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Artículo

Population density of the Multicolored tanager (*Chlorochrysa nitidissima*) in the Important Bird Area Barbas-Bremen (Quindío, Colombia)

Densidad poblacional de la tangara multicolor (*Chlorochrysa nitidissima*) en el área importante para las aves Barbas-Bremen (Quindío, Colombia)

Diego A. Gómez-Hoyos[1], Oscar Humberto Marín-Gómez[2], Yuly Lorena Caicedo Ortiz[3], Pedro José Cardona Carmona[4]

[1]Grupo de Investigación y Asesoría en Estadística / Grupo de Herpetología (GHUQ), Universidad del Quindío, Armenia, Colombia; ProCAT Internacional / Sierra to Sea Institute Costa Rica, Puntarenas, Costa Rica
[2]Red de Ambiente y Sustentabilidad, Instituto de Ecología, A.C., Carretera Antigua a Coatepec 351, El Haya, Xalapa, Veracruz 91070, México
[3]SELVA: Investigación para la conservación en el Neotrópico, Bogotá DC., Colombia
[4]Fundación Ornitológica del Quindío. Filandia, Quindío
oschumar@gmail.com, biodiego88@gmail.com, yulylcaicedo@gmail.com, pedropajaros@yahoo.com

Abstract

Distance sampling and repeated counts are important tools to estimate the population density of birds. In this study we use a model-based approach to assess the population density of a threatened bird, the Multicolored Tanager (*Chlorochrysa nitidissima*). We used fixed point counts for four months to sample the Multicolored Tanager using visual and aural detections in four habitats: forest edge, mature, secondary, and riparian forest. We used spatially replicated counts, distance sampling, and multinomial-Poisson mixture models to estimate the population density. We accumulated a sampling effort represented by 576 repetitions in 144-point counts (96 h of observation). The multinomial-Poisson mixture model showed the best fit due to the low variance of density estimations in comparison to the conventional distance sampling and the spatially replicated counts. Results of this model evidenced remarkable higher density estimates (1.3–2.05 individuals/ha) of the Multicolored Tanager, particularly in mature and secondary forests. We discuss the advantages of a model-based approach over density indexes to analyze population densities of endangered species as the Multicolored Tanager.

Key words: abundance, Andean, density, endemic, population size

Resumen

Los muestreos por distancias y los conteos repetidos son herramientas importantes para estimar la densidad de población de las aves. Aquí utilizamos un enfoque basado en modelos para evaluar la densidad de población de un ave amenazada, la tangara multicolor (*Chlorochrysa nitidissima*). Durante cuatro meses, realizamos 144 muestreos de conteo de puntos fijos para muestrear la Tangara multicolor por medio de detecciones visuales y auditivas en cuatro hábitats: borde de bosque, bosque maduro, bosque secundario y bosque ribereño. Utilizamos conteos replicados espacialmente, muestreos de distancia y modelos mixtos multi-nominales de Poisson para estimar la densidad de población. Acumulamos un esfuerzo de muestreo representado por 576 repeticiones en 144 puntos con 96 h de observación. El modelo mixto multinomial de Poisson mostró el mejor ajuste debido a la baja varianza de las estimaciones de densidad en comparación con los métodos de distancia convencional y los conteos replicados espacialmente. Los resultados de este modelo evidenciaron una notable estimación de mayor densidad (1.3 - 2.05 individuos / ha) de la Tangara multicolor, particularmente en bosques maduros y secundarios. Discutimos las ventajas de un enfoque basado en modelos en relación con los índices de densidad para analizar las densidades de población de especies en peligro de extinción como la tangara multicolor.

