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# Impact of Fires on Key Biodiversity Areas (KBAs) and Priority Bird Species for Conservation in Bolivia

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**Abstract:** Key Biodiversity Areas (KBAs) are sites that contribute significantly to the protection of the planet's biodiversity. In this study, we evaluated the annual burned areas and the intensity of the fires that affected Bolivia and its 58 KBAs (23.3 million ha) over the last 20 years (2001–2020). In particular, we analyzed the impact of wildfires on the distribution of Bolivian birds at the levels of overall species richness, endemic species and threatened species (Critically Endangered, Endangered, Vulnerable). We found that at the KBA level, the cumulative area of wildfires was 21.6 million ha, while the absolute area impacted was 5.6 million ha. The KBAs most affected by the wildfires are located in the departments of Beni and Santa Cruz; mainly in the KBAs Área Natural de Manejo Integrado San Matías, Oeste del río Mamoré, Este del río Mamoré, Noel Kempff Mercado and Área Natural de Manejo Integrado Otuquis. The wildfires impacted the distribution of 54 threatened species and 15 endemic species in the KBAs. Based on the results of this study, it is a priority to communicate to Bolivian government authorities the importance of KBAs as a strategy for the conservation of the country's biodiversity and the threats resulting from anthropogenic fires.

**Keywords:** fire ecology; fire scars; conservation; distribution patterns; threatened species

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## 1. Introduction

Globally, wildfire regimes are changing, with increasingly longer seasons, mainly induced by climate and human activities [1,2]. Recent estimates obtained from remote sensing reveal that the area affected annually by wildfire ranges from 3.5 to 5 million km$^2$ [3,4]. In South America, a significant increase in burning and wildfire activity has been detected during the period 2001–2018, and a severe wildfire crisis strongly linked to deforestation and forest degradation was recorded in 2019 [4].

Fire is a fundamental component of most of the Earth's terrestrial ecosystems [5], and the relationship between wildfire and biodiversity is complex [6]. Biodiversity loss is associated with high frequency, large-scale intensity, or absence of fires [7]. The new era of wildfire poses a global challenge in understanding how to maintain biodiversity [8]. Fire is an important ecological factor for numerous species inhabiting some dry ecosystems, such as the Cerrado [9–11], but for other ecosystems such as tropical rainforests, wildfire can lead to the destruction or loss of native species and habitats [12]. In both cases, the response of these ecosystems when the seasonality or frequency of burning exceeds their resilience is poorly understood [13].

Large-scale forest wildfires have become the main cause of forest degradation in Bolivia in the last two decades. These wildfires have occurred annually [14], mainly in the lowlands, and have become more frequent and severe in recent years [15]. Although wildfires originate mainly in areas that were recently deforested [16], these spread to protected areas (national and subnational). The subjacent causes for the increase and severity of these are inadequate fire management in the *chaqueos* (slash-and-burn agriculture to prepare land for planting), mechanized agriculture for commercial purposes, and inadequate pasture management for cattle ranching [17–20]. Between 2000 and 2015, the absolute area impacted by wildfires in the country was 16 million ha, of which 28% occurred in forested areas [17].

Due to the combination of environmentally destructive agricultural–economic policies [21] and the increasing severity of the droughts [22], wildfires have increased in recent years. The burned area in 2019 was three times larger than in 2018 and exceeded the average of the 2001–2018 period by 51% [4]. These events reopened the debate on the problem of wildfires in Bolivia, the impact they generate on biodiversity, and the potential strategies that could be developed for the effective restoration of impacted ecosystems.

In Bolivia, progress has been made in the development of spatial analyses to determine the impact of wildfires on biodiversity [23–26]. However, it is necessary to prioritize the evaluation of areas that have been identified as the most important biodiversity areas for species of conservation concern [27]. The Key Biodiversity Areas (KBAs) are a global network of more than 16,000 sites that contribute significantly to the global persistence of biodiversity (http://www.keybiodiversityareas.org/kba-data, accessed on 15 August 2021). These sites were identified using standardized criteria and quantitative thresholds [28]. In Bolivia, there are 58 KBAs, most of which were initially identified as Important Bird Areas (IBAs), and they are distributed across all ecoregions of the country [29,30]. The pressure exerted on these sites by human activities threatens the survival of many species dependent on these areas.

In this study, we analyze the impact that wildfires have had on the geographic patterns of general bird species richness, endemic bird species richness, and threatened bird species richness between 2001 and 2020. The geographic scope of the present study is national, but we place particular emphasis on the impact of the wildfires on all Bolivian KBAs and the bird species that inhabit these areas of high biodiversity importance. We hope that the results presented here can serve as a basis for the development of strategies for immediate conservation and monitoring actions for those KBAs most threatened by wildfires.

## 2. Materials and Methods

### 2.1. Study Area

Geomorphologically, two regions can be distinguished in Bolivia. In the west, the Andean region is largely formed by the Cordillera Occidental and the Cordillera Oriental. Both ranges enclose the Andean Altiplano, a comparatively flat region located between 3400 and 4000 m.a.s.l. To the east and north of the Andes are the country's lowlands (<1000 m.a.s.l.), which occupy more than 60% of the national territory. This region also includes scattered low-altitude mountain ranges, particularly in eastern Bolivia, such as the Huanchaca (Parque Nacional Noel Kempff Mercado) and Sunsás (Área Natural de Manejo Integrado San Matías). According to Ibisch et al. [31], there are 12 ecoregions in Bolivia: Humid Puna, Dry Puna, inter-Andean Dry Valleys, Prepuna, Yungas, Boliviano-Tucumano Forest, Southwest Amazonia, Cerrado, seasonally flooded savanna, Chiquitania, Chaco and Chaco Serrano.

In general, the study area covered the entire country, and the analyses were carried out in all 58 KBAs that are distributed throughout Bolivia (Figure 1). The total area occupied by KBAs in Bolivia is 23,326,168 ha (ranging from 2064 ha to 3,282,376 ha, with an average of 402,175 ha), which represents 21% of the national territory. KBAs are not necessarily protected areas and were identified following 11 criteria that are grouped into five categories that evaluate the elements of threatened biodiversity they harbor, geographically restricted biodiversity (endemism), ecological integrity, biological processes and irreplaceability [28]. The network of these KBAs covers 83% of the total area of Bolivia's national protected areas [30].


**Figure 1.** Bolivia's Key Biodiversity Areas (KBA) affected by wildfires in the last two decades: (**a**) KBA Parque Nacional Noel Kempff Mercado, Serranía de Huanchaca (Claudia Belaunde/FCBC), (**b**) KBA Oeste del río Mamoré, río Ormi (Asociación Armonía), (**c**) KBA Área Natural de Manejo Integrado San Matías (Hermes Justiniano).

### 2.2. Species Distribution

In this research, we used birds as indicators to measure the impact of wildfires on biodiversity in Bolivia. The use of birds as indicators of the state of the environment in regional analyses is commonplace because, as a taxonomic group, they are widespread, sensitive to environmental changes, their ecology is well known, and their taxonomy is relatively stable [32]. At present, 1445 bird species have been recorded in Bolivia (https://birdsofbolivia.org/; accessed on 15 August 2021), and the country is the sixth most bird-species-rich country on the planet and the fifth in the Americas [33]. In this study, birds considered priority species for conservation include Bolivia's 16 endemic bird species and 54 globally threatened species following IUCN criteria (http://datazone.birdlife.org/species/search; accessed on 16 May 2021): Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). Seven of the Bolivian endemics also are globally threatened, so the total number of Bolivian priority bird species is 60. The habitats of many of these priority species are impacted by wildfires (Figure 2). For this analysis, a national classification of threatened species [34] was not considered for two reasons: (1) although the criteria used are different, the system contains the same categories, and approximately 80% of the species are found in the same categories in both systems; (2) the IUCN has a global scope and is formally recognized by most governments and international organizations that allocate funds for the protection of threatened species.


