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Avian Behavior, Ecology, and Evolution

Movements and habitat selection of fledgling Boreal Chickadees *Poecile hudsonicus* in lowland conifer forests

Movimientos y selección de hábitat de volantones de Carbonero Boreal *Poecile hudsonicus* en bosques de coníferas de baja altitud

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ABSTRACT. Avian habitat associations during the post-fledging period are lacking for many bird species, which impairs the development of management plans that address the full annual cycle of birds. We used radio telemetry to study the post-fledging movements and vegetation cover-type associations of 22 broods of fledgling Boreal Chickadees (*Poecile hudsonicus*) at both the microhabitat and landscape scales in northern Minnesota, USA from 2020 to 2022. We used habitat measurements taken at fledgling locations and at paired random points to compare habitat use vs. availability at the microhabitat scale via generalized linear mixed-effects models. We also used compositional analysis, modified with age-specific movements, to assess cover-type selection by fledglings during the post-fledging period. These analyses were conducted on the entire post-fledging period as well as during dependent (with parental care) and independent (without parental care) periods. Fledgling Boreal Chickadees of all ages used habitat disproportionately with respect to its availability. Cover types that contained productive and/or stagnant black spruce were strongly preferred, and areas with deciduous trees were strongly avoided. Within black spruce cover types, Boreal Chickadee fledglings selected microhabitats that contained higher percent canopy cover. Fledglings did not shift cover types at any time in the post-fledging period. Results from this study can be used by managers to develop conservation strategies that will provide and maintain critical habitat to support this species.

RESUMEN. Las asociaciones de hábitat de las aves durante el período posterior al emplumamiento se desconocen para muchas especies de aves, lo que perjudica el desarrollo de planes de manejo que aborden el ciclo anual completo de las aves. Usamos radiotelemetría para estudiar las asociaciones de los movimientos posteriores al emplumamiento y el tipo de cobertura vegetal de 22 nidadas de volantones de Carbonero Boreal (*Poecile hudsonicus*) a escalas de microhábitat y paisaje en el norte de Minnesota, EUA, desde 2020 hasta 2022. Utilizamos medidas de hábitat tomadas en ubicaciones de volantones y en puntos aleatorios emparejados para comparar uso de hábitat vs. disponibilidad a escala de microhábitat mediante modelos lineales generalizados mixtos. También usamos análisis composicional, modificado con movimientos específicos por edad, para evaluar selección del tipo de cobertura por los volantones durante el período posterior al emplumamiento. Estos análisis fueron realizados durante todo el período posterior al emplumamiento como así también durante los períodos dependiente (con cuidado parental) e independiente (sin cuidado parental). Los volantones de Carbonero Boreal de todas las edades usaron el hábitat desproporcionadamente con respecto a su disponibilidad. Los tipos de cobertura que contenían abetos negros productivos y/o inactivos fueron fuertemente preferidos, y las áreas con árboles caducifolios fueron fuertemente evitadas. Dentro de los tipos de cobertura de abeto negro, los volantones de Carbonero Boreal seleccionaron microhábitats que contenían un mayor porcentaje de cobertura del dosel. Los volantones no cambiaron los tipos de cobertura en ningún momento durante el período posterior al emplumamiento. Los resultados de este estudio pueden ser usados por los gestores para desarrollar estrategias de conservación que proporcionarán y mantendrán un hábitat crítico para sustentar a esta especie.

Key Words: *Boreal Chickadee; dispersal; habitat selection; post-fledging*

INTRODUCTION

The post-fledging period, i.e., the time between when a young bird fledges and when it migrates or settles into its nonbreeding area, is a critical life-history phase and a period of high mortality due to the abrupt shift in biotic and abiotic factors that individuals face after fledging (Wells et al. 2008, Anthony et al. 2013, Naef-Daenzer and Grüebler 2016). Acquiring detailed information about the post-fledging movements and habitat use of species of conservation concern is necessary because land managers and conservationists strive to maximize the productivity of birds during the breeding season. Without proper understanding of this life-cycle stage, any implementation of management or conservation strategies will be incomplete at best and detrimental at worst (Cox et al. 2014). The assumption that habitat used by singing males exactly matches that used by nesting females and fledglings is increasingly viewed as incomplete; it is possible that management recommendations based on these data alone are similarly lacking.

There is a growing body of evidence that fledgling songbirds of many species use habitats and landscape scales that are remarkably different from those used by breeding adults (Marshall et al. 2003, Streby et al. 2011, Vitz and Rodewald 2011, Fiss et al. 2020). Species that shift habitats during the post-fledging period require that each of the habitats be within reach of relatively immobile juvenile birds (Streby et al. 2011, Streby and Andersen 2012, Fiss et al. 2020). Alternatively, species that do not shift habitats are especially reliant on breeding habitats for both nesting and post-fledging. Moreover, post-fledging habitat selection patterns may change between the dependent stage, when

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juveniles receive parental care, and independent periods during which juveniles must become self-sufficient. To obtain accurate estimates of productivity, it is necessary to understand the factors that influence post-fledging movements and survival, such as site-specific microhabitats and landscape-level cover types, and integrate them into management and conservation planning for species of conservation concern.

