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ECOLOGICAL FACTORS AFFECTING RESPONSE OF DARK-EYED JUNCOS TO PRESCRIBED BURNING

JINELLE H. SPERRY,[1,2,4] T. LUKE GEORGE,[1] AND STEVE ZACK[3]

ABSTRACT.—We compared abundance, daily survival rate, nest site characteristics, food availability, nest activity, and nestling size of Dark-eyed Juncos (*Junco hymenalis*) between burned and unburned mechanically-thinned ponderosa pine (*Pinus ponderosa*) forest units. Dark-eyed Junco territory density, number of detections in point counts, and daily nest survival were similar between treatments. Average bare ground was 4.8 times higher and litter cover was 2.6 times lower at nest sites in burned units compared to unburned nest sites. However, there was 28% less burned area around nests compared to random points in burned units, indicating that juncos placed nests in unburned portions of burned units. They also selected non-traditional nesting sites in burned units such as root holes and in trees. Arthropod abundance was higher in burned units 1-year post burn although numbers were similar in the second-year post burn. Nest attentiveness and feeding rates were three times higher in burned units, possibly in response to increased food availability. The potentially negative effect of prescribed burning through reduction of litter and increase in bare ground was offset by novel nesting strategies and increased food availability. *Received 21 November 2006. Accepted 26 May 2007.*

Traditional management practices, such as logging and fire suppression, have dramatically altered the structure and composition of ponderosa pine (*Pinus ponderosa*) forests in the western United States (Covington and Moore 1994, Veblen et al. 2000). These forests were frequently swept by low-intensity fires, prior to European settlement, that maintained open stands (Covington and Moore 1994, Skinner and Change 1996, Fry and Stephens 2006). Decades of fire suppression have resulted in an accumulation of understory fuels, increased stand density, and encroachment of fire-intolerant species, such as white fir (*Abies concolor*), which can lead to high intensity, stand replacing fires (Covington and Moore 1994). Land managers often use prescribed burning in conjunction with silvicultural thinning to restore ponderosa pine forests to historical conditions and minimize fire risk (Weatherspoon 1996, Covington et al. 1997).

Prescribed burns result in changes in forest structure, soil properties, plant species composition, understory vegetation, ground cover, and arthropod biomass (Rogers 1996, DeLuca and Zouhar 2000, Griffis et al. 2001, Waltz et al. 2003). These changes may positively or negatively affect forest nesting birds by altering habitat structure or food availability. The effects of prescribed burning on birds generally vary with ground and shrub-foraging species typically increasing in abundance following burning (Bock and Lynch 1970, Finch et al. 1997, Bock and Bock 1983, Saab and Powell 2005). Increased abundance of ground-nesting birds following a burn seems unexpected given that burning alters the habitat in ways that should be detrimental.

Our objective was to examine the response of Dark-eyed Juncos (*Junco hyemalis*) to prescribed burning in a mechanically-thinned forest. Specifically, we examined if predicted increase in abundance following prescribed burning results from habitats becoming ecological traps through decreases in ground nest cover or whether behavioral flexibility allows juncos to exploit these habitats successfully.

METHODS

Study Area.—We conducted the study within the Goosenest Adaptive Management Area (GAMA) on the Klamath National Forest in northern California (41° 30 N, 121° 52 W) at an elevation of 1,500 to 1,700 m. The site is

[1] Department of Wildlife, Humboldt State University, 1 Harpst Street, Arcata, CA 95521, USA.

[2] Current address: Program in Ecology, Evolution and Conservation Biology, University of Illinois Urbana-Champaign, 606 E. Healey, Champaign, IL 61820, USA.

[3] Current address: Wildlife Conservation Society, 718 SW Alder Street, Suite 210, Portland, OR 97205, USA.

[4] Corresponding author; e-mail: jhutch@uiuc.edu

dominated by ponderosa pine, white fir, incense-cedar (*Libocedrus decurrens*), and sugar pine (*Pinus lambertiana*).

The U.S. Forest Service and other cooperators initiated a long-term study in 1996 at GAMA to examine alternative approaches to accelerating late-succession forest characteristics. Five replicates of three silvicultural treatments and a non-treatment "control" were randomly applied to 20 units within GAMA. Each unit was 40 ha and included a 100-m buffer where the silvicultural treatment extended beyond the unit boundary to reduce possible edge effects within the unit. The pine emphasis treatment involved removal of small-diameter trees while retaining large-diameter pines. The pine-emphasis-with-fire treatment involved the same thinning treatment as the pine emphasis units followed by a prescribed burn. Another thinning treatment was applied to five of the units but was not monitored in this study (Ritchie and Harcksen 1999). The most intensive aspects of our study were conducted on the five pine emphasis and five pine-emphasis-with-fire units. We refer to these treatments as unburned and burned treatments, respectively. We also monitored nests on two additional control (unthinned) units although too few juncos were found to include these units in analyses. Thinning treatments started in 1998 and were completed in 2000. The five burned units were prescribed burned in fall 2001. We conducted this study during May–August 2002 and 2003.

