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Distribution and habitat assessment of an Endangered hummingbird: the Grey-bellied Comet *Taphrolesbia griseiventris*

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Research Article

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Summary

The Grey-bellied Comet (*Taphrolesbia griseiventris*) is a hummingbird species endemic to northern Peru and listed as Endangered by IUCN due to its small and fragmented population. Despite this, little has been attempted to increase knowledge of its natural history and ecology to provide current information and better evaluate its conservation status. Here, we used known curated records of the species from the literature to generate a model of its potential distribution using MaxEnt, and we then validated the model in the field through direct observation in selected areas. Where the species was confirmed, we conducted a habitat characterisation with field data, and a threat assessment of the landscape using secondary data in ArcGIS. We found five new records of the species in the department of La Libertad at two different sites, confirming a new population. The habitat mostly comprised Andean scrub (17.6%) throughout its distribution, and the main threat in the habitat was human-induced fires for agricultural purposes and as a means of waste disposal. Our findings revealed new information on the distribution of the species with a potential habitat occupancy of 4–6% within its range. Furthermore, areas that were previously reported to harbour a population of the species no longer showed records despite intensive searches in the field. Finally, we discuss the implications for its conservation. Our results indicated that conservation measures to protect the Grey-bellied Comet are urgently needed, especially the declaration of a reserve in La Libertad, which might be the only area where the species is reliably present with good quality habitat.

Resumen

El Cometa de Vientre Gris (*Taphrolesbia griseiventris*) es una especie de colibrí endémica del norte de Perú y clasificada como En Peligro según la UICN debido a su pequeña y fragmentada población. A pesar de esto, poco se ha hecho para mejorar el conocimiento de su historia natural y ecología, y así proveer información actualizada sobre su estado de conservación. En esta investigación, usamos registros de la literatura para generar un modelo de distribución potencial utilizando MaxEnt, y luego validamos el modelo en campo a través de la observación directa en áreas seleccionadas. En los lugares donde se confirmó la presencia de la especie, realizamos una caracterización del hábitat con datos de campo y una evaluación de amenazas al paisaje utilizando datos secundarios en ArcGIS. Encontramos cinco nuevos registros de la especie en el departamento de La Libertad en dos sitios diferentes, lo que confirma una nueva población. El hábitat estaba compuesto principalmente por matorral andino (17,6%) en toda su distribución, y la principal amenaza al hábitat fueron incendios antropogénicos con fines agrícolas y como método de disposición de residuos. Nuestros hallazgos revelan nueva información sobre la distribución de la especie con una ocupación potencial del hábitat del 4–6% dentro de su área de distribución. Además, las áreas que albergaban una población de la especie ya no muestran registros a pesar de búsquedas intensivas en el campo. Finalmente, discutimos las implicaciones para su conservación. Nuestros resultados instan a la acción para mejorar las posibilidades de conservación del Cometa de Vientre Gris, especialmente con la creación de un área protegida en La Libertad donde la especie está presente actualmente.

Introduction

Knowledge of the distribution, habitat use, and threats of endangered species is essential to carry on conservation actions. Assessing current and potential distribution helps conservation action in known localities and directs future searches for sites with a high probability of occurrence. Accurate species distribution models and maps are increasingly proposed to support conservation decision-making (Guisan *et al.* 2013, Huang *et al.* 2021). These also contribute to assessing the species extinction risk by adding important information to this process, such as the size of the population, area of occupancy and occurrence, and locations (IUCN 2022), and contribute to protected area design and establishment. Hence, they are a good tool for predicting the conservation status of endangered species for which knowledge is limited.

The Grey-bellied Comet (*Taphrolesbia griseiventris*) is a hummingbird species endemic to northern Peru, considered Endangered by IUCN (BirdLife International 2022) and Critically Endangered by the Peruvian government (SERFOR 2018) because of its small population, with suspected declines due to the degradation and loss of its habitat. Schulenberg *et al.* (2010) consider it "inexplicably rare" in montane scrub between 2,750 m and 3,200 m. a.s.l. on the west side of the Marañón valley, with the known records coming from the departments of Cajamarca, La Libertad, Ancash, and Huánuco (Lloyd and Cuadros 2021). The current Grey-bellied Comet's distribution comprises two Endemic Bird Areas recognised by BirdLife International, i.e. the Peruvian High Andes and the Marañón Valley (Stattersfield *et al.* 1998), and at least two Important Bird and Biodiversity Areas (IBAs), the Río Cajamarca and Cullcui (Angulo Pratolongo 2009), highlighting the importance of its habitat-based conservation. However, the only protected area containing the species (Huascaran National Park) has few and sparse records. On the other hand, in the region with the highest density of records, i.e. the Chonta valley in the department of Cajamarca, the habitat is rapidly changing due to human expansion, which poses a threat to the species (SERFOR 2018).

The lack of existing information on the species' ecology and distribution, together with the threat to its habitat, highlights the importance of performing basic research on this species to address proper conservation efforts. There are species in Peru whose threat category has improved after rigorous research on their distribution (e.g. *Aglaeactis aliciae*) (Lambert and Angulo 2007). However, this has not been carried out yet for the Grey-bellied Comet. Here, we 1) modelled the potential distribution of the Grey-bellied Comet and validated the model in the field, 2) characterised the landscape and habitat of the existing records, and 3) assessed potential threats and discuss conservation implications for the species.

Methods

Study area

The study area encompasses all known records of the Grey-bellied Comet (see next section) and includes the north-central Andes of the western side of Peru. This area politically lies over the departments of Cajamarca, La Libertad, Ancash, and Huánuco, within the watersheds of the Santa river (Pacific slope), and Alto Marañón and Crisnejas rivers (Atlantic slope) (INDECI 2003).

The study area is dominated by four ecosystem types that replace each other from lower to higher parts: seasonally inter-Andean dry forest, near the Marañón river, from 500 m to 2,500 m, Andean scrub, ranging from 1,500 m to 4,500 m, High Andean grassland, above 3,600 m, and agriculture occurring at all elevations (MINAM 2018).