Palabras clave: abundancia, Andina, densidad, endémica, estimaciones poblacionales, tamaño poblacional

Introduction

Estimating densities is a basic step to evaluate the status of a population. For land birds, the most accurate results of density arise from a combination of different methods as point counts, linear transects, territory mapping of marked individuals, and nest monitoring (Ralph *et al.* 1995, Bibby *et al.* 2000). However, intensive sampling and financial resources are required to ensure collecting enough data. Hence point counts have become the standard and non-expensive method to assess the abundance and density of bird populations around world (Ralph *et al.* 1995, Bibby *et al.* 2000). Distance sampling and repeated counts are model-based estimations that improve the confidence of the parameters by considering observer bias, habitat, and site conditions because of the inclusion of the detection probability function (Buckland *et al.* 2001, Norvell *et al.* 2003, Royle 2004, Hutto 2016). This model-based approach is useful to understand the population trends of Neotropical birds, particularly of those endemics to montane ranges, which typically show low population densities (Jankowski & Rabenold 2007). However, the population estimates of endangered bird species are still scarce (Kanegae 2012) and mainly focused on large frugivores (Kattan *et al.* 2014, 2015, Denis *et al.* 2016, González-García *et al.* 2017, Quiñónez-Guzmán *et al.* 2017). Furthermore, the few available estimations are not corrected for differences in sampling effort or habitat (*e.g.* Renjifo *et al.* 2014), a piece of crucial information to evaluate the conservation status of species with conservation issues.

The Multicolored Tanager, *Chlorochrysa nitidissima*, is an endemic and global endangered species listed as vulnerable due to its small distribution range and population declining (Fierro-Calderón & Johnston-González 2014, BirdLife International 2015). This tanager is restricted to montane forests between 900 and 2200 m of the Western and Central Andes of Colombia and inhabits primary forests, forest edges, and second growth forests (Collar *et al.* 1992, Hilty & Brown 2001, Angarita & Renjifo 2002). The species forages in pairs in the sub-canopy eating fruits of species of *Cordia*, *Miconia*, *Palicourea*, and *Ficus* (Collar *et al.* 1992), searching larvae in bromeliads (Cuervo *et al.* 2008), gleaning underside of leaves (Isler & Isler 1987), and joining to mixed-species flocks (Marín-Gómez & Arbeláez-Cortés, 2015). The population density of the Multicolored Tanager is low compared to other tanager species (Collar *et al.* 1992) because of the fragmentation and loss of 79.3% of its habitat (Renjifo *et al.* 2014). Therefore, population density studies along the distribution range of this tanager are essential to determine its vulnerability and responses to habitat disturbance, since it could optimize conservation efforts.

Despite being a colorful bird, the Multicolored Tanager is relatively difficult to detect during point counts sampling, due to its secretive behavior and rapid foraging movements in the canopy (Cárdenas *et al.* 2007, Fierro-Calderón *et al.* 2009, Marín-Gómez & Arbeláez-Cortés 2015). Thus, its lower detectability could be related to differences in habitat type (Fierro-Calderón & Johnston-González 2014). Population estimations based on models are needed to assess these biases to improve further comparisons among studies (Anderson 2003, Moore & Kendall 2004) and provide guidelines about conservation issues. Among the plethora of models to estimate population trends, robust spatially explicit models are the best tool to assess the density and abundance of unmarked animals (Chandler & Royle 2013). However, these models require spatially correlated count data from sample locations near one another (Chandler & Royle 2013), an assumption not fulfilled in many bird point count studies due to the assumption of independence among sampling locations. Therefore, this kind of data can be analyzed using traditional methods such as distance sampling and emerging methods as N-mixture models, which estimate population parameters with imperfect detection. Considering this scenario, in this study we use multiple estimation methods as N-mixture models and distance sampling to compare the population density of the Multicolored Tanager in an important Bird Area of Central Andes of Colombia.

Materials and methods

Study area. – The Cañón del río Barbas-Bremen Important Bird Area (BirdLife International 2017) is located on the western slope of the Central Andes of Colombia between 1500 and 2100 m asl (Fig. 1). The landscape is characterized by low montane forest patches and exotic plantations (*Eucalyptus* sp. and *Pinus patula*) immersed in a pasture grassland matrix (Fig. 1). The two largest patches are the Cañón del río Barbas (04º42'38'' N; 75º38'52'' W) with 790 ha, and the Reserva Natural Bremen-La Popa (04º40'27'' N; 75º37'56'' W) with 747 ha. These patches have some areas of well-preserved forest located in deep canyons with abrupt topography (BirdLife International, 2017). Details of the study area are provided by Gómez-Hoyos *et al*. (2014).

