Ciencia, Tecnología y Salud, Vol. 11, Núm. 2, 2024
ISSN: 2409-3459 (impreso) / 2410-6356 (electrónico)
https://doi.org/10.36829/63CTS.v11i2.1865

Artículo Científico / Scientific Article

Use of Telemetry for Tracking Two Individuals of Resplendent Quetzal *(Pharomachrus mocinno mocinno)* in the Mountains of Baja Verapaz, Guatemala

Uso de telemetría para el seguimiento de dos individuos de Quetzal Resplandeciente (Pharomachrus mocinno mocinno) en las montañas de Baja Verapaz, Guatemala

Michelle Bustamante-Castillo *, Bianca Bosarreyes , Manuel A. Barrios-Izás

Instituto de Investigaciones, Centro Universitario de Zacapa (Cunzac),
Universidad de San Carlos de Guatemala, Guatemala

***Autor al que se dirige la correspondencia:** michelle.amazilia.bustamante@gmail.com

Recibido: 11 de noviembre 2024 / Revisión: 25 de noviembre 2024 / Aceptado: 20 de diciembre 2024

Abstract

Telemetry tracking provides essential insights into avian movements and habitat preferences, aiding the identification of critical resources and conservation areas for endangered species such as the Resplendent Quetzal. In this study, we tracked two radio-tagged Resplendent Quetzals in a mountainous cloud forest region containing national protected areas, private reserves, and indigenous lands. Both individuals primarily remained within the protected Biotopo del Quetzal reserve and nearby areas for approximately five months; however, during the non-breeding season, one individual exhibited increased mobility, moving outside the reserve for three months and utilizing lower-elevation areas up to 5.5 km away. These areas are embedded in a modified landscape, comprising agricultural fields, roads, and human settlements. Together with previous telemetry data from Central America's Resplendent Quetzal populations, these findings support the occurrence of seasonal migratory behavior in this species, indicating reliance on distinct habitats at different times of the year. Establishing biological corridors could provide safe passage between these habitats, facilitating access to vital foraging and roosting sites while mitigating genetic isolation effects through enhanced connectivity and genetic resilience. Key non-protected sites within the study area, such as Ranchitos del Quetzal and forest patches along the Panimá River basin, offer valuable opportunities for targeted conservation aimed at improving habitat connectivity, safeguarding critical resources, and engaging local communities. Finally, preserving and restoring plant species identified as primary food sources should be prioritized in protected and adjacent areas to ensure adequate nutrition for Resplendent Quetzals throughout their migratory and breeding cycles.

Keywords: Avian migration, habitat connectivity, conservation biology, cloud forest, ecological corridors

Resumen

El seguimiento por telemetría proporciona información esencial sobre los movimientos y las preferencias de hábitat de las aves, lo que facilita la identificación de recursos críticos y áreas de conservación para especies en peligro, como el Quetzal Resplandeciente. En este estudio, rastreamos dos Quetzales Resplandecientes con radiotransmisores en una región montañosa de bosque nuboso que incluye áreas protegidas nacionales, reservas privadas y tierras indígenas. Ambos individuos permanecieron principalmente dentro del bosque nuboso protegido del Biotopo del Quetzal y en áreas cercanas durante aproximadamente cinco meses; sin embargo, durante la temporada no reproductiva, uno de ellos mostró un aumento en su movilidad, desplazándose fuera de la reserva durante tres meses y utilizando áreas de menor elevación, a una distancia de hasta 5.5 km. Estas áreas se encuentran en un paisaje modificado que incluye campos agrícolas, carreteras y asentamientos humanos. Junto con datos previos de telemetría de poblaciones de Quetzales Resplandecientes en Centroamérica, estos hallazgos apoyan la ocurrencia de un comportamiento migratorio estacional en esta especie, lo cual indica una dependencia de hábitats distintos en diferentes épocas del año. El establecimiento de corredores biológicos podría proporcionar un paso seguro entre estos hábitats, facilitando el acceso a sitios de alimentación y descanso vitales, al tiempo que mitiga los efectos de aislamiento genético mediante una mayor conectividad y resiliencia genética. Sitios clave no protegidos dentro del área de estudio, como Ranchitos del Quetzal y parches de bosque a lo largo de la cuenca del río Panimá, ofrecen valiosas oportunidades para la conservación dirigida, con el objetivo de mejorar la conectividad del hábitat, salvaguardar recursos críticos e involucrar a las comunidades locales. Finalmente, la preservación y restauración de especies de plantas identificadas como fuentes alimenticias primarias deben priorizarse en áreas protegidas y adyacentes para asegurar una nutrición adecuada para los Quetzales Resplandecientes a lo largo de sus ciclos migratorios y reproductivos.

