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RAPID COLONIZATION OF ECUADOR BY THE TROPICAL MOCKINGBIRD (*MIMUS GILVUS*)

Juan M. Aguilar[1] · Juan F. Freile[2] · Boris A. Tinoco[1]

[1]Escuela de Biología, Ecología y Gestión, Universidad del Azuay, Av. 24 de Mayo 7-77 y Hernán Malo, Cuenca, Ecuador.

[2]Comité Ecuatoriano de Registros Ornitológicos, Casilla Postal 17-12-122, Quito, Ecuador.

E-mail: Juan M. Aguilar · juanmaguilaru@yahoo.com

ABSTRACT
Some species benefit from anthropogenic ecosystem disturbance expanding their distribution ranges rapidly into altered areas. Given the current availability of anthropogenic landscapes in the Neotropic, it is important to document cases of species' range extensions to better understand the factors that influence their distribution. In this manuscript, we document the colonization process of the Tropical Mockingbird (*Mimus gilvus*) in Ecuador since its arrival from Colombia in 1996, and analyze its range expansion to predict its future distribution based on a potential distribution climate model. Data collected indicate that the species has expanded 300 km southwards since first recorded in Ecuador. Given the availability of suitable climate conditions and the availability of disturbed land, it is expected that *M. gilvus* will continue its current range expansion southwards, occupying most Ecuador, mainly along inter-Andean valleys.

RESUMEN · La rápida colonización del Sinsonte Tropical (*Mimus gilvus*) en Ecuador
Algunas especies se benefician del disturbio antropogénico sobre los ecosistemas, expandiendo rápidamente sus rangos de distribución hacia áreas alteradas. Dada la disponibilidad actual de paisajes antropogénicos en el Neotrópico, es importante documentar los casos de expansión de rango de las especies para comprender mejor los factores que influyen en la distribución de estas. Aquí documentamos el proceso de colonización del Sinsonte Tropical (*Mimus gilvus*) en Ecuador, desde su arribo de Colombia en 1996, y analizamos su expansión de rango para predecir su futura distribución en base a un modelo climático de su rango potencial. Los datos obtenidos indicaron que la especie se ha expandido 300 km hacia el sur desde su primer reporte en Ecuador. Dada la disponibilidad de condiciones climáticas favorables y de áreas disturbadas, se espera que *M. gilvus* continúe su actual expansión hacia el sur, ocupando la mayor parte del Ecuador, principalmente los valles interandinos.

Key words: Anthropogenic disturbance · Distribution · Ecuador · *Mimus gilvus* · Niche · Range expansion

INTRODUCTION

Some species benefit from anthropogenic disturbance by expanding their distribution range into altered areas (Walther et al. 2002, Didham et al. 2007). These range expansions are usually rapid (Shea & Chesson 2002, Walther et al. 2002, Young 2009), and often have detrimental consequences for biodiversity if the colonizing species outcompete native fauna (Kolar & Lodge 2001, Shea & Chesson 2002). Given the current availability of human-altered landscapes at global scale (Young 2009), it is important to document cases of species range expansions to such areas, to gain a better understanding of the global consequences of anthropogenic disturbance (Didham et al. 2007).

The range expansion of a species can be attributed to a process of range-filling or evolutionary niche expansion (Gaston 2003, Sexton et al. 2009). Range-filling corresponds to expansions into geographic areas that are within the climatic niche of a species but that were not occupied before due to historical (e.g. dispersion) or biotic (e.g. competition) constraints (Thomas 2001, Svenning & Skov 2004). Evolutionary niche expansions result from changes in the climatic niche of a species driven by evolutionary processes (Broennimann et al. 2007, Duckworth & Badyaev 2007, Strubbe et al. 2015). Reports of niche expansion are uncommon in the

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literature because most species tend to maintain their ecological niche through time (Peterson et al. 1999, Tingley et al. 2009, Petitpierre et al. 2012), a concept known as niche conservatism (Wiens & Graham 2005). However, determining the process that influence species range expansion is an ongoing task, especially in the Neotropics.