Bird Abundance and Nest Survival.—We estimated junco density in each unit using spot mapping and point counts. A 9-ha area (300 × 300 m) in the center of each treatment unit was marked with wire flags every 50 m to assist with spot mapping. Each unit was visited 7–8 times in both 2002 and 2003, and the location, movements, and behavior of all Dark-eyed Juncos were plotted on maps. At the conclusion of the nesting season, territories were delineated and counted following methods described in Bibby et al. (1992). Partial territories were counted if the majority of the territory was within the spot-mapping area.

Point counts were conducted during May and June for both years. Nine points, each 200 m apart, were established within the 9-ha grid area on each unit and each point was surveyed twice by different observers in each year. Point count surveys were started within 15 min of local sunrise and continued until all points on a unit were completed. Count duration was 8 min and started upon arrival at the point. Point counts were not conducted during steady rain, snow, or strong winds (>20 km/hr). All junco detections <100 m from the point were used in analysis. Nest searches were conducted following Martin and Geupel (1993). Nests were monitored every 1–4 days until their fate was ascertained.

Vegetation.—Vegetative characteristics were measured around nest sites and at random grid points in both burned and unburned units. Overstory canopy cover was estimated as the average of four densiometer readings taken 5 m from the site in the four cardinal directions and at the site for a total of 20 readings per site. Shrub cover and woody debris were estimated along two perpendicular 30.8-m transects centered on the nest or random site. Only woody debris with a diameter greater than 7.5 cm and shrubs greater than 0.25 m in height were included.

We also measured vegetative characteristics in a 1-m circle centered on the nest or random site. Litter depth was measured 1 m from the nest or random site in the four cardinal directions. Herbaceous, grass, bare ground, log, and rock cover were visually estimated in a 1-m circle around each nest or random location (Martin et al. 1997). We also estimated the proportion of the area within 1 m of the nest or random site that was burned. Nest concealment directly over the nest cup was visually estimated at every nest where the nest remained intact. All nests, including those in which eggs were not observed, were included in habitat measurements.

Arthropod Sampling.—Arthropod abundance was estimated using pitfall and sticky board traps. Dark-eyed Juncos typically forage on or near the ground (Holmes and Robinson 1988) and our methods targeted ground dwelling or low-flying arthropods. Sticky board traps were made of 30.5 × 30.5 cm corrugated plastic. Each sticky board was covered with a thin layer of Tanglefoot® and placed vertically 4 cm above the ground on metal wires. Following collection, sticky boards were covered in plastic wrap to preserve the samples. Pitfall traps consisted of

TABLE 1. Mean (± SE) number of Dark-eyed Junco territories on 9-ha spot-mapping plots, point count detections, and nesting success of Dark-eyed Juncos on five burned and five unburned units at Goosenest Adaptive Management Area, Klamath National Forest, California, 2002–2003.

Year	Variable	Territories	Detections	Nests (*n*)	Obs. days	Nest success	Daily survival (95% CI)
2002	Burned	5.8 ± 0.6	16.6 ± 3.1	18	207.5	0.29	0.95 (0.92–0.97)
	Unburned	5.0 ± 0.3	17.8 ± 3.8	14	99.5	0.23	0.95 (0.93–0.95)
2003	Burned	2.8 ± 0.7	8.0 ± 0.6	12	191.5	0.41	0.97 (0.96–0.97)
	Unburned	2.8 ± 0.5	7.8 ± 1.1	16	189.5	0.34	0.96 (0.95–0.97)

450-ml containers with holes cut in a circle around the top. Containers were placed with the holes flush to the ground. A lid was placed on the trap to ensure that precipitation and non-target species were excluded. Pitfall traps contained nontoxic propylene glycol as a preservative.