Field sampling. – We used fixed-point counts of 50 m radius to estimate the population density of the Multicolored Tanager (Ralph *et al*. 1995, Bibby *et al*. 2000). From 03March to 06June 2009, we sampled 144 points placed along lines at intervals of 150 meters distributed in four habitat types (Table 1). Habitat types were characterized in the field and defined by canopy height and dominant tree species (Table 1). We sampled each point once per month. Before sampling, we marked each counting station using flagging tape at 5 m intervals from the point center towards four cardinal points. Data collection was carried out by two observers starting 30 min after local sunrise (06:30) and continued for three hours. Counts were made under similar weather conditions (avoiding rainy and cloudy situations) using 10 x 42 binoculars and a field recorder (Marantz PMD 222 with a Sennheiser ME66) to record any bird sound detected. The observers arriving at each station waited one minute before start counting all the individuals of the Multicolored Tanager detected in a 50 m ratio for 10 minutes. The type of record (aural or visual), time of the first contact, sex, foraging activity, vertical strata, and radial distance was recorded for each encounter. Vocalization distances were calculated by observer criteria, which is a source of error for the conventional distance sampling model but can be mitigated by the Multinomial-Poisson mixture model by using discrete intervals. To calculate radial distance, we use measure tape from the point center (or the flagging marks intervals) to the place where the bird was detected. In some cases, the exact distance could not be measured, so we assigned the detection to the nearest marked interval.

Data analysis. – We used N-mixture models for spatially replicated counts (Royle, 2004) and distance sampling models (Royle *et al*. 2004, Thomas *et al*. 2010) to assess the population density of the Multicolored Tanager (data analysis available on: https://github.com/biodiego88/Population-density-of-the-Multicolored-Tanager). The model with the best performance was selected for its sampling requirements and precision in the estimation of population parameters, which are useful for monitoring. N-mixture models and distance sampling models estimate abundance with imperfect detection and are based on counts (repeated counts during multiple surveys in N-mixture models; single or multiple surveys, and distance measurements in