Palabras clave: Migración aviar, conectividad del hábitat, biología de la conservación, bosque nuboso, corredores ecológicos

Introduction

The Resplendent Quetzal (*Pharomachrus mocinno mocinno*) is a flagship species of cloud forest ecosystems, which are among the most biodiverse yet severely threatened habitats in Mesoamerica. The conservation of this species is closely tied to the preservation of its habitat, which also benefits numerous other species that coexist in these environments (Şekercioğlu et al., 2007). Despite its iconic status, the Resplendent Quetzal faces significant threats across its range, largely driven by the increasing conversion of cloud forests into agricultural land due to population expansion (Schulz & Eisermann, 2017). This habitat loss and fragmentation not only depletes essential resources but also isolates Resplendent Quetzal populations, impeding genetic exchange and amplifying their risk of extinction (Benscoter et al., 2013).

In addition to these external threats, Resplendent Quetzal's own ecological characteristics further exacerbate its vulnerability. The species relies on a specialized diet that includes fruits, insects, and snails, particularly important during the breeding season (Carleton & Smith, 2016; Wheelwright, 1983). The availability of fruiting plants, especially those from the Lauraceae family, is critical for the species' reproductive success and influences its migratory behavior (Solórzano et al., 2000). Furthermore, the Resplendent Quetzal exhibits complex altitudinal migration patterns (Powell & Bjork, 1994), which appear to be influenced, in part, by seasonal fluctuations and food availability by seasonal fluctuations and food availability (Solorzano et al., 2000; Wheelwright, 1983). These traits underscore the species' sensitivity to habitat changes, making it especially vulnerable to the disruptions caused by habitat fragmentation.

To address the conservation challenges faced by endangered species like the Resplendent Quetzal, understanding their movement patterns and habitat use at important areas of its distribution is essential. Telemetry tracking provides a powerful tool in this regard, offering real-time data on bird movements and critical insights into various ecological and environmental needs. For instance, telemetry facilitates the analysis of habitat selection, helping prioritize areas for protection and restoration to ensure that vital resources are available year-round (Martin et al., 2009). Moreover, telemetry offers valuable information on feeding behavior by identifying key foraging sites, important food items, and seasonal fluctuations in food availability. This data is crucial for tailoring conservation efforts to meet the dietary requirements of species, especially in habitats affected by human disturbances and the changing climate (Bolaños-Sittler et al., 2019), ensuring habitat management aligns with species-specific needs.

Furthermore, by assessing how birds move between fragmented habitats, telemetry can inform conservation strategies aimed at maintaining genetic diversity. The work of Gillies et al. (2011) emphasizes the importance of understanding movement patterns to evaluate the connectivity of populations, which is essential for preserving genetic diversity and reducing the risks of inbreeding. This is particularly relevant for species that may face genetic isolation due to habitat fragmentation (Gillies et al., 2011). This is particularly crucial for species that rely on specific habitats for breeding, migration, or foraging, as specialist species are more susceptible to the impacts of forest fragmentation compared to generalist species, posing a significant threat to their survival (Khimoun et al., 2016).

The aim of this survey was to describe the movement and habitat use of radio-tagged Resplendent Quetzals tracked via telemetry in the mountain region of Baja Verapaz, a key conservation area for the species in Guatemala.

In Guatemala, where information on *P. mocinno* is limited (Bolaños-Sittler et al., 2019), this study provides essential data to inform conservation strategies, such as establishing protected areas, restoring habitats, and implementing community-based initiatives. Integrating this knowledge into broader efforts will better support the preservation of the species and its critical cloud forest habitats.