The Tropical Mockingbird (*Mimus gilvus*) is a polytypic species (Lovette et al. 2012) that has been rapidly expanding in the Neotropics. This range expansion has been linked to its ability to occupy forest edges and disturbed areas (Estela & López-Victoria 2005, Lau Pérez 2008, Muñoz et al. 2013). To our knowledge, range expansion of *M. gilvus* has been documented since the 1980s, when new localities for *M. g. tobagensis* were reported in Trinidad (ffrench 1985). In the 1990s, the subspecies *M. g. gracilis* and *M. g. magnirostris* were first recorded in Nicaragua and El Salvador (Komar 2001, Wiedenfeld et al. 2001, Cody 2005). Currently, *M. gilvus* is distributed in southern Mexico, most Central America, western Colombia and northern Ecuador, across northern Venezuela, the Lesser Antilles, Trinidad, Tobago, the Guianas, and northern Brazil, following the Atlantic coast south to Rio de Janeiro (Brewer & MacKay 2001, Zanon et al. 2015).

In Ecuador, *M. gilvus* was first reported near Otavalo, Imbabura province, in 1996 (Cisneros-Heredia & Henry 2004). *M. gilvus* records in Ecuador have been assigned to *M. g. tolimensis,* a subspecies distributed across southwest Colombia (Cisneros-Heredia & Henry 2004, Cody 2005, Gill & Donsker 2010). Since then, it has spread southwards, occupying dry Andean valleys heavily disturbed by anthropogenic activities (Cisneros-Heredia & Henry 2004, Young 2009). In the last two decades several new localities have been reported in Ecuador (Ridgely & Greenfield 2001), and it is expected that it will further expand southwards (Ridgely & Greenfield 2001, Weidenfeld 2001, Muñoz et al. 2013).

Here we (1) describe the colonization chronology of *M. gilvus* in Ecuador, (2) explore if the colonization of Ecuador corresponds to a process of range-filling or niche expansion, and lastly (3) create a species distribution model to predict the future distribution range of *M. gilvus* in Ecuador.

METHODS

We gathered all occurrence records of *M. gilvus* in Ecuador using information from literature, online resources (eBird 2012), and unpublished records by the authors. To document the chronology of range expansion of *M. gilvus* in Ecuador, occurrence records were classified in five-year periods from 1996 to 2015. Records from the same locality were excluded, using a grid cell size of 1 km^2, leaving only one record in each cell; moreover, for the chronological analysis we kept the oldest record from each location.

To analyze if the presence of *M. gilvus* in Ecuador corresponds to a process of range-filling or niche expansion, we assessed differences in the species' environmental niche space between populations from Colombia and Ecuador. We gathered occurrence localities for the species from southwest Colombia (below 2°N and west of 73°W) and used one record from each 1 km^2 cell. We obtained eight WorldClim (Hijmans et al. 2005) non-correlated bioclimatic layers related to annual and seasonal variables, at a resolution of 1 km^2 (Mean annual temperature, temperature seasonality, temperature of warmest quarter, temperature of coldest quarter, annual precipitation, precipitation seasonality, precipitation of wettest quarter and precipitation of driest quarter). Then, we compared the environmental niche space of occurrence localities in southern Colombia and the ones in Ecuador using a principal component analysis (PCA) (Broennimann et al. 2007, Guisan et al. 2014). The PCA was constructed using a correlation matrix and was performed in PAST ver.2.17c (Hammer et al. 2001).

To predict the future distribution of *M. gilvus* in Ecuador, we used all occurrence localities from southwest Colombia and Ecuador to construct a maximum entropy distribution model (MAXENT) in Maxent Software, ver. 3.3.3K (Phillips et al. 2006). This model was constructed using the same data employed to determine the environmental niche space of the species. The area under the curve value (AUC) was used to evaluate the model with 30% of random test points in a ten replicate bootstrapped run (Phillips et al. 2006). AUC values have a range from 0 to one; values close to one indicate a perfect model performance, values of 0.5 indicate a model not better than random, and values under 0.5 of AUC describe a poor prediction (Phillips et al. 2006). Finally, due to *M. gilvus* affinity for disturbed areas, from the resulting occurrence probability map we removed all predicted areas that lay in natural vegetation, using a distribution map of undisturbed areas in Ecuador (Ministerio del Ambiente 2013).