**Figure 2.** Some priority species for conservation, whose distribution areas were most affected by wildfires during the period 2001–2020: (**a**) Blue-throated Macaw *Ara glaucogularis* (Gerrit Vyn/Asociación Armonía), (**b**) Cock-tailed Tyrant *Alectrurus tricolor* (Lennart Verheuvel/Asociación Armonía), and (**c**) Sharp-tailed Tyrant *Culicivora caudacuta* (Lennart Verheuve/Asociación Armonía).

The distribution maps developed for the Birds of Bolivia Field Guide [33] were used in this study. Each species' map was constructed under a deductive species distribution modeling approach based on expert opinion [35]. This procedure reduced the overestimation of the resulting maps (false-positive errors). The data used for the development of the maps were extracted from Asociación Armonía's distributional database for Bolivian birds, which contains >120,000 occurrence records from >1400 georeferenced localities [35]. Each map was developed based on occurrence records in vegetation types [36], ecoregions [31] and the known or expected elevational range, using NASA's Shuttle Radar Topography Mission (SRTM) digital elevation model of 90 m (0.81 ha) to remove grid cells above and below the known or expected upper or lower elevation limit, respectively [35].

Individual distribution maps of each species were processed with the help of the Cell Statistics tool of ArcMap to construct maps of total species richness, endemic species richness and threatened species richness. Each species' map was then constructed at a spatial resolution of $1' \times 1'$ latitude-longitude grid cells (ca. $1.86 \times 1.86$ km). For the analysis of endemic species, Coppery Thorntail (*Discosura letitiae*) was excluded from the list since the distribution of this species is unknown, and it is probably already extinct, as it is known only from skins that were collected in the 19th century [37]. In the case of threatened species, distribution maps were not prepared for Black-bellied Thorntail (*Lophornis gouldii*), because the single historical record is unreliable, and Lemon-browed Flycatcher (*Conopias cinchoneti*), because the species has been reported only from one observation of a single individual each at only two localities [33], which is insufficient for the preparation of a geographic distribution map of this species in Bolivia.

### *2.3. Impact of Wildfires*

To determine the area impacted by wildfires in Bolivia, we used the monthly product MCD64A1 ver. 6 from the combination of Terra and Aqua (MODIS) satellites, with a spatial resolution of 500 m (https://lpdaac.usgs.gov/products/mcd64a1v006, accessed on 15 February 2021). This product is generated from an automated algorithm that detects rapid patterns of changes in surface reflectivity time-series detected by MODIS sensors [3]. In the cloud computing platform Google Earth Engine (GEE [38]), a script was developed to generate and download annual cumulative images of the time series from 2001 to 2020. Subsequently, the burned areas were cross-referenced with the KBAs, and the area by year and frequency was quantified. In this study, we report the accumulated burned area and the absolute burned area. The first is the total for all years, while the absolute burned area is the annual quantification.

We assessed the impacts of wildfires on Bolivian ecosystems and KBAs, using the MODIS Land Cover Type Product (MCD12Q1.006, https://lpdaac.usgs.gov/products/mcd12q1v006, accessed on 1 December 2021), a series of global land cover maps with yearly intervals and 500 m spatial resolution from 2001 to 2019. We downloaded the University of Maryland (UMD) classification (Type 2) with the help of the GEE platform and merged the 15 land cover types into 7 categories: water bodies, forests, shrublands, savannas, grasslands, croplands, and barren. We used the fire scars and cross-referenced them with a previous year of the cover type map to obtain the annual percentage impact values (2002–2020).

### *2.4. Wildfire Intensity*

Fire activity can be quantified by obtaining the Fire Radiative Power (FRP [39,40]), which describes the rate of radiative energy release from wildfires when they are active. FRP allows distinguishing between fires of different intensities, which is useful for estimating fire risks. The FRP data are in units of Megawatts (MW) and were obtained from the MODIS Collection 6.1 product (1 km pixel resolution), from the FIRMS (https://firms.modaps.eosdis.nasa.gov, accessed on 25 June 2021), from the Terra and Aqua satellites, for the period 2001–2020 (20 years). Subsequently, an interpolation was performed using the inverse distance weighted distance (IDW) technique in ArcMap. Based on the classification proposed by Ichoku et al. [41], the interpolation results were grouped into 5 categories related to fire intensity: (1) <100 MW; (2) 100–499 MW; (3) 500–999 MW; (4) 1000–1499 MW and (5) $\geq$1500 MW.

### *2.5. Statistical Analysis*

The spatial autocorrelation or spatial dependence of the geographic pattern of the annual wildfire area (2001–2020) was analyzed with the global Moran's I index through the Spatial Autocorrelation tool of ArcMap. A positive spatial autocorrelation indicates that fires tend to cluster spatially (Moran's I values greater than zero), while a negative spatial autocorrelation indicates a tendency to dispersion (Moran's I values less than zero). In addition, we calculated fire frequencies in KBAs and distribution for priority bird species in ranges of annual occurrence events (1, 2–4, 5–7, 8–10, >10).

## 3. Results

### *3.1. Biodiversity in the KBAs*

The pattern of total bird species richness in Bolivia is characterized by strong latitudinal and altitudinal gradients. Species density (number of species per $1' \times 1'$ pixel) peaks in the northern Bolivian Amazon (Pando department) and in the humid foothill and lower montane Yungas forests of the department of La Paz (Figure 3). In the lowlands, species density moderately decreases southward and is lowest in parts of the Chaco and Chiquitanía ecoregions. The altitudinal decrease in species density is steep and particularly low in the western Altiplano and the Cordillera Occidental. The KBAs with the highest local species density (pixels) are Tahuamanu (474 species), Yungas Inferiores de Madidi (464 species), Reserva Nacional Amazónica Manuripi (464 species), Federico Román (463 species) and Yungas Inferiores de Pilón Lajas (450 species) (Figure 3, Table 1).

The geographic pattern of threatened bird species richness (Critically Endangered, Endangered, Vulnerable) changes in relation to the species richness map (compare Figures 3 and 4). The highest species richness of threatened birds is found in the Amazonian rainforest area of eastern Bolivia and in the Yungas (especially in the department of La Paz). The KBAs with the highest richness of threatened species were Noel Kempff Mercado (KBA 20) with 12 species, the Yungas Superiores de Apolobamba (KBA 15) and Yungas Inferiores de Madidi (KBA 30), both with 11 species. They are followed by the Yungas Inferiores de Isiboro-Sécure (KBA 31), Yungas Superiores de Madidi (KBA 16) and Reserva de Inmovilización de Iténez (KBA 40) with 10 species each (Figure 4, Table 1).

The areas with the highest species richness of endemic birds by pixel are located in the inter-Andean Dry Valleys, Yungas and small sectors of the Humid Puna of the department of La Paz (Figure 5). The KBAs with the highest richness of endemic species/pixel are the Upper Yungas of Carrasco (KBA 33), Caine and Mizque River Basins (KBA 8), the Upper Yungas of Amboró (KBA 32) and Cuenca Cotacajes (KBA 7) with 5 species, followed by Yungas inferiores de Carrasco (KBA 12), Yungas Superiores de Mosetenes y Cocapata (KBA 14), Cristal Mayu y alrededores (KBA 25), and Vertiente Sur del Parque Nacional Tunari (KBA 23), with 4 species each (Figure 5, Table 1).