Until recently, the post-fledging period was poorly understood in many species, largely because of technological and detectability challenges inherent in following fledglings once they leave the nest. While the number of post-breeding dispersal studies in the literature has rapidly increased in the last two decades, there remains a lack of studies that focus on resident (i.e., non-migratory) passerines in the Americas, despite an increase in studies of European resident species in recent years (e.g., Matthysen 2002, van Overveld et al. 2017). Resident species face different annual cycle challenges compared to those faced by migratory species. Resident birds do not contend with issues that arise during migration and stopover, but they must prepare themselves for an often long and challenging nonbreeding season during which unfavorable climatic conditions and diminished food resources are the major factors governing survival (Sandercock and Jaramillo 2002, Zúñiga et al. 2017).

Studies that focus on the post-fledging ecology of cavity-nesting passerines are also lacking. Due to lower nest predation rates, species that use cavities remain in the nest longer than those that build open-cup nests (Martin et al. 2018, Şahin Arslan and Martin 2022). This, in turn, allows fledglings additional time to grow more fully developed wings by the time of fledge. Older age and enhanced wing development at time of fledge appears to increase post-fledging survival rates in fledgling songbirds (Martin et al. 2018). The delayed fledging time in cavity nesters also has been shown to change their post-fledging behaviors. Fledglings from cavity nests are more likely to travel greater distances earlier in the post-fledging period and stay together as a family unit until independence due to their enhanced ability to evade predators (Şahin Arslan and Martin 2022).

The Boreal Chickadee (*Poecile hudsonicus*) is a resident cavity-nesting passerine that breeds throughout the boreal forests of North America (Ficken et al. 2020). This species is strongly tied to coniferous forests, especially those dominated by spruce (*Picea* spp.) and fir (*Abies* spp.), and is typically uncommon throughout its range. Range-wide population trend estimates have a low degree of confidence because Boreal Chickadees lack a territorial song and occupy remote breeding areas in the boreal forest that are difficult to survey (Ficken et al. 2020). Caveats aside, Breeding Bird Survey data suggest that Boreal Chickadee populations are slightly decreasing range wide, with populations at the southern edge of the species' breeding range and those in eastern Canada driving the bulk of these declines (Sauer et al. 2020). Recent eBird relative abundance trends show significant declines throughout much of its North American range, especially in eastern Canada and on the southern half of the species' range (Fink et al. 2022). For example, the estimated relative abundance of Boreal Chickadee decreased between 59.8% and 70.3% in Maine and 39.4% and 50.7% in Minnesota from 2012 to 2022. Declines were also detected in Québec (15–35%) and New Brunswick (44–66.1%) during the same time (Fink et al. 2022). The reasons for these declines are unknown, but many of the ecosystems in which Boreal Chickadees spend their full annual cycle are experiencing stressors such as peat mining, logging, and forest pests, in addition to climate change, which is predicted to have widespread effects on boreal forests (Dussart and Payette 2002, Price et al. 2013, Cadieux et al. 2020).

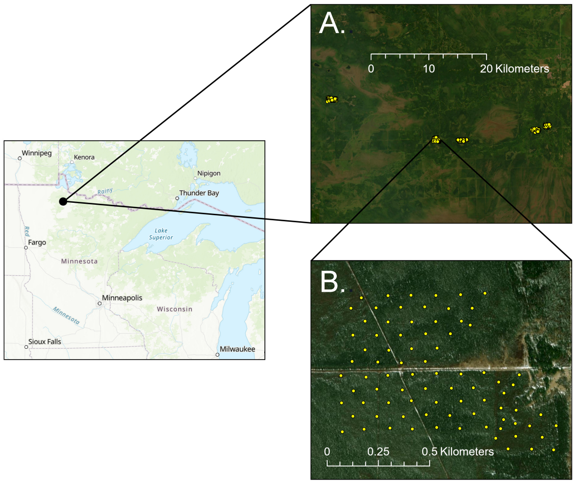
We used radio telemetry to study post-fledging ecology, focusing on cover-type associations of fledgling Boreal Chickadees at both the microhabitat and landscape scales in northern Minnesota. Our study aimed to describe: (1) post-fledging movements of Boreal Chickadees and (2) habitat selection and degree of habitat shifting during this period. We hypothesized that fledgling movements would be lowest in the first few days outside the nest. We also predicted that fledglings would shift cover types as they progress throughout the post-fledging period from dependent to independent periods.