Niche modelling

We compiled past and current records of the Grey-bellied Comet using primary and secondary data sources including citizen science (e.g. eBird 2021), collections (GBIF 2020), databases, data from museum specimens (e.g. American Museum of Natural History), and records from the literature (Collar *et al.* 1992, Garrigues 2001, Angulo *et al.* 2008). We filtered the records from eBird to improve data reliability, excluding records that could not be confirmed. When the record occurred in areas with unsuitable habitats (i.e. near urban areas, cities, and open grasslands), we contacted the users to ask for evidence of the record. If evidence was not available, we discarded the record.

The filtered records were used to model the species' potential distribution using MaxEnt (Phillips *et al.* 2006), since it is a presence-only model, and it has been shown to be one of the best tools for species distribution modelling (Elith *et al.* 2006, Tinoco *et al.* 2009, Gormley *et al.* 2011). We used the layers provided by WorldClim (Fick and Hijmans *et al.* 2017) with a spatial resolution of 0.008338 (~1 km), altitude (NASA 2019), and ecosystems (NatureServe 2009) as covariates for the model. To filter the bioclimatic variables, we selected the variables *a priori* choosing the ones that were most appropriate for the studied species and we ran a Pearson correlation in R 3.5.2 (R Core Team 2018) of the variables within our study area to reduce the number of variables included. Thus, variables with high correlation ($P \geq 0.9$) were excluded from the model (Table 1). We then ran the algorithm in the MaxEnt software using logistic values. The resulting model was then processed in ArcGis 10.3 (ESRI 2010) and we used the areas with an occurrence probability greater than 90% to make the final distribution model (Figure 1). The selected areas were processed in ArcGIS and explored with Google Earth Pro to search for potentially suitable habitats in more detail. We included areas with steep slopes and deep canyons in Andean valleys to select sites that were later intensively searched in the field. We excluded areas beyond the known distribution range according to Schulenberg *et al.* (2010) and BirdLife International (2022) in southern Peru (e.g. Cusco, Apurimac, and Puno departments) (Figure 1). The fieldwork took place between 2017 and 2020, and each selected site was visited at two or more different times of a year to account for seasonal variations that could determine the presence/absence of the species, and three or four observers conducted the searches at each site (SC, FA, and research assistants). A total of 99 sites were surveyed accounting for a total of 452 hours in the field. For each site, point counts were made adding to four hours of observations per season where the species was present (112 hours of observation), and two hours of observations per season where the species was not recorded (340 hours of observation). Observations started at 06h00 until 18h00, with a pause between 12h00 and 14h00 since bird activity reduced significantly. Due to logistic limitations and the inaccessibility of some sites, we were not able to assess some of the areas in the model (e.g. areas between Ancash and La Libertad departments and central La Libertad department). Hence our effort in the field yielded a total of 0.03 individuals per hour of observation.

Table 1. Bioclimatic variables used to model the potential distribution of the Grey-bellied Comet (Fick and Hijmans 2017).

Bioclimatic variable	Code
Annual mean temperature	bio1
Mean diurnal temperature range	bio2
Maximum temperature of warmest month	bio5
Minimum temperature of coldest month	bio6
Precipitation of wettest month	bio13
Precipitation of driest month	bio14

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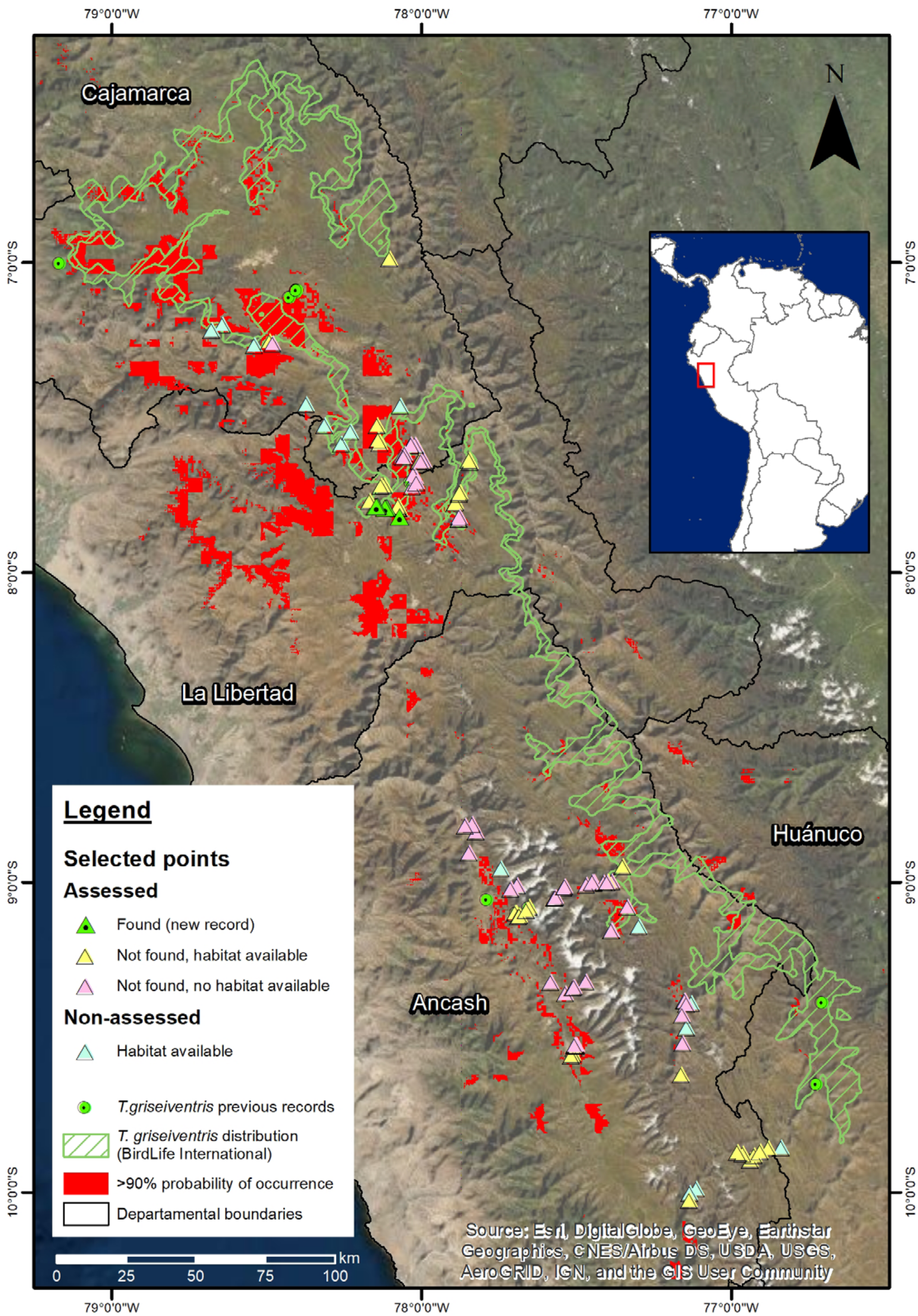