RESULTS

We obtained 54 occurrence localities for the *M. gilvus* in Ecuador (Table 1). Chronologically, the number of localities where the species has been reported in Ecuador has been increasing: 2 in 1996–2000, 8 in 2001–2005, 8 in 2006–2010, and 36 in 2011–2015 (Figure 1). According to data available, the species likely expanded southwards from Colombia during the 1996–2000 period, reaching Imbabura and Napo provinces. In the 2001–2010 decade, records increased along the inter-Andean valleys of northern Ecuador, also crossing the Andes eastwards to reach the Andean-Amazonian foothills (i.e., it arrived to Archidona, Napo province, in 2005). In the 2011–2015 period, it reached the Andean western slopes and eastern Amazonian lowlands. Currently, the southernmost record is Macas, Morona Santiago

Table 1. Reported localities for the Tropical Mockingbird (*Mimus gilvus*) in Ecuador until July 2015, ordered from north to south.

Province	Lat.	Long.	Locality	Year	Source
Carchi	0.8972	-78.1153	Maldonado	2013	eBird
Carchi	0.865	-78.0499	Chilmá Bajo	2013	eBird
Carchi	0.8341	-78.1675	Maldonado 2	2014	eBird
Carchi	0.7926	-78.0065	Cerro Golondrinas	2014	eBird
Imbabura	0.7495	-78.2504	Guadual	2014	eBird
Imbabura	0.5562	-78.1267	Ibarra-San Lorenzo road	2013	eBird
Pichincha	0.5259	-78.1561	Pichincha mountain	2013	eBird
Imbabura	0.5212	-78.1518	Salinas, Río Palacara	2008	eBird
Imbabura	0.4482	-78.0074	Ambuquí	2006	eBird
Imbabura	0.4056	-78.1761	Hacienda San José	2014	eBird
Imbabura	0.3666	-78.1166	Yahuarcocha	2002	Cisneros-Heredia & Henry 2005
Imbabura	0.3391	-78.1636	Hostería Chorlaví	2007	eBird
Imbabura	0.3026	-78.3666	Cuicocha	2001	Cisneros-Heredia & Henry 2005
Imbabura	0.2333	-78.2666	Otavalo	1996	Cisneros-Heredia & Henry 2004
Sucumbíos	0.2112	-76.8497	Lago Agrio, Tarapoa	2014	eBird
Pichincha	0.2087	-78.737	Chontal, Finca Morales	2014	eBird
Pichincha	0.1128	-78.422	Perucho	2013	eBird
Pichincha	0.1006	-78.7057	San Jorge de Milpe	2011	eBird
Pichincha	0.0784	-78.4363	Road to Perucho	2013	eBird
Pichincha	0.0131	-78.6754	Tandayapa	2015	eBird
Pichincha	0.004	-78.4882	Calacalí	2010	eBird
Pichincha	0.0018	-78.3556	Jerusalem	2009	eBird
Pichincha	-0.0007	-78.5151	Calacali vicinity	2011	eBird
Pichincha	-0.0023	-78.4559	San Antonio de Pichincha	2010	eBird
Pichincha	-0.0038	-78.6615	Alambi	2015	eBird
Sucumbíos	-0.0333	-76.5666	Lago Agrio	2014	Juan F. Freile
Pichincha	-0.0413	-78.447	Parque Metropolitano	2015	eBird
Pichincha	-0.0521	-78.81	Mindo	2013	eBird
Pichincha	-0.0643	-78.5794	Nono	2015	eBird
Pichincha	-0.0689	-78.5889	Nono-Tandayapa Road	2015	eBird
Pichincha	-0.0915	-78.4807	Museo Inti Ñan	2013	eBird
Pichincha	-0.1063	-78.4093	Quito, north	2013	eBird
Pichincha	-0.1085	-78.5619	Road to Yanacocha	2015	eBird
Pichincha	-0.1098	-78.365	Quito, airport pond	2015	eBird
Pichincha	-0.1433	-78.4877	Quito, Bicentenario	2014	eBird
Pichincha	-0.1634	-78.3088	Yaruquí	2013	eBird
Pichincha	-0.1656	-78.3613	Puembo, Birding Garden	2015	eBird
Pichincha	-0.1668	-78.4698	Tumbaco2	2013	eBird
Pichincha	-0.1833	-78.35	Puembo	2003	Henry 2005
Pichincha	-0.1865	-78.4858	Quito, Jardín Botánico	2014	eBird
Pichincha	-0.1886	-78.3442	Tababela	2013	eBird
Pichincha	-0.1913	-78.3766	Tumbaco3	2013	eBird
Pichincha	-0.193	-78.4268	Cumbayá	2009	eBird
Pichincha	-0.2093	-78.4985	Quito, Parque El Ejido	2008	eBird
Pichincha	-0.211	-78.3796	Tumbaco1	2004	eBird
Pichincha	-0.2238	-78.5133	Quito	2002	eBird
Pichincha	-0.3166	-78.4666	San Rafael	2002	Henry 2005
Pichincha	-0.3364	-78.3976	Agua Viva camp	2014	eBird
Napo	-0.3739	-78.1464	Papallacta	2012	eBird
Pichincha	-0.3813	-78.5045	Amaguaña	2013	eBird
Pichincha	-0.4398	-78.499	Pasochoa	2003	eBird
Napo	-0.5818	-77.8667	Cosanga	1998	Cisneros-Heredia & Henry 2004
Napo	-0.9106	-77.8065	Archidona	2005	Juan F. Freile
Morona- Santiago	-2.3793	-78.1623	Templo de la Amazonía	2014	Juan M. Aguilar & Boris A. Tinoco