METHODS

Study area

The study area was located in the Red Lake Wildlife Management Area during the 2020 to 2022 Boreal Chickadee breeding seasons of May to August (Fig. 1). The Red Lake Wildlife Management Area is managed by the Minnesota Department of Natural Resources and is characterized by stagnant (< 7 m at age 50) and productive (> 7 m at age 50) black spruce (*Picea mariana*) and tamarack (*Larix laricina*) forests, with interspersed upland forest species such as jack pine, aspen, and ash (Zlonis et al. 2017, Stelling et al. 2023). Boreal Chickadees in the region are strongly associated with lowland black spruce bogs (Bednar et al. 2015, Zlonis et al. 2017). Approximately 90% of the lowland conifer forests in the region are owned and managed by the state of Minnesota. The major threat to lowland black spruce habitats in the region is logging.

Fig. 1. Location of the study area. (A) Nest boxes (yellow circles) were placed in five black spruce stands in the Red Lake Wildlife Management Area, Minnesota, USA from 2018 to 2020. (B) Nest boxes were placed in a grid-like manner and were spaced between 125 and 150 m apart.



Nest box deployment and nest monitoring

Nest boxes (N = 288) were placed in spring and fall 2018 and fall 2019 and 2020 in five stagnant and productive black spruce stands in which Boreal Chickadees had been detected during previous surveys (Bednar et al. 2015). Boxes were constructed using a schematic from Cornell NestWatch (https://nestwatch.org/) and were placed on black spruce or tamarack trees approximately 1.75 m from the ground with entrance holes facing east (against the prevailing wind direction in the study area) and spaced between 125 and 150 m apart. Sites ranged from 86–136 ha and were typically surrounded by upland habitats (Fig. 1).

Nestling banding and transmitter attachment

In all years, nest boxes were checked every two to four days during anticipated date ranges for nest building and incubation (mid- to late May) and monitored until near anticipated hatch day to observe hatching. Nestlings were removed from the nest box at day 15 (2–3 days prior to expected fledge date) and banded with three plastic color leg bands and a metal U.S. Geological Survey band. We randomly selected two to four (typically three) nestlings on which we placed radio transmitters. We used 0.39 g VHF radio transmitters (< 3% of body mass; NTQB2-2, Lotek Wireless) attached with a modified figure-eight leg-loop harness (Rappole and Tipton 1991). All nestlings were promptly returned to the nest box after banding and transmitter attachment, and the nest box was monitored from a distance to ensure provisioning from adults resumed following banding. All bird handling methods were approved by University of Minnesota IACUC Protocol ID 2201-39723A and the USGS Bird Banding Lab permit #24165.

Fledgling tracking

We tracked fledglings daily using ground-based telemetry methods with a three-element Yagi antenna and hand-held receivers (SRX800, Lotek Wireless). We visually located individuals each day throughout the dependent post-fledging period (approximately 18 days) and well into the independent post-fledging period (typically at least 30 days). Transmitters were often detectable > 1 km away when birds were alive and foraging near the top of trees, but this distance lessened when birds and/or tags were on or near the ground (e.g., after predation or during the initial hours post-fledge). We tracked fledglings until either (1) mortality, (2) radio transmitter batteries failed, or (3) signal loss. We assumed fledgling mortality when tags disappeared within the first seven days or when the transmitter was found with remains (e.g., feathers) nearby. Upon locating and identifying each fledgling via color band resight and/or tag signal strength (when tags were present, but birds were too hidden in the canopy to be seen), we recorded the location of the initial tree in which the bird or brood was located with a handheld GPS unit (Garmin 64st). At each location, we recorded all birds present, their fate (alive or dead), and made note of any behaviors such as the location of the fledgling in the tree, flocking with other species, and presence of an attending adult. We tracked individuals in random order to reduce differences in locations that may be associated with time of day, and the analysis of daily movement patterns was restricted to morning (04:30–11:00 CST).

Vegetation sampling

We conducted detailed vegetation surveys at every telemetry location and at paired random locations to characterize stand- and microhabitat-level vegetation features. The vegetation sampling protocol used was a modified version of the methods described by the Breeding Biology Research and Monitoring Database program field protocol (Martin et al. 1997). Vegetation was measured within an 11.3 m radius circular plot. Random plots were located 30 m from fledgling locations in a random direction generated by spinning a compass for a random amount of time. We used a separation of 30 m between observed and random points because this distance falls within the range of 0–50 m that is frequently used for habitat vs. availability in passerine post-fledging studies (e.g., King et al. 2006, Vitz and Rodewald 2011, Jones et al. 2017, Grinde et al. 2023), the desire to detect potential differences in microhabitats that would be easily reached by fledglings of any age, and for logistical considerations due to the difficulty in traversing peatland habitats. At each fledgling and random location, we recorded the percent of each canopy tree via densiometer, counted canopy trees by species and size class (small = 8–23 cm diameter at breast height [DBH], medium = 24–38 cm DBH, large = > 38 cm DBH), estimated the total percentage of canopy trees to species, and calculated the average canopy height by choosing a representative tree and measuring its height and distance from observer with a clinometer or rangefinder and then calculating the tangent of the resultant distance ratio or by using the Pythagorean theorem.