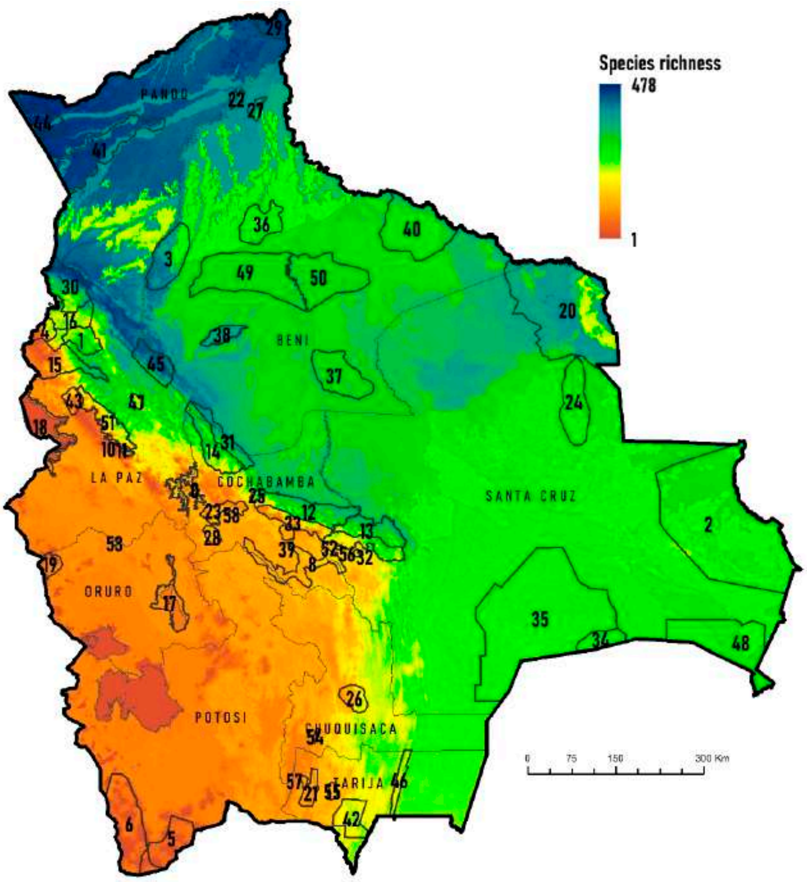


**Figure 3.** Total bird species richness in relation to the KBAs of Bolivia.

**Table 1.** Maximum pixel value of $1' \times 1'$ for total, endemic and threatened bird richness in the KBAs of Bolivia.

| KBA Code | KBA Name | Richness | Threatened | Endemic |
|---|---|---|---|---|
| 1 | Apolo | 326 | 9 | 1 |
| 2 | Área Natural de Manejo Integrado San Matías | 319 | 3 | - |
| 3 | Bajo Río Beni, Región Tacana | 426 | 9 | 1 |
| 4 | Bosque de *Polylepis* de Madidi | 262 | 9 | - |
| 5 | Lagunas de Agua Dulce de Potosí | 65 | 2 | - |
| 6 | Lagunas Salinas de Potosí | 73 | 2 | - |
| 7 | Cuenca Cotacajes | 193 | 3 | 5 |
| 8 | Cuencas de los Ríos Caine y Mizque | 184 | 3 | 5 |
| 9 | Bosque de *Polylepis* de Sanja Pampa | 71 | 2 | 3 |
| 10 | Bosque de *Polylepis* de Mina Elba | 77 | 3 | 2 |
| 11 | Bosque de *Polylepis* de Taquesi | 91 | 4 | 3 |
| 12 | Yungas Inferiores de Carrasco | 355 | 9 | 4 |
| 13 | Yungas Inferiores de Amboró | 359 | 8 | 2 |
| 14 | Yungas Superiores de Mosetenes y Cocapata | 394 | 9 | 4 |
| 15 | Yungas Superiores de Apolobamba | 344 | 11 | 1 |
| 16 | Yungas Superiores de Madidi | 415 | 10 | 1 |
| 17 | Lago Poopó y Río Laka Jahuira | 87 | 2 | - |
| 18 | Lago Titicaca (Sector Boliviano) | 95 | 2 | - |
| 19 | Parque Nacional Sajama | 84 | 3 | - |
| 20 | Noel Kempff Mercado | 429 | 12 | - |
| 21 | Reserva Biológica Cordillera de Sama | 132 | 4 | - |
| 22 | Cercanías de Riberalta | 420 | 7 | 1 |
| 23 | Vertiente Sur del Parque Nacional Tunari | 145 | 3 | 4 |
| 24 | Alto Paraguá | 318 | 4 | - |
| 25 | Cristal Mayu y alrededores | 331 | 9 | 4 |
| 26 | Azurduy | 218 | 4 | 1 |
| 27 | Cerrado de Riberalta | 403 | 6 | - |
| 28 | Cerro Q'ueñwa Sandora | 132 | 3 | 3 |
| 29 | Federico Román | 463 | 6 | - |
| 30 | Yungas Inferiores de Madidi | 465 | 11 | - |
| 31 | Yungas Inferiores de Isiboro-Sécure | 418 | 10 | 2 |
| 32 | Yungas Superiores de Amboró | 308 | 8 | 5 |
| 33 | Yungas Superiores de Carrasco | 308 | 7 | 5 |
| 34 | Palmar de las Islas | 269 | 1 | - |
| 35 | KAA-Iya del Gran Chaco | 282 | 2 | - |
| 36 | Laguna Rogaguado y Ginebra | 336 | 6 | - |
| 37 | Loreto | 333 | 7 | - |
| 38 | Estación Biológica del Beni | 378 | 5 | - |
| 39 | Quebrada Mojón | 133 | 3 | - |
| 40 | Reserva de Inmobilización de Iténez | 349 | 10 | - |
| 41 | Reserva Nacional Amazónica Manuripi | 464 | 7 | - |
| 42 | Reserva Nacional de Flora y Fauna Tariquia | 240 | 4 | - |
| 43 | Tacacoma-Quiabaya y Valle Sorata | 193 | 4 | 2 |
| 44 | Tahuamanu | 474 | 7 | 1 |
| 45 | Yungas Inferiores de Pilón Lajas | 450 | 9 | 3 |
| 46 | Serranía de Aguaragüe | 248 | 4 | 3 |
| 47 | Serranía Bella Vista | 303 | 7 | 1 |
| 48 | Área Natural de Manejo Integrado Otuquis | 297 | 2 | - |
| 49 | Oeste del río Mamoré | 333 | 8 | 2 |
| 50 | Este del río Mamoré | 333 | 8 | 2 |
| 51 | Cotapata | 301 | 9 | 4 |
| 52 | Comarapa | 209 | 3 | 3 |
| 53 | Río Huayllamarca | 80 | - | - |
| 54 | Culpina | 108 | 3 | - |
| 55 | Río Guadalquivir | 148 | 3 | - |
| 56 | Pampa Redonda | 213 | 4 | 2 |
| 57 | Prepuna del área del río San Juan | 113 | 2 | - |
| 58 | Cochabamba | 114 | 1 | 2 |

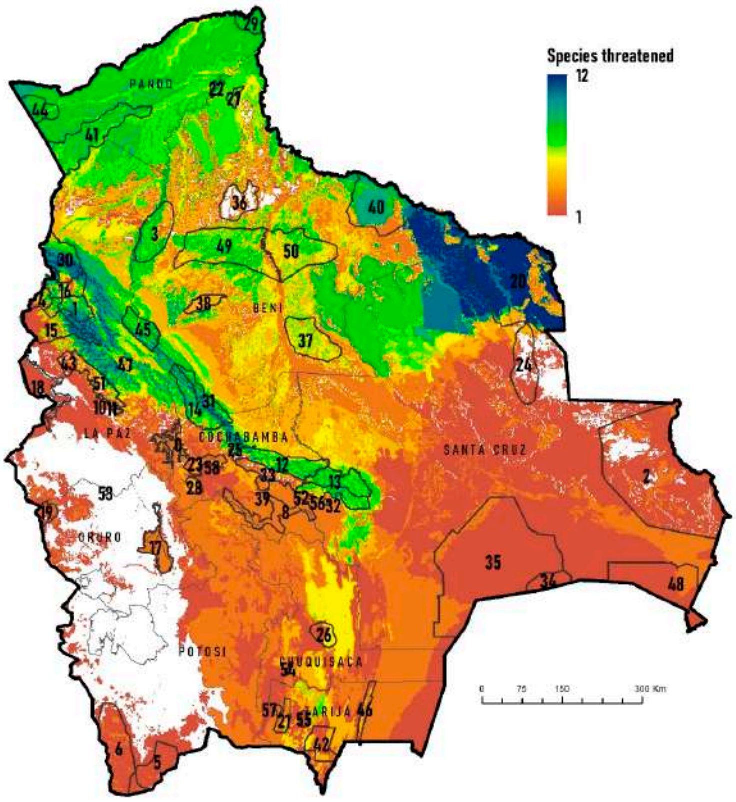


**Figure 4.** Threatened bird species (Critically Endangered, Endangered, Vulnerable) in relation to Bolivia's KBAs.

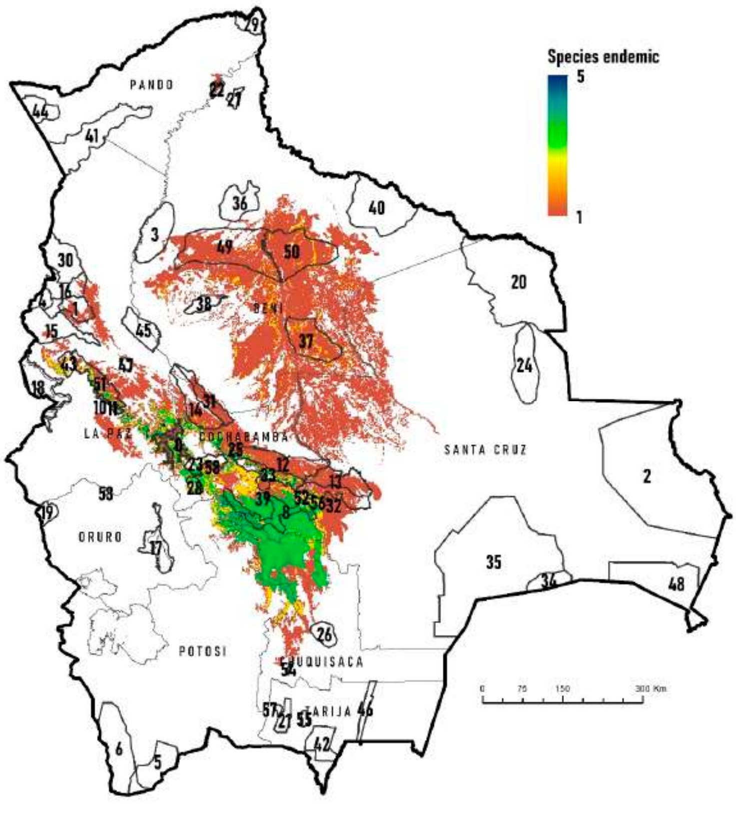


**Figure 5.** Endemic bird species in relation to the KBAs of Bolivia.

### 3.2. Impact of Wildfires on the KBAs

At the national level, the cumulative area of wildfires in the period 2001–2020 was 74.3 million ha, while the absolute area was 23.6 million ha (21.5% of the national territory). These fires occurred mainly in the lowlands, and the most extensive burnt areas were reported in 2010 (9.2 million ha), 2004 (6.4 million ha), 2005 (5.7 million ha), and 2019 (5.4 million ha) (Figure 6). Moran's I index was significant and positive for all years, except 2011 and 2019 (Table 2).

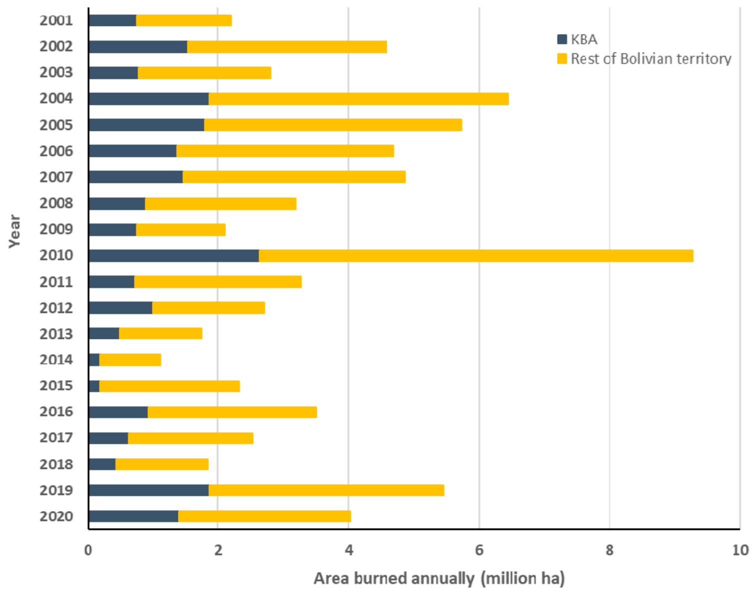


**Figure 6.** Area burned annually in the period 2001–2020 in the KBAs and in the rest of the national territory.

**Table 2.** Global Moran's I index of Bolivia's burned areas during 2001–2020. Significance ($p < 0.05$) is represented by an asterisk.

| Year | Moran's Index | z-Score | *p*-Value | Distance Threshold (km) |
|---|---|---|---|---|
| 2001 | 0.0056 | 2.6243 | 0.0087 * | 113.4 |
| 2002 | 0.0033 | 5.4408 | 0.0000 * | 188.1 |
| 2003 | 0.0163 | 10.3768 | 0.0000 * | 70.3 |
| 2004 | 0.0028 | 2.6478 | 0.0081 * | 90.4 |
| 2005 | 0.0039 | 2.9402 | 0.0033 * | 91.0 |
| 2006 | 0.0045 | 5.6274 | 0.0000 * | 247.9 |
| 2007 | 0.0039 | 3.2603 | 0.0011 * | 125.9 |
| 2008 | 0.0120 | 7.3701 | 0.0000 * | 114.1 |
| 2009 | 0.0070 | 5.2465 | 0.0000 * | 101.6 |
| 2010 | 0.0034 | 2.4988 | 0.0125 * | 86.2 |
| 2011 | 0.0042 | 1.6745 | 0.0940 | 67.5 |
| 2012 | 0.0069 | 2.6792 | 0.0074 * | 87.0 |
| 2013 | 0.0083 | 3.7917 | 0.0002 * | 128.2 |
| 2014 | 0.0237 | 13.2323 | 0.0000 * | 150.9 |
| 2015 | 0.0122 | 6.6271 | 0.0000 * | 150.5 |
| 2016 | 0.0062 | 7.7785 | 0.0000 * | 311.1 |
| 2017 | 0.0109 | 6.7389 | 0.0000 * | 165.3 |
| 2018 | 0.0142 | 7.8238 | 0.0000 * | 128.7 |
| 2019 | 0.0015 | 1.2075 | 0.2272 | 150.5 |
| 2020 | 0.0156 | 5.7412 | 0.0000 * | 86.0 |

At the KBA level, the cumulative area of wildfires was 21.6 million ha (2001–2020), while the absolute area impacted was 5.6 million ha, representing 24.5% of the KBA. These results indicate that 24.5% of the KBAs were burned at least once during the study period. The years with the largest wildfire-impacted areas within the KBAs were 2010 (2.6 million ha), 2019 (1.8 million ha), 2004 (1.8 million ha), and 2005 (1 million ha) (Figure 6).

The KBAs most affected by wildfires in terms of the number of hectares are located in the departments of Beni and Santa Cruz (Figure 7), mainly in the Área Natural de Manejo Integrado San Matías (1.7 million ha), Oeste del río Mamoré (778 thousand ha), Este del río Mamoré (652 thousand ha), Noel Kempff Mercado (459 thousand ha) and Área Natural de Manejo Integrado Otuquis (395 thousand ha) (Table A1). However, the KBAs proportionally more affected were Este del río Mamoré (85.2%), Alto Paraguá (74.4%), Loreto (71.5%), Oeste del río Mamoré (70.6%) and Laguna Rogaguado y Ginebra (53.8%) (Table A1).