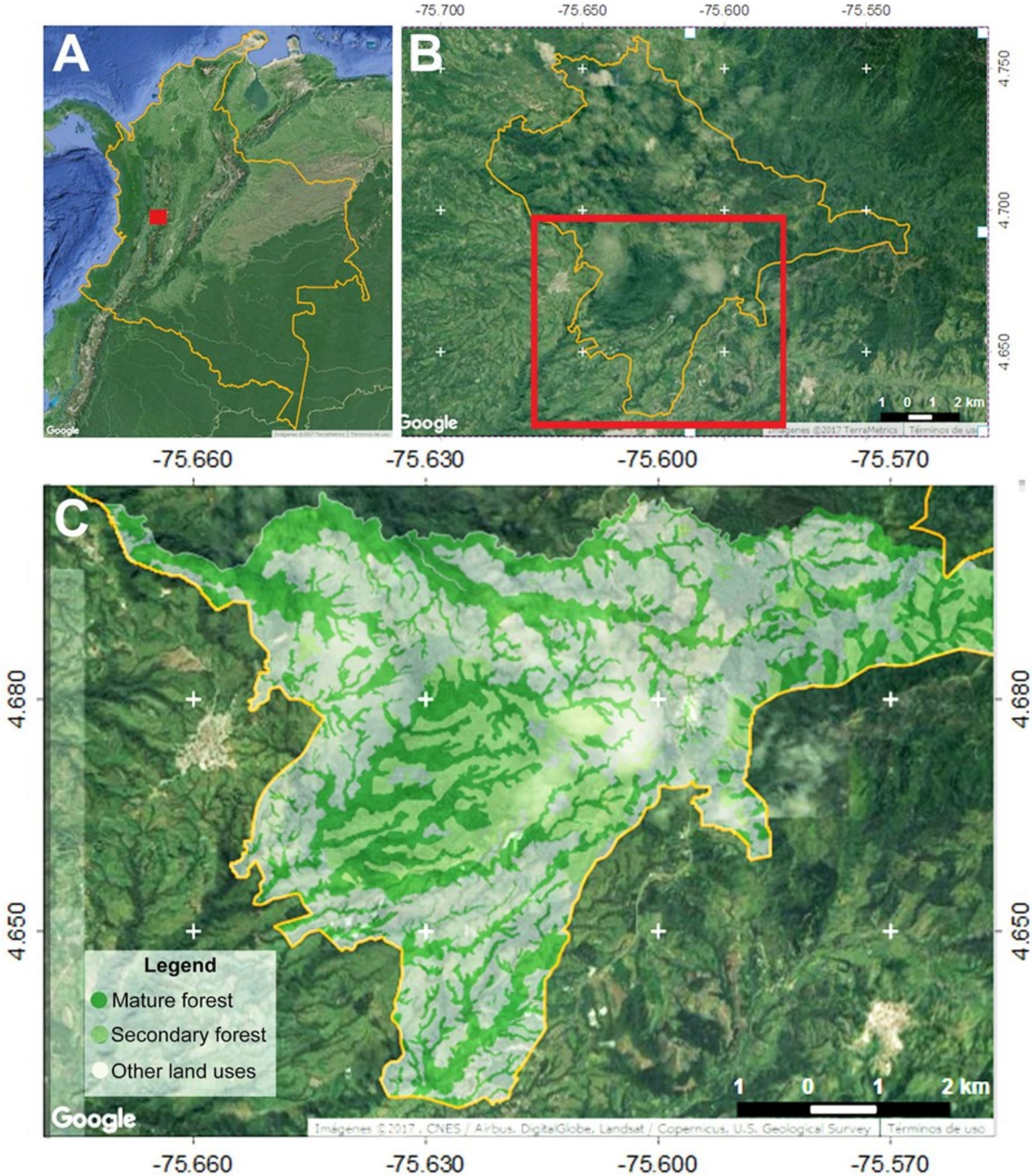

Figure 1. Location of the Cañón río Barbas-Bremen Important Bird Area (BB IBA) in the Central Andes of Colombia **(A)**, limits of BB IBA **(B)** and detail of the study area **(C)**

distance sampling). The strategy to estimate individual-level detection probability is different between models, N-mixture models use repeated surveys and closed population assumption while the distance sampling uses the distance to the observer (Dénes *et al*. 2015).

Table 1. Description of the habitat type where the population density of the Multicolored Tanager was studied.

Habitat type	Description	Canopy height	Dominant tree species	Sampling points
Mature forest (MF)	Well preserved forest remnants located in sharp slopes, with a dense understory	35 m	*Sphaeropteris quindiuensis*, *Prestoea acuminata*, *Chrysochlamis dependens*, *C. colombiana*, *Gustavia superba*, *Otoba lehmannii*, *Palicourea angustifolia*, *Cecropia telealba*, *Calatola colombiana*, and *Vismia guianensis*.	24
Secondary forest (SF)	Disturbed forest remnants with open understory, pioneer trees and shrub species	30 m	*Palicourea angustifolia*, *Symplocos quindiuensis*, *Chrysochlamis colombiana*, *Sphaeropteris quindiuensis*, *Ladenbergia oblongifolia*, *Hedyosmum bonplandianum*, *Miconia* sp., *Gustavia superba*, *Alchornea coelophylla*, *Cyathea* sp., *Oreopanax floribundum*, *Ocotea microphylla*, *Axinaea microphylla*, *Miconia lehmannii*, and *Meriania speciosa*.	67
Riparian forest (RF)	Native vegetation patches along the streams with open understory and dominance of herbaceous and shrub species, and some old trees	20 m	*Meriania speciosa*, *Miconia* sp., *Hedyosmum bonplandianum*, *Geonoma undata*, *Hyeronima scabrida*, *Symplocos quindiuensis*, *Palicourea angustifolia*, *Otoba lehmannii*, *Sphaeropteris quindiuensis*, *Oreopanax floribundum*, *Miconia lehmannii*, *Chrysochlamis dependens*, *Croton magdalenensis*, and *Miconia* sp.	29
Forest edge (FE)	Open understory with herbaceous and shrub species and some old trees	15 m	*Meriania speciosa*, *Cecropia telealba*, *Miconia lehmannii*, *Croton magdalenensis*, *Symplocos quindiuensis*, *Heliocarpus popayanenses*, *Hedyosmum bonplandianum*, *Montanoa quadrangularis*, *Palicourea angustifolia*, *Chrysochlamis colombiana*, *Miconia* sp., *Hyeronima scabrida*, *Palicourea acetosoides*, *Cupressus lusitanica*, *Oreopanax floribundum*, and *Cordia cilindrostachya*.	24

