slated for timber harvest in the winter of 2017-2018 (Cline and Stepanauskas 2016a). In May 2016, TMCC established 28 bird count points and associated vegetation plots to assess pre-treatment conditions in this area. Monitoring in Unit 1 will resume after the harvest, allowing a direct comparison of pre- and post-treatment bird and vegetation characteristics in close proximity to Bear Paw, albeit with only one year of pre-treatment monitoring data.

Despite lacking a baseline comparison, in accordance with other studies (Campbell 2007, Duguid et al. 2016), we expected to detect temporal increases in species associated with early successional habitat and declines in mature forest species following harvests in Bear Paw. Early successional habitat typically includes saplings and shrubs, both of which were more prevalent in the Bear Paw cuts than transitional areas or E Plot. According to a study of a group-selection harvested forest in Maine, responses of early successional birds were short-lived, lasting eight years at most, while abundance of nearly all species returned to pre-harvest levels within 15 years (Campbell 2007). If birds responded similarly to single-tree selection harvests in Bear Paw, we could already expect diminution of early successional species in the 2008 cut. However, in a study of strip cuts and single-tree selection harvests in Quebec, 13 of 20 focal bird species still showed significant differences in abundance between treatments ten years post-harvest (Doyon et al. 2005). Continued bird and vegetation monitoring will help to determine the duration of potential harvest effects in Bear Paw, although effects on certain early-succession species may already be waning with the amount of time elapsed since initial harvests.

Of the focal species we considered, the chestnut-sided warbler is the only species specifically associated with early successional or “shrubland” habitat (Hunt et al. 2011). In all years, chestnut-sided warblers were more abundant in the 2008 cut than transitional areas and E Plot. In 2012 and 2013, chestnut-sided warblers were also more abundant in the 2008 cut than the 2010 and 2011 cuts. However, from 2014 to 2016, they were more abundant in all three cuts than in transitional areas or E Plot (Table 4). This suggests possible delayed colonization in the 2010 and 2011 cut following the timber harvest. A number of years may have elapsed before the shrub and sapling understory regenerated sufficiently to attract and support chestnut-sided warblers, which were positively correlated with number of saplings per plot in all years (Table 5). Red-eyed vireos and yellow-bellied sapsuckers, both of which are non-exclusively associated with regenerating forests (Guide to North American Birds 2016), were positively correlated with the number of saplings per plot in Bear Paw as well (Table 5).

Sapling growth resulting from harvest activities in Bear Paw likely supports these and other species, although the significant correlations between most vegetation characteristics (Appendix Table 16) makes it impossible to determine relative importance of these characteristics without additional modeling. Furthermore, our vegetation surveys may have neglected important habitat characteristics. Non-vegetative habitat characteristics (for example, the proximity of wetlands) are important for some species (Hunt et al. 2011), but they were not considered in this study. The 2008 cut abuts multiple wetlands and floodplains (R. Fortin, personal communication, 2017 April 14), but we did not specifically consider the proximity or extent of such wetlands in this study. Additionally, our surveys included *Rubus* sp. and hobblebush cover, but they did not assess any other shrub types, which are a key habitat component for certain species (Guide to North American Birds 2016), changing rapidly within the first several years post-harvest (Ward and Worthley 2003).

Two other common Bear Paw species also have specific habitat requirements, particularly edges and clearings: eastern wood-pewees and least flycatchers (Guide to North American Birds 2016). Both were consistently less abundant in transitional areas and E Plot than in the 2010 cut. In most years, least flycatchers were most abundant in the 2010 cut by a large margin over any other treatment. Eastern wood-pewees were relatively common in the 2008 and 2011 cuts as well (Table 4, Figure 5). While eastern wood-pewees had no significant correlations with vegetation characteristics across multiple years, harvest-formed clearings may have been too small or isolated to be detected during vegetation surveys, masking a potential relationship between eastern wood-pewees and clearings or reduced canopy cover. Eastern wood-pewees are more prevalent in areas of open rather than closed canopy, more so than least flycatchers (McCarty 1996). Interestingly, however, portions of the 2010 cut may have been harvested more heavily than intended (R. Fortin, personal communication, 2017 February 28). Although the measured basal areas of the 2010 and 2011 cuts are similar, sampling bias may have overestimated the basal area and canopy cover in the 2010 cut, which has widely spaced trees with a dense understory of saplings and *Rubus* sp. in some areas. We suspect that both flycatchers are relying on the sizable gaps in the 2010 cut. The least flycatcher, which prefers drier forests (Briskie 2008), may be less common than eastern wood-pewees in the 2008 cut due to the more extensive wetlands in this area or to other differences that predate the harvests.

Abundance of certain other species differed predictably between treatments. Black-throated green warblers, which prefer coniferous breeding habitat (Guide to North American Birds 2016), were positively correlated with the percent of conifers in each plot (Table 5). Correspondingly, in most years, they were least abundant in the 2011 cut (25.9% conifers, the smallest percentage of conifers in any of the treatments).

Observations of black-throated blue warblers were a departure from expected patterns. Black-throated blue warblers usually breed in expanses of “relatively undisturbed” forest with “dense undergrowth of shrubs” (Guide to North American Birds 2016). They nest and feed primarily in the lower canopy (Holmes et al. 2005, Guide to North American Birds 2016), which is less prevalent in the transitional areas and E Plot than in the cuts (Figure 7, Appendix Tables 13, 14, and 15). Black-throated blue warblers were always most abundant in the 2008 cut (Table 4). From 2014 to 2016, they were more abundant in the 2011 cut than in transitional areas or E Plot as well, exhibiting positive correlations with both the number of saplings per plot (2013 to 2016) and the percent cover of *Rubus* sp. (2013 to 2015) as well as a negative correlation with basal area (2014 to 2016, Table 5). Based on these correlations, black-throated blue warblers may prioritize the shrub layer over mature, undisturbed forests, either for breeding or for foraging purposes. Others have also noted that black-throated blue warblers colonized harvested areas when understory vegetation was absent from undisturbed forests in Michigan (Holmes et al. 2005). However, a more detailed assessment of Bear Paw's shrub layer would be beneficial in assessing the black-throated blue warbler's local habitat preferences.

Ovenbirds, also typically associated with mature, contiguous forests (Porneluzi et al. 2011, Guide to North American Birds 2016), were detected least often in the 2011 cut in most years (Table 4). While we expected that ovenbirds would be most prevalent in the relatively more mature and undisturbed control areas, a similar study of a shelterwood harvest in Connecticut found that ovenbirds were "abundant" in harvested areas as soon as 13 years post-harvest, even though they remained most abundant in the mature forest areas (Duguid et al. 2016). Duguid et al. (2016) suggest that this ground-nesting species might benefit from the increased shrub cover following harvest. However, we found no correlations between ovenbird abundance and hobblebush cover, *Rubus* sp. cover, or number of saplings. Rather, we found significant positive correlations with basal area and negative correlations with coarse woody debris cover in three of five years (Table 5), which still suggests a preference for mature forest characteristics despite similar ovenbird abundance between the 2008 cut, 2010 cut, transitional areas, and E Plot.

While we observed increases in detections for individual species from various foraging guilds, relative abundance of different guilds changed between years. In 2012, IUG were the most common in all treatment types. In 2013, ILG increased to become the most abundant foraging guild in the 2008 cut. In 2014, 2015, and 2016, ILG were the most abundant in all three cuts, and IUG remained the most abundant guild in the control areas (Figure 4, Appendix Table 4). This shift may be related to the development of the understory, particularly saplings. Saplings, which would support the lower canopy foragers, were most abundant in the 2008 cut and increased throughout all three cuts in each successive year.

Based on five years of post-harvest data, the Bear Paw cuts appear to provide greater habitat diversity than transitional areas and E Plot, particularly in the understory, thereby supporting a greater diversity of bird species and foraging guilds. Although the 2016 Bear Paw management plan recommends non-commercial "timber stand improvement" in the next "10-15 years," no other future harvests are currently planned (Cline and Stepanauskas 2016b). However, repeated cuts and development of uneven-aged stands may help to maintain populations of both early and late successional bird species like those that Bear Paw currently supports.

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APPENDIX

Table 1. Differences in number of total observations between individual years within each treatment as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that the number of observations was greater in the year on the left than in the "comparison year." Data from 2012 are excluded due to the shorter survey season.

		Comparison Year			
Treatment	**Year**	2013	2014	2015	2016
2008 Cut	2013		**0.9784**	0.0007	<0.0001
	2014	0.9784		0.0002	<0.0001
	2015	**0.0007**	**0.0002**		0.8419
	2016	**<0.0001**	**<0.0001**	**0.8419**	
2010 Cut	2013		0.3730	<0.0001	0.0005
	2014	**0.3730**		<0.0001	0.0502
	2015	**<0.0001**	**<0.0001**		**0.0696**
	2016	**0.0005**	**0.0502**	0.0696	
2011 Cut	2013		0.0002	<0.0001	<0.0001
	2014	**0.0002**		0.0149	0.0042
	2015	**<0.0001**	**0.0149**		0.9728
	2016	**<0.0001**	**0.0042**	**0.9728**	
Transitional	2013		0.2635	<0.0001	0.0005
	2014	**0.2635**		0.0007	0.0703
	2015	**<0.0001**	**0.0007**		**0.3797**
	2016	**0.0005**	**0.0703**	0.3797	
E Plot	2013		0.9397	<0.0001	<0.0001
	2014	**0.9397**		<0.0001	0.0002
	2015	**<0.0001**	**<0.0001**		**0.9971**
	2016	**<0.0001**	**0.0002**	0.9971	

Table 2. Differences in number of effective species between individual years within each treatment as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that number of effective species was greater in the year on the left than in the "comparison year."

		Comparison Year				
Treatment	**Year**	2012	2013	2014	2015	2016
2008 Cut	2012		0.1765	0.0807	0.0001	0.0017
	2013	**0.1765**		0.9961	0.1150	0.4172
	2014	**0.0807**	**0.9961**		0.2377	0.6488
	2015	**0.0001**	**0.1150**	**0.2377**		**0.9526**
	2016	**0.0017**	**0.4172**	**0.6448**	0.9526	
2010 Cut	2012		0.7371	0.0034	0.0002	0.1924
	2013	**0.7371**		0.0931	0.0099	0.8621
	2014	**0.0034**	**0.0931**		0.9070	**0.5201**
	2015	**0.0002**	**0.0099**	**0.9070**		**0.1193**
	2016	**0.1924**	**0.8621**	0.5201	0.1193	
2011 Cut	2012		0.0163	<0.0001	<0.0001	<0.0001
	2013	**0.0163**		<0.0001	0.0003	0.0047
	2014	**<0.0001**	**<0.0001**		**0.6690**	**0.2175**
	2015	**<0.0001**	**0.0003**	0.6690		**0.9319**
	2016	**<0.0001**	**0.0047**	0.2175	0.9319	
Transitional	2012		0.5994	0.0097	<0.0001	0.0055
	2013	**0.5994**		0.2944	0.0038	0.1898
	2014	**0.0097**	**0.2944**		0.3624	0.9976
	2015	**<0.0001**	**0.0038**	**0.3624**		**0.5914**
	2016	**0.0055**	**0.1898**	**0.9976**	0.5914	
E Plot	2012		0.1951	<0.0001	<0.0001	<0.0001
	2013	**0.1951**		0.0043	<0.0001	0.0397
	2014	**<0.0001**	**0.0043**		0.5685	**0.9391**
	2015	**<0.0001**	**<0.0001**	**0.5685**		**0.1692**
	2016	**<0.0001**	**0.0397**	0.9391	0.1692	

Table 3. Differences in number of effective guilds between individual years within each treatment as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that number of effective species was greater in the year on the left than in the "comparison year."

		Comparison Year				
Treatment	**Year**	2012	2013	2014	2015	2016
2008 Cut	2012		0.9631	0.8508	0.6042	0.6766
	2013	**0.9631**		0.9970	0.9366	0.9640
	2014	**0.8508**	**0.9970**		0.9925	0.9977
	2015	**0.6042**	**0.9366**	**0.9925**		**1.0000**
	2016	**0.6766**	**0.9640**	**0.9977**	1.0000	
2010 Cut	2012		0.9110	0.7641	0.0624	0.7338
	2013	**0.9110**		0.9977	0.3447	1.0000
	2014	**0.7641**	**0.9977**		0.5343	0.9958
	2015	**0.0624**	**0.3447**	**0.5343**		**0.5679**
	2016	**0.7338**	**0.9958**	**1.0000**	0.5679	
2011 Cut	2012		0.1032	<0.0001	0.0097	0.0419
	2013	**0.1032**		0.0623	0.9001	0.9959
	2014	**<0.0001**	**0.0623**		**0.3726**	**0.1451**
	2015	**0.0097**	**0.9001**	0.3726		**0.9852**
	2016	**0.0419**	**0.9959**	0.1451	0.9852	
Transitional	2012		0.5250	0.0226	<0.0001	0.0026
	2013	**0.5250**		0.5344	0.0121	0.1445
	2014	**0.0226**	**0.5344**		0.3552	0.9113
	2015	**<0.0001**	**0.0121**	**0.3552**		**0.8732**
	2016	**0.0026**	**0.1445**	**0.9113**	0.8732	
E Plot	2012		0.4721	<0.0001	<0.0001	<0.0001
	2013	**0.4721**		0.0003	0.0002	0.0096
	2014	**<0.0001**	**0.0003**		1.0000	**0.7630**
	2015	**<0.0001**	**0.0002**	**1.0000**		**0.8069**
	2016	**<0.0001**	**0.0096**	0.7630	0.8069	

Table 4. Percentage of total observations of the most common foraging guilds by year and treatment. The most common guild in each year and treatment is shaded. Common guilds are as follows: insectivore air salliers (IASA), insectivore bark gleaners (IBG), insectivore ground gleaners (IGG), insectivore lower canopy gleaners (ILG), insectivore upper canopy gleaners (IUG), omnivore bark excavators (OBE), and omnivore ground foragers (OGF).

		Guild							
Year	**Treatment**	IASA	IBG	IGG	ILG	IUG	OBE	OGF	Other
2012	2008 Cut	8	5	15	28	34	4	3	2
	2010 Cut	9	5	16	17	41	5	2	4
	2011 Cut	20	13	9	4	44	5	3	3
	Transitional	2	5	21	12	48	2	5	5
	E Plot	1	1	25	10	62	0	0	1
2013	2008 Cut	5	4	13	37	28	4	6	2
	2010 Cut	7	4	21	15	39	5	6	3
	2011 Cut	14	11	15	13	37	2	5	4
	Transitional	1	6	19	23	37	1	7	6
	E Plot	0	2	26	12	54	2	4	1
2014	2008 Cut	4	3	16	37	26	6	7	2
	2010 Cut	7	4	19	28	30	4	3	4
	2011 Cut	6	9	15	28	27	4	6	5
	Transitional	4	6	20	23	32	4	6	5
	E Plot	3	5	23	15	40	5	6	3
2015	2008 Cut	4	4	12	39	24	5	9	3
	2010 Cut	5	4	12	28	34	5	8	4
	2011 Cut	8	8	11	37	23	4	5	5
	Transitional	3	8	17	26	27	5	9	7
	E Plot	3	7	19	18	43	1	6	3
2016	2008 Cut	3	5	17	37	25	4	7	3
	2010 Cut	3	5	14	31	34	5	6	3
	2011 Cut	7	10	9	41	22	3	4	4
	Transitional	2	9	23	24	25	4	9	5
	E Plot	2	6	30	14	40	1	5	2

Table 5. Difference in the number of observations per point per day between years (2014 as compared to either 2015 or 2016) within each treatment for three experienced observers as indicated by p-values derived from two-tailed Student's t-tests. Significant p-values are shaded. Bold values indicate that number of observations was greater in 2014 than in the "comparison year." NA indicates no data or insufficient data.

		Comparison Year	
Observer	**Treatment**	2015	2016
CMB	2008 Cut	NA	**0.0101**
	2010 Cut	NA	**<0.0001**
	2011 Cut	NA	**<0.0001**
	Transitional	NA	**0.0762**
	E Plot	NA	NA
MLC	2008 Cut	**0.2284**	NA
	2010 Cut	NA	NA
	2011 Cut	**0.2877**	NA
	Transitional	**0.0413**	NA
	E Plot	NA	NA
SEA	2008 Cut	NA	NA
	2010 Cut	NA	NA
	2011 Cut	**0.3150**	NA
	Transitional	NA	NA
	E Plot	NA	NA

Table 6. Difference in the number of observations per point per day between three experienced observers and all other observers within each year and treatment as indicated by p-values derived from two-tailed Student's t-tests. Significant p-values are shaded. Bold values indicate that number of observations was greater for the average of all observers than for the individual observer. NA indicates no data or insufficient data.

		Observer		
Year	**Treatment**	CMB	MLC	SEA
2014	2008 Cut	0.6834	0.0589	NA
	2010 Cut	**0.0083**	NA	NA
	2011 Cut	**0.0833**	**0.0065**	0.0130
	Transitional	**0.6153**	**0.8152**	0.0116
	E Plot	NA	NA	**0.1620**
2015	2008 Cut	NA	**<0.0001**	NA
	2010 Cut	NA	NA	**0.9952**
	2011 Cut	NA	**<0.0001**	**0.5498**
	Transitional	NA	**<0.0001**	0.5153
	E Plot	NA	NA	NA
2016	2008 Cut	**0.5154**	NA	NA
	2010 Cut	**0.3281**	NA	NA
	2011 Cut	0.4141	NA	NA
	Transitional	**0.449**	NA	NA
	E Plot	NA	NA	NA

Table 7. Differences in number of observations between treatments within each year as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that number of observations was greater in the treatment on the left than in the "comparison treatment."

		Comparison Treatment				
Year	**Treatment**	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
	2008 Cut		**0.0980**	**<0.0001**	**<0.0001**	**<0.0001**
	2010 Cut	0.0980		**<0.0001**	**<0.0001**	**<0.0001**
2013	2011 Cut	<0.0001	<0.0001		**0.9716**	**0.8218**
	Transitional	<0.0001	<0.0001	0.9716		**0.9935**
	E Plot	<0.0001	<0.0001	0.8218	0.9935	
	2008 Cut		0.9835	**0.5997**	**0.0002**	**<0.0001**
	2010 Cut	**0.9835**		0.2866	**<0.0001**	**<0.0001**
2014	2011 Cut	0.5997	0.2866		**0.0080**	**<0.0001**
	Transitional	0.0002	<0.0001	0.0080		**0.4055**
	E Plot	<0.0001	<0.0001	<0.0001	0.4055	
	2008 Cut		0.1284	**0.2582**	**0.0162**	**0.0001**
	2010 Cut	**0.1284**		**0.0002**	**<0.0001**	**<0.0001**
2015	2011 Cut	0.2582	0.0002		**0.6093**	**0.0379**
	Transitional	0.0162	<0.0001	0.6093		**0.7088**
	E Plot	0.0001	<0.0001	0.0379	0.7088	
	2008 Cut		**0.9053**	**0.0180**	**<0.0001**	**<0.0001**
	2010 Cut	0.9053		**0.1959**	**<0.0001**	**<0.0001**
2016	2011 Cut	0.0180	0.1959		**0.0010**	**0.0002**
	Transitional	<0.0001	<0.0001	0.0010		**0.9992**
	E Plot	<0.0001	<0.0001	0.0002	0.9992	

Table 8. Differences in number of effective species between treatments within each year as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that number of effective species was greater in the treatment on the left than in the "comparison treatment."

		Comparison Treatment				
Year	**Treatment**	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
2012	2008 Cut		0.3267	**0.0191**	**0.0003**	**<0.0001**
	2010 Cut	**0.3267**		**<0.0001**	**<0.0001**	**<0.0001**
	2011 Cut	0.0091	<0.0001		**0.5727**	**0.0019**
	Transitional	0.0003	<0.0001	0.5727		**0.1597**
	E Plot	<0.0001	<0.0001	0.0019	0.1597	
2013	2008 Cut		0.8079	**0.5642**	**0.0023**	**<0.0001**
	2010 Cut	**0.8079**		**0.0760**	**<0.0001**	**<0.0001**
	2011 Cut	0.5642	0.0760		**0.0840**	**<0.0001**
	Transitional	0.0023	<0.0001	0.0840		**0.0451**
	E Plot	<0.0001	<0.0001	<0.0001	0.0451	
2014	2008 Cut		0.1526	0.0116	**0.9890**	**0.1059**
	2010 Cut	**0.1526**		0.9277	**0.0474**	**<0.0001**
	2011 Cut	**0.0116**	**0.9277**		**0.0019**	**<0.0001**
	Transitional	0.9890	0.0474	0.0019		**0.2586**
	E Plot	0.1059	<0.0001	<0.0001	0.2586	
2015	2008 Cut		0.4183	0.8847	0.9877	**0.0257**
	2010 Cut	**0.4183**		**0.8809**	**0.7394**	**<0.0001**
	2011 Cut	**0.8847**	0.8809		**0.9953**	**0.0007**
	Transitional	**0.9877**	0.7394	0.9953		**0.0072**
	E Plot	0.0257	<0.0001	0.0007	0.0072	
2016	2008 Cut		0.9929	0.9176	**0.8220**	**0.0003**
	2010 Cut	**0.9929**		0.9961	**0.5884**	**<0.0001**
	2011 Cut	**0.9176**	**0.9961**		**0.3006**	**<0.0001**
	Transitional	0.8220	0.5884	0.3006		**0.0137**
	E Plot	0.0003	<0.0001	<0.0001	0.0137	

Table 9. Differences in number of effective guilds between treatments within each year as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that number of effective guilds was greater in the treatment on the left than in the "comparison treatment."

		Comparison Treatment				
Year	**Treatment**	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
2012	2008 Cut		0.6709	**0.8551**	**0.0060**	**<0.0001**
	2010 Cut	**0.6709**		**0.1301**	**<0.0001**	**<0.0001**
	2011 Cut	0.8551	0.1301		**0.0530**	**<0.0001**
	Transitional	0.0060	<0.0001	0.0530		**0.0086**
	E Plot	<0.0001	<0.0001	<0.0001	0.0086	
2013	2008 Cut		0.5661	0.9513	**0.3203**	**<0.0001**
	2010 Cut	**0.5661**		**0.8997**	**0.0098**	**<0.0001**
	2011 Cut	**0.9513**	0.8997		**0.0536**	**<0.0001**
	Transitional	0.3203	0.0098	0.0536		**0.0013**
	E Plot	<0.0001	<0.0001	<0.0001	0.0013	
2014	2008 Cut		0.7124	0.1131	**1.0000**	**0.4023**
	2010 Cut	**0.7124**		0.8276	**0.6505**	**0.0274**
	2011 Cut	**0.1131**	**0.8276**		**0.0830**	**0.0003**
	Transitional	1.0000	0.6505	0.0830		**0.4307**
	E Plot	0.4023	0.0274	0.0003	0.4307	
2015	2008 Cut		0.1805	0.9437	0.3494	**0.2159**
	2010 Cut	**0.1805**		**0.4784**	**0.9960**	**0.0004**
	2011 Cut	0.9437	0.4784		0.7271	**0.0252**
	Transitional	**0.3494**	0.9960	**0.7271**		**0.0014**
	E Plot	0.2159	0.0004	0.0252	0.0014	
2016	2008 Cut		0.5288	0.9796	0.8564	**0.0010**
	2010 Cut	**0.5288**		**0.8044**	**0.9812**	**<0.0001**
	2011 Cut	**0.9796**	0.8044		0.9866	**<0.0001**
	Transitional	**0.8564**	0.9812	**0.9866**		**<0.0001**
	E Plot	0.0010	<0.0001	<0.0001	<0.0001	

Table 10. Common species observed in Bear Paw along with their statewide population trends (Hunt et al. 2011), preferred breeding habitat characteristics (Guide to North American Birds 2016), and characteristics of their primary breeding season foraging guilds (DeGraaf 1984, Guide to North American Birds 2016, Robinson and Holmes 1982). *Species was observed at least fifty times in each year, making it a "focal species" in this study.

Species	Alpha Code	Scientific Name	New Hampshire Population Trend	Preferred Habitat	Foraging Guild	Foraging Guild Code
Black-capped chickadee*	BCCH	*Poecile atricapillus*	Uncertain	Open mixed woods; edges	Insectivore lower canopy gleaner	ILG
Blue-headed vireo*	BHVI	*Vireo solitarius*	Stable	Open mixed woods	Insectivore lower canopy gleaner	ILG
Blackburnian warbler*	BLBW	*Setophaga fusca*	Stable	Conifers	Insectivore upper canopy gleaner	IUG
Black-throated blue warbler*	BTBW	*Setophaga caerulescens*	Stable	Interior deciduous or mixed forests; dense undergrowth	Insectivore lower canopy gleaner	ILG
Black-throated green warbler*	BTNW	*Setophaga virens*	Stable	Conifers	Insectivore upper canopy gleaner	IUG
Chestnut-sided warbler*	CSWA	*Setophaga pensylvanica*	Declining	Second-growth deciduous woods; brush	Insectivore lower canopy gleaner	ILG
Eastern wood-pewee*	EAWP	*Contopus virens*	Declining	Deciduous forests; clearing margins	Insectivore air sallier	IASA
Hermit thrush*	HETH	*Catharus guttatus*	Increasing	Conifers or mixed woods	Insectivore ground gleaner	IGG
Least flycatcher	LEFL	*Empidonax minimus*	Declining	Open mixed woods; clearings or edges	Insectivore upper canopy gleaner	IUG
Ovenbird*	OVEN	*Seiurus aurocapilla*	Stable	Mature deciduous or mixed forests; closed canopy	Insectivore ground gleaner	IGG
Red-eyed vireo*	REVI	*Vireo olivaceus*	Uncertain	Open deciduous or mixed woods; saplings	Insectivore upper canopy gleaner	IUG
Scarlet tanager*	SCTA	*Piranga olivacea*	Declining	Deciduous forests	Insectivore upper canopy gleaner	IUG
Yellow-bellied sapsucker*	YBSA	*Sphyrapicus varius*	Increasing	Mixed woods	Omnivore bark excavator	OBE

Table 11. Differences in number of observations per point between treatments within each year as indicated by p-values derived from ANOVA. Significant p-values are shaded.

	Year				
Species	2012	2013	2014	2015	2016
Black-capped chickadee	0.0013	0.0638	0.9597	0.2296	0.3392
Blue-headed vireo	<0.0001	0.4911	0.0003	0.0076	0.0002
Blackburnian warbler	0.0017	0.0006	0.1956	0.0053	0.0071
Black-throated blue warbler	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Black-throated green warbler	0.0010	0.0686	0.3713	0.0007	0.0005
Chestnut-sided warbler	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Eastern wood-pewee	<0.0001	<0.0001	<0.0001	0.0004	0.0002
Hermit thrush	0.1342	0.0046	0.0075	0.0728	0.0239
Least flycatcher	0.0009	<0.0001	0.0002	<0.0001	<0.0001
Ovenbird	<0.0001	0.0484	0.5781	0.0001	<0.0001
Red-eyed vireo	<0.0001	0.2907	0.0084	0.3085	0.1142
Scarlet tanager	0.8410	0.0125	0.0161	0.7962	0.2840
Yellow-bellied sapsucker	0.0002	<0.0001	0.0003	<0.0001	<0.0001

Table 12. Differences in proportion of conifers between treatments as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that the proportion of conifers was greater in the treatment on the left than in the "comparison treatment."

	Comparison Treatment				
Treatment	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
2008 Cut		0.1502	**<0.0001**	**<0.0001**	**0.9201**
2010 Cut	**0.1502**		**<0.0001**	**<0.0001**	**0.0137**
2011 Cut	<0.0001	<0.0001		0.8068	<0.0001
Transitional	<0.0001	<0.0001	**0.8068**		<0.0001
E Plot	0.9201	0.0137	**<0.0001**	**<0.0001**	

Table 13. Differences in number of saplings per plot between treatments within each year as indicated by p-values derived from Tukey's post-hoc tests. Significant p-values are shaded. Bold values indicate that number of saplings was greater in the treatment on the left than in the "comparison treatment."