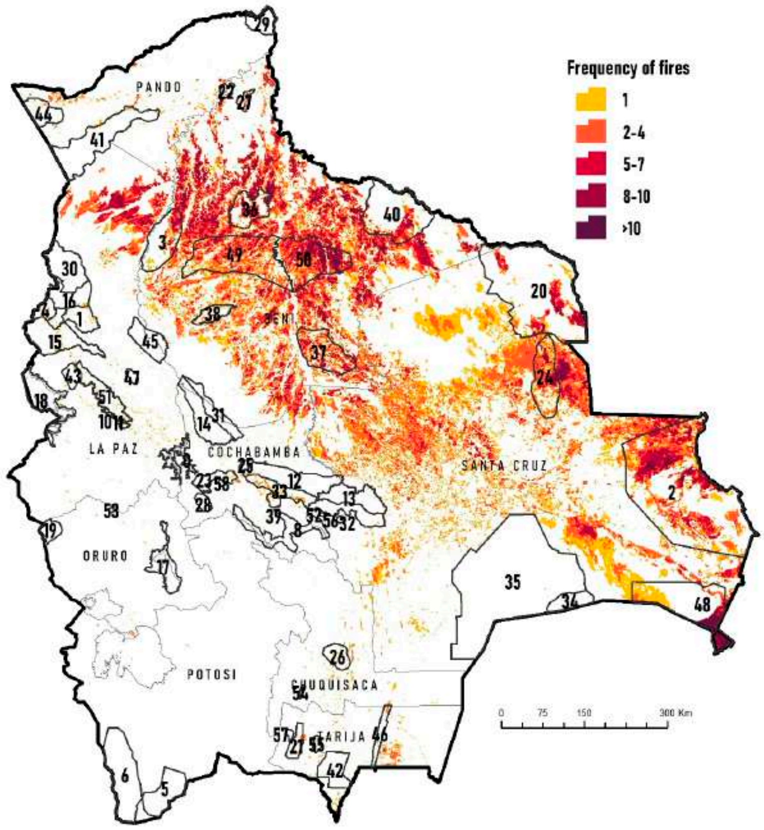


**Figure 7.** Frequency of wildfires in the KBA of Bolivia, in the period 2001–2020 based on the MCD64A1 product.

In terms of frequency at the national level, the occurrence of wildfires was mainly recorded between one year (36.6%) and two to four years (39.5%). At the KBA level, 15 sites were impacted by wildfire on at least one year. Another 17 KBAs recorded a series of wildfires between two to four years, four KBAs evidenced fire occurrences between five to seven years, one KBA between eight to ten years, and the other 13 KBAs with wildfires for more than ten years (Figure 8, Table A1). The highest frequency of burns (>10 years) was recorded in the Área Natural de Manejo Integrado Otuquis (23%), Oeste del Río Mamoré (11.7%), Cerrado de Riberalta (8.3%) and Laguna Rogaguado y Ginebra (7.6%) (Figure 7, Table A1).

Savannas, which are located in the Bolivian lowlands (Cerrado, Llanos de Moxos, Pantanal), are proportionally the most affected ecosystems. Between 42% and 62% of their surface is annually burnt (55% mean). These ecosystems are also the most affected ones within the KBAs (33% to 65%, with a mean of 52%), while forests are affected to a lesser degree (12% to 53%, with an average of 28%) (Figure 9).

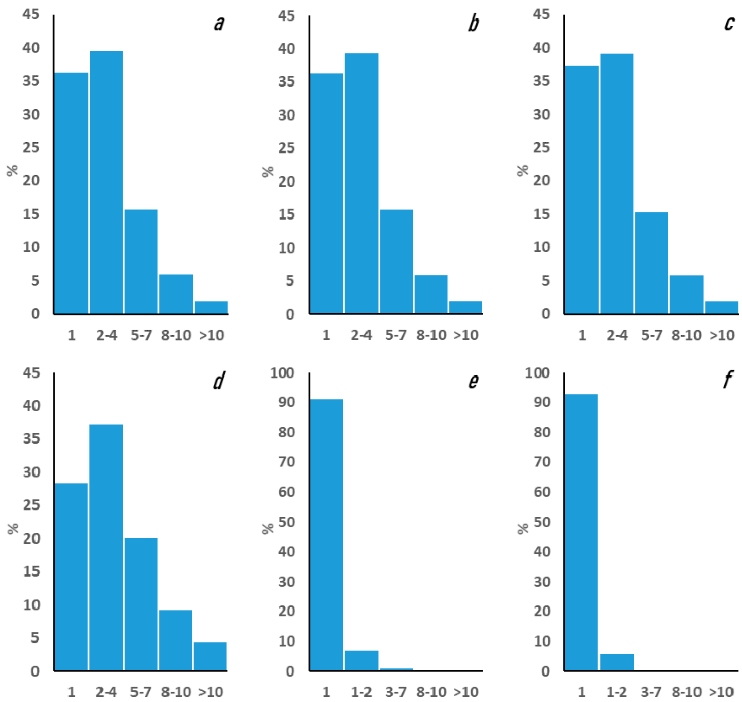


**Figure 8.** Frequency of annual forest wildfires (%) in relation to total bird richness in Bolivia (**a**) and only KBA (**b**), threatened bird species in Bolivia (**c**) and only KBA (**d**), endemic bird species in Bolivia (**e**) and only KBA (**f**).

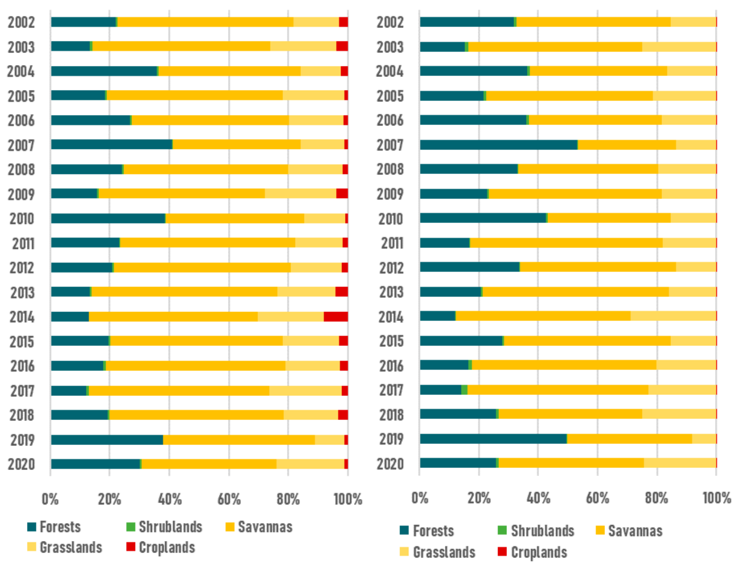


**Figure 9.** Percentage of annual fire impact by land cover types in the period 2002–2020, in Bolivia (**left**) and the KBAs (**right**).

### 3.3. Impact of Wildfires on Biodiversity

The fires recorded in the period 2001–2020 affected the entire bird richness within the KBAs (5.6 million ha). Of the 96.1 million ha over which the 54 threatened bird species are distributed, 22 million ha were affected by the wildfires, 5 million ha of which were found within KBAs. For the threatened species, most of this area affected by fire (1.4 million ha) was burned between one and five times during the study period. In the case of the 15 endemic bird species, which are a subset of the threatened species, 5.4 million ha were affected by wildfire, with 1.6 million ha found within 22 KBAs; 90% of this affected area was burned only once, and the remaining 10% burned twice (between 2001 and 2020).

*3.4. Impact of Wildfires on the Distribution of Priority Species*

The species of conservation concern whose distribution areas were most affected by wildfires during the period 2001–2020 mainly inhabit seasonally flooded savanna, Cerrado and Pantanal. These species were Cock-tailed Tyrant (*Alectrurus tricolor*, VU), Black-masked Finch (*Coryphaspiza melanotis*, VU), Sharp-tailed Tyrant (*Culicivora caudacuta*, VU), Rufous-faced Crake (*Laterallus xenopterus*, VU), Blue-throated Macaw (*Ara glaucogularis*, CR), Hyacinth Macaw (*Anodorhynchus hyacinthinus*, VU), Great-billed Seed-Finch (*Sporophila maximiliani*, EN), Campo Miner (*Geositta poeciloptera*, VU), Black-and-tawny Seedeater (*Sporophila nigrorufa*, VU) and White-winged Nightjar (*Eleothreptus candicans*, VU). The percentage of the distributional ranges of these species affected by wildfire ranged from 58% to 83% (Table A2). The percentage of distributional ranges of these species within the KBAs was variable, ranging from very light impact (*E. candicans*) to very severe (*L. xenopterus*, 91%).

With respect to forest-associated bird species, Unicolored Thrush (*Turdus haplochrous*, endemic to Bolivia) and Bare-faced Curassow (*Crax fasciolata*, VU), whose habitats are gallery and varzea forests for the former and Amazonian rainforests of eastern Bolivia and Chiquitano dry forest for the latter, were also significantly affected by wildfires during the time period analyzed (40% and 32%, respectively).

*3.5. Wildfire Intensity*

The values obtained with the FRP interpolation for the whole of Bolivia indicate that historically (2001–2020), the highest percentage of intensities were concentrated in category one (<100 MW) with 91.2% (Figure 10). However, in focal areas, wildfires with high intensities have been recorded, especially in the southern area of the country, where wildfires were recorded releasing extremely high amounts of energy that fall into category five (>1500 MW), reaching up to 11,551 MW in 2019. At the KBA level, excluding outliers, annual average values range between 29 MW and 43 MW, with the highest intensity recorded in the Área Natural de Manejo Integrado Otuquis.

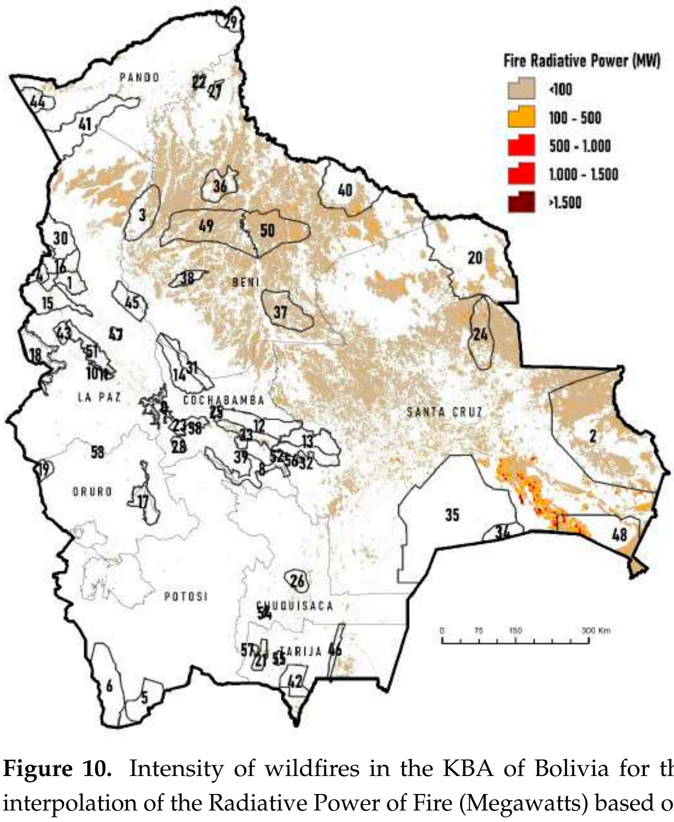


**Figure 10.** Intensity of wildfires in the KBA of Bolivia for the period 2001–2020, based on the interpolation of the Radiative Power of Fire (Megawatts) based on the MODIS Collection 6.1 product.

## 4. Discussion

The patterns of bird species richness in Bolivia are consistent with the results found by Herzog et al. [42], in the sense that the areas with the highest concentration of species are located in the Amazonia and mountain humid forest (Yungas) regions. The highest concentration of threatened species is found in the Yungas of La Paz and in the northeastern region of the department of Santa Cruz, where the transition from Amazonian rainforest to Chiquitano dry forest takes place. These regions should be prioritized for the establishment of effective protected areas. The Bajo Paraguá region (Chiquitano dry forest) that lies to the west of the KBA Parque Nacional Noel Kempff Mercado is a region that is experiencing very high levels of human pressure. Fortunately, a municipal protected area was declared in this area in 2021 to address increasing deforestation pressure and the construction of a national highway [43].

The geographic pattern of endemic species richness in Bolivia indicates that the existing KBAs in the western Andean region of the country, especially in the department of La Paz, do not coincide with the geographic distributions of these species. This suggests that it is necessary to evaluate the location and extent of some KBA in this region of Bolivia.

Just under a half of the KBAs (44%) are found within national protected areas, and six (12%) overlap [30]. In principle, this implies that at least part of the KBA's protection should be guaranteed by the state. However, the protected area's capacities to safeguard biodiversity within their territories needs to be improved significantly for at least three protected areas, where over 2.5 million ha were burnt at least once between 2001 and 2020 (KBAs San Matías, Otuquis and Noel Kempff Mercado). It is also important to highlight that most wildfires take place in the Bolivian lowlands, where the geographical overlapping between KBAs and protected areas is smaller compared with the Andean region of Bolivia. Finally, ten KBAs (5.1 million ha) do not overlap with any national protected area and are among the most vulnerable ones to wildfires. The protection and proper management of all KBAs can offer a major opportunity to combat biodiversity loss [44].

All KBAs are a priority for conservation due to their unique biodiversity characteristics [30]. However, there are not enough economic and human resources to effectively protect all KBAs, so it is necessary to prioritize them based on their biological value, vulnerability, and other social–economic criteria. Yepez et al. [45] carried out prioritization of the IBAs (Important Bird Areas) in the Amazonia region and determined that 9 of the 13 IBAs in Bolivia are at a critical priority level. For most of these, Soria-Auza and Hennessey [29] identified fire-associated activities among the pressures over these IBAs in Bolivia (including annual burns for pasture replacement, out-of-control grassland burns, grassland burns, burns for the renovation of cultivated areas, and arson). The only known study on the historical incidence of wildfires in IBAs was mentioned by Maillard et al. [30]. These authors reported the highest concentration of fires to be located in San Matías (KBA 2). The results obtained in our study can serve, together with other environmental and socioeconomic variables, as a basis for updating a national prioritization list of KBAs.

Wildfires are more frequent and widespread in the Bolivian lowlands, and, consequently, their impacts are also far more extensive in the KBAs located in this part of the country. On the other hand, wildfires are less frequent in the Bolivian Andes, and therefore their impact on Andean KBAs are also less extensive. However, a much more detailed analysis needs to be conducted for range-restricted bird species, or birds that have very local and patchy distributions, whose key habitats (e.g., *Polylepis* forests and high Andean scrublands) are frequently affected by uncontrolled wildfires (e.g., *Poospiza garleppi*).

Controlled burns have been the most frequent agriculture practice to clear crops areas or renew pastures for many years [16,46]. These agriculture activities take place mostly between July and October [15,17,20]. However, strategies used by farmers to control burns are not effective, and very frequently, burns initiate large-scale wildfires that affect millions of hectares every year [15,17,19,22]. These are causing a series of ecological, economic and social problems [44]. The scenario is worrisome, especially for the Chiquitano dry forests, where wildfires have been more frequent in recent years. Devisscher et al. [47] simulated possible future risk scenarios for the Chiquitano forest and estimated that until 2025, the probability of increased wildfire risk will be approximately up to 1.8 times more than the estimates for 2010.

For most dry ecosystems, fire is an important ecological force that plays a role in maintaining biodiversity [48]. Generally, fire has beneficial effects for some species but detrimental effects for others [8,9,12,49–51]. Most vertebrates are able to escape from wildfires, but mortality rates due to starvation or predation while wandering around until new territories are established increase [51,52]. Loss of habitat, territories, and food [49] provoked by fire might even become a driving force for the local extinction of some species [53]. Species whose main habitat are forests are especially vulnerable, as these are less abundant and more sensitive to disturbance and habitat-specialists [54,55]. In Bolivia, very few studies have examined the impacts of fires on vertebrates. Some investigations carried out in the Chiquitano forest demonstrated that some groups (e.g., small mammals) increase in abundance or even species richness, while abundance and richness for other groups (e.g., birds) decrease [54,56]. The dry and humid forests in the north of the Santa Cruz department changed in structure and composition of tree species as a response to wildfires. These changes are related to plant species-specific abilities to survive and regenerate after wildfires [47,57–61]. All in all, it is evident that visible changes in habitat take place after wildfires affect forests, and it is still poorly understood whether forest structure and composition might return to its previous state (and how long might this process take). This raises the question of how IUCN vulnerable-to-extinction bird species such as *Tinamus tao*, *Crax fasciolata*, *Patagioenas subvinacea* and *Hypocnemis ochrogyna* might cope with new habitat conditions/characteristics.

Common sense might lead us to consider that threatened species inhabiting in ecoregions where fire plays a key role in ecosystem dynamics might not be at risk. However, the situation for these species is not straight. It is known that *Geositta poeciloptera* (also Vulnerable of extinction) also inhabits grasslands regularly burnt [62,63], but the effect that changes in wildlife regimes (i.e., increasing in the frequency of fires) might have over this species remains to be studied. In the case of *Ara glaucogularis* (Critically Endangered) that inhabits in the Llanos de Moxos, a tropical seasonally flooded savanna that contains small palm forest islands (key for this species), wildfires are key in the ecosystem dynamics of this savanna. However, the frequency of provoked fires during the XXI century is presumably higher than during the XX century and more extensive as well. Therefore, the higher frequency of fires might be affecting the habitat quality for this species or its capacity to recover. Something similar has been documented about the effect of bad cattle-management practices over palm-forest islands regeneration in the Llanos de Moxos [64]. However, it remains to be evaluated the specific role of provoked fires within the whole package of bad cattle-management practices. A similar situation might be expected for *Anodorhynchus hyacinthinus* (vulnerable to extinction) that in Bolivia inhabits in the Pantanal of San Matías (also a tropical seasonally flooded savanna), Cerrado, Mauritia palm stands and gallery forests.

Monitoring is an essential component of conservation and is necessary to identify threats to biodiversity [65]. Monitoring land surface change has been one of the main uses of remote sensing over the past decades [66], and the multiscale capability of remote sensors makes them particularly suitable for quantifying patterns of variation of wildfire impacts in space and time [67]. However, it is a priority to continue field monitoring of bird populations, as they represent one of the best indicators to assess the state of the environment since it is a group sensitive to environmental changes and therefore useful to measure biodiversity trends [44]. Future research should consider studies of bird populations in the field, in combination with remote sensing analyses, in order to understand how sensitive species respond to wildfire regimes at different temporal and spatial scales. In these analyses, it is important to assess fuel consumption and fire spread patterns, intensity (energy release), severity (ecosystem impact), frequency, and seasonality [5]. These studies can help researchers and policymakers to guide actions in the restoration planning of fire-impacted ecosystems in KBAs.

## 5. Conclusions

KBAs in Bolivia provides key criteria to protect biodiversity and ecology. One of the greatest challenges to maintaining these KBAs are human-caused fires, which have tended to increase in area, frequency and intensity in recent years. Although fire is an ecological element that in certain landscapes contributes to the maintenance of biodiversity, especially for fire-dependent ecosystems such as the Cerrado savannas, the increase in provoked fires represents one of the greatest threats to ecosystems species of conservation concern (threatened and endemic species). During approximately two decades, wildfires impacted 24.5% of the KBA, mainly in the lowlands of Bolivia (Santa Cruz and Beni departments) and affected significantly the distributional range of several species of conservation concern (e.g., *Ara glaucogularis*, *Anodorhynchus hyacinthinus*, *Crax globulosa*). However, the effect of fires on the population dynamics of these species needs to be researched to have a more complete understanding of the magnitude of the impact that fires have on these species. Satellite monitoring, in combination with field monitoring, could help to understand more about the effects on bird populations and thus guide actions in the restoration planning of fire-impacted ecosystems. The increase in human-caused fires requires an adjustment in Bolivia's public policies, especially in the land-use regulations currently in force in the country. Based on the results of this study, it is a priority to communicate to Bolivian government authorities the importance of KBAs as a strategy for the conservation of the country's biodiversity and the threats resulting from anthropogenic fires.

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## Appendix A

**Table A1.** Area and frequency of fires in the KBAs of Bolivia, in the period 2001–2020.

| KBA Code | KBA Name | Area (ha) | Burnt Area 2001–2020 (ha) | Burnt Area 2001–2020 (%) | Frequency of Fires (% KBA) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2–4 | 5–7 | 8–10 | >10 |
| 1 | Apolo | 193,503 | 13,501 | 7.0 | 89.6 | 10.4 | - | - | - |
| 2 | Área Natural de Manejo Integrado San Matías | 3,282,376 | 1,731,288 | 52.7 | 25.3 | 39.4 | 22.7 | 10.1 | 2.5 |
| 3 | Bajo Río Beni. Región Tacana | 485,525 | 161,984 | 33.4 | 31.5 | 30.5 | 25.7 | 11.3 | 1.0 |
| 4 | Bosque de *Polylepis* de Madidi | 103,456 | 3243 | 3.1 | 88.4 | 11.6 | - | - | - |
| 5 | Lagunas de Agua Dulce de Potosí | 346,301 | 0 | 0.0 | 100 | - | - | - | - |
| 6 | Lagunas Salinas de Potosí | 682,821 | 0 | 0.0 | 100 | - | - | - | - |
| 7 | Cuenca Cotacajes | 155,658 | 1561 | 1.0 | 100 | - | - | - | - |
| 8 | Cuencas de los Ríos Caine y Mizque | 373,471 | 150 | 0.0 | 100 | - | - | - | - |
| 9 | Bosque de *Polylepis* de Sanja Pampa | 2064 | 50 | 2.4 | 100 | - | - | - | - |
| 10 | Bosque de *Polylepis* de Mina Elba | 6350 | 325 | 5.1 | 74.4 | 25.6 | - | - | - |
| 11 | Bosque de *Polylepis* de Taquesi | 3799 | 225 | 5.9 | 88.7 | 11.3 | - | - | - |
| 12 | Yungas Inferiores de Carrasco | 466,993 | 9300 | 2.0 | 98.4 | 1.6 | - | - | - |
| 13 | Yungas Inferiores de Amboró | 329,261 | 4095 | 1.2 | 86.9 | 12.7 | 0.4 | - | - |
| 14 | Yungas Superiores de Mosetenes y Cocapata | 369,386 | 1334 | 0.4 | 87.2 | 12.8 | - | - | - |
| 15 | Yungas Superiores de Apolobamba | 474,724 | 18,843 | 4.0 | 92.3 | 7.7 | - | - | - |
| 16 | Yungas Superiores de Madidi | 262,217 | 7807 | 3.0 | 100 | - | - | - | - |
| 17 | Lago Poopó y Río Laka Jahuira | 264,652 | 1622 | 0.6 | 100 | - | - | - | - |
| 18 | Lago Titicaca (Sector Boliviano) | 421,641 | 75 | 0.0 | 29.2 | 29.2 | 28.1 | 12.0 | 1.5 |
| 19 | Parque Nacional Sajama | 107,975 | 100 | 0.1 | 39.3 | 60.7 | - | - | - |
| 20 | Noel Kempff Mercado | 2,247,479 | 459,975 | 20.5 | 40.1 | 39.8 | 12.6 | 5.3 | 2.2 |
| 21 | Reserva Biológica Cordillera de Sama | 104,929 | 10,977 | 10.5 | 97.5 | 2.5 | - | - | - |
| 22 | Cercanías de Riberalta | 49,747 | 10,266 | 20.6 | 27.9 | 48.5 | 14.9 | 5.4 | 3.2 |
| 23 | Vertiente Sur del Parque Nacional Tunari | 140,906 | 7094 | 5.0 | 100 | - | - | - | - |
| 24 | Alto Paraguá | 516,552 | 384,187 | 74.4 | 97.1 | 2.9 | - | - | - |
| 25 | Cristal Mayu y alrededores | 32,312 | 225 | 0.7 | 29.7 | 34.7 | 14.2 | 13.0 | 8.3 |
| 26 | Azurduy | 147,552 | 9326 | 6.3 | 100 | - | - | - | - |
| 27 | Cerrado de Riberalta | 55,099 | 17,080 | 31.0 | 100 | - | - | - | - |
| 28 | Cerro Q'ueñwa Sandora | 63,749 | 75 | 0.1 | 100 | - | - | - | - |
| 29 | Federico Román | 173,674 | 1629 | 0.9 | 100 | - | - | - | - |
| 30 | Yungas Inferiores de Madidi | 405,756 | 1200 | 0.3 | 97.6 | 2.4 | - | - | - |
| 31 | Yungas Inferiores de Isiboro-Sécure | 212,090 | 125 | 0.1 | 74.3 | 25.7 | - | - | - |
| 32 | Yungas Superiores de Amboró | 269,645 | 4150 | 1.5 | 100 | - | - | - | - |
| 33 | Yungas Superiores de Carrasco | 226,003 | 42,034 | 18.6 | 85.5 | 13.2 | 1.3 | - | - |
| 34 | Palmar de las Islas | 185,485 | 200 | 0.1 | 17.9 | 36.2 | 23.9 | 14.4 | 7.6 |
| 35 | Kaa-Iya del Gran Chaco | 3,231,642 | 1896 | 0.1 | 24.1 | 44.4 | 22.2 | 7.9 | 1.4 |
| 36 | Laguna Rogaguado y Ginebra | 341,746 | 183,818 | 53.8 | 64.3 | 33.0 | 2.7 | - | - |
| 37 | Loreto | 512,455 | 366,174 | 71.5 | 92.1 | 7.9 | - | - | - |
| 38 | Estación Biológica del Beni | 135,248 | 33,689 | 24.9 | 21.7 | 37.8 | 26.4 | 11.9 | 2.3 |
| 39 | Quebrada Mojón | 44,441 | 5670 | 12.8 | 72.8 | 27.2 | - | - | - |
| 40 | Reserva de Inmobilización de Iténez | 909,454 | 239,288 | 26.3 | 97.6 | 2.4 | - | - | - |
| 41 | Reserva Nacional Amazónica Manuripi | 766,353 | 20,858 | 2.7 | 88.1 | 11.9 | - | - | - |
| 42 | Reserva Nacional de Flora y Fauna Tariquia | 254,856 | 2930 | 1.1 | 73.9 | 23.7 | 2.4 | - | - |
| 43 | Tacacoma-Quiabaya y Valle Sorata | 95,877 | 2979 | 3.1 | 100 | - | - | - | - |
| 44 | Tahuamanu | 224,083 | 10,431 | 4.7 | 53.4 | 46.6 | - | - | - |
| 45 | Yungas Inferiores de Pilón Lajas | 272,561 | 425 | 0.2 | 100 | - | - | - | - |
| 46 | Serranía de Aguaragüe | 110,845 | 8784 | 7.9 | 42.7 | 12.2 | 4.9 | 17.3 | 23 |
| 47 | Serranía Bella Vista | 36,556 | 375 | 1.0 | 27.1 | 49.3 | 19.0 | 4.3 | 0.4 |
| 48 | Área Natural de Manejo Integrado Otuquis | 972,400 | 395,228 | 40.6 | 10.6 | 35.8 | 27.8 | 14.2 | 12 |
| 49 | Oeste del río Mamoré | 1,103,157 | 778,302 | 70.6 | 27.1 | 49.3 | 19.0 | 4.3 | - |
| 50 | Este del río Mamoré | 766,016 | 652,382 | 85.2 | 10.6 | 35.8 | 27.8 | 14.2 | 12 |
| 51 | Cotapata | 291,140 | 21,191 | 7.3 | 100 | - | - | - | - |
| 52 | Comarapa | 6473 | - | - | - | - | - | - | - |
| 53 | Río Huayllamarca | 5760 | - | - | - | - | - | - | - |
| 54 | Culpina | 6091 | - | - | - | - | - | - | - |
| 55 | Río Guadalquivir | 35,328 | - | - | - | - | - | - | - |
| 56 | Pampa Redonda | 11,174 | - | - | - | - | - | - | - |
| 57 | Prepuna del área del río San Juan | 18,073 | - | - | - | - | - | - | - |
| 58 | Cochabamba | 11,290 | - | - | - | - | - | - | - |

**Table A2.** Impact of fires on endemic and threatened bird species in Bolivia and the KBAs. CR = Critically Endangered, EN = Endangered, VU = Vulnerable.

| Species | Endemic | UICN Category | Bolivia (ha) | KBA (ha) | Burnt Area/Bolivia (ha) | Burnt Area/KBA (ha) | Burnt Area/Bolivia (%) | Burnt Area/KBA (%) |
|---|---|---|---|---|---|---|---|---|
| *Tinamus tao* | | VU | 25,259,872 | 5,916,650 | 2,799,725 | 308,325 | 11.1 | 5.2 |
| *Tinamus osgoodi* | | VU | 158,567 | 140,981 | 2875 | 2675 | 1.8 | 1.9 |
| *Nothoprocta taczanowskii* | | VU | 114,061 | 78,742 | 14,575 | 11,250 | 12.8 | 14.3 |
| *Crax globulosa* | | EN | 818,032 | 320,374 | 128,875 | 36,350 | 15.8 | 11.3 |
| *Crax fasciolata* | | VU | 25,001,932 | 5,659,089 | 7,980,425 | 1,454,725 | 31.9 | 25.7 |
| *Pauxi unicornis* | X | CR | 974,109 | 743,220 | 10,325 | 4850 | 1.1 | 0.7 |
| *Phoenicoparrus andinus* | | VU | 685,870 | 384,107 | 1975 | 1550 | 0.3 | 0.4 |
| *Rollandia microptera* | | EN | 597,987 | 537,810 | 1550 | 1500 | 0.3 | 0.3 |
| *Patagioenas subvinacea* | | VU | 31,754,317 | 5,809,445 | 5,474,875 | 457,292 | 17.2 | 7.9 |
| *Neomorphus geoffroyi* | | VU | 6,614,728 | 2,398,584 | 182,750 | 59,575 | 2.8 | 2.5 |
| *Eleothreptus candicans* | | VU | 219,799 | 232 | 129,225 | 0 | 58.8 | 0.0 |
| *Aglaeactis pamela* | X | | 976,049 | 218,893 | 67,875 | 36,000 | 7.0 | 16.4 |
| *Psophia viridis* | | VU | 26,619 | 16,740 | 275 | 200 | 1.0 | 1.2 |
| *Laterallus xenopterus* | | VU | 623,010 | 180,166 | 471,300 | 163,325 | 75.6 | 90.7 |
| *Agamia agami* | | VU | 18,050,717 | 4,494,573 | 2,020,150 | 346,350 | 11.2 | 7.7 |
| *Vultur gryphus* | | