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An Update on the Distribution and Abundance of the Endemic and Threatened Olalla's Titi Monkey (*Plecturocebus olallae*)

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Abstract: Population size is crucial knowledge for biodiversity conservation. The Olalla's titi monkey (*Plecturocebus olallae*) is endemic to Bolivia and one of the most threatened primate species in the Neotropics. We report a new occurrence zone for this species that increases their previously known distribution from 267.4 to 383.4 km². With a playback point count survey to assess the presence of these primates, we estimated a density of 7.5 groups/km². Based on this expanded distribution, we estimate a total population of 2,855 individuals for *P. olallae* (adding 640 individuals to previous estimates). We also provide new information on uncontrolled fires as a conservation threat to the habitat of *P. olallae*. These findings provide hope for the conservation of these highly threatened primates restricted to naturally fragmented forests and will be helpful for the development of appropriate monitoring and protection.

Keywords: Beni, Bolivia, conservation, fragmented forests, threats

Introduction

An understanding of the distribution and abundance of wildlife species, including primates, is key to assessing and monitoring their conservation status and to prioritize conservation actions (IUCN 2012; Estrada *et al.* 2017). Information in this regard is especially relevant for highly threatened species for which every contribution can mean substantial improvements in conservation efforts. The Olalla's titi monkey (*Plecturocebus olallae*) is endemic to Bolivia, and among the world's most threatened primates (Martinez and Wallace 2016a, 2019). Described by Lönnberg in 1939, field information on these primates has been available only since the beginning of the century, revealing a small population of about 2,000 individuals restricted to an area of just 267 km² in a region of natural savannahs with fragmented forests (Fig, 1; Martinez and Wallace 2010; Wallace *et al.* 2013). This species faces considerable risks due to forest loss associated with uncontrolled fires linked to the management of grasslands as pasture for cattle ranching, the main economic activity in the region, as well as the improvement of a major road passing close to its range (North Corridor; Martinez and Wallace 2010; Porter *et al.* 2013; Wallace *et al.* 2013). High levels of forest fragmentation can promote unusual and risky terrestrial displacements of *P. olallae* while trying to reach feeding sites, and even the smoke from a nearby fire was found to be the cause of the loss of a titi monkey territory (Martinez and Wallace 2011).

Knowledge on the endemism and conservation needs for *P. olallae* was shared with local stakeholders, including authorities of the municipalities of Santa Rosa and Reyes, which cover most of this species' range. This outreach, together with local interest in consolidating ecotourism to promote sustainable development in the region, facilitated the creation of two municipal protected areas (Wallace *et al.* 2013, Fig. 1). These protected areas were created to preserve the natural patrimony that constitutes the attractiveness of the region, and the Olalla's titi monkeys are conservation priorities for both areas.

Further conservation research has demonstrated that these monogamous primates have home ranges of approximately 7 ha (Martinez and Wallace 2015, 2016a). Outreach work has raised awareness among local people about the presence and importance of *P. olallae* in the region (Martinez *et al.* 2015). Important progress on the management of subnational protected areas was recently achieved, including

Figure 1. Location of La Asunta and Palo Escrito sample sites within the distribution of *Plecturocebus olallae* (outlined by the orange line). The North Corridor and the two Municipal Protected Areas (MPA) are shown, as well as the grid system established for the presence assessment of *P. olallae*.

the development of management plans for the Pampas del Yacuma Municipal Protected Area in Santa Rosa (GAMSRY 2016), and subsequently the Rhukanrhuka Municipal Protected Area in Reyes, the name of which means titi monkey in the Maropa native language (HCMSR 2019).

There is an urgent need for updated information on the *P. olallae* population to further design conservation measures and continue monitoring efforts. Here we present updated information on the abundance and distribution of this endemic primate, as well as threats to their conservation.

Methods

Study area

In October 2019, we searched for groups of Olalla's titi monkeys in and around the cattle ranches of La Asunta (66°58'40.32"W; 14°14'32.24"S) and Palo Escrito (67°6'25.27"W; 14°23'13.90"S). Both sites were in the largest forested areas in the range of *P. olallae* (Fig. 1) and were selected based on prior knowledge of their distribution (Martinez and Wallace 2007, 2010; Wallace *et al.* 2013).

Following local reports about the presence of titi monkeys, we visited a third site at the Oriente del Yacuma community for three days in December 2019. This zone was outside of the known distribution of *P. olallae* (Fig. 1).