Cover type classification

We classified cover types within 3 km of each study site with ArcGIS Pro 2.7.2 (Environmental Systems Research, Redlands, California) using a combination of Minnesota Department of Natural Resources Forestry Inventory Module, ArcGIS online aerial imagery, and personal familiarity with the study sites to create a contiguous cover-type map of our study area (Appendix 1). Rasters were created from these shapefiles in ArcGIS Pro and then loaded into R as .tiff files with 5-m resolution using the R package landscapemetrics (Hesselbarth et al. 2019).

Daily movement and available habitats

Using the locations of Boreal Chickadee fledglings obtained from daily tracking, minimum movement distances were measured daily for each brood using the R package geodist. From these data, we calculated a cumulative maximum distance moved for each fledgling age across all broods that equaled the largest daily movement ever observed for a given age during the 3-year study. We used this greatest distance traveled by any fledgling between consecutive daily locations as an estimate of the maximum straight-line movement capability by all fledglings of that age. We then used the daily estimated availability method (Streby and Andersen 2013): the cumulative running maximum of these distances was used as the radii for circles of available habitat for each corresponding fledgling age. We then plotted these circles around each fledgling location and measured the percentage of each cover type available for each bird using the R package landscapemetrics. This procedure resulted in a matrix in which each row represented a single Boreal Chickadee brood and each column contained the average percentage of all available habitat circles for each cover type. For each brood, we then calculated the percentage of fledgling points that used each cover type, resulting in a matrix in which each row represented a single Boreal Chickadee brood and each column contained the average percentage of telemetry points found within each cover type. Use or availability of a cover type was only reported if either was > 1% for any brood.

Statistical analysis

We used generalized linear mixed-effects logistic regression models to determine the relationship between vegetation characteristics and use/non-use by fledglings using the R package lme4 (Bates et al. 2015). Vegetation variables were assessed for collinearity. Values of $r > 0.75$ were considered highly correlated; if collinearity occurred, we chose the variable that was easiest to interpret and biologically relevant to include in the models. We tested all fledgling ages together and the dependent and independent periods separately. We fit all possible model combinations of the vegetation metrics using the R package MuMIn (Bartoń 2012) and used the Akaike information criterion for small sample size (AICc) model selection to rank and compare models using ΔAICc values (Burnham and Anderson 2002). Brood was included as a random effect in all models. Models with nonsignificant terms were considered equivalent when model ΔAICc < 2.0. We considered a variable to have an effect on fledgling Boreal Chickadee microhabitat use if it was in one of the supported models and the 95% confidence interval for the model coefficient failed to overlap zero.

We used compositional analysis (Aebischer et al. 1993) to compare used vs. available habitat derived from the daily estimated availability method by Boreal Chickadee fledglings using the R package adehabitatHS (Calenge 2024). Compositional analysis is used for the habitat selection analysis of radio-marked animals when habitats are defined by several categories (e.g., those described in the cover-type classification described above). We examined habitat selection for all fledgling ages and for the dependent (1–18) and independent (≥ 19) ages separately and removed any cover type from analysis that was not used by or available to fledglings at ≥ 5% for any brood. Significance levels for the tests were at $\alpha = 0.05$. All statistical tests were performed in R v.4.2.2 (R Core Team 2022).

RESULTS

Fledgling movement

We radio-tracked 50 fledglings (*N* = 29 in 2020, *N* = 7 in 2021, *N* = 14 in 2022) from 22 broods (*N* = 14 in 2020, *N* = 3 in 2021, *N* = 5 in 2022) in four of the five stands in which boxes were placed. The mean tracking duration was 27.3 ± 13.3 standard deviation (SD) days (range 0–52). In total, we collected 629 telemetry locations between 2020 and 2022. Tracked Boreal Chickadees fledged from nestboxes from 8 June to 18 July (mean = 20 June ± 8.5 days).

Minimum daily distance traveled and the variance associated with this measure increased with age in Boreal Chickadees, especially as birds transitioned from the dependent to independent periods (Fig. 2). The average daily distance moved from the previous day's location was 187.6 m (SD = 181 m, range = 0–1695.2 m, *N* = 560) for all ages combined. The average daily distance moved during the dependent period was 132.3 m (SD = 84.1 m, range = 1.0–465.0, *N* = 328) and during the independent period was 269.3 m (SD = 244.3 m, range = 0.0–1695.16 m, *N* = 232). Daily distance moved increased incrementally until the end of the dependent period, at which point daily distances increased dramatically (Fig. 2). The running cumulative maximum movement observed by ages of Boreal Chickadee fledglings was 315 m (1–9 days post-fledge), 465 m (10–18), 1575 m (18–38), and 1695 m (> 39; Fig. 3).

Fig. 2. Daily movements from previous day made by fledgling Boreal Chickadees in 2020–2022 in northern Minnesota, USA. The dashed line represents the average age post-fledge of independence from parents.

