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FORAGING ECOLOGY OF THE CERULEAN WARBLER (*SETOPHAGA CERULEA*) IN ANDEAN AGROFORESTRY ECOSYSTEMS

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Resumen. – **Ecología alimentaria de la reinita cerulea (*Setophaga cerulea*) en ecosistemas agroforestales Andinos**– La ecología alimentaria permite conocer los requerimientos de las especies y enfocar los esfuerzos de conservación. Estudiamos la ecología alimentaria de la migratoria Neotropical reinita cerúlea (*Setophaga cerulea*) durante el invierno boreal en sus cuarteles de invierno en ecosistemas agroforestales de café en las cordilleras Occidental y Central de los Andes en Colombia. La reinita cerúlea se alimenta activamente en el follaje, picando principalmente en el haz de hojas verdes y en flores. Frecuentan arbustos y árboles de tamaño medio-alto donde se alimentan en el subdosel y sotobosque usando el estrato distal. Machos y hembras difirieron en la altura de alimentación, con los primeros alimentándose en las partes más altas de los árboles. Las reinitas usualmente forman parejas o pequeños grupos que se unen a bandadas mixtas. Adicionalmente documentamos el comportamiento social de la reinita cerúlea e interacciones competitivas con las migratorias *Setophaga fusca* y *S. castanea*.

Abstract. – Foraging ecology provides insight into species requirements and focus conservation efforts. We studied foraging ecology of the Neotropical migrant Cerulean warbler (*Setophaga cerulea*) during the winter season in coffee agroforestry ecosystems of the Central and Western Cordillera of the Andes in Colombia. Our findings show that this species is an active foliage gleaner. Cerulean Warbler primarily gleans prey off the upper surface on green leaves and flowers. It frequents shrubs and medium-high trees and forage most often in subcanopy and understory using the outer strata. There were sex differences in the foraging height. Frequently, Cerulean Warbler was encountered in pairs or small groups rather than join in mixed bird flocks. Additionally we documentedteh social behavior and competitive interaction with *Setophaga fusca* and *S. castanea*.

Key words: *Setophaga cerulea*, Neotropical migrant, foraging ecology, winter ground, agroforestry ecosystems, Colombia.

INTRODUCTION

Recent population declines in the Neotropical migrant Cerulean Warbler have been widely documented (Buehler *et al.* 2008). However, most research efforts have been focused on the breeding grounds, and few studies have been published on the migratory and winter periods (Robbins *et al.* 1992, Faaborg *et al.* 2010). Despite the lack of information on limiting factors for this bird and other migrants on their wintering grounds, several studies suggest that habitat quality during the non-breeding season may strongly influence population performance and survival for at least some species of Neotropical migrants (Marra & Holmes 2001, Latta & Faaborg 2002, Sherry *et al.* 2005).

Cerulean Warbler spends the boreal winter along the Andes mountains of northern South

America (Hamel 2000) and occurs within a limited elevational range (~ 500–2000 m, Robbins *et al.* 2002) that has been heavily modified to agricultural land use. The high rate of conversion of natural to agricultural landscape and the potential negative consequences for biological diversity, have led to an increase interest in evaluating the role of agroecosystems in the sustainability of natural populations and biodiversity (Pimentel *et al.* 1992, Thiollay 1995) and on their suitability as nonbreeding grounds for migrants. In particular, agroforestry ecosystems (e.g. shade coffee) have been widely suggested to have high conservation value by supporting higher levels of biodiversity compared to other agricultural habitats (Petit & Petit 2003, Komar 2006, Botero *et al.* 2010).

Some research has focused on avian diversity in coffee plantations in the Neotropics (Wunderle & Latta 1996, Greenberg *et al.* 1997, Petit *et al.* 1999), but the suitability of this agroforestry ecosystem as wintering grounds for migratory birds, including some species of conservation concern such as Cerulean Warbler, is still a key issue in ecology and conservation. While interest in wintering grounds appears to be growing (Faaborg *et al.* 2010), different aspects of the ecology and habitat use of this species such as foraging ecology, that can help to assess habitat quality (Lyons 2005) and focus conservation efforts (Petit *et al.* 1995), is weakly documented (Strong 2000). In this paper, we describe the foraging ecology of Cerulean Warbler in shade coffee plantations on the Western and Central Cordillera of the Colombian Andes. We also evaluate the social behavior and interspecific relationships of *Setophaga cerulea* that we have observed.