Uncontrolled fires annually affect large areas in this region and often arise from the traditional management of grasslands as pasture for cattle ranching (Martinez and Wallace 2010). Although dramatic changes in forest coverage were not identified, alterations in plant composition may occur in forest patches affected by fires, reducing habitat suitability for titi monkeys and other wildlife species (Wallace *et al.* 2013).

Data collection and analysis

We used a grid system with 250 × 250 m cells in which the presence of *P. olallae* groups was assessed. As the cell size of 6.25 ha is similar to the home range of these titi monkeys (7.2 ha; Martinez *et al.* 2015), each cell was considered as a potential space where a group could be found. Based on satellite imagery (IKONOS – Space Imaging 4-m MS and Global Mapper – Blue Marble Geographics), we identified cells with at least 75% forest cover, thereby avoiding grassland areas not inhabited by primates. From the forested cells, we defined two sampling areas of 300 cells for the La Asunta and Palo Escrito study sites (Fig. 1).

At each grid cell, we assessed the presence of Olalla's titi monkeys by means of six point counts separated by 75 m in which we performed the playback of their territorial calls and waited for any vocal or visual response for five minutes. We sampled cells in two working teams (two

people each), from approximately 6:30 to 12:30 h during 23 fieldwork days. The playback technique was chosen based on previous work with this species (Martinez and Wallace 2007; Lopez-Strauss and Wallace 2015), and the number of point counts per cell was established from pilot sampling. Although playback permits the detection of titi monkeys at times when they do not normally vocalize (Martinez and Wallace 2007, 2016b; Lopez-Strauss and Wallace 2015), we collected data only until midday to maximize detection probability and avoid time bias.

For each point count we registered the time of playback, the georeferenced location, and a description of the habitat. When we obtained a vocal response or observed titi monkeys after playback, we recorded their location based on a compass bearing and estimated distance. For observed groups, we registered the number of individuals and their age category based on body size (Martinez and Wallace 2007; Lopez-Strauss and Wallace 2015). We also used playback at the Oriente del Yacuma community to assess the presence of *P. olallae* through an exhaustive search based on local information.

Identification of the titi monkeys was based on color patterns of body and tail fur, as well as relative fur length (Martinez and Wallace 2007, 2010; Martinez *et al.* 2013). This was relevant due to the close distributional proximity and morphological similarity between Olalla's titi monkey and the Beni titi monkey (*Plecturocebus modestus*: Martinez and Wallace 2007, 2010; Wallace *et al.* 2013). Although previous knowledge demonstrates the non-overlapping ranges of these two Bolivian endemic primate species, we aimed to directly observe detected individuals to make sure of their identity.

To obtain density and population size estimations, we combined the number of groups per sample area with the size of titi monkey groups (Lopez-Strauss and Wallace 2015). Firstly, we processed the distance and compass bearing records of each point count to obtain a map with which to plot observed group locations ('Bearing Distance to Line' tool, ArcMap v.10.4) and determine the number of groups found at each sampling site. For each site we also calculated the forest sampled area by multiplying the sampled area (from the number of cells assessed, 6.25 ha each) with the average proportion of forest coverage in the cells. We combined the number of detected groups and the forest sampled area to obtain a group density estimation per km² of forest for each sample site.

As the satellite imagery data used for this study has a higher resolution than in previous work, allowing a more accurate identification of forest patches, we adjusted the distribution polygon of *P. olallae* and estimated the forest area within the new polygon. We multiplied the polygon area by previously calculated average group densities, obtaining an estimated total number of groups. We calculated mean titi monkey group size from the number of individuals in observed groups, to produce an estimated population size for *P. olallae*.

Results

We sampled a total of 380 grid cells, covering an area of 23.75 km² (6.69 and 17.06 km² at the La Asunta and Palo Escrito sites, respectively), detecting a total of 86 groups of Olalla's titi monkeys (Table 1). We were able to directly observe 55 groups, which ranged between one to five individuals (mean group size = 2.4 individuals, SD = 1.1).

Our adjusted polygon of the *P. olallae* distribution range had an area of 269.8 km² in which forest coverage was approximately 45% (Fig. 2). The average proportion of forest coverage in assessed grid cells varied between sampling sites (0.51 and 0.86 for La Asunta and Palo Escrito, respectively), resulting in forest sampled areas of 3.4 km² for La Asunta and 14.7 km² for Palo Escrito. At La Asunta, areas dominated by shrubs up to 3 m in height and very few trees were not sampled, as this habitat is not suitable for primates. Tall forest (20 m) at Palo Escrito was dominated by motacú palm (*Attalea* sp.), where most of our capuchin monkey (*Sapajus apella*) observations occurred, and where we did not register *Plecturocebus*.