Figure 1. Distribution map of the Gray-bellied Comet.

Landscape configuration and habitat characterisation

We used the records of species presence ($n = 14$) to create a 5-km buffer around each location in ArcGIS 10.3. These buffers were then merged and the resulting polygon was used to assess the ecosystems present in the area (MINAM 2018). The percentage values for each ecosystem were calculated. In addition, between 2018 and 2021, we conducted a habitat characterisation in these sites (Table 2). We were not able to include the Huánuco department due to logistic limitations in accessing these sites. To characterise the habitat, we selected a plot of 2,500 m^2 (50 m × 50 m) at the centre of every identified territory. At each site, we collected: environmental data including type of ecosystem

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Table 2. Environmental variables in the sites where the Grey-bellied Comet has been recorded.

Site	Department	Altitude (m)	Slope (°)	Highest temperature (°C)	Lowest temperature (°C)	Average humidity (%)
1	La Libertad	2,790	90	23.8	−4.2	35
2	La Libertad	2,855	90	23.8	−4.2	35
3	La Libertad	2,990	70	23.8	−4.2	35
4	Cajamarca	2,790	60	29.8	−4.3	35
5	Cajamarca	2,850	70	29.8	−4.3	50
6	Cajamarca	2,880	70	29.8	−4.3	50
7	Cajamarca	2,900	90	29.8	−4.3	50
8	Cajamarca	2,860	60	29.8	−4.3	50
9	Cajamarca	2,790	45	29.8	−4.3	50
10	La Libertad	2,650	40	31.5	0.3	35
11	Áncash	3,490	50	11.0	−6.0	15
12	Áncash	3,810	90	11.0	−8.0	15
13	Áncash	3,650	90	11.0	−8.0	15
14	La Libertad	2,960	30	31.5	0.3	35

(MINAM 2018), habitat, altitude (m), slope (%), wind intensity (Beaufort scale), cloud cover (%), and precipitation observation; vegetation cover including number of vegetation strata, tree density (%), and dominant vegetation species; water source available including average distance to the closest water source (m) and type of water source; food sources (abundance of flowering species); nectarivorous birds' communities including other hummingbird species and *Diglossa* sp. This habitat characterisation was repeated in the two distinct seasons in the region (dry and wet seasons) to account for habitat variability.

Anthropogenic disturbance and conservation implications

To account for anthropogenic disturbances, we used the records of the species to calculate the average distance to human settlements (MINEDU 2020) and roads (MTC 2018). Additionally, we created a 10-km buffer around each record and calculated the percentage of settlement areas, areas affected by fires (Chuvieco *et al.* 2018), cattle density (Robinson *et al.* 2014), vegetation loss (Reymondin *et al.* 2012), and human disturbance measured through the Human Footprint

Index WCS and CIESIN 2005. This index combines eight variables including built environments, population density, electric infrastructure, agriculture fields, cattle fields, roads, train rails, and waterways (Venter *et al.* 2018), and it is measured between 0 and 100. To compare the degree of disturbance between regions we classified Human Footprint Index values as low (0–25%), moderate (26–50%), high (51–75%), and very high (76–100%) (adapted from Correa Ayram *et al.* 2017).

Results

Niche modelling

After filtering the data, we used 14 records of the species between 1883 and 2021 representing all the sites where the species was recorded. The model predicted areas with a high probability of occurrence in the central Andes, with an AUC value of 0.912, which indicates the model is accurate at predicting the presence of the species (Pearson 2007). In addition, the variables that most contributed to the distribution model were ecosystem type (43.3%) and minimum temperature of the coldest month (bio6, 42.5%). The model selected (Figure 1) shows the areas with a probability of occurrence higher than 90%, the areas with the most suitable habitat according to our model, the sites that were chosen to search for the species, and the newly confirmed records.

Landscape configuration and habitat characterisation

A total of 14 records were assessed for habitat characterisation using the same point counts as described above. Elevations ranged from 2,650 m to 3,810 m a.s.l. and slopes from 30° to 90°, with most areas containing slopes equal to or greater than 60° (71%) (Table 2). The most common natural ecosystem (MINAM 2018) found was Andean scrub (17.6%), followed by High Andean grasslands (12.5%). Urban areas were not common across the study area (1.1%). Interestingly, agriculture was the most dominant ecosystem (56.3%), with La Libertad and Cajamarca being the most heavily cultivated departments (Figure 2). The habitat in most sites mainly comprised Andean scrub, which was seen to be used by the species during fieldwork. The most frequent ornithophilous flower (as described by Van der Pijl 1961) present was *Tillandsia* sp., suggesting it could be an important element in the diet. *Delostoma integrifolium* was only present in Cajamarca, while *Oreocallis grandiflora* was present in all other departments (Table 3). Although all study areas were located within the Andean region, they showed a different nectarivorous composition. The bird community found in Ancash was significantly different from the communities in Cajamarca and La Libertad (Figure 3). We did not assess the habitat or bird community for the Huánuco department due to logistics restraints.