METHODS

Study area. We conducted foraging observations of *Setophaga cerulea* in shade coffee plantations ranging from 1400–1680 m.a.s.l. located in the municipalities of Fredonia (5°56'N, 75°39'W), Jerico (5°48'N, 75°48'W), and Tamesis (5°45'N, 75°42'W) in Antioquia Department, in the Central and Western Cordillera of the Andes in Colombia during the winter season 2010–2011. The study period embraced the dry season in this region.

Foraging observations. A focal individual approach was used to collect foraging observations. Focal individuals of Cerulean Warbler were located using systematic searching from 6:00–12:00 h and 14:00–17:00 h walking along trails through the study habitat while listening and searching visually for birds. Once identified, individuals were followed and observations were made beginning 15 s after the initial sighting for up to 30 s. After an observation was finished, we typically moved 150 m from the location before collecting additional data to avoid resampling the same bird. Each site was surveyed once every three days during the boreal winter period, resulting in 20 days of fieldwork in each location. Information registered for each focal bird included sex, foraging height, substrate type (green leaf, dead leaf, flower, branch, air), substrate side (upper or lower surface, apex, base, middle), horizontal position within the tree (inner, middle, outer), vertical position (canopy, subcanopy, understory), and foraging maneuvers following the classification suggested by Remsen & Robinson (1990). Additionally, if the bird was attending a mixed species flock, composition and flock size were recorded. Foraging records were documented using a voice recorder. Foraging rate was estimated as the number of prey capture attempts per min.

Data analysis. We tested for sex-related differences in foraging rate and foraging height using analysis of variance. In addition, we used a χ^2 test to discern preferences in the substrate type, substrate surface and strata and we applied linear relation to evaluate the

degree of association between foraging rate and season and the group size effect. All analyses were conducted using SPSS version 19.0 (IBM company 2010). Data were checked for normality. Statistical tests were considered significant at $P = 0.05$, values reported are means ± SE.

RESULTS

Individual-based foraging observations were collected on 75 birds of undetermined age, 46 males and 29 females. Cerulean Warbler was an active foliage-gleaner. The primary foraging substrate was leaves (75%), followed by branches (17%) and flowers (3%). Individuals most often used green leaves ($\chi^2 = 409.26$, df = 1, $P < 0.0005$) compared with dead leaves. 77% of the foraging events of the Cerulean Warbler occurred on the lower surface of the leaves ($\chi^2 = 132.71$, df = 1, $P < 0.0005$), significantly more often than the upper surface (23%). 32% of the times birds were sighted feeding in the middle part of the leaves' surface (Table 1). They usually foraged using non aerial maneuvers (87%) such as glean (80%) and hang (7%); aerial (13%) maneuver such as sally-hover (5%), sally-strike (3%), flush pursue (2%), tumble-chase (3%) and leap (0.1%) made up a smaller proportion of the foraging attempts. Glean was the most common foraging maneuver for male (87% observations) and female (73%), but males used this maneuver more frequently than females ($\chi^2 = 9.14$, df = 1, $P < 0.01$). However, the other maneuvers were used proportionally by both sexes ($\chi^2 = 3.95$, df = 1, $P > 0.1$).

Cerulean Warbler foraged most often in the subcanopy ($\chi^2 = 15.37$, df = 1, $P < 0.0005$) and in the outer horizontal strata ($\chi^2 = 39.56$, df = 1, $P < 0.0005$) of trees. The species was never observed foraging on coffee plants or feeding on the ground. Males and females differed in the mean foraging height ($F_{1,74} = 4.48$, $P = 0.03$) with females foraging at 7.2 ± 0.71 (range 2.0–20.0 m) and males foraging higher at 10.5 ± 0.92 (range 3.0–30.0 m).

TABLE 1. Foraging maneuver used by Cerulean Warbler.