From the sampled forest area and the number of detected groups, our density estimations were 12 *P. olallae* groups/km² of forest at La Asunta and 3.1 groups/km² of forest at Palo Escrito. Using the average of these values (7.5 groups/km²) and the forest area in the distribution polygon (121.4 km²), we obtained an overall estimate of 916 groups that, adjusted with average group size (2.4 individuals), resulted in an estimated population size for *P. olallae* of 2,215 individuals.

Our visit to the Oriente del Yacuma community confirmed the presence of Olalla´s titi monkeys with the observation of three groups (3, 3, and 2 individuals, respectively) in an area about 11 km south of the known distributional limit for this species. Based on this result and additional local information, we adjusted the distribution polygon of *P. olallae* again, increasing the polygon to 383.4 km² in which forest coverage is about 54% (Fig. 2). Due to habitat similarity, we used the Palo Escrito density estimation to calculate abundance in the new distribution area (113.6 km² with proportional forest coverage of 0.76), obtaining 264.8 groups and 640.3 individuals. By combining our abundance

Table 1. Number of *Plecturocebus olallae* groups detected and observed at each sample site.

Sample site	Area sampled (km²)	Groups detected	Groups observed
La Asunta	6.69	41	26
Palo Escrito	17.06	45	29

Figure 2. Original (orange thin line) and adjusted (green broad line) range estimate of *P. olallae* based on 2013 information. The new 2020 polygon (yellow broad line) expands the distribution to the south based on our findings at the Oriente del Yacuma community. Locations of *P. olallae* groups known to date are marked with small circles, while orange pentagons show the new southern records.

estimations, we obtained a total population of size of 1,180.7 groups or 2,855.1 individuals of *P. olallae* in its new and expanded distribution range.

All the observed titi monkeys, including the groups found at Oriente del Yacuma, had a reddish-brown body. The body fur was also relatively long, causing a recognizable fluffy appearance. The tail was dark grayish. They had white ear-tufts of distinct sizes, as well as a vertically elongated head shape. The hands and feet were predominantly black. In some cases, we observed the capillary coloration of the body fur consisting of a broad orange band and a darker tip, without any agouti color pattern. Some individuals had a narrow darker zone surrounding the face.

Field observations suggest that no significant forest habitat loss had occurred at La Asunta in the last five years, despite the occurrence of fires there. We found some new connections between forest patches previously visited, including the territory of a previously studied *P. olallae* group. Local people at Palo Escrito reported that, in mid-September 2019, an uncontrolled fire reached the area from the north, burning the margins of some forest areas. We found evidence of the effects of that fire in 83 grid cells (5.2 km²), corresponding to 30.4% of our sampling area at Palo Escrito (Fig. 3), with the shrubby understorey the most affected stratum (Fig. 4). After the fire, the general shape of forest patches remained quite similar, although in some areas the understorey was almost completely lost. We found groups of *P. olallae* in 17 cells affected by fire (20.5% of burned cells), where the understorey still retained most of its original shrub and vine coverage.

Discussion

This study updates the previously documented distribution and population estimate for Olalla's titi monkeys (Martinez and Wallace 2007, 2016a; Lopez-Strauss and Wallace 2015; Wallace *et al.* 2013). The new information increases the distribution and population size, and provides complimentary information on conservation threats, together representing important findings to update conservation actions for these endemic primates.

Regarding the identity of observed titi monkeys, the fur coloration corresponds to *P. olallae* (Martinez and Wallace 2007, 2010). Apart from the general coloration, the observed absence of an agouti banding pattern in the hair is the main difference with *P. modestus* that do have several alternating light and dark bands, resulting in a non-uniform grayish brown body fur coloration (Martinez *et al.* 2013). Also, the grayish tail of *P. modestus* clearly contrasts with body color while in *P. olallae* the contrast is lower. In this way, we confirmed that all the observed titi monkeys were *P. olallae*, and not its nearest neighbor, *P. modestus*.

In addition, although the nearest record of *P. modestus* is reported at the Las Abras community around 8 km northeast from Oriente del Yacuma, local people reported a seasonally flooded area between both communities, where vegetation is mainly shrubby, with few trees, and with no resident primates. This description of the vegetation indicates it is similar to the areas where no titi monkeys are found at the La Asunta site and concurs with previous suggestions that flooded areas act as a barrier between the *P. olallae* and *P. modestus* populations (Martinez and Wallace 2010; Wallace *et al.* 2013).