Both trap types were set for two 7-day sampling periods. The first sampling period coincided with Dark-eyed Junco nest building stage (late May 2002, early Jun 2003) and the second coincided with the nestling phase (late Jun 2002, early Jul 2003). Five sticky board and 10 pitfall traps were placed at randomly chosen grid points in each unit. Arthropods were identified to taxonomic order and measured to nearest millimeter. Length-weight ratios were calculated using the general equation in Rogers et al. (1976). Only arthropods 3–20 mm in length were used in the analysis as smaller prey items (<3 mm) and extremely large prey have been shown to be under-represented in the diet of many bird species (Quinney and Ankney 1985, Raley and Anderson 1990, Van Horne and Bader 1990).

Nest Activity.—Digital video cameras were placed at nests for 3 hrs, starting at sunrise, to measure food delivery rates. Nests were videotaped when young were 6 days old and only nests that had four nestlings were used to control for variation in food demands as a function of nestling age and number. We recorded the times when an adult delivered food to the nestlings and the start and end time of each brooding event.

Nestling Measurements.—Wing chord, tarsus, and weight of each nestling in 2003 were measured on the sixth day after hatching. Wing chord and tarsus lengths were recorded with calipers to the nearest 0.5 mm, and weight was measured with an electric balance to the nearest 0.1 g.

Statistical Analysis.—Dark-eyed Junco territory numbers and point count detections were compared between burned and unburned units using two-sample *t*-tests. We used PROC LOGISTIC following Hazler (2004) to analyze daily survival rates (DSR) of nests (SAS Institute 2000). Models were developed using three variables: treatment, mean arthropod biomass by unit, and year. These models were likely to explain variation in daily survival rate of junco nests on our study sites. The candidate set of models was evaluated using Akaike's Information Criteria (Burnham and Anderson 2002) corrected for small sample size (AIC_c). All models were ranked based on relative AIC_c weight (w_i). The model with the lowest ΔAIC_c and highest w_i is considered the best approximating model from the set of candidate models tested (Burnham and Anderson 2002). Actual DSR values were calculated by back transforming logit-scale regression equations. Only nests in which an egg was observed were included in nest survival analysis. Nest/random site characteristics, arthropod biomass, nest activity rates, and nestling measurements were compared between treatments with ANOVAs with unit nested within treatment. Nestling length and weight measurements were averaged for each nest. All ANOVAs and *t*-tests were completed using NCSS (Hintze 2001) statistical program.

RESULTS

Abundance and Nest Survival.—Dark-eyed Junco abundance did not differ significantly between burned and unburned units for either year (Table 1). However, both average number of junco territories and point count detections per unit were higher in 2002 than 2003 (t = 2.23, df = 18, P = 0.04 and t = 3.99, df = 18, P = <0.001, respectively) (Table 1).

Thirty-two nests were monitored in 2002

TABLE 2. Model selection results from Mayfield logistic regression explaining survival of Dark-eyed Junco nests on burned and unburned units at Goosenest Adaptive Management Area, Klamath National Forest, California, 2002–2003. K = number of parameters in each model including the intercept, ΔAIC_c = difference between each model and the model with the lowest AIC_c score, and AIC_c weight = the relative support for each model. Models are ranked based on AIC_c weights.

Model	K	ΔAIC_c	AIC_c (wt)	w_i	Rank
Constant survival	1	0	244.24	0.601	1
Arthropod biomass	2	2.45	246.68	0.177	2
Year	2	3.55	247.79	0.101	3
Treatment	2	4.02	248.26	0.081	4
Year + Arthropod	3	6.47	250.71	0.024	5
Year + Treatment	3	7.54	251.78	0.014	6
Year * Treatment	4	11.68	255.91	0.002	7

with 18 nests in burned units and 14 in unburned units. We monitored 28 nests in 2003 with 12 in burned units and 16 on unburned. Daily nest survival was similar between burned and unburned units in both 2002 and 2003 (Table 1). The constant daily survival model received the lowest ΔAIC_c and the greatest AIC_c weight (Table 2).

Nest Activity.—Sample sizes in 2002 were small as few nests survived to day 6 of the nestling period. Four nests in burned and three in unburned units were videotaped. Females spent an average of 35% of their time on the nest in the burned units compared to 12% in the unburned (F = 8.15, df = 1, P = 0.036). Females spent more time on nests in burned units and we observed more provisioning trips to nests in burned than unburned units (mean ± SE; 0.33 ± 0.06 and 0.11 ± 0.08 trips/min, respectively, F = 4.27, df = 1, P = 0.09). Sample sizes were also small in 2003 with four nests videotaped in burned and two in unburned units. No differences were detected between burned and unburned units for time spent at nests or number of provisioning trips/min.

Nestling Size.—Mean (±SE) nestling wing chord length on day 6 did not differ between burned and unburned units (21.9 ± 2.02 and 19.5 ± 1.47 mm, respectively; F = 0.98, df = 1, P = 0.25) nor did mean nestling mass (10.7 ± 0.52 and 9.6 ± 0.67 g, respectively; F = 1.52, df = 1, P = 0.25).

Nest Site.—Litter depth in 2002 was lower and percent bare ground cover was higher at random sites and around Dark-eyed Junco nests (Table 3) in burned compared to unburned units. Nest concealment did not differ between burned and unburned units (Table 3). There was less burned area around nests than at random locations in burned units (23.8 and 51.7%, respectively; F = 4.09, df = 1, P =

TABLE 3. Mean (± SE) values of habitat variables at random sites on burned and unburned units at Goosenest Adaptive Management Area, Klamath National Forest, California, 2002–2003.

Year	Variable	Random burned	Random unburned	P	Nest burned	Nest unburned	P
2002	Woody debris, %	0.86 ± 0.45	2.58 ± 0.44	0.14	0.82 ± 0.56	2.53 ± 0.56	0.068
	Shrub cover, %	1.15 ± 2.33	6.12 ± 2.29	0.21	3.01 ± 2.83	8.10 ± 2.83	0.36
	Litter depth, cm	0.52 ± 0.32	2.75 ± 0.31	0.001	0.89 ± 0.40	2.35 ± 0.40	0.038
	Bare ground, %	49.27 ± 4.72	24.01 ± 4.62	0.005	35.59 ± 6.31	7.35 ± 3.27	0.002
	Nest concealment, %				80.0 ± 6.23	87.79 ± 3.63	0.33
	n	25	25		17	17	
2003	Woody debris, %	1.27 ± 0.85	4.88 ± 0.85	0.052	2.29 ± 1.06	6.24 ± 1.03	0.090
	Shrub cover, %	2.82 ± 1.28	5.35 ± 1.28	0.37	3.32 ± 1.66	6.35 ± 1.51	0.35
	Litter depth, cm	1.29 ± 0.46	2.51 ± 0.41	0.037	1.96 ± 0.46	3.26 ± 0.41	0.066
	Bare ground, %	36.8 ± 4.10	24.00 ± 4.10	0.058	20.62 ± 4.66	20.00 ± 7.61	0.95
	Nest cover, %				86.64 ± 5.44	82.87 ± 4.66	0.61
	n	25	25		15	18	

TABLE 4. Mean (± SE) values of arthropod biomass (g) on burned and unburned units at early and late sampling dates at Goosenest Adaptive Management Area, Klamath National Forest, California, 2002–2003. Arthropod biomass was estimated using general length-weight ratios (Rogers et al. 1976).

Year	Trap type	Season	Burned	Unburned
2002	Sticky board	Early	40.39 ± 2.16	22.27 ± 2.68
	Sticky board	Late	28.33 ± 2.31	20.97 ± 2.68
	Pitfall	Early	24.84 ± 3.62	35.80 ± 4.02
	Pitfall	Late	22.64 ± 3.44	21.14 ± 3.90
2003	Sticky board	Early	16.22 ± 1.05	15.54 ± 1.14
	Sticky board	Late	9.53 ± 1.40	13.04 ± 1.51
	Pitfall	Early	19.74 ± 2.67	20.66 ± 3.00
	Pitfall	Late	20.65 ± 3.34	27.02 ± 2.75

0.048). Percent bare ground in 2003 was higher, litter depth was lower, and there was less woody debris at random sites in burned compared to unburned units (Table 3). None of the nest site variables differed between burned and unburned units and none differed between nest and random sites on either treatment in 2003 (Table 3).

Two severe wind events during winter 2002–2003 caused extensive windfall on the study units. There were more fallen trees in 2003 around nest sites than at random sites in both the burned (mean ± SE; 3.07 ± 0.65 and 1.52 ± 0.50, respectively; $F = 5.51$, df = 1, $P = 0.026$) and unburned units (3.3 ± 0.59 and 1.6 ± 0.50, respectively; $F = 3.41$, df = 1, $P = 0.074$).

Arthropod Abundance.—Coleopterans and dipterans accounted for most arthropods caught on sticky board traps. Both treatment (burned vs. unburned) and sampling periods differed in 2002 (Tables 4, 5) while only sampling period differed in 2003 (Table 5). Mean biomass was higher in burned units compared to unburned and higher in May compared to June (Table 4). Most arthropods caught in pitfall traps in both burned and unburned units were Hymenoptera (ants) and Diptera. Mean arthropod biomass in pitfall traps did not differ between treatments, sampling period or year (Tables 4, 5).