Maneuver	Frequency	Males	Females
Aerial	51		
Leap	3	2	1
Sally-strike	22	19	3
Sally-hover	11	7	4
Flush-pursue	7		1
Tumble-chase	9	7	2
Not aerial	496		
Glean	466	433	33
Hang	30	26	4

Cerulean Warbler foraging rate was about 5.4 ± 0.45 captures per minute. No differences between the sexes were observed in the mean foraging rate ($F_{1,74} = 1.42$, $P = 0.23$), nor in the vertical ($\chi^2 = 0.37$, df = 1, $P = 0.83$), or horizontal($\chi^2 = 0.001$, df = 1, $P = 0.97$) strata used for foraging.

Cerulean Warblers were mostly found in pairs or in small groups of 3–8 individuals (2 ± 0.2 birds) often associated with mixed species flocks (97% of observations). Eighty resident and 27 migratory species participated in these flocks with an average number of 14 ± 8 species (range 4-46). Cerulean Warbler was the third most common Neotropical migrant foraging in mixed species flocks in the study area (Table 2). Direct and indirect agonistic interactions (e.g. chases and fights) by *Setophaga fusca (17* males and 7 females) and *S. castanea* (2 males and 4 females) on *S. cerulea* in flocks larger than 12 species were observed. In addition, foraging rate remained constant across group size (β = 0.0024 ± 0.0027, $t = 0.885$, $P > 0.05$; Fig. 1). We also detected an increase in the foraging rate throughout the season (β = 0.0279 ± 0.0098, $t = 2.86$, $P < 0.01$).

DISCUSSION

Migratory birds may experience dramatic seasonal shifts in habitat types and food resources as they move between breeding and wintering grounds. Despite the preference Cerulean Warbler shows for undisturbed mature forest while on the breeding grounds (Hamel 2000, Weakland & Wood 2005) and for mature mesophytic forest in West Virginia and Kentucky (George 2009), second growth forest and coffee plantations have shown to be common habitats on the wintering grounds (Perfecto *et al.* 1996, Greenberg *et al.* 1997, Jones *et al.* 2000)

Cerulean warbler was a relatively common migrant in coffee plantations across the study

TABLE 2. Common migrant species occurring in 104 mixed species bird flocks.

	Participation in flocks	
Species	**N**	**%**
Setophaga fusca	93	90
Oreothlypis peregrina	71	68
Setophaga cerulea	58	56
Piranga rubra	45	43
Mniotilta varia	45	43
Pheucticus ludovicianus	34	33
Cardellina canadensis	32	31
Empidonax virescens	28	27
Setophaga ruticilla	13	13
Vermivora chrysoptera	12	12

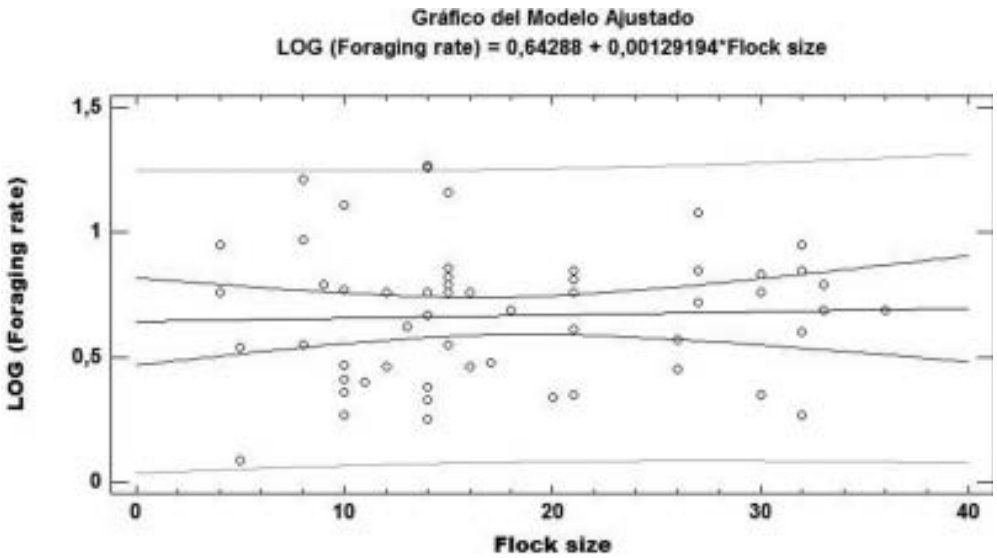

FIG. 1. Foraging rate (captures/min) of *Setophaga cerulea* participating in flocks of different size (species number) in coffee plantations in Colombian Andes.