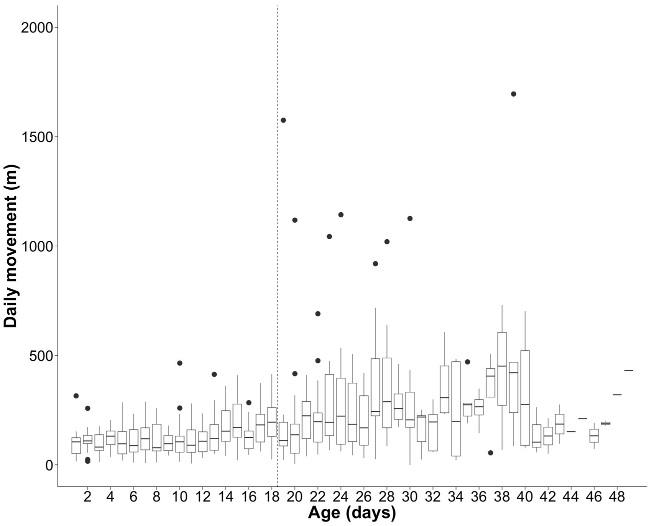
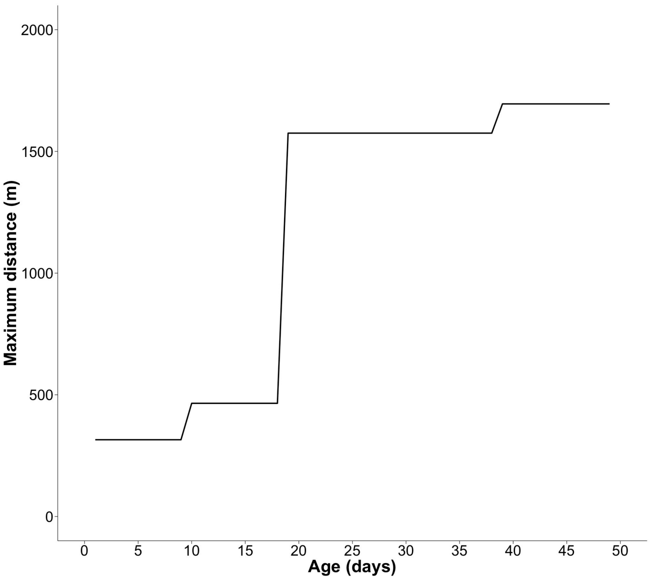


Fig. 3. Observed maximum daily movement by any fledgling Boreal Chickadee of a given age from 2020–2022 in northern Minnesota, USA.



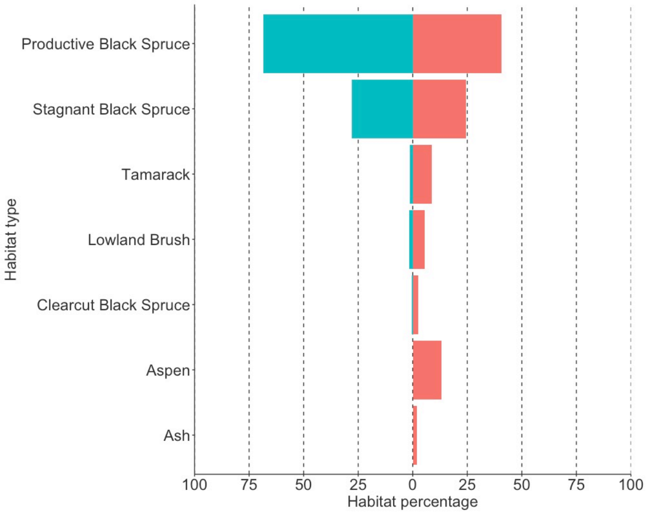
Fledgling microhabitat selection

We collected vegetation data at 550 fledgling Boreal Chickadee locations and 550 paired available locations to document microhabitat use. All of the best supported GLMM models included percent canopy cover as an important predictor of habitat use by fledgling Boreal Chickadees, regardless of age (Table 1). Canopy cover percent was higher at used vs. available

Table 1. Best-supported habitat selection models for all ages, dependent period, and independent period of Boreal Chickadee fledglings.

Model	ΔAICc	*w*	Variable	β	95% confidence limits
All ages					
Canopy cover	0.00	0.14	CC	0.014	0.005, 0.02
Age + Canopy cover	1.72	0.06	AGE	−0.003	−0.014, 0.01
			CC	0.014	0.006, 0.02
Canopy cover + Total black spruce	1.79	0.06	CC	0.014	0.005, 0.023
			TBS	−0.001	−0.005, 0.003
Canopy cover + Total trees	1.96	0.05	CC	0.012	0.005, 0.022
			TT	−0.0004	−0.004, 0.003
Dependent period (1–18 days)					
Canopy cover	0.00	0.18	CC	0.014	0.004, 0.025
Canopy cover + Total black spruce	1.65	0.08	CC	0.016	0.004, 0.029
			TBS	−0.002	−0.008, 0.004
Canopy height + Canopy cover	1.96	0.07	CH	0.005	−0.031, 0.04
			CC	0.015	0.004, 0.026
Canopy cover + Percent black spruce	1.99	0.07	CC	0.015	0.004, 0.026
			%BS	−0.001	−0.009, 0.007
Independent period (≥ 19 days)					
Canopy cover	0.00	0.15	CC	0.013	0.001, 0.025
Age + Canopy cover	1.79	0.06	AGE	−0.007	−0.033, 0.019
			CC	0.013	0.001, 0.026
Canopy cover + Total trees	1.82	0.06	CC	0.013	0.001, 0.027
			TT	−0.001	−0.001, 0.004
Canopy height + Canopy cover	1.99	0.05	CH	−0.004	−0.04, 0.03
			CC	0.013	0.001, 0.025