N-mixture models are useful in studies of factors affecting variation in abundance (Chandler & Royle 2013). These Poisson N-mixture models were used for the repeated counts during consecutive visits to the point counts, which were replicated temporally and spatially during the sampling period (Royle, 2004). Nevertheless, interpretation of model parameters is dependent on the assumption that populations are closed (Chandler & Royle 2013). Due to the length of this study, we are not sure that the closed population assumption is met. We fitted models with abundance and detection constant -y(null) p(null) - or explained by habitat type (mature forest, secondary forest, riparian forest, and forest edge) -y(hab) p(hab)-, as well as the different possible combinations: y(null) p(hab), and y(hab) p(null). We chose the upper limit of model integration (k) as 50, which represents an additional unit to the maximum number of individuals detected for point count, multiplied this value by 10 (Wenger 2008). Since this model estimates the abundance and to compare with the other estimates, we calculated the density dividing the abundance by detection area in each point as pi*r2 (3.1416*282), where r is the effective detection radius estimated with the distance sampling method. We used the Poisson distribution due to its best adjustment to count data. Models were generated using the *pcount* function in the *Unmarked* package (Fiske et al. 2015) of R language (R Core Team 2017).

The distance sampling methods were adjusted to conventional models (Buckland *et al.* 2001, Thomas *et al.* 2010). The models were generated using Distance 6 release 2 (Thomas *et al.* 2010) and they were based on the Half Normal, Uniform, Hazard rate, and Negative exponential functions in combination with the Cosine, Simple Polynomial, and Hermite polynomial expansion series. The analyses were stratified by habitat type. On the other hand, we used the Multinomial -Poisson mixture model (Royle *et al.* 2004) to evaluate the covariate effects of the habitat type on species density (Royle *et al.* 2004). The model was adjusted to point counts and the distances generated in discrete intervals using the *distsamp* function in the *Unmarked* package (Fiske *et al.* 2015). These models included the detection functions described above in combination with a null model for the detection and the abundance, as well as models where these parameters are affected by habitat type.

The best-fitting models were selected based on the Akaike Information Criteria with a correction for small sample sizes (AICc) where the values with less AICc indicate the most plausible model (Burnham & Anderson, 2002). The model with the best fit was used to estimate the Multicolored Tanager density and the detection probability. When we found uncertainty about the best fitting model, we reported all estimations of top-ranked models (Delta AICc < 2) according to Arnold (2010).

Results

Sampling effort. - The accumulated sampling effort was of 576 repetitions in 144-point counts with 96 h of observation. Thirty-three records of 56 individuals of the Multicolored Tanager, mostly in May and June (30 individuals) were obtained. Most records (73%) were aural, which correspond presumably to pairs. We also detected solitary individuals and conspecific groups conformed by a male, a female, and an immature. Most of the visual records corresponded to birds foraging in pairs or conspecific groups in the canopy or joining mixed flocks (44%).

Spatially replicated counts. – The best fitting model for spatially replicated counts was abundance non-affected by habitat type and detection explained by habitat type (Table 2). The estimate of density was 1.3 individuals/ha (SE=0.62; IC 95% = 0.59 – 2.87) with a detection probability from 0.036 (SE=0.023; IC 95% = 0.01 – 0.12) in secondary forest to 0.11 (SE=0.062; IC 95% = 0.033 – 0.299) in mature forest (Table 2). The second-best model included the abundance explained by habitat type with estimates from 0.95 individuals/ha (SE=0.58; IC 95% = 0.29 –3.11) in secondary forest to 2.98 (SE=1.74; IC 95% = 0.95 – 9.37) in mature forest (Fig. 2).