area, primarily foraging in the forest subcanopy using the outer strata by gleaning insects from leaf surfaces as described for the same habitat in Venezuela during the non-breeding season (Jones *et al.* 2000, 2002, Bakermans *et al.* 2009, 2011). Moreover, our results are similar to those reported on the breeding grounds in terms of frequency of foraging maneuvers and absence of sex differences. For example, gleaning was the primary foraging maneuver observed in West Virginia, Kentucky and Venezuela (65–95% of all maneuvers), and birds used more non-aerial maneuvers, which tend to be energetically less expensive (Remsen & Robinson 1990) and decreases the exposition of the individual to predation. This consistent pattern in foraging ecology across the year may suggest a fairly limited repertory of foraging methods in Cerulean Warblers, as reported for Prothonotary Warbler (*Protonotaria citrea*) in North Carolina (Lyons 2005).

Mean foraging rate for the species was consistent with previous studies of foraging behavior of other warblers in the Neotropics. Detailed recent studies on foraging behavior of Cerulean Warblers during the non-breeding (Jones *et al.* 2000, Bakermans *et al.* 2011) and the breeding season (George 2009) did not report data on foraging rate. American Redstarts (*Setophaga ruticilla*) attacked prey at a mean rate of about 5 attacks/minute during summer in a mature forest in New Hampshire , and 3.2 attacks/min during winter in mangrove in Jamaica (Lovette & Holmes 1995).

Our data suggest that Cerulean Warbler increases its food intake throughout the winter season evidenced by increasing its foraging rate. This is consistent with the improvement in body condition of this warbler throughout the non-breeding season documented by Colorado (2011) in shaded agroecosystems in the same study area. Conversely, Lovette & Holmes (1995) documented a decrease in the foraging rate of American Redstarts in the late winter, attributing it to a low prey availability due to a decrease in leaf canopy cover. Although we did not measure any environmental variables, our study sites did

not experience any substantial change in both climate conditions or vegetation cover throughout the study period as reported by Lovette & Holmes (1995).

The foraging activities of Cerulean Warblers were concentrated in the subcanopy of the shading trees with male and female segregated vertically. This may indicate dominance by sex. Similar results of habitat segregation were observed for the species in Venezuela by Bakermans *et al.* (2011). However, these results differ from those published by Jones *et al.* (2000) who described that males and females appeared to forage at similar heights. Further study is needed to determine whether these differences correspond to sex segregation or to a particular distribution of food items in this agroforestry system.

Our data suggest Cerulean Warblers are strongly social both intra- and interspecifically during the winter season, virtually always associated with mixed-species flocks of resident and migratory birds. Our work does not provide evidence of an effect of group size on the foraging rate of the species. This pattern where foraging rate remained constant has been documented in studies that reported an increase in aggressive interactions with group size (Beauchamp, 1998). Consistently, Cerulean Warblers had interspecific agonistic interactions with other migrants in larger flocks, in which the smaller Cerulean Warblers were attacked and typically displaced by the larger individuals of other species. Thus our work suggests a possible negative effect of group size on the foraging of the species.

In addition, this research provides further evidence that coffee plantations are frequently used by migrants, including the globally vulnerable species Cerulean Warbler. These agroforestry systems can regularly support the mixed-species bird flocks with which Cerulean Warbler associates.

Finally, our study shows that foraging behavior can provide insights into the ecology of Neotropical migrants and can shed additional insights on their requirements and thus on their overall conservation needs. Comparative studies of foraging ecology and habitat quality between mature and disturbed habitats for migrants in the non-breeding season are needed in order to assess the value of these managed landscapes for Neotropical migrants. Measures using the survival rates of the birds themselves or a variety of proxies for survival such us resource availability through foraging rate and overwinter site persistence are needed in order to conduct effective conservation activities such as those described by Skolnik *et al.* (2012).

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