Anthropogenic disturbance and conservation strategies

Cattle

Cattle densities did not vary significantly in the study sites (Figure 4), with the highest values found in Cajamarca (83 heads/

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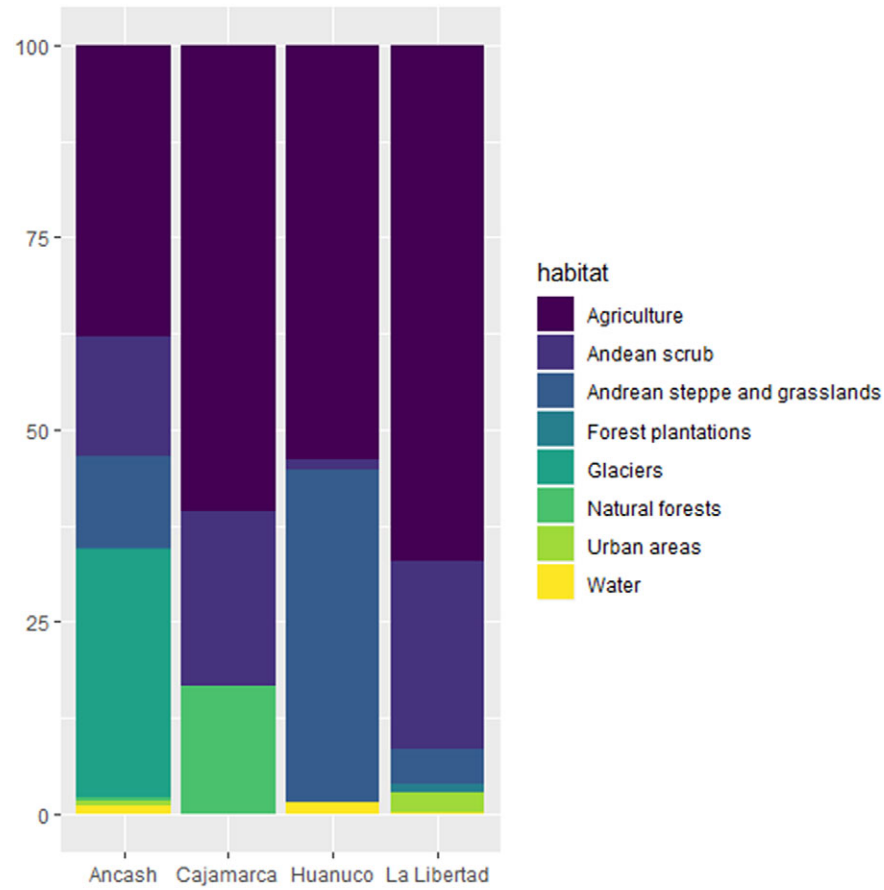

Figure 2. Landscape configuration in the habitat of the Gray-bellied Comet.

km^2) and La Libertad (82 heads/km^2), and the lowest values found in Ancash (12.7 heads/km^2).

Vegetation loss

The area with the greatest vegetation loss from 2004 until 2019 was Cajamarca, with accumulated values of 3 km^2 in the study area, followed by La Libertad (1.5 km^2) and Ancash (0.19 km^2). Huánuco was the region with the least vegetation loss, with none recorded during this period.

Fires

Fires occurred in all four regions, with most fires occurring in August followed by September (dry season). The area most affected by fires was La Libertad ($\bar{x} = 15.3\%$ of the buffer area), followed by Huánuco ($\bar{x} = 11.1\%$), Ancash ($\bar{x} = 10.9\%$), and Cajamarca ($\bar{x} = 6.2\%$).

Human Footprint Index

Overall, the Human Footprint Index values were higher for Cajamarca ($\bar{x} = 33.5\%$), followed by Huánuco ($\bar{x} = 32.5\%$) and Ancash ($\bar{x} = 30.9\%$). La Libertad was the area with less human impact ($\bar{x} = 26.3\%$). In addition, all areas presented mostly low and moderate human footprint values (<50%) except Cajamarca, which had areas with high values of the Human Footprint Index (50–75%, 15.4%).

Distribution map

Based on our findings we proposed an updated distribution map for the species. This map includes the density of occurrences of the Grey-bellied Comet and its potential habitat according to our model. Combining this with the anthropogenic disturbances previously identified, we suggested priority important conservation areas and key elements that need to be addressed to ensure the long-term conservation of this species and its habitat. The current distribution map proposed by IUCN encompasses a total area of 5,557.9 km^2 (4,120.21 km^2 extant, 1,434.97 km^2 possibly extant, 3 km^2 extinct) (BirdLife International 2022).

However, this map does not include the Huascaran National Park area records in Ancash, which are included in our map (253 km^2) (Figure 5). After carrying out exhaustive searches during fieldwork we were not able to find the species in Ancash department. In addition, other searches carried out by FA in both Paucal and Bosque de Cachil and surrounding areas (southwestern Cajamarca department) between May and June 2010, did not find the species. Thus, we propose that these areas are treated as "possibly extant" instead of "extant" as per IUCN, to show a more comprehensive approach to the species' range. We also excluded city areas and adjusted the map in La Libertad to include the new sites where we recorded the species (Figure 5). Hence, the total distribution area would be limited to an extant area of 1,894 km^2 (within Cajamarca, La Libertad, and Ancash departments), and a possibly extant area of 4,068 km^2 (including IUCN's distribution and Huascaran National Park area), making a total of 5,962 km^2.

Discussion

Niche modelling

The MaxEnt model for the Grey-bellied Comet yielded interesting results with the new records in areas of high probability (90%)

Table 3. Habitat variables in the sites where the Grey-bellied Comet has been recorded.