Materials and Methods

Study area

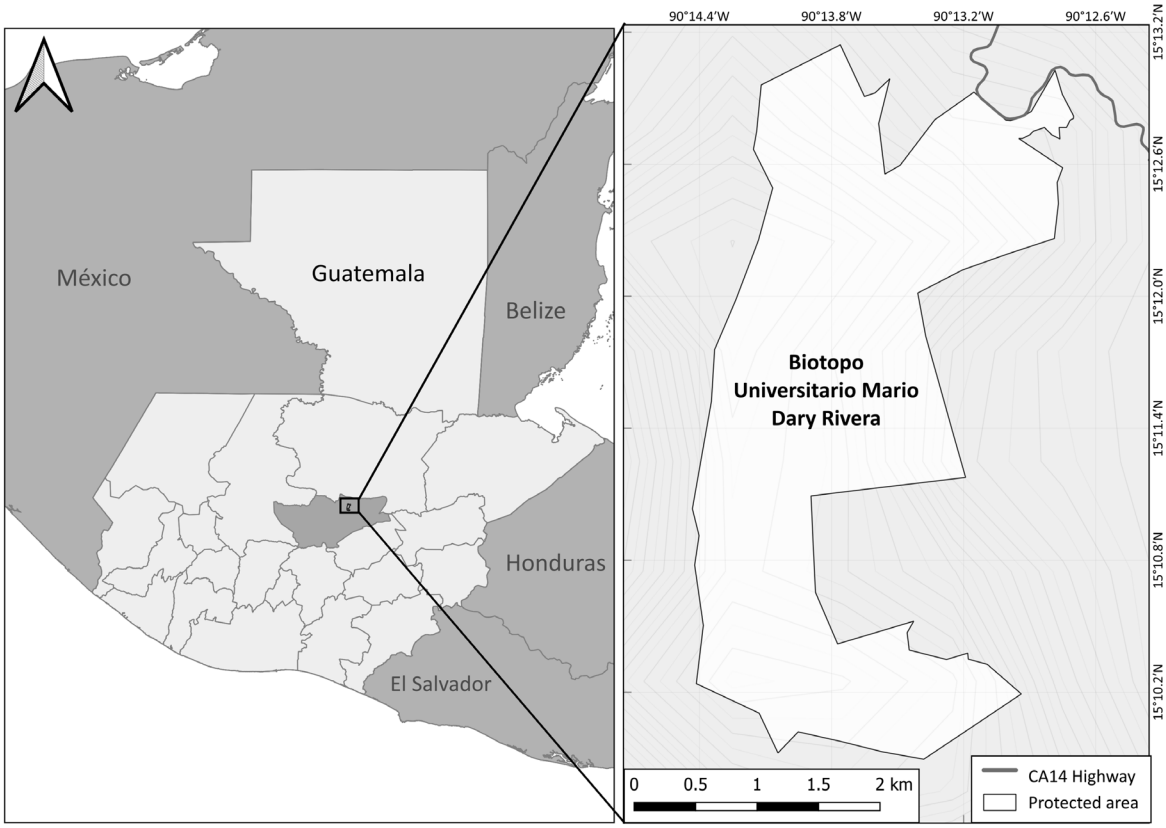
The study was conducted in a mountainous region of the department of Baja Verapaz, in northern Guatemala. The primary study site was the Biotopo del Quetzal, a protected area managed by the University of San Carlos of Guatemala (Figure 1). However, the research also included surrounding areas that are part of the Cloud Forest Biological Corridor, which encompasses several national protected areas, private

nature reserves, and indigenous communities. The Resplendent Quetzals tracked with telemetry were captured within the Biotopo del Quetzal.

The Biotopo del Quetzal is characterized predominantly by very humid lower montane tropical forest (bmh-MBT), with a smaller portion of humid pre-montane tropical forest (bh-MBT) (Instituto de Investigación y Proyección sobre Ambiente Natural y Sociedad, Universidad Rafael Landívar [IARLA-URL], 2018). The area experiences an average temperature of 18 °C, a relative humidity of 93.9%, and an average annual rainfall of 2,092 mm (Centro de Estudios Conservacionistas, 1999). The landscape surrounding the Biotopo del Quetzal includes several private protected areas and patches of cloud and mountain forest, either as part of restaurants, hotels, or farms with various land uses. Notable locations include Hotel Posada Montaña del Quetzal, Cerro Verde, Hotel y Restaurant Ranchitos del Quetzal, and Biotopín, all of which are classified as very humid pre-montane tropical forest (bmh-PMT).

Figure 1

Map of the study area showing the location of the Biotopo del Quetzal protected area in Baja Verapaz, Guatemala



Capture Methods and Telemetry Deployment for Resplendent Quetzals

We captured Resplendent Quetzals within the touristic sector of the Biotopo del Quetzal using a combination of five vertical mist nets (12 m long, 12 shelves, 38 mm mesh) and five horizontal mist nets (12 m long, 38 mm mesh). The nets were strategically placed in front of previously identified feeding trees, including Aguacatillo (*Persea donnell-smithii* Mez), Guarumo (*Cecropia peltata* L.), and Ciprecillo (*Podocarpus oleifolius* D. Don). Capture efforts took

place over 16 sampling periods, each lasting five days, from February to July 2011 and October 2011 to April 2012.

Captured individuals were fitted with Telenax radio transmitters (TXN-008B model), which weighed less than 4% of the average Resplendent Quetzal body mass (185-388 g) (Dayer, 2020; Solórzano & Oyama 2010). The transmitters had a battery life of seven months and a coverage range of up to 20 km in a straight line without obstacles.

Radio transmitters were secured to the birds using a nylon harness fitted on their back. Movements of the tagged individuals were monitored using a portable receiver (Telenax RX-TLNX) and a handheld antenna.

Monitoring and Tracking Radio-Tagged Resplendent Quetzals

The tracking was conducted for 15 days each month during the sampling period from July 2010 to June 2011. The daily monitoring was done regularly from 5:00 a.m. to 5:30 p.m. Bird locations were plotted on a digital map with forest cover and reserve boundaries using ArcGIS software. Additionally, behavioral observations were recorded, including feeding, resting, grooming, flying, movement, and sleeping behaviors. The identification of Resplendent Quetzal food plants was carried out by collecting botanical samples, which were pressed and identified with the help of expert botanists. These specimens were deposited in the USCG herbarium at the University of San Carlos of Guatemala. However, due to the common nature of some species and the herbarium's capacity limitations, not all specimens were formally archived. We also recorded the fruits and other food items consumed by the Resplendent Quetzal at the study site, categorizing their frequency of consumption as follows: Common (more than 10 observations per month), Moderately common (1 to 10 observations per month), and Rare (1 to 3 times per month).