Conventional distance sampling. – The models that included the Hazard rate function with the three-expansion series (Simple Polynomial, Hermite polynomial, and Cosine) were the better adjusted to the distribution of radial distances to the point counts with the lower values of AICc (Table 3). The density of the Multicolored Tanager was 1.86 individuals/ha with these models (IC 95% = 1.05 – 3.27; CV = 28.53%; Table 3). The higher densities were found in mature forest and riparian forest compared to the forest edges and secondary forest. However, the estimations were not accurate enough to have certainty in the magnitude of the differences in the density among habitat types (Fig. 2). The estimated probability of detection was 49.24% (IC 95% =

Table 2. Top-ranked models for N-mixture models and density estimation for the Multicolored Tanager. y: abundance; p: probability of detection; MF: mature forest; RF: riparian forest; SF: secondary forest; FE: forest edge.

Model	AICc	ΔAICc	AICc weight	k	Habitat type	Density (ind./ha; CI 95%)
y(Null) p(hab)	401.01	0	0.4	5	-	1.3 (0.51-3.34)
y(hab) p(Null)	401.56	0.55	0.3	5	MF	2.98 (0.95-9.37
					RF	1.3 (0.37-4.59)
					SF	0.95 (0.29-3.12)
					FE	1.3 (0.43-3.91)
y(hab) p(hab)	402.41	1.4	0.2	8	MF	2.84 (0.36-22.35)
					RF	0.52 (0.17-1.62)
					SF	0.66 (0.14-3.01)
					FE	27.83 (5.38-143.91)

32.27 – 75.13; CV = 20.94%) with a radial effective detection of 28.01 m (IC 95% = 22.68 – 34.73; CV = 10.47%).

Multinomial-poisson mixed models. – Based on the AICc values, the models with the best fit included the function Hazard rate with habitat type affecting both the detection probability and species density (Table 4). According to this model, the estimated density for the Multicolored Tanager varied between 2.05 individuals/ha (SE = 1.12; CI 95%: 1.12 – 3.72) in mature forest and 0.79 (SE=0.26; CI 95%:0.45 –1.59) in secondary forest (Fig. 2). The highest density was found in mature forest and riparian forest (Fig. 2). The detection probability was highest in secondary forest 30.93% (SE=2.96; CI 95%: 26.44 – 36.2), followed by mature forest (24.16%; SE=2.99; CI 95%: 19.71 – 29.63), riparian forest (20.36%; SE=2.27; CI 95%: 16.95 – 24.47) and forest edge (20.07%; SE=1.83; CI 95%: 17.27 – 23.33).

Discussion

The different methods used here to estimate the population density of the Multicolored Tanager support the low detectability of the species across its distribution (Renjifo *et al.* 2014). This pattern could be explained by natural history and habitat requirements of this species as it prefers dense cloud forests where forages in sub-canopy and canopy strata, which make its detection difficult (Hilty & Brown 2001, Angarita & Renjifo 2002). Furthermore, the Multicolored Tanager is vocally active when joining to mixed-species flocks (Marín-Gómez & Arbeláez-Cortés 2015), where pairs emit constant short contact calls and males sing for few time intervals (Marín-Gómez obs. pers). Hence, aural detections are useful to detect this species.

The Multicolored Tanager is restricted to montane forests from the Western and Central Andes slopes of Colombia (Hilty & Brown 2001, Angarita & Renjifo 2002). Although its abundance has been reported higher in the Western than the Central Andes (Renjifo *et al.* 2014), there are few available densities estimates to support this difference. Surprisingly, our results evidenced the opposite, higher density estimates (1.3 – 2.05 individuals/ha) in a locality of the Central Andes. The available studies using point counts have reported a population density of 0.13 ± 0.16 ind/ha (Fierro-Calderón *et al.* 2009), and 0.15 ind/ha (Cárdenas *et al.* 2007). However, those results are probably underestimated, since they are based on density indexes which require a constant detection probability, a very difficult task to accomplish (Thompson *et al.* 1998, Anderson 2001, 2003).