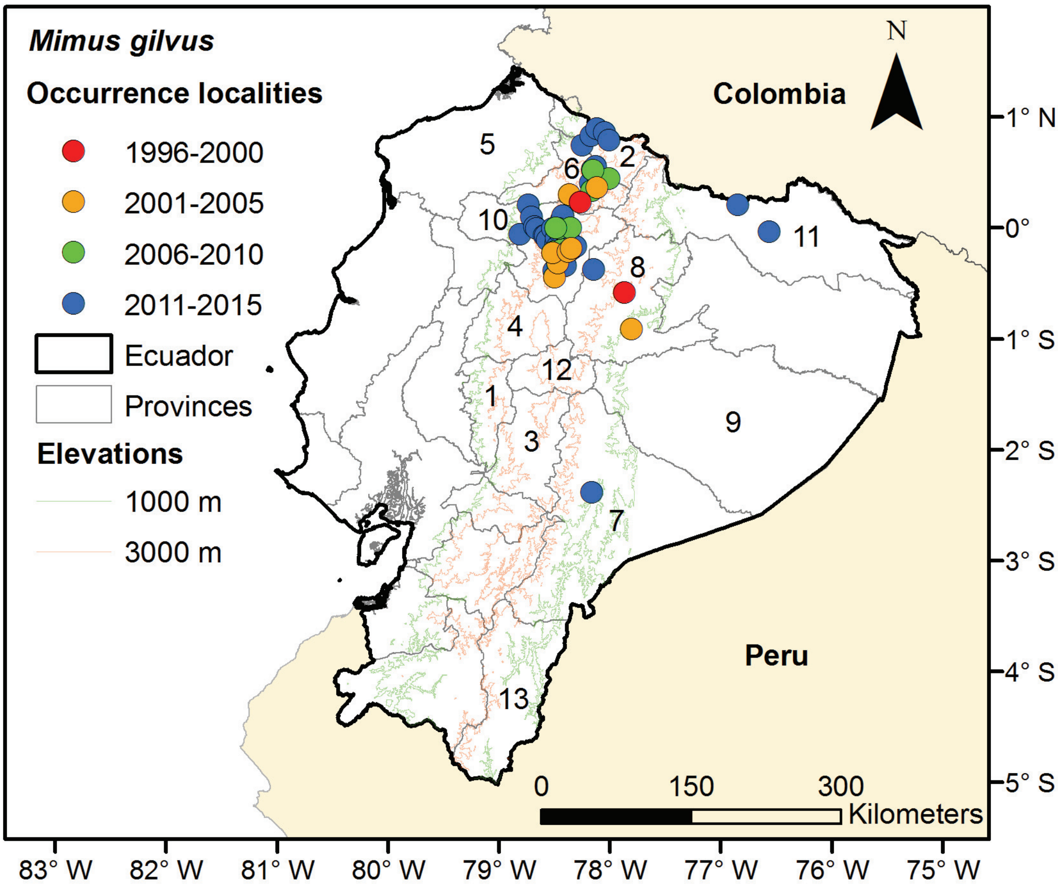

Figure 1. Distribution of the Tropical Mockingbird (*Mimus gilvus*) in Ecuador. Chronology of 54 Ecuador records arranged in five years periods; map includes named provinces: (1) Bolívar, (2) Carchi, (3) Chimborazo, (4) Cotopaxi, (5) Esmeraldas, (6) Imbabura, (7) Morona Santiago, (8) Napo, (9) Pastaza, (10) Pichincha, (11) Sucumbíos, (12) Tungurahua and (13) Zamora Chinchipe.

Table 2. Contribution of bioclimatic variables in a Principal Component Analysis obtained from occurrence localities of the Tropical Mockingbird (*Mimus gilvus*) in southern Colombia and Ecuador.

Variable	Component 1	Component 2
Mean annual temperature	0.42	0.25
Temperature seasonality	0.34	0.09
Temperature of warmest quarter	0.42	0.25
Temperature of coldest quarter	0.41	0.25
Annual precipitation	0.38	-0.35
Precipitation seasonality	0.06	0.53
Precipitation of wettest quarter	0.38	-0.26
Precipitation of driest quarter	0.25	-0.57

province, were two individuals were observed by JMA and BT in December 2014, at "El Templo de la Amazonía" (02°22.760'S 78°09.736'W; 918 m a.s.l.). This last record represents a range expansion of 160 km south from Archidona, Napo province, the previous southernmost locality in east Ecuador.