Fig. 4. Proportion of habitat used (teal) compared to habitat available (salmon) by fledgling Boreal Chickadees throughout the dependent and independent periods in northern Minnesota, USA from 2020–2022. When teal bars are larger, this habitat is preferred, but when salmon bars are larger, this habitat is avoided.



locations for fledglings of all ages (β = 0.014, 95% confidence interval [CI]: 0.005, 0.022), for dependent-age fledglings (β = 0.014, CI: 0.004, 0.025), and for independent-age fledglings (β = 0.013, CI: 0.001, 0.025). Other supported models for all ages included age, average canopy height, total count of black spruce, age group, and total tree count, but these estimates overlapped zero (Table 1).

Fledgling landscape habitat selection

The average number of cover types within 3 km of each study site was 20.5 ± 5.2 SD (range 13–24). The most common cover types within this area were tamarack (19.7% ± 11.8%), aspen (18.5% ± 7.1%), productive black spruce (16.2% ± 7.9%), lowland brush (15.3% ± 5.5%), and stagnant spruce (8.3% ± 9.0%; Appendix 1).

Boreal Chickadee fledglings used cover types disproportionately with respect to availability throughout the post-fledging period ($\Lambda = 0.016$, $P < 0.001$; Fig. 4). Fledglings also used cover types disproportionately with respect to availability during the dependent ($\Lambda = 0.353$, $P < 0.001$) and independent ($\Lambda = 0.014$, $P < 0.001$) periods. Fledglings of all ages strongly selected for productive black spruce over all cover types and strongly selected against aspen (Table 2). Fledglings during the dependent stage selected for productive black spruce and stagnant spruce (Table 3), and fledglings during the independent stage selected for productive black spruce (Table 4).

This study also provided basic ecological and baseline information about Boreal Chickadees in the post-fledging period. For example, Boreal Chickadees rarely split broods after fledging, despite large clutch sizes; both parents attended to the fledglings together. During the first hours after fledging, fledglings are typically low to the ground, but within the first day out of the nest, fledglings make their way to the canopy and remain in this part of the forest for the duration of the post-fledging period. Fledgling Boreal Chickadees leave the care of their parents approximately 19 days after fledging, at which point they typically make larger movements (often > 1 km/day) until they find suitable habitat away from their natal territory. At this point, the fledglings settle into the new area, typically joining large mixed flocks of juvenile warblers (especially Nashville Warblers [*Leiothlypis ruficapilla*] and Yellow-rumped Warblers [*Setophaga coronata*]), Boreal Chickadees from unrelated broods, and Golden-crowned Kinglets (*Regulus satrapa*) and Ruby-crowned Kinglets (*Regulus satrapa*). We did not see any evidence for adult Boreal Chickadees attempting a second brood, although we did see some evidence of attempted re-nesting after full broods were predated in the nest or died early during the post-fledging period.

DISCUSSION

The post-fledging period is a critical yet understudied stage of the annual life cycle of breeding birds. To our knowledge, this is the first study documenting the post-fledging ecology of Boreal Chickadees. Our results show that black spruce is strongly preferred throughout the dependent and independent periods. Within black spruce cover types, Boreal Chickadee fledglings select microhabitats that contain higher percent canopy cover. Moreover, we found no evidence of habitat shifting in the post-fledging period.

Fledglings increased their daily movements as they aged, as expected from studies on other forest species (e.g., Streby and Andersen 2013, van Overveld et al. 2017). However, mean daily dispersal distances were greater than what has been reported for many other forest-nesting passerine species (e.g., Jenkins et al. 2017) and those in similar habitats (Grinde et al. 2023). Boreal

Table 2. Compositional analysis showing preference or avoidance of cover types in rows compared to those in columns by fledgling Boreal Chickadees of all ages based on comparisons of used (derived via telemetry) vs. available (derived via cover-type classification and observed daily fledgling movement ability) cover types. +++ indicates significant preference and - - - indicates significant avoidance at α = 0.05. Ranks range from 1 (most preferred) to 7 (least preferred).