Results

Two Resplendent Quetzals were captured for tracking: one male on July 17, 2010, using a vertical mist net set 5 meters high in a Guarumo (*Cecropia peltata* L.) tree, and one female on January 24, 2012, using a horizontal net placed approximately 3 meters high in front of an Aguacatillo (*Persea donnell-smithii* Mez) tree. Both individuals were trapped near the parking lot of the Biotopo del Quetzal Reserve.

The male weighed 214 grams and displayed no signs of body fat or molting. Its tarsus measured 3.52 cm, and its tail length was 42.5 cm (Figure 2). The female weighed 211 grams and displayed moderate fat reserves in the abdomen and flanks. Her tail measured 18.20 cm, and her tarsus was 3 cm long (Figure 2).

Figure 2

Male Resplendent Quetzal with a radiotransmitter (left and bottom) and female (top right) tracked in Biotopo del Quetzal and the Corredor Biológico del Bosque Nuboso, Baja Verapaz, Guatemala.

During the first four months of tracking (July to October 2010), the male primarily slept and foraged within the touristic area of the Biotopo del Quetzal, moving daily from his overnight roost at 1,959 meters above sea level (masl) to his main feeding site

at 1,600 masl near the reserve's border. He followed a consistent routine. At dawn (approximately 5:00-5:45 a.m.), he would leave his roost in a tall tree and descend gradually to lower-altitude foraging areas, taking around 30 min with pauses. Feeding sessions at his primary site near the reserve boundary lasted about 30 min, during which he obtained fruit either in flight or while perched. After feeding, he typically rested for 45 min to 1 h, perching on the feeding tree or nearby branches, preening, and regurgitating previously consumed fruits.

Inside the Biotopo del Quetzal, the male primarily utilized a roosting site known as Entrada a Quisis (coordinates: 15.20885, -90.22247), situated at an elevation of 1,959 m.a.s.l. He also frequented Rancho de Conclusiones (coordinates: 15.21274, -90.22045) at 1,809 m.a.s.l., where he fed fruits from Guarumo and Guarumo flaco (*C. silvicola*), Ciprecillo, and occasionally butterfly caterpillars. Another feeding site was along the Los Helechos trail (coordinates: 15.21301, -90.21694) at 1,625 m.a.s.l., where he consumed Guarumo, Frutillo (*Cornus disciflora*), and Ciprecillo. Additionally, he foraged along the CA-14 highway at elevations between 1,600 and 1,630 m.a.s.l., including areas at the edge of the Biotopo del Quetzal, where he fed on guarumo, frutillo, *Rhamnus capreifolia*, and *Clusia guatemalensis* Hemsl. Vegetation from the Hotel Ranchitos del Quetzal and Biotopin areas provided additional food sources, such as Guarumo, Frutillo, and *Prunus* sp.

During this observation period, several regurgitated fruits were collected, including Aguacatillo (twice), Frutillo (four times), *Syzygium jambos* (once) (a cultivated species found in the tourist areas of both Ranchitos del Quetzal and Biotopín), and *Prunus brachybotrya* (once). Examination of the fruits revealed that the pulp, skin, and flesh were not fully ripe, often showing a slightly green or pale coloration. It is likely that regurgitation occurred because the fruits were under-ripe, as previously noted by Ávila et al. (1996).

While the Resplendent Quetzal male was frequently observed alone, he was seen with a female on seven occasions and with both a female and another male on five occasions. Between 11 a.m. and 2 p.m., the male regularly rested and resumed feeding activities between 3:30 and 4:00 p.m. Typically, in the late afternoon, between 5:00 and 5:30 p.m., the male would begin his ascent to the roosting site after a prolonged resting period from 3:00 to 5:00 p.m.

During the tracking period, the male was recorded feeding on 12 plant species (Table 1). The most frequently consumed fruits were guarumo and frutillo. Additionally, occasional consumption of worms (observed twice) and flying insects (observed three times) was noted.

Table 1

Fruit-bearing plant species consumed by male Resplendent Quetzal tracked at the study site from July 2010 to January 2011. Monthly consumption frequencies categorized as: Common (C) = more than 10 observations, Moderate (M) = 3-10 observations, and Rare (R) = 1-3 observations

				Month						
N.	Family	*Plant* specie	Commun local name	Jul 2010	Aug 2010	Sep 2010	Oct 2010	Nov 2010	Dec 2010	Jan2011
1	Clusiaceae	*Clusia salvinii* Donn. Sm.	Oreja de burro	R	R	R				
2	Cornaceae	*Cornus disciflora* D.C.	Frutilo	C	C	C	C	C	C	
3	Lauraceae	*Ocotea* sp.	Aguacatillo					R		
4	Lauraceae	*Persea donnell-smithii* Mez	Aguacatillo					R		
5	Myrtaceae	*Syzygium jambos* (L.) Alston				R	M	M		

Tabla 1 (Continuación)

N.	Family	*Plant* specie	Commun local name	Month						
				Jul 2010	Aug 2010	Sep 2010	Oct 2010	Nov 2010	Dec 2010	Jan2011
6	Podocarpaceae	*Podocarpus oleifolius* D. Don	Cipresillo	M	M	C	C			
7	Rhamnaceae	*Rhamnus capreifolia* Schltdl.				M	M	M		
8	Rosaceae	*Prunus brachybotrya* Zucc.				R	R	R		
9	Rosaceae	*Prunus* sp.					M	R		
10	Rosaceae	*Rubus* sp.	moras	R	R	R			R	
11	Urticaceae	*Cecropia peltata* L.	Guarumo	C	C	C	C			
12	Urticaceae	*Cecropia sylvicola* Standl. & Steyerm.	Gurarumo flaco		C	C	C			

From November 2010 to February 2011, the male began using sites beyond the Biotopo del Quetzal and nearby areas for sleeping, resting, feeding, and roosting (Figure 2). The first recorded site, on November 10, was 600 meters from the Biotopo in a straight line, at a leatherleaf fern (*Rumohra adiantiformis*) farm with degraded forest cover. At this site, the male was observed feeding twice on *Ocotea* and *Persea* fruits. During a 10-day sampling period, he was recorded on this area five times before the transmitter signal was lost, and he was not relocated until around December 10, 2010.

From December 12 to 20, the male traveled up to 5.5 km from his previous location, reaching elevations of 1,350 to 1,479 meters across bmh-MBT and bh-PMT forest types. Tracking was challenging due to intermittent transmitter signals, which prevented visual confirmation. By December 22, he was detected in a well-preserved forest remnant along the Panimá River basin, near Panimaquito and Sachut. Steep, rocky terrain limited access, and while his transmitter signal was detectable, his position in a ravine made him unreachable, where he remained for about a week.

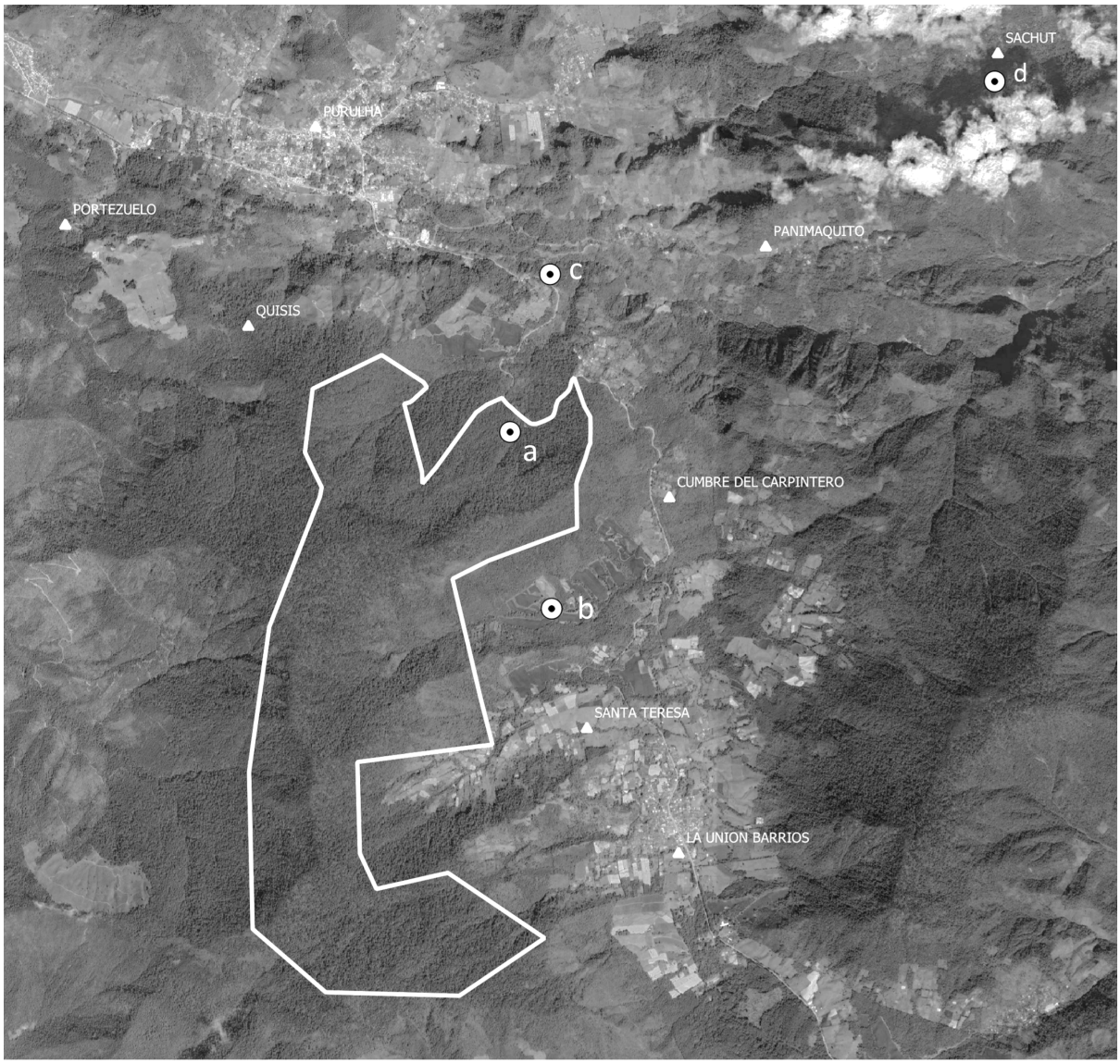
By the end of January 2011, the male returned to the Biotopo del Quetzal and stayed within its boundaries until the radio transmitter's battery was depleted around February 5, 2011.