DISCUSSION

Several studies have documented increases in abundance of ground-nesting birds following prescribed burning (Bock and Lynch 1970, Bock and Bock 1983, Saab and Powell 2005). We found Dark-eyed Juncos were equally abundant in burned and unburned units suggesting that response of ground-nesting birds to prescribed fire is variable. Responses may depend on a variety of factors including the nesting and foraging ecology of the bird species, size of the burn, burn severity, and time since burn (Finch et al. 1997).

Daily nest survival did not differ between

TABLE 5. Effects of treatment (burned and unburned, df = 1), unit (df = 8), sampling date (df = 1) and interactions from nested ANOVA on biomass of arthropods in sticky board and pitfall traps at Goosenest Adaptive Management Area, Klamath National Forest, California, 2002–2003. Arthropod biomass was estimated using general length-weight ratios (Rogers et al. 1976).

	Treatment		Date		Unit		Treatment × Date		Unit × Date	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
2002										
Sticky board	13.61	0.006	7.34	0.045	4.75	0.061	1.98	0.045	1.01	0.43
Pitfall	0.49	0.50	5.04	0.055	2.75	0.14	1.88	0.058	0.58	0.80
2003										
Sticky board	0.36	0.57	12.73	0.007	2.66	0.14	2.77	0.005	0.81	0.59
Pitfall	2.60	0.15	1.52	0.25	0.85	0.38	1.28	0.25	2.18	0.026

treatments (burned vs. unburned), year, or as a function of arthropod biomass. Juncos achieved equal nesting success in burned and unburned units indicating they were able to overcome the effects of reduced nesting cover. Burned habitats did not function as ecological traps and our results were broadly consistent with the behavioral flexibility hypothesis.

Nest concealment is a major factor affecting nest success of passerines and an important aspect of nest-site selection (Martin and Roper 1988, Howlett and Stutchbury 1996, Flaspohler et al. 2000, Weidinger 2002). We expected that nest concealment would be substantially lower on burned than unburned units but we found no difference between treatments. Similarity in nest concealment, despite a decline in suitable cover in burned units, can be explained by two nesting strategies used by juncos. First, juncos often placed their nests in unburned patches in burned units as ground cover on the burned units did not burn uniformly, which is common for both prescribed burns and wild fires in this forest type (Weatherspoon 1996). Second, juncos used non-traditional nesting sites. Two nests were on mats of pine needle >10 m high in trees and many nests were found under overhanging rocks or in burned root holes. Juncos were not observed nesting in these types of sites in unburned units or in burned units prior to burning. These results suggest that nest concealment was an important nest site criterion for juncos on our study area.

A large wind throw event during winter 2002–2003 provided abundant down wood on all units in 2003, further reducing the difference between burned and unburned units. Dark-eyed Juncos used this increased ground structure by placing their nests in areas of greater wind throw compared to random sites, regardless of treatment.

We documented an overall increase in low-flying arthropod biomass, particularly dipterans and coleopterans, in burned units in the spring following the prescribed burn. Biomass of ground arthropods in pitfall traps was similar between burned and unburned units. These results are broadly consistent with previous studies that demonstrated that wood and bark boring beetles increased following fire to exploit weakened trees (McCullough et al. 1998, Santoro et al. 2000) while ground arthropods generally declined due to decreased litter, altered soil properties, and direct fire mortality (McCullough et al. 1998, Wikars and Schimmel 2001, Dress and Boerner 2004). Many arthropods associated with ground or shrub foliage, such as homopterans and Lepidoptera larvae, were not present in large numbers at our study site due to reduction in vegetation caused by thinning treatments and prescribed burns. All arthropod Orders known to be used as prey by juncos increased in burned units 1 year after burning suggesting there may have been more food available.

Analysis of junco nest activity demonstrated that adults spent more time on the nest in burned than in unburned units. Provisioning rates were also greater in burned units, possibly due to higher nest visitation rates by the non-brooding adult. Higher arthropod abundance in burned units may have influenced nest attentiveness and provisioning rates.

Dark-eyed Juncos demonstrated flexibility in nest placement in areas that were prescribed burned. By using novel nesting strategies, juncos were able to find suitable nesting cover. The behavioral plasticity displayed by Dark-eyed Juncos seems likely to be an evolved response that has allowed them to exploit recurring changes in habitat. The positive response to prescribed burning documented in other ground-nesting bird species may be a product of similar behavioral plasticity.

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