Site	Number of vegetation strata	Most abundant vegetation type	Percentage covered (%)	Maximum number of flowering plants recorded	Dominant flowering plant
1	4	Andean scrub	60	13	*Tillandsia* sp. *Pitcairnia pungens*
2	4	Andean scrub	60	9	*Tillandsia* sp. *Oreocallis grandiflora* *Eucalyptus* sp.
3	4	Andean scrub	60	18	*Oreocallis grandiflora Pitcairnia pungens*
4	3	Andean scrub	60	21	*Delostoma integrifolium* *Eucalyptus* sp.*Tillandsia* sp.
5	3	Andean scrub	50	11	*Delostoma integrifolium* *Cortaderia* sp.
6	4	Andean scrub	50	17	*Delostoma integrifolium* *Tillandsia* sp.*Salvia* sp.
7	4	Andean scrub	50	12	*Tillandsia* sp. *Bomarea* sp.
8	3	Shrubs	50		*Delostoma integrifolium* *Eucalyptus* sp.
9	3	Andean scrub	60		–
10	4	Shrubs	60	6	*Cavendishia* sp. *Leonotis leonurus*
11	4	Shrubs	60	12	*Lupinus* sp. *Rubrus* sp.
12	4	Shrubs	50	8	*Tillandsia* sp. *Passiflora cumbalensis*
13	5	Trees (*Polylepis* sp.)	50	10	*Oreocallis grandiflora* *Salvia* sp.
14	4	Shrubs	70	13	*Tillandsia* sp. *Salvia* sp.

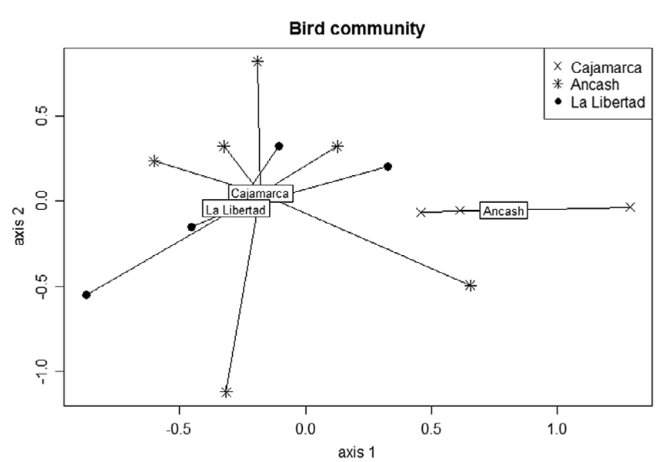

Figure 3. Bird community in the habitat of the Gray-bellied Comet.

according to the model. Despite the accuracy of these results, because of the limited number of surveys per site (two–three) and the low detectability (given the intense searches conducted without any observations) of the species in the field, we cannot draw conclusions on the overall efficiency of the model in predicting species distribution. The model should be further validated in the future to test its efficiency and used to estimate population size of the species.

Landscape configuration and habitat characterisation

The main ecosystem types found in the overall area of the Grey-bellied Comet were Andean scrub and High Andean grasslands, which are widely available in the central Andes. Furthermore, the specific sites where the species was recorded during this study were also Andean scrub in all regions. This finding supports previous knowledge of the species. For example, a brief description given by Collar *et al.* (1997) mentions Grey-bellied Comets occurring in dry deciduous forests (including scrub), which is consistent with our field observations. Although the species has not been recorded in High Andean grasslands, this ecosystem naturally occurs adjacent to Andean scrub due to the strong vertical gradient in the Peruvian Andes. Thus, we cannot discount the possibility that the species uses it occasionally to forage. In addition, our findings conclude that the species uses areas with steep slopes in canyons, which supports Baron's (1897) observations of the species in Cajamarca, where he found it in rocky and steep inaccessible canyons. These features were also observed by Garrigues (2001), when he discovered two nests of Grey-bellied Comets being built near Cajamarca in hilly areas with *Agave* sp. and cacti, which is supported by our field data. These sites with steep slopes near water systems also provide a microclimate with greater humidity which also ameliorates high temperatures, especially where these reach freezing at night, and promotes the presence of flowering species like *Tillandsia* sp., which are known to be an important nectar source for many hummingbird species (e.g. Gardner 1986, Garcia-Franco and