Combining records from Colombia and Ecuador, we gathered 251 occurrence localities for *M. gilvus*. These localities were used to explore the environmental niche space of the species by a PCA. The first two components of the PCA (PC 1 and PC 2) explained 80% of the accumulated variance. The first component was mainly related with temperature variables: mean annual temperature, temperature of the driest quarter, and temperature of the wettest quarter (Table 2); the second component was mainly

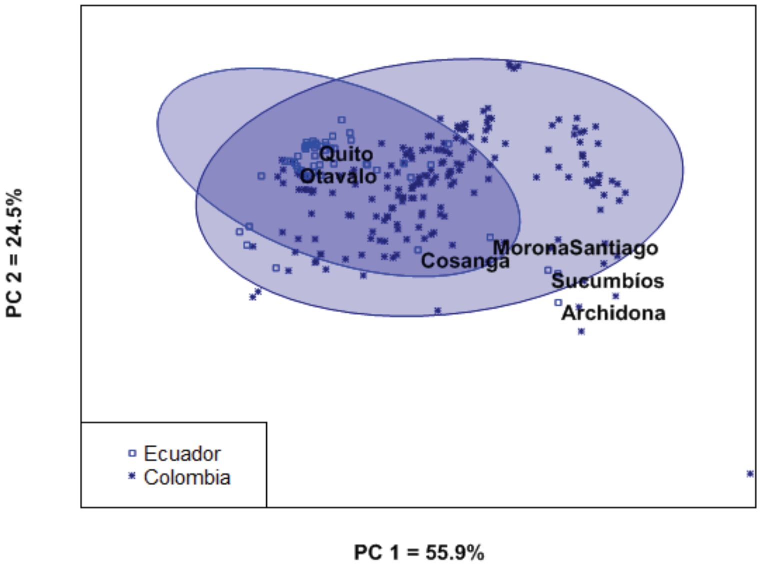

Figure 2. Multivariate climate space of the Tropical Mockingbird (*Mimus gilvus*) with mentioned important Ecuador localities. Plot of first two components of a Principal Component Analysis using eight bioclimatic variables from occurrence localities in southwest Colombia and Ecuador. These components account for 80% of the variance and mainly reflect temperature (PC 1) and precipitation (PC 2). Grey areas correspond to 95% confidence ellipses from data for each country.

associated with precipitation variables (Table 2). The PCA indicated that all *M. gilvus* records in Ecuador are within 95% confidence ellipse of the environmental niche space occupied by records from southwestern Colombia occurrences (Figure 2).