The higher density estimates for this species in

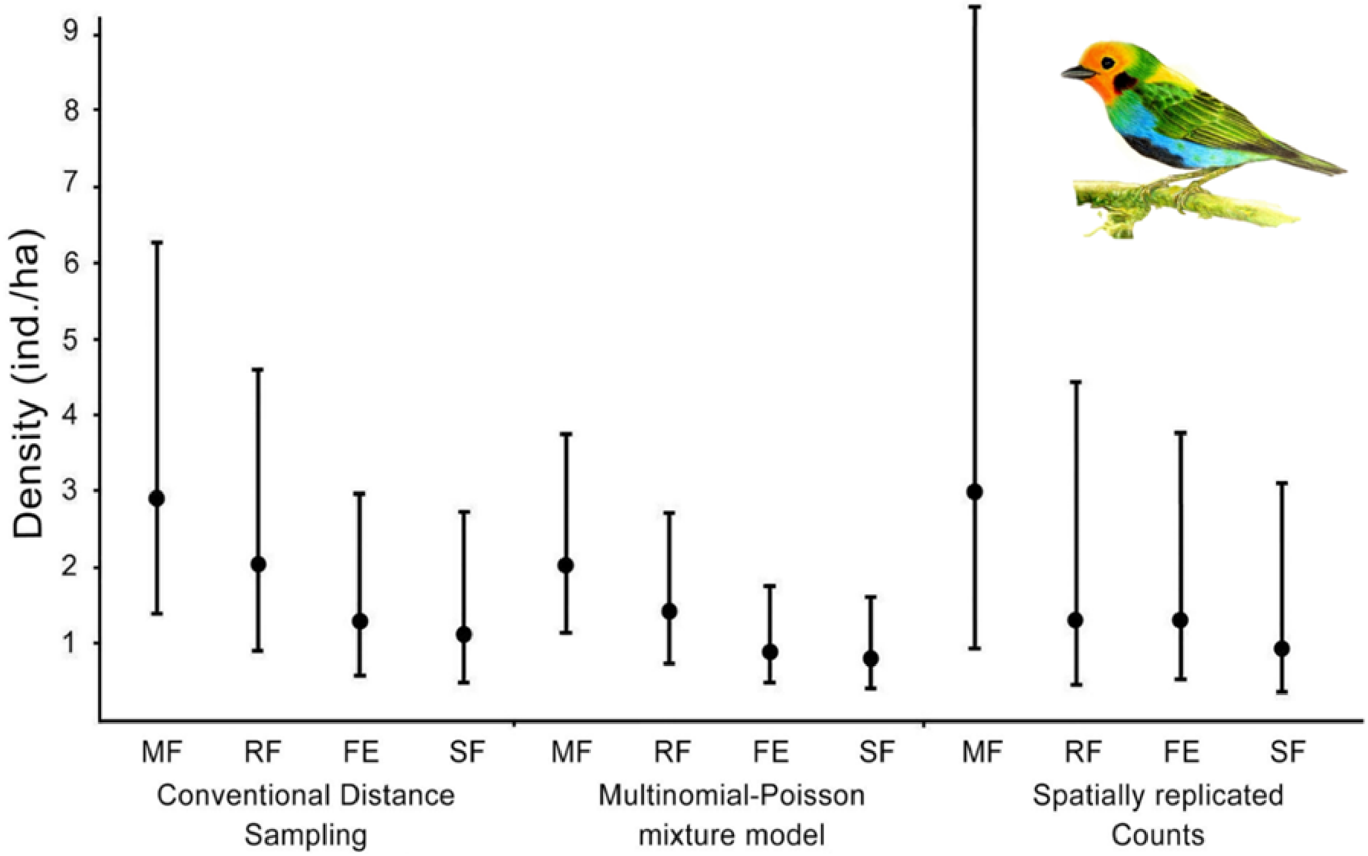

Figure 2. Density estimation for the Multicolored Tanager with different methods by habitat type. MF., Mature Forest; RF., Riparian Forest; FE., Forest edge; SF., Secondary Forest. Error bars: confidence intervals 95%. Illustration by Lwdin David Franco.

our study could be related to model-based analysis with detection correction in contrast to index density-based in the other studies, instead of sampling effort. Cárdenas *et al.* (2007) sampled 80 km of linear transects for three months, and Fierro *et al.* (2009) sampled 100-point counts for six months, which is similar to our sampling effort. Therefore, using a detection correction approach reduce potential biases caused by differences in sampling effort and habitat type (as suggested in the present study), which frequently led to underestimation of abundances or densities.