Variations in forest structure and plant composition constitute distinct habitat conditions for primates (Wiafe 2014). We were able to identify variations in forest coverage not recognizable from satellite imagery, with areas of shrubs and very few trees clearly not suitable habitat for the titi monkeys. Titis were also absent in tall forests with a clear dominance of motacú palm (*Attalea* sp.). The presence of

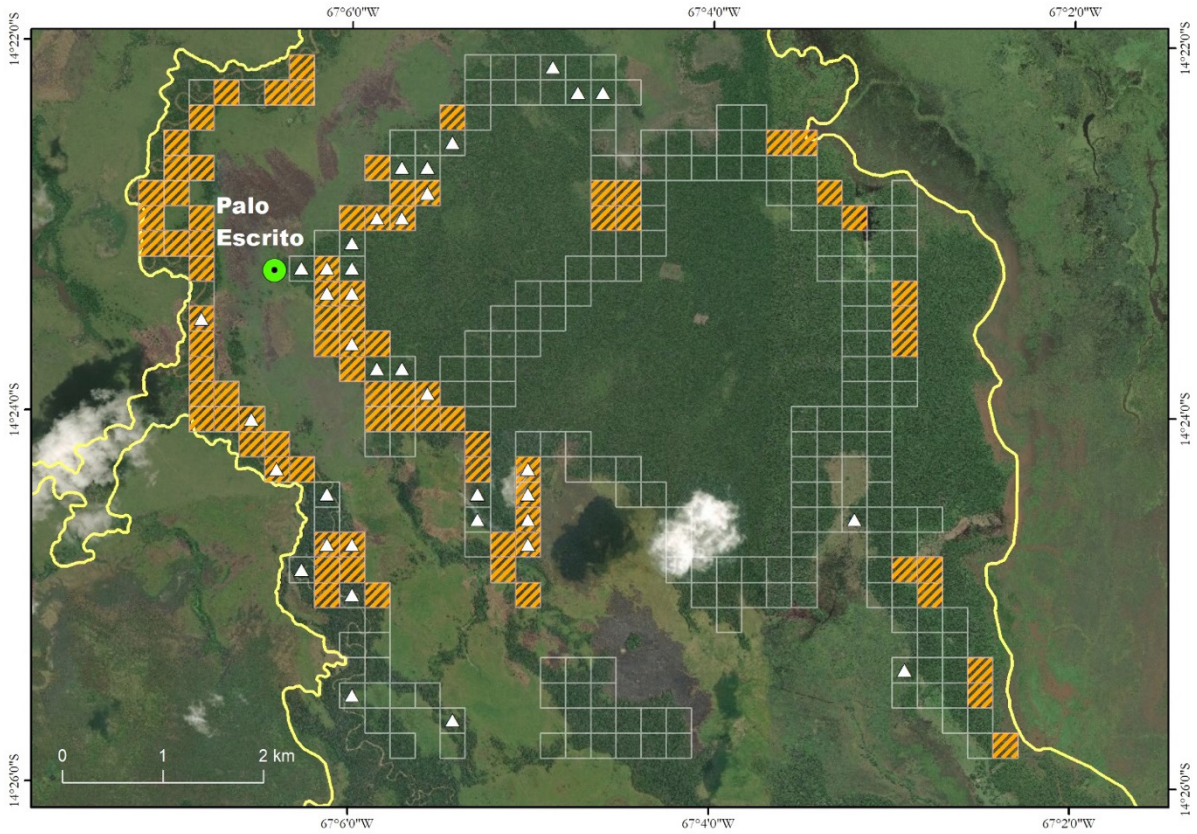

Figure 3. Assessed cells affected by fires at the Palo Escrito site are marked with orange stripes. White triangles indicate cells with presence of titi monkey groups.

Figure 4. Burned vegetation at Palo Escrito site, one month after the fire and showing effects on the understorey.

this palm species was previously considered a habitat indicator for *P. olallae* (Martinez and Wallace 2007, 2010) but high palm densities may reduce the variety and abundance of tree and liana species, as the shade of palms reduces the growth rates of other plants (Denslow *et al.* 1991). Although a proper vegetation assessment is required, our observations suggest that these palm groves have insufficient food resources for *P. olallae*, especially considering their territorial nature, which demands a variety of food resources to avoid competition with neighboring groups (Bicca-Marques and Heymann 2013).