The radio-tagged female stayed within the Biotopo del Quetzal and neighboring areas, such as Ranchitos del Quetzal and Biotopín, for five months, until her transmitter ceased functioning. These areas are located adjacent to the Biotopo's boundary, causing the bird to travel just a few meters beyond Biotopo's limits to access them.

She roosted at the forest edge near Hotel Ranchitos del Quetzal, starting her day around 5:00 a.m. by moving to fruit-bearing trees near the road in the Biotopo's tourist section. During a 20-day sample period, she was recorded in 12 days. Like the male, she fed actively from 6:00 to 11:00 a.m., with occasional 30-40-minute breaks for grooming, regurgitating, and digesting. From noon to 3:00 p.m., she was less active, perching in one spot or moving minimally. Feeding resumed in a broader area from 3:00 to 4:30 or 5:00 p.m., after which she returned to her root by 5:30 p.m. During this time, she fed fruits from seven species including aguacatillo (*Persea donnell-smithii*

Figure 3

Sites visited by the radio-tagged Resplendent Quetzal male during the survey. a) borders of the BUCQ reserve (marked in white), b) Leather leaf (Rumohra adiantiformis) farm at Santa Teresa Village, c) forest patch along the Panimá river basin and d) Forest surrounding Sachut Village.



near the reserve's border, as well as from Frutillo, *C. disciflora,* and Guarumo (Table 2). The female relied on the Biotopo del Quetzal as her primary habitat but also ventured into nearby areas for feeding and resting during the breeding season.

Table 2

Fruit-bearing plant species consumed by female Resplendent Quetzal tracked at the study site from January to May 2012 with monthly consumption frequencies categorized as Common (C) = more than 10 observations, Moderate (M) = 3-10 observations, and Rare (R) = 1-3 observations.

				Month			
N.	Family	Plant specie	Commun local name	Jan	Feb	Mar	Apr
1	Cornaceae	*Cornus disciflora* D.C.	Frutilo			C	C
2	Lauraceae	*Persea donnell-smithii* Mez	Aguacatillo	C	R		
3	Rhamnaceae	*Rhamnus capreifoli*a Schltdl.				M	M
4	Rosaceae	*Prunus brachybotrya* Zucc.				R	R
5	Rosaceae	*Prunus* sp.				R	M
6	Rosaceae	*Rubus* sp.	Moras		R	R	
7	Urticaceae	*Cecropia peltata* L.	Guarumo	C	C	C	C

Discussion

Our telemetry data showed that the two tracked Resplendent Quetzals stayed within specific areas of their primary habitat in the Biotopo del Quetzal Cloud Forest for at least five months, following established routines. However, during the non-breeding season, the male exhibited increased mobility, moving to lower altitudes. Similar patterns observed in other telemetry studies (Paiz, 1996; Powell & Bjork, 1994) emphasize the need to conserve both breeding and migratory habitats.

The causes of Resplendent Quetzal's altitudinal migration are partially understood but are closely tied to ecological factors, such as food availability and habitat conditions. These seasonal movements reflect a strategic adaptation to secure vital resources, particularly ripe Lauraceae fruits, which are scarce in breeding areas at certain times of the year (Carleton & Smith, 2016; Solórzano et al., 2000).

Our observations indicate that these birds not only traverse degraded areas but also utilize them for foraging and resting. This behavior has been observed in other studies, which show that Resplendent Quetzals rely on degraded habitats for essential activities such as foraging and resting (Solórzano et al., 2000, 2004).

However, dependence on these disturbed habitats increases their vulnerability to threats like predation and vehicle collisions, particularly in urbanized areas (Bolaños-Sittler et al., 2019). Addressing these challenges requires habitat restoration and the establishment of ecological corridors to connect fragmented habitats. Corridors enable quetzal movement across elevations, improving access to resources and maintaining genetic diversity (Şekercioğlu et al., 2007). Additionally, these corridors support ecosystem resilience and biodiversity by linking habitat patches and facilitating species adaptation to environmental changes (Clark, 2004; Rogers & Allen, 2011).