Cover type	Ash	Aspen	Clearcut black spruce	Productive black spruce	Tamarack	Stagnant black spruce	Lowland brush
Ash	0	+++	-	- - -	+	- - -	+++
Aspen	- - -	0	- - -	- - -	- - -	- - -	- - -
Clearcut black spruce	+	+++	0	- - -	+++	-	+++
Productive black spruce	+++	+++	+++	0	+++	+++	+++
Tamarack	-	+++	- - -	- - -	0	- - -	+
Stagnant black spruce	+++	+++	+	- - -	+++	0	+++
Lowland brush	- - -	+++	- - -	- - -	-	- - -	0
Rank	4	7	3	1	5	2	6

Table 3. Compositional analysis showing preference or avoidance of cover types in rows compared to those in columns by fledgling Boreal Chickadees during the dependent period (1–18 days post-fledge) based on comparisons of used (derived via telemetry) vs. available (derived via cover type classification and observed daily fledgling movement ability) cover types. +++ indicates significant preference and - - - indicates significant avoidance at α = 0.05. Ranks range from 1 (most preferred) to 6 (least preferred).

Cover type	Aspen	Clearcut black spruce	Productive black spruce	Tamar-ack	Stagnant black spruce	Lowland brush
Aspen	0	-	- - -	- - -	- - -	-
Clearcut black spruce	+	0	- - -	-	- - -	+
Productive black spruce	+++	+++	0	+	-	+
Tamarack	+++	+	-	0	- - -	+
Stagnant black spruce	+++	+++	+	+++	0	+++
Lowland brush	+	-	-	-	- - -	0
Rank	6	4	2	3	1	5

Chickadee average daily movement of 187.6 ± 181 m for the first ~27 days post-fledge was larger than estimates for open-cup nesting Ovenbird (*Seirus aurocapila;* 63.9 ± 53.7 m) and Acadian Flycatcher (*Empidonax virescens;* 46.4 ± 45.6 m; Jenkins et al. 2017) over the same period. Boreal Chickadee daily movement during the first six days post-fledge (107.8 ± 65.2 m; distance matched to 6-day measurements observed by Şahin-Arslan and Martin 2022) was also larger than estimates for the similarly sized Mountain Chickadee (*Poecile gambeli;* 36.8 ± 26.2 m) and Northern House Wren (*Troglodytes aedon;* 23.3 ± 19.5 m), the much larger Western Bluebird (*Sialia mexicana;* 49.8 ± 53.7 m), all of which are cavity nesters (Şahin-Arslan and Martin 2022). The large movements of Boreal Chickadee fledglings shortly after leaving the nest are likely related to their extended nestling stage afforded by their cavity nesting, but why their movements are greater than those reported for other cavity nesters remains unknown.

Boreal Chickadee post-fledging habitat use was non-random during both the dependent and independent periods and showed a strong preference for black spruce and near total avoidance of other lowland-conifer forests such as tamarack and cedar, as well as deciduous or mixed forest types. Boreal Chickadees do not shift habitats from breeding to post-fledging periods, unlike many other species (e.g., Streby et al. 2011, Streby and Andersen 2012, Fiss et al. 2020). Increased canopy cover was the greatest predictor for Boreal Chickadee microhabitat use compared to available habitat throughout the dependent and independent post-fledgling periods. Higher canopy cover is presumably tied to cover from predators, but also may be related to diet, and is often preferred by forest-breeding fledglings (e.g., Raybuck 2020), but not by other birds (e.g., Vitz and Rodewald 2011).

Current harvest practices are likely extremely detrimental to the Boreal Chickadee and its habitat. In North America, black spruce forests are conventionally (and currently) managed using even-aged silvicultural systems, typically via clearcut without reserves (Viereck and Johnston 1990, Groot 1995, Youngblood and Titus 1996). This action eliminates Boreal Chickadee habitat for decades; this species was only regularly detected during previous studies in the area in mature black spruce > 80 years old (Bednar et al. 2015, Zlonis et al. 2017). Forest harvest also increases fragmentation, which may have potentially positive (Ibarzabal and Desrochers 2004) or negative (Muukkonen et al. 2012) effects on peatland bird species; more study is needed in Boreal Chickadees during the breeding season (but see Hadley and Desrochers 2008).

Boreal Chickadees are habitat specialists that use a single cover type for most or all of their annual cycle. Because black spruce is required throughout the year, current forest management may be particularly detrimental to Boreal Chickadees and other cavity nesters in additional ways beyond strict cover-type loss during the post-fledging period. Clearcutting removes trees in which cavities could form or be created. Because they are weak excavators, Boreal Chickadees either rely on woodpeckers to create cavities or, more often, wait for trees to die and rot so that they can excavate cavities themselves (Ficken et al. 2020). Interestingly, when nest boxes were placed in regenerating black spruce stands that were ~30 years old (and thus contained no natural cavities), some were used by Boreal Chickadees. This observation suggests that Boreal Chickadees may use much younger stands than previously thought if some trees, stumps, or cavity trees were left during harvest. Further investigation into cavity availability in lowland black spruce systems is needed in this species, especially in relation to forest management. The timing of black spruce harvest may also be particularly detrimental to Boreal Chickadees. All black spruce harvest operations occur in the winter months under

Table 4. Compositional analysis showing preference or avoidance of cover types in rows compared to those in columns by fledgling Boreal Chickadees during the dependent period (≥ 19 days post-fledge) based on comparisons of used (derived via telemetry) vs. available (derived via cover type classification and observed daily fledgling movement ability) cover types. +++ indicates significant preference and - - - indicates significant avoidance at $\alpha = 0.05$. Ranks range from 1 (most preferred) to 7 (least preferred).