Distance sampling has been the prevailing method to estimate bird densities, due to providing better estimations in comparison to abundance and density indexes based on count data (Norvell *et al.* 2003). However, count data are biased by detection errors and zero-inflation affecting the inferential power of population status (Dénes *et al.* 2015). It has been also demonstrated that density estimations using the distance sampling method can reflect the real density of bird populations (Ekblom 2010). Distance sampling methodology modeling covariate effects assumes that the sampling units are spatially replicated, and the distance data are recorded in discrete intervals (Royle *et al.* 2004). The record of distances in discrete intervals is useful for species as the Multicolored Tanager, as it is difficult to obtain exact measures of perpendicular distances (Ekblom 2010), breaking one of the assumptions of the conventional distance sampling (Buckland *et al.* 2001, Thomas *et al.* 2010). In fact, most obtained records of this study are from vocalizations, which make it difficult to measure distance precisely, so in these cases, the discrete intervals are recommended

Table 3. Top-ranked models for conventional distance sampling and density estimation for the Multicolored Tanager.

Function	Series expansion	AICc	ΔAICc	k	Density (ind. /ha; CI 95%)
Hazard Rate	Hermite polynomial	229.11	0	2	1.86 (1.05-3.27)
	Simple polynomial	229.11	0	2	1.69 (0.96-2.95)
	Cosine	229.11	0	2	1.69 (0.96-2.95)
Uniform	Hermite polynomial	230.32	1.2	2	3.01 (1.46-6.19)
	Simple polynomial	230.32	1.2	2	3.01 (1.46-6.19)
	Cosine	231.05	1.94	1	2.77 (1.77-4.35)

(Royle *et al.* 2004).

Among our assessed models, the Multinomial-Poisson mixture model was more precise due to the relatively low variance of density estimations in comparison to the conventional distance sampling and the spatially replicated counts. This model has the advantage of including abundance covariate effects within distance-sampling models (Royle *et al.* 2004). Under this scenario, if we used the Multinomial-Poisson mixture model we do not need to have temporal replications as in replicated counts (Kéry *et al.* 2005, Dénes *et al.* 2015), which saves time and budget to implement a monitoring program. However, replicated count methods are very competitive when compared to the other rigorous methods for estimating the abundance of highly-density species and at large spatial scales (Kéry *et al.* 2005).

Perfect and constant detectability assumptions are key in a conventional monitoring program using index-based estimations (Kéry *et al.* 2005). Knowing that in our study the Multicolored Tanager detectability was <1 and heterogeneous among habitats, the perfect and constant detectability assumptions are not ensured. Therefore, to design a monitoring program for this species, it would be necessary to use models consider differences on its detectability. It is important to point that for low-density species, as is the case of the Multicolored Tanager, it is necessary to increase the spatial representatively of the sampling but not the temporal (in the case of replicated counts) to mitigate the effect of zero counts (zero-inflation) on parameter estimates and the inferential capacity of models (Dénes *et al.* 2015). Therefore, we recommend using the Multinomial-Poisson mixture model for parameter estimates during population assessments or monitoring of the species. Further studies could apply our sample design to access population trends in some small Andean bird species. Those studies could use point-counts (50 m radius) located at a minimum distance of 150 m from each other to assure that sampling sites do not spatially overlap with maximal recording distances. Counts session need to include both aural and visual detections, particularly in the morning (06:00-09:00 h). Using a rangefinder to obtain precise measurements of distance is desirable instead of flagging marks in the field. Finally, sample size and site selection depend on the extension and the representation of different vegetation cover or land use. However, we recommend a minimum of ten-point counts by each habitat category.

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Table 4. Multinomial-Poisson mixture models generated for density estimation of the Multicolored Tanager. y: abundance; p: probability of detection; k: number of parameters

Models	Function	AICc	ΔAICc	AICc weight	k
y(hab) p(hab)	Hazard rate	381.31	0	0.88	9
y(hab) p(null)	Hazard rate	387.36	6.05	0.04	6
y(null) p(hab)	Hazard rate	388.12	6.81	0.03	6
y(hab) p(hab)	Half normal	388.16	6.84	0.03	8
y(hab) p(null)	Half normal	390.05	8.73	0.01	5
y(null) p(null)	Hazard rate	390.97	9.66	0.01	3

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