		Comparison Treatment				
Year	Treatment	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
2012	2008 Cut		**0.0036**	**0.9998**	**0.3395**	**0.9968**
	2010 Cut	0.0036		0.0029	0.3000	0.0070
	2011 Cut	0.9998	**0.0029**		**0.3644**	**0.9997**
	Transitional	0.3395	**0.3000**	0.3644		0.5086
	E Plot	0.9968	**0.0070**	0.9997	**0.5086**	
2013	2008 Cut		**0.0017**	**0.0002**	**<0.0001**	**0.0016**
	2010 Cut	0.0017		**0.9983**	**0.7727**	0.9996
	2011 Cut	0.0002	0.9983		**0.8723**	0.9834
	Transitional	<0.0001	0.7727	0.8723		0.6037
	E Plot	0.0016	**0.9996**	**0.9834**	**0.6037**	
2014	2008 Cut		**0.0009**	**0.0021**	**<0.0001**	**<0.0001**
	2010 Cut	0.0009		0.9748	**0.0037**	**0.0012**
	2011 Cut	0.0021	**0.9748**		**0.0001**	**<0.0001**
	Transitional	<0.0001	0.0037	0.0001		**0.9984**
	E Plot	<0.0001	0.0012	<0.0001	0.9984	
2015	2008 Cut		**0.0065**	**<0.0001**	**<0.0001**	**<0.0001**
	2010 Cut	0.0065		**0.2193**	**0.5531**	**0.1160**
	2011 Cut	<0.0001	0.2193		0.9884	**0.9941**
	Transitional	<0.0001	0.5531	**0.9884**		**0.9155**
	E Plot	<0.0001	0.1160	0.9941	0.9155	
2016	2008 Cut		**0.0084**	**0.0018**	**<0.0001**	**<0.0001**
	2010 Cut	0.0084		**0.9997**	**<0.0001**	**<0.0001**
	2011 Cut	0.0018	0.9997		**<0.0001**	**<0.0001**
	Transitional	<0.0001	<0.0001	<0.0001		**0.9971**
	E Plot	<0.0001	<0.0001	<0.0001	0.9971	

Table 14. Mean percent plot coverage of hobblebush in each year and treatment. Standard deviations are in parentheses below the mean.

	Treatment				
Year	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
2013	0.00 (0.00)	0.36 (0.78)	0.00 (0.00)	1.26 (1.76)	7.62 (8.02)
2014	0.87 (1.22)	1.33 (1.29)	0.69 (2.83)	2.55 (3.64)	5.99 (4.00)
2015	0.74 (1.33)	2.06 (2.18)	0.65 (2.42)	3.47 (4.72)	13.27 (12.03)
2016	0.46 (0.71)	0.53 (0.97)	0.20 (0.97)	1.19 (2.97)	5.20 (7.12)

Table 15. Mean percent plot coverage of *Rubus* sp. in each year and treatment. Standard deviations are in parentheses below the mean.

	Treatment				
Year	2008 Cut	2010 Cut	2011 Cut	Transitional	E Plot
2013	28.21 (19.08)	15.44 (12.19)	8.98 (8.75)	1.07 (3.56)	0.00 (0.00)
2014	16.64 (13.68)	18.85 (12.90)	13.86 (11.76)	0.95 (3.12)	0.00 (0.00)
2015	11.28 (9.71)	21.47 (17.05)	13.76 (13.38)	1.25 (3.11)	0.00 (0.00)
2016	4.85 (0.46)	9.92 (7.16)	7.07 (7.82)	0.58 (1.57)	0.67 (2.58)

Table 16. Significant correlations (positive or negative) between vegetation characteristics across all years. Blanks indicate that no significant relationship exists. Correlations are according to linear regressions at a significance level of p≤0.05.

	Basal area (ft^2/ acre)	Percent canopy cover	Number of saplings	Percent groundcover of hobblebush	Percent groundcover of *Rubus* sp.	Percent groundcover of coarse woody debris	Percent coniferous trees
Basal area (ft^2/ acre)		+	-	+	-	-	+
Percent canopy cover	+		-	+	-	-	+
Number of saplings	-	-			+	+	
Percent groundcover of hobblebush	+	+			-	-	
Percent groundcover of *Rubus* sp.	-	-	+	-		+	
Percent groundcover of coarse woody debris	-	-	+	-	+		
Percent coniferous trees	+	+					