Cover type	Ash	Aspen	Clearcut black spruce	Productive black spruce	Tamarack	Stagnant black spruce	Lowland brush
Ash	0	+++	- - -	- - -	+	- - -	+
Aspen	- - -	0	- - -	- - -	-	- - -	- - -
Clearcut black spruce	+++	+++	0	- - -	+++	-	+++
Productive black spruce	+++	+++	+++	0	+++	+++	+++
Tamarack	-	+	- - -	- - -	0	- - -	+
Stagnant black spruce	+++	+++	+	- - -	+++	0	+++
Lowland brush	-	+++	- - -	- - -	-	- - -	0
Rank	4	7	3	1	5	2	6

frozen ground conditions that allow large equipment to access forest stands that are otherwise too wet for vehicular access. Boreal Chickadees (along with Canada Jays) store food throughout the late summer and fall, and this behavior is likely essential for winter survival (Ficken et al. 2020). Thus, the winter timing of black spruce harvest not only removes the cover type that Boreal Chickadees rely on but also removes the food source that was likely being relied on for overwinter survival.

CONCLUSION

Among passerines, post-fledging research is skewed toward migratory, open-cup nesting species, and we aim to augment our understanding of this period with this study of a habitat-specialist, resident, cavity-nesting species of conservation concern. The population status of the Boreal Chickadee is uncertain and much remains to be learned about this cavity-nesting resident of the boreal forest. Despite indications of declining populations and a lack of past research focusing on many parts of their annual cycle, the Boreal Chickadee remains poorly studied. The Boreal Chickadee distribution is strongly tied to boreal forest regions that are dominated by spruce and fir. Boreal coniferous forests may be particularly vulnerable to climate change and are expected to decrease in extent as temperatures rise, especially along the biome's southern edge. Recent climate modeling predicts that > 50% of the current range of Boreal Chickadee will be lost over the next 100 years (Wilsey et al. 2019). These findings suggest that the maintenance and reduced management of black spruce-dominated forests are crucial for supporting Boreal Chickadee populations. Conservation efforts should prioritize conservation habitat management for climate-vulnerable specialists like the Boreal Chickadee, Canada Jay, and Connecticut Warbler to mitigate population declines.

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Data Availability:

The data for this study are available at the Data Repository for the University of Minnesota: https://hdl.handle.net/11299/277263.

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Table S1. Cover types within three kilometers of each study site at which fledgling Boreal Chickadees were tracked via radio telemetry 2020-2022.

Cover type	CRR	MOOSE	OAKS	WRR	Average
Tamarack	8.4	35.6	20.9	13.8	19.7
Aspen	24.9	24.3	13.0	11.8	18.5
Productive Black Spruce	22.4	4.7	18.3	19.5	16.2
Lowland Brush	12.7	23.3	10.7	14.6	15.3
Stagnant Black Spruce	1.9	0.3	11.5	19.7	8.3
Ash	13.3	0.2	3.9	4.0	5.3
White Cedar	0.4	2.5	6.1	3.1	3.0
Stagnant Tamarack	0.0	6.7	0.7	1.7	2.3
Clearcut Black Spruce	1.4	0.0	3.1	4.2	2.2
Lowland Hardwoods	4.2	0.0	1.6	1.8	1.9
Balsam Fir	0.4	1.9	2.8	1.6	1.7
Lowland Grass	2.3	0.2	0.7	0.5	0.9
Stagnant Cedar	0.2	0.1	2.4	0.7	0.9
Birch	1.7	0.1	0.6	0.2	0.6
Jack Pine	1.6	0.0	0.0	0.5	0.5
Marsh	0.0	0.0	1.8	0.0	0.5
Nonpermanent Water	1.8	0.0	0.0	0.0	0.4
Clearcut Tamarack	0.1	0.0	0.4	1.2	0.4
Oak	1.2	0.0	0.0	0.0	0.3
Upland Grass	0.5	0.0	0.4	0.3	0.3
Road	0.2	0.1	0.2	0.2	0.2
White Spruce	0.0	0.0	0.4	0.2	0.1
Balm of Gilead	0.1	0.0	0.2	0.0	0.1
White Pine	0.0	0.0	0.0	0.3	0.1
Upland Black Spruce	0.0	0.0	0.2	0.0	0.0
Industrial Development	0.2	0.0	0.0	0.0	0.0
Offsite Oak	0.2	0.0	0.0	0.0	0.0
Muskeg	0.0	0.0	0.0	0.1	0.0
Norway Pine	0.0	0.0	0.0	0.1	0.0