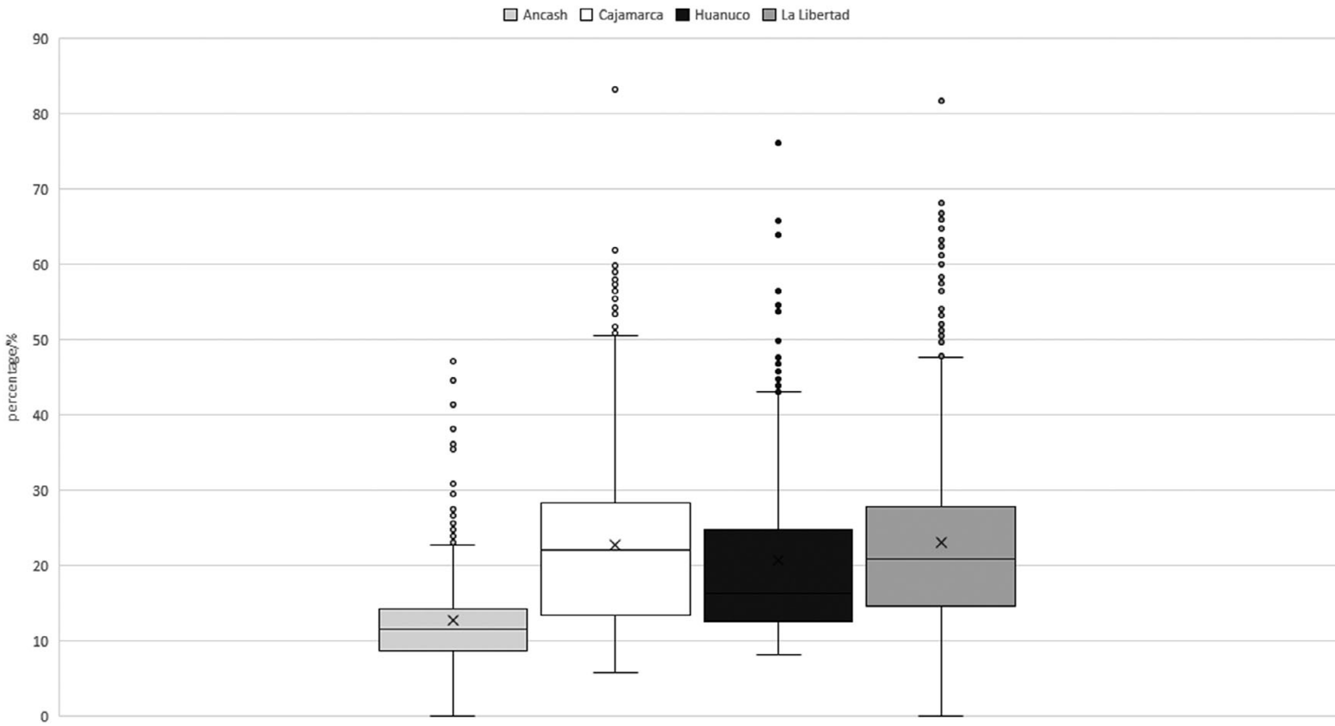

Figure 4. Cattle density in the habitat of the Gray-bellied Comet.

Rico-Grey 1991, García-Franco *et al.* 2001, Gutiérrez 2005, Rojas 2005, Schmidt-Lebuhn *et al.* 2007, Freile *et al.* 2011, Maglianesi 2014, Fonseca *et al.* 2015), and the presence of invertebrates which are also an important source of proteins for hummingbirds (Remsen *et al.* 1985, Stiles 1995). Our findings show that *Tillandsia* sp. was the most common flowering species in all sites and was used by the Grey-bellied Comet. Interestingly, *O. grandiflora* was present in every study area except in Cajamarca (see Cuadros 2019), and was used in three different territories found in the new sites in La Libertad. This suggests that this flower is an important part of the diet of the Grey-bellied Comet, and it was also used by other hummingbird species (e.g. Giant Hummingbird *Patagona gigas,* Shining Sunbeam *Aglaeactis cupripennis,* Tyrian Metaltail *Metallura tyrianthina,* and Black Metaltail *Metallura phoebe*). However, the specific preferences for different flowers have not been studied in these sites (study in prep.). Conversely, *D. integrifolium* was only present in Cajamarca. Previous observations suggested that this flower is one of the main components of the diet given the high frequency of use in Cajamarca (ECOAN 2019). However, our findings contradict this idea since this flower is not present in La Libertad. In addition, our field observations confirmed the suggestions made in a previous study (Cuadros 2019) that Grey-bellied Comets can only use *D. integrifolium* after the flower has been pierced by a Flowerpiercer (in this case, Black-throated Flowerpiercer *Diglossa brunneiventris*), and therefore its use is only opportunistic when flowers are available. Further studies are required to understand how the bird community could potentially influence the presence of the species through competition or symbiosis, however, this aspect was not included in the present study.

Interestingly, temperature changes and the bird community showed differences west and east of the Andes, with the Ancash area (west) showing lower overall values of minimum and maximum temperatures (-8°C and 11°C) compared with Cajamarca and La Libertad (0.3°C and 30.5°C) (Table 2), and showing a significantly distinct nectarivorous community (Figure 3). These community differences are due to the Andes mountains acting as a geographical barrier to many species because of their high elevation, promoting the formation of distinct biotic communities on each side of the Andes (Hazzi *et al.* 2018), and possibly different populations of Grey-bellied Comets as well.

Anthropogenic disturbance and conservation strategies

Agriculture was the main ecosystem found in all surveyed areas. This suggests that the sites where the species has been recorded have been significantly modified, especially in La Libertad and Cajamarca. This is supported by the values for vegetation loss, especially in recent years when values were higher (e.g. 2014–2018), which show that these were the areas with the highest losses. Unfortunately, we could not assess vegetation loss in the years before 2004 due to a lack of satellite data which limits our analysis in understanding how occupancy could have changed over the years. For example, Baron (1897) observed and collected individuals near the town of Cajabamba, and his observations indicated that the species was found below the town. We surveyed these areas on three different occasions over two years and we did not find any individuals. Although we cannot conclude that the species is no longer present in the area due to its low detectability, the area currently mostly comprises orchards and agriculture plantations, which suggests it has been modified from its natural habitat. In addition, Cajabamba has expanded over the years, hence reducing potential habitat which could have extirpated the local population. The degree to which the habitat has changed requires further study. Interestingly, in the sites where the species is currently present (e.g. Cajamarca and La Libertad), the adjacent areas are heavily cultivated, and small patches of agriculture and forest plantations surrounded the areas used by the species. This finding suggests that the species shows some plasticity and can tolerate some degree of

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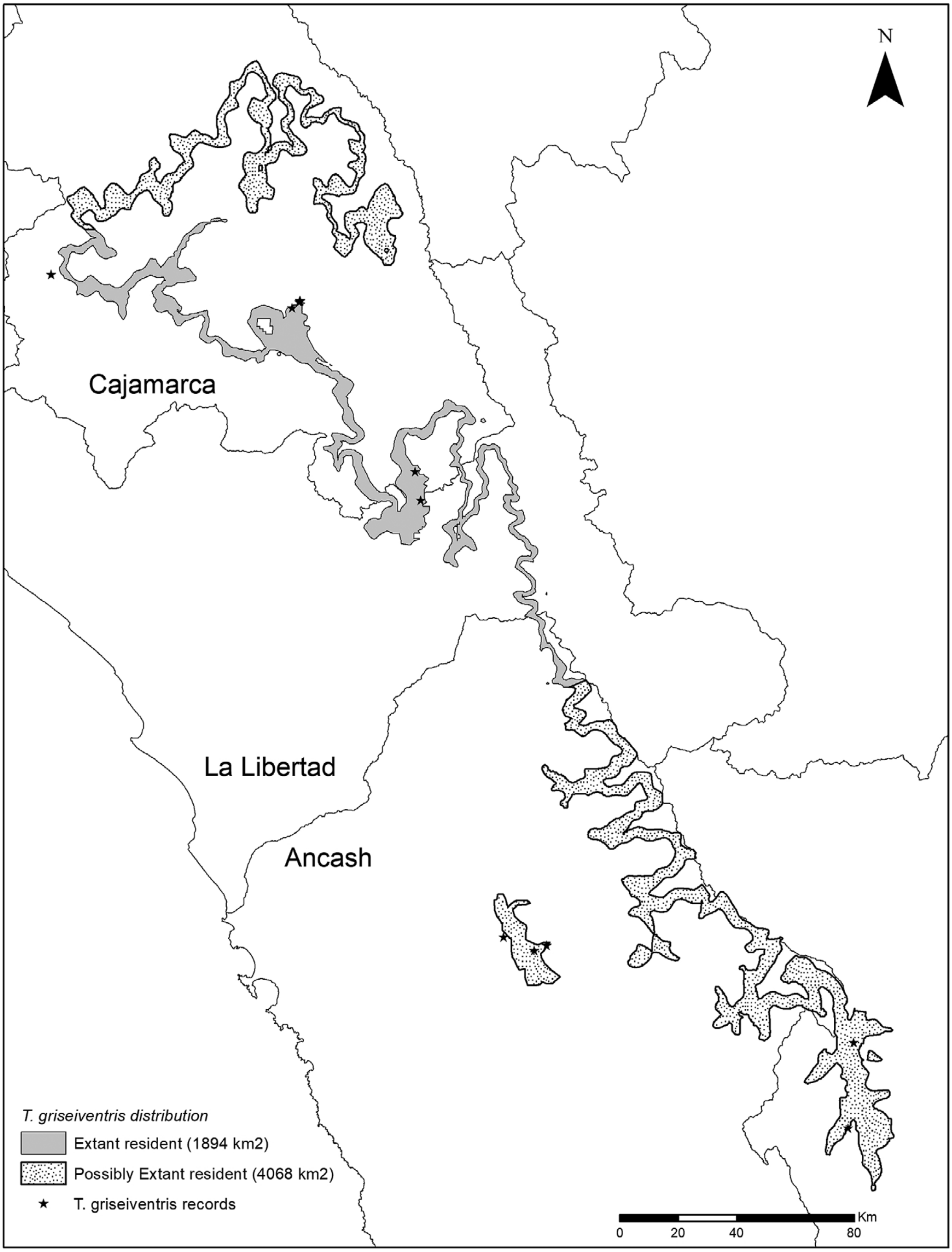

Figure 5. Proposed updated distribution map of Gray-bellied Comet.

disturbance (e.g. feeding on *Eucalyptus* sp.). However, the degree of habitat fragmentation it can tolerate requires further study, and due to its apparent low density and rarity (Baron 1897, Schulenberg *et al.* 2010), this scenario should be avoided.

Cattle were present in all sites, with the highest values occurring in the two areas where the species has been confirmed in recent years. However, habitat conversion for cattle ranching did not occur in the species' habitat, but in its surroundings, where this activity is a threat (INEI 1994). This finding suggests that the species is not affected by this type of farming activity, which is also supported by the fact that most of the species' habitat occurs on steep slopes, which is not suitable for farming. Fires were also present in all sites and, unlike cattle, they do appear to be a major threat to the habitat, mainly in La Libertad. Natural wildfires are not frequent in Andean valleys and are exacerbated by human activity when organic waste is burned for agricultural purposes, as a method

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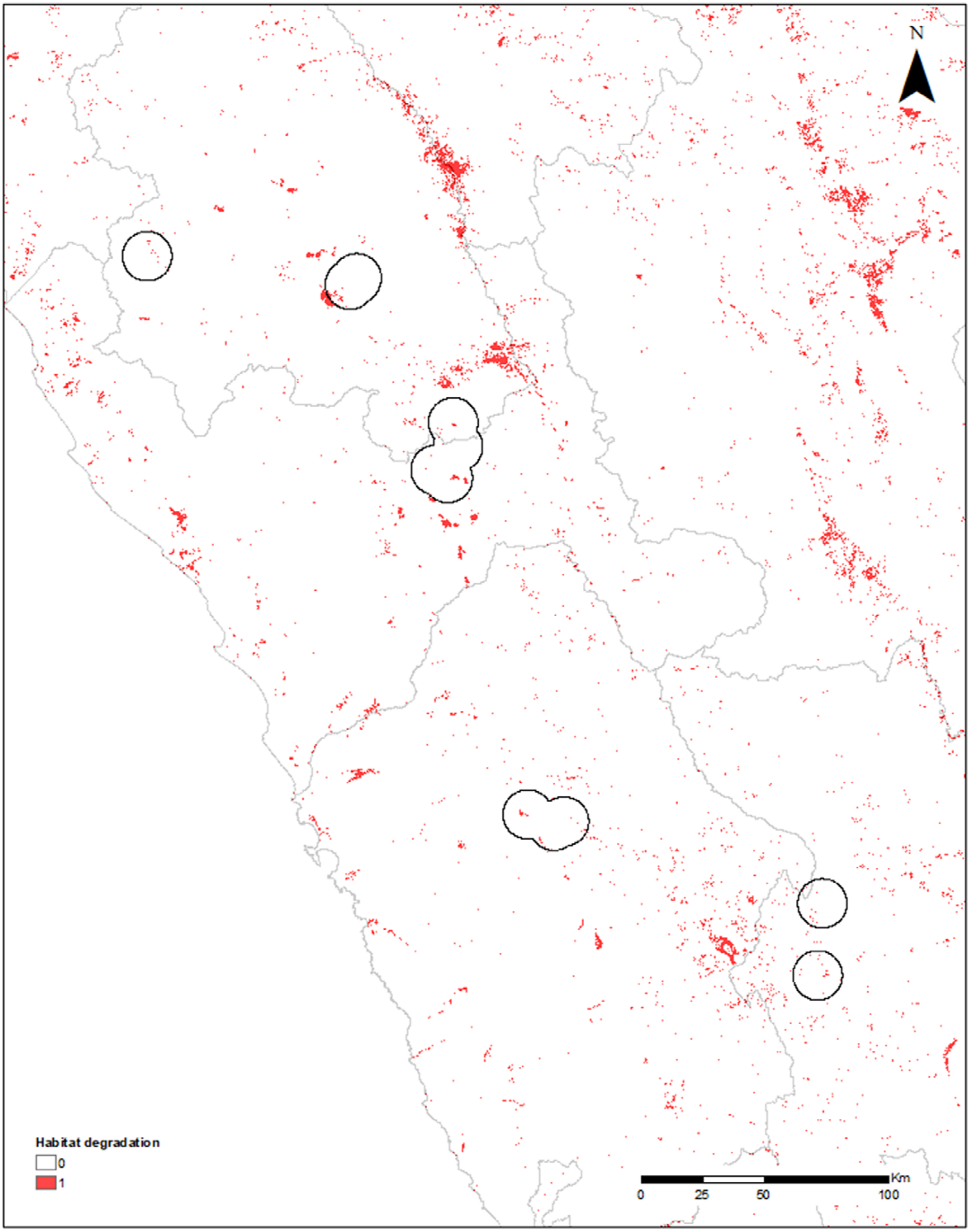

Figure 6. Burned areas in the habitat of the Gray-bellied Comet.

of waste disposal, and to a less extent, due to the belief that it will attract rains (Manríquez Zapata 2019). The former is especially true during the driest months (August–October), before the start of the wet season, worsening the problem since these ecosystems are naturally dry and therefore spread fire easily. This, combined with vegetation losses in the study area, has resulted in a loss of net primary productivity (Figure 6), which could lead to further habitat loss. Additionally, the Human Footprint Index shows the region of Cajamarca as the most affected, with values significantly higher than the other regions.

Overall, the two areas with the highest disturbance are Cajamarca and La Libertad. These results suggest a problem for the conservation of the Grey-bellied Comet since these are the two regions where the species is confirmed to exist at present. It also suggests that urgent conservation plans need to be implemented here to reduce further habitat loss and fragmentation (Cuadros 2021).

Distribution map and conservation areas

Our map shows a total distribution area of 5,962 km^2, with a total extant area of 1,894 km^2 and a possibly extant area of 4,068 km^2. The current distribution map proposed by IUCN encompasses a total area of 5,557.9 km^2 (4,120.21 km^2 extant, 1,434.97 km^2 possibly extant, 3 km^2 extinct) (BirdLife International 2022). Although our map increases the total range by 404 km^2, the extant area is significantly reduced (54%), which is a better reflection of the current occupation of the species on the ground. These areas (possibly extant) require more intensive surveys in the future. This would enable us to determine whether the species is present at these sites, or if they should be deleted from their range, highlighting the conservation of other areas that harbour present known populations.

In recent work, the Area of Habitat (defined as "habitat available to a species, that is, habitat within its range" (Brooks *et al.* 2019) calculated for the Grey-bellied Comet was 252 km^2, which represents 6% of the range published by the IUCN (Huang *et al.* 2021), and 4% of our proposed range. This implies that a very small portion of the species' range is available for the species' use. However, this study was mainly aimed at understanding forest species, thus, the results of their analysis for other habitat-dwellers are not applicable. Our results, especially the confirmed new localities, can contribute to improving this analysis in future studies providing a more accurate Area of Habitat, therefore providing more detailed information for a conservation status assessment.

Currently, the only area with legal protection within the species range is the Huascaran National Park in Ancash, however, despite our efforts to find the species, we did not find it in four visits over the course of three years. Although this does not rule out its presence, it could mean that the densities here are lower, and future research should focus on determining whether this population is stable, if it belongs to a remnant fragmented habitat, or if it currently exists. Conversely, the areas with the highest frequency of sightings (and potentially greater population densities) have no degree of legal protection. This is especially important since currently the species is at least listed as Endangered (BirdLife International 2022), but the rapid rate of habitat conversion due to human expansion and the increase in dryness due to climate change (Vuille and Bradley 2000, Vuille *et al.* 2008, Román-Cuesta *et al.* 2014, Manta *et al.* 2018) could result in the species being uplisted to Critically Endangered. Our findings emphasise the urgency to take action and conserve these habitats since current known localities are not in legally protected areas and particularly, because this habitat (Andean scrub) is underrepresented, with only 8% in the National Protected Areas System (SERNANP 2009), with prioritised conservation sites being Cajamarca and La Libertad where there are confirmed recent records. Although the map we propose here is based on our model and our findings in the field are a starting point to continue looking for the species and expand the habitat assessment, conservation actions in the already confirmed sites should become a priority for governments to comply with their Aichi Targets and the National Strategy for the Conservation of Biodiversity in the protection of threatened species (MINAM 2014), which is especially important for endemic species like the Grey-bellied Comet, and could further lead to the sustainable development of these areas through birdwatching.

Currently, there are two IBAs triggered by the Grey-bellied Comet, i.e. Río Cajamarca and Cullcui (Angulo Pratolongo 2009). Since IBAs are also Key Biodiversity Areas (KBAs) identified for birds (IUCN 2016), that is, sites of importance for the global persistence of biodiversity, we propose a new KBA, Huamachuco, based on the confirmed presence of this Endangered hummingbird species following criteria A1 (0.5% of the total population, estimated as a maximum of 999 according to Birdlife International 2022). Thus, we encourage the Peruvian government and NGOs to work towards the formal protection of spaces where this species is reliably present.

Conclusions

Our study reveals new information on the distribution, occupancy, and threats to the habitat of the Endangered Grey-bellied Comet. The findings of this study indicate that both Cajamarca and La Libertad harbour current populations of the species, thus suggesting these areas as conservation priority sites. We also propose that the main threats are uncontrolled anthropogenic fires, which are likely to increase due to exacerbated dryness of Andean scrub and grasslands in the context of climate change. Although further research on distribution remains to be carried out in other areas (Ancash and La Libertad), our findings improve the knowledge of the species, which will be key to re-assessing its conservation status.

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