The MAXENT model had an AUC = 0.974, indicating an accurate model performance. The resulting model predicted highly suitable conditions for *M. gilvus* in Ecuador, across Andean valleys and the eastern Andean foothills (Figure 3). In contrast, the eastern and western lowlands of Ecuador had low suitable environmental conditions for the species (Figure 3).

DISCUSSION

Mimus gilvus has been rapidly expanding in Ecuador, apparently aided by its ability to exploit human-disturbed areas (Cisneros-Heredia & Henry 2004, Muñoz et al. 2013), and the availability of suitable environmental conditions. Our results indicate that it has expanded 300 km south since first recorded in Ecuador in only two decades. Moreover, our distribution model predicts that it will continue to expand under suitable climate conditions along disturbed inter-Andean valleys to the south, as well as along the eastern and western Andean slopes, foothills, and lowlands of Ecuador.

After the first record of *M. gilvus* in Ecuador in 1996 (Cisneros-Heredia & Henry 2004), the species has been expanding following a mosaic of anthropogenic ecosystems along inter-Andean valleys (Figures 1 and 3). The record of the species in Cosanga, Napo province, in the 1996–2000 period indicates that it was able to cross the Eastern Andean Cordillera following a low pass or a valley that dissects the Andean cordillera (e.g., via the Quijos-Cosanga area or the Pastaza River Valley; Krabbe 2008). During the 2001–2005 period, reports of juveniles indicated that the species had begun to establish breeding populations throughout its range in northern Ecuador (Cisneros-Heredia & Henry 2004, Henry 2005). Periods 2001–2005 and 2006–2010 would also correspond to establishing breeding populations throughout its range, as suggested by the increase in the number of records in northern Ecuador. The last five years (2010–2015) were likely a new period of range expansion, indicated by new records in the northwestern Andean slopes of Imbabura and Pichincha provinces, as well as records from the eastern lowlands and foothills, in Sucumbíos and Morona Santiago provinces. Our record from Morona Santiago suggests that the species moved south from Archidona to Macas in a brief 10-year period, and should also be present in the eastern Andean foothills in Tungurahua and Pastaza provinces. Current records also point out that the species might be occupying localities at higher elevations or that it is capable of dispersing through high elevation areas (Cisneros-Heredia & Henry 2004, Henry 2005), as indicated by the record at 3600 m a.s.l. in eastern Andes of Napo province (eBird 2012), although breeding populations have not been reported over 2300-2500 m a.s.l.

We are aware of the potential inaccuracy in the colonization chronology (i.e., the chronology of records in Table 1, does not necessarily reflects a chronology of invasion). The increase in numbers of records towards the present might be related to an increase in ornithological activities throughout Ecuador (Freile et al. 2014). Nonetheless, the general patterns shown seemingly reflect the species' spreading process given that *M. gilvus* is a conspicuous species and some areas covered by this study (e.g., northern