Even though forest cover was reduced at La Asunta, the density of *P. olallae* was higher there than in Palo Escrito. Density increases in disturbed areas has been reported for other titi monkeys, including the nearby and closely related, *Plecturocebus donacophilus* (v. Pyritz *et al.* 2010), and even some preference for disturbed habitat has been suggested based on the generalist ecology of the Callicebinae (Benchimol and Peres 2013). Nevertheless, a similar relationship between density and habitat disturbance was identified as a stage in a process of population reduction in howler monkeys, also considered generalists (*Alouatta guariba*, Silva and Bicca-Marques 2013). Long-term population monitoring is, therefore, required to assess if density variations of *P. olallae* among distinct zones across its range are a continuous or temporal trend.

Local variations in habitat conditions can explain differences in individuals, groups, and populations of primates due to the spatial and temporal availability of food and other resources as well as predation pressures (Marshall 2010). The southern range of *P. olallae* is a forest area close to a continuous forest formation, and with high observation rates of capuchin monkeys (*S. apella*) in Palo Escrito. The degree of habitat variation needs to be assessed in more detail to better understand the effects on *P. olallae* group size and composition, and to develop density variation models (Cavada *et al.* 2016). Local reports from the Oriente del Yacuma community within the range extension reported herein indicate that titi monkeys are not ubiquitously distributed, and that they do not occur in locations further south precisely due to the dominance of tall forests that are not suitable habitat for these primates.

Moreover, local reports confirm previous considerations regarding the titi monkey (*P. olallae* and *P. modestus*) habitat in the region, which consists of lower canopy forests (canopy heights up to 15 m) with the presence of vines and palms (Martinez and Wallace 2007, 2010). Predation of titi monkeys (*Plecturocebus moloch*) by tufted capuchins (*S. apella*) has been observed in tall and continuous forests where titi monkeys are not expected to occur in great abundance (Sampaio and Ferrari 2005). We have observed that both Olalla's and Beni titi monkeys remain quiet or move away when capuchins (*S. apella*) approach, apparently trying to avoid potentially risky direct encounters (WCS unpubl. data). The presence of capuchin monkeys in tall and extensive forests may, therefore, be a factor in habitat suitability for titi monkeys, which predominantly occur in lower and fragmented forests where competition with other monkey species and predation risks are lower.

Regarding conservation threats for *P. olallae*, we observed the effects of uncontrolled fires at Palo Escrito, most likely arising from grassland management for cattle ranching, and affecting a significant portion of the forest edge (Martinez and Wallace 2010; Wallace *et al.* 2013). The floods at the beginning of 2019 may have rendered the region more vulnerable to fire due to the relocation of combustible vegetation from the main course of the Yacuma river and tributaries (Siles *et al.* 2019), particularly when combined with strong winds. Although we found groups of *P. olallae* in areas affected by fires, there is no certainty about the long-term effects of fire damage to forests on these primates, underlining the importance of implementing monitoring for these threatened primates to better understand their tolerance and resilience to habitat changes. Our observations also highlight the need to work with local people to develop alternative practices for cattle-ranching management to mitigate or prevent similar accidental fires.

Hunting of titi monkeys is reported as extremely rare by local people as previously reported for *P. olallae* (Martinez and Wallace 2007, 2010, 2016a, 2019). There was some hunting several decades ago, mainly motivated by curiosity to see them in detail. Moreover, previous outreach work conducted on the conservation of *P. olallae*, as well as *P. modestus*—the other Bolivian endemic titi in the same region (Martinez *et al.* 2015)—resulted in a remarkable general awareness about the need to conserve these endemic titi monkeys that are not found anywhere else. Although local people sometimes cannot differentiate the two endemic titi monkeys, their knowledge about the conservation needs of these species reflects the positive results of outreach work on biodiversity conservation, which should be strengthened with education programs to ensure permanent favorable attitudes towards biodiversity (Gursky and Fields 2018).

Our study provides important population updates for the Olalla's titi monkey, highlighting that not all forested areas recognizable from satellite imagery represent suitable habitat for these endemic primates. Further research should be dedicated to better understand the ecological flexibility of *P. olallae* that is restricted to savanna ecosystems, a challenging environment for primates (Hansen *et al.* 2020). Our study has revealed a larger distribution and a higher abundance of *P. olallae* and represents a new hope for the conservation of these endemic and threatened primates, and a target for monitoring and conservation actions into the future.

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