In the region, significant progress has been made with the establishment of the Cloud Forest Biological Corridor, which encompasses multiple protected areas, private reserves, and green spaces within

tourist sites. While this initiative is crucial, it must be expanded as habitat degradation continues to threaten the region's ecological integrity. Expanding the corridor and establishing protected areas across high and low elevations remain critical for the Resplendent Quetzal's seasonal migrations and the long-term conservation of its ecological role (Fraser et al., 2010).

Our observations indicate that Resplendent Quetzals not only traverse degraded areas but also utilize them for foraging and resting, as documented in previous studies (Solórzano et al., 2000, 2004). However, reliance on disturbed habitats increases their vulnerability to threats such as predation and vehicle collisions in urbanized landscapes (Bolaños-Sittler et al., 2019). Addressing these challenges requires habitat restoration and the establishment of ecological corridors that connect fragmented habitats, enabling quetzal movement across elevations while maintaining genetic diversity and access to critical resources (Şekercioğlu et al., 2007). These corridors also enhance ecosystem resilience and biodiversity by linking habitat patches (Rogers & Allen, 2011).

In the region, progress has been made with the Cloud Forest Biological Corridor, which includes several protected areas, private reserves, and green spaces in tourist sites. However, the corridor must be expanded to address ongoing habitat degradation. Our data identified several critical areas, including Ranchitos del Quetzal, forest patches in the Panimá River basin, and forests near Sachut and Santa Teresa villages, as key migratory habitats for the Resplendent Quetzal. These sites provide essential resources during the non-reproductive season and function as inter-reproductive habitats that support the quetzal population from the Biotopo del Quetzal Cloud Forest (BUCQ) during the latter part of the year.

Although our survey tracked each Resplendent Quetzal for less than a year, data from both individuals, along with Paiz's (1999) study in the Sierra de las Minas Biosphere Reserve, show that some quetzals from northern Guatemala migrate to lower altitudes during the non-breeding season to forage, roost, and rest. Multiple studies support that this migratory behavior is consistent across populations, further validating the importance of our findings in enhancing the understanding of quetzal movement patterns in different regions.

Although the fieldwork for this study was conducted over a decade ago (2011-2012), its findings remain relevant for several reasons. It provides a historical baseline for Resplendent Quetzal presence and ecological behavior in the region, essential for understanding long-term trends in habitat use, population dynamics, and distribution patterns. This is particularly important given ongoing environmental changes and deforestation that may have altered site conditions. Additionally, the study adds valuable data to the limited research on Resplendent Quetzal´s habitat needs, informing future conservation strategies. Finally, it offers an opportunity to compare historical and recent data, identifying areas for further research and conservation.

Acknowledgments

The authors would like to thank the National Council of Science and Technology (Consejo Nacional de Ciencia y Tecnología) and the Government of Guatemala through the National fund for Science and Technology [Fondo Nacional de Ciencia y Tecnología (FODECYT 40-2009)] for given financial support for the research. To Lic. Mayra Oliva, director of the protected area Biotopo del Quetzal, for her collaboration and support throughout the study. Without her help, this study would not have been possible.

Contribution of authors

Drafting and revising the manuscript: M.B-C.
Conception and design of the study: M.B-C., M.A.B-I.
Collecting of data: all the authors
Cleaning data, performing the analysis, and/or interpretation of data: M.B-C., M.A.B-I.
Editing the manuscript critically for important intellectual content: all the authors

Supplementary Materials

Data are within the paper.

References

Ávila, M., Hernandez, V., & Verlarde E. (1996). The diet of resplendent Quetzal *(Pharomachrus Moncinno mocinno:* Trogonidae) in a Mexican cloud forest. *Biotropica, 28*(4b), 720-727. https://doi.org10.2307/2389058

Benscoter, A. M., Reece, J. S., Noss, R. F., Brandt, L. A., Mazzotti, F. J., & Romañach, S. S. (2013). Threatened and endangered subspecies with vulnerable ecological traits also have high susceptibility to sea level rise and habitat fragmentation. *PLOS One, 8*(8), Article e70647. https://doi.org/10.1371/journal.pone.0070647

Bolaños-Sittler, P., Sueur, J., Fuchs, J., & Aubin, T. (2019). Vocalisation of the rare and flagship species Pharomachrus mocinno (aves: Trogonidae): Implications for its taxonomy, evolution and conservation. *Bioacoustics, 29*(6), 654-669. https://doi.org/10.1080/09524622.2019. 1647877

Carleton, S. A., & Smith, K. G. (2016). Adult nest attendance and diet of nestling resplendent quetzals *(pharomachrus mocinno)* in the Talamanca mountains of Southern Costa Rica. *Ornitología Neotropical, 27,* 181-188. https://doi.org/10.58843/ornneo.v27i0.116

Chen, J., & Wang, Y. (2024). Effects of habitat fragmentation on bird behavior and extinction mechanisms. *International Journal of Molecular Zoology, 14*(2), 97-110. https://doi.org/10.5376/ijmz.2024.14.0011

Centro de Estudios Conservacionistas. (1999). *Plan Maestro 2000 -2004 Biotopo Universitario "Mario Dary Rivera" para la Conservación del Quetzal.* Universidad de San Carlos de Guatemala.