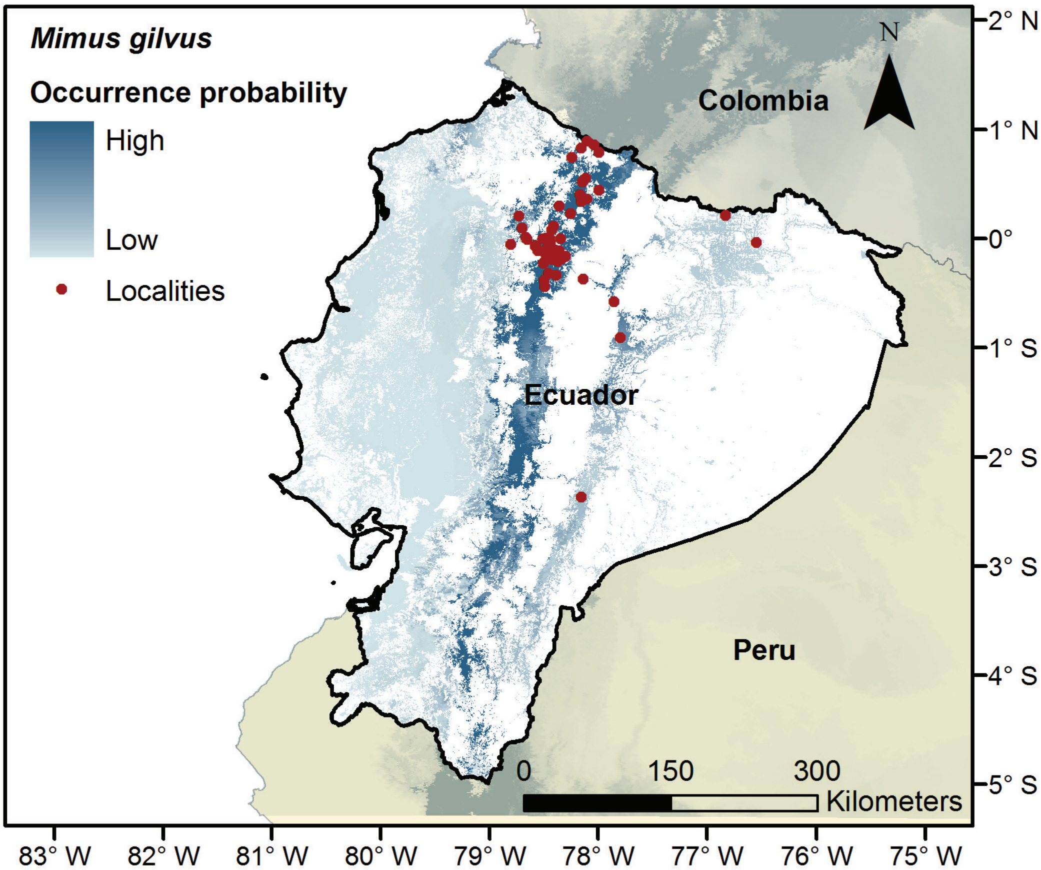

Figure 3. MAXENT occurrence probability model of the Tropical Mockingbird (*Mimus gilvus*) in disturbed areas of Ecuador. Occurrence in natural vegetation was removed from map.

Ecuador) have been popular bird-watching destinations over the last two decades (Greenfield et al. 2010).

M. gilvus in Ecuador has spread into areas that are within the environmental niche space occupied by populations from southwest Colombia. Thus, the rapid expansion of the species in Ecuador corresponds to a process of range-filing, related to suitable climatic conditions. Therefore, niche conservatism likely plays an important role in the expansion potential of the species (Peterson et al. 1999). Moreover, all the records of the species in Ecuador come from disturbed areas, indicating that *M. gilvus* has also benefited by the availability of disturbed areas in this country. The importance of the availability of disturbed areas in the colonization process is shown by the presence of the species in heavily disturbed areas but with low probability of occurrence in our models (e.g. eastern lowlands). However, the absence of records in the western lowlands, a region severely transformed by human activities, suggests that it is challenging for *M. gilvus* to colonize areas with unfavorable climatic conditions. Furthermore, a range expansion of *M. gilvus* to the Ecuadorian western lowlands might be limited by competitive interactions with its congener *Mimus longicaudatus,* which currently is widely distributed in this region (Cody 2005). Certainly, more monitoring is needed in the forthcoming years to determine if the species fails to colonize the western lowlands.

Occurrence probabilities of *M. gilvus* indicate that it will likely continue to expand its range in Ecuador (Henry 2005), mainly through the inter-Andean, disturbed valleys; thus it is expected that in the near future *M. gilvus* will be reported from Cotopaxi and Tungurahua southwards. Moreover, it seems likely that it will keep spreading along the west Andean slopes of Imbabura, Cotopaxi, Bolívar, and Chimborazo provinces, as well as towards the northwest lowlands, mainly along major rivers in Esmeraldas province. In the eastern Andean foothills, the species has already reached central Ecuador, and from there it could continue spreading south towards Zamora Chinchipe province, and we also expect more frequent records from eastern lowlands. Although we have not modeled the range of the species in Peru, the species may reach this country in the coming decades.

Documenting and understanding the factors that influence species' expansions have important implications for predicting the responses of biodiversity to anthropogenic disturbance and scenarios of climate change. *Mimus gilvus* has established populations in the northern Andes of Ecuador, and is rapidly expanding its range south; future ornithological activities in Ecuador will test our predictions of its potential expansion in this country. Finally, future research should focus on assessing the ecological consequences of the presence of this novel species on the local biodiversity.

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