Clark, M. R. (2004). Using the spectacled bear as a conservation tool in the condor bioreserve, Ecuador. *Journal of Sustainable Forestry, 18*(2-3), 223-236. https://doi.org/10.1300/j091v18n02_10

Dayer, A. A. (2020). Resplendent Quetzal *(Pharomachrus mocinno)* (version 1.0). In T. S. Schulenberg (Ed.), *Birds of the World* Cornell Lab of Ornithology. https://doi.org/10.2173/bow.resque1.01

Fraser, K., McKinnon, E., & Diamond, A. (2010). Migration, diet, or molt? interpreting stable-hydrogen isotope values in neotropical bats. *Biotropica, 42*(4), 512-517. https://doi.org/10.1111/j.1744-7429.2009.00608.x

Gillies, C., Beyer, H., & Clair, C. (2011). Fine-scale movement decisions of tropical forest birds in a fragmented landscape. *Ecological Applications, 21*(3), 944-954. https://doi.org/10.1890/09-2090.1

Instituto de Investigación y Proyección sobre Ambiente Natural y Sociedad de la Universidad Rafael Landívar. (2018). *Ecosistemas de Guatemala basado en el sistema de clasificación de zonas de vida.*

Martin, J., Tolon, V., Van Moorter, B., & Calenge, C. (2009). On the use of telemetry in habitat selection studies. In D. Barculo & J. Daniels (Eds.), *Telemetry: Research, technology and applications* (pp. 1–18). Nova Publishers.

McKinnon, E. A., Fraser, K. C., & Stutchbury, B. J. M. (2013). New discoveries in landbird migration using geolocators, and a flight plan for the future. *Ornithology, 130*(2), 211-222. https://doi.org/10.1525/auk.2013.12226

Paiz, M. C. (1996). Migraciones estacionales del Quetzal (Pharomachrus mocinno mocinno de la Llave) *en la región de la Sierra de las Minas, Guatemala y sus implicaciones en la conservación de la especie* [Tesis de licenciatura, inédita]. Universidad del Valle de Guatemala.

Powell, G. V. N., & Bjork, R. D. (1994). Implications of Altitudinal Migration for Conservation Strategies to Protect Tropical Biodiversity: A Case Study of the Resplendent Quetzal *Pharomachrus mocinno* at Monteverde, Costa Rica. *Bird Conservation International, 4*(1), 161-174. https://doi.org/10.1017/S0959270900002744

Rogers, M. W., & Allen, M. S. (2011). An ecosystem model for exploring lake restoration effects on fish communities and fisheries in Florida. *Restoration Ecology, 20*(5), 612-622. https://doi.org/10.1111/j.1526-100x.2011.00819.x

Schulz, U., & Eisermann, K. (2017). Morphometric differentiation between subspecies of Resplendent Quetzal *(Pharomachrus mocinno mocinno* and P. *m. costaricensis)* based on male uppertail-coverts. *Bulletin of the British Ornithologists' Club, 137*(4), 287-291. https://doi.org/10.25226/bboc.v137i4.2017.a6

Şekercioğlu, Ç., Loarie, S. R., Brenes, F. O., Ehrlich, P. R., & Daily, G. C. (2007). Persistence of forest birds in the Costa Rican agricultural countryside. *Conservation Biology, 21*(2), 482-494. https://doi.org/10.1111/j.1523-1739.2007.00655.x

Solórzano, S., Baker, A. J., & Oyama, K. (2004). Conservation priorities for resplendent quetzals

based on analysis of mitochondrial DNA control-region sequences. *Ornithological Applications, 106*(3), 449-456. https://doi.org/10.1093/condor/106.3.449

Solórzano, S., Castillo, S., Valverde, T., & Ávila, L. (2000). Quetzal abundance in relation to fruit availability in a cloud forest in southeaestern México. *Biotropica, 32*(3), 523-532. https://doi.org/10.1111/j.1744-7429.2000.tb00498.x

Solórzano, S., García-Juárez, M., & Oyama, K. (2009). Genetic diversity and conservation of the resplendent Quetzal *Pharomachrus mocinno* in Mesoamerica. *Revista Mexicana de Biodiversidad, 80*(1), 241-248. https://doi.org/10.22201/ib.20078706e.2009.001.600

Solórzano, S., & Oyama, K. (2010) Morphometric and molecular differentiation between Quetzal subspecies of *Pharomachrus mocinno* (Trogoniformes: Trogonidae). *Revista de Biología Tropical, 58*(1), 357-371.

Wheelwright, N. T. (1983). Fruits and the ecology of resplendent quetzals. The Auk, 100(2), 286-301. https://doi.org/10.1093/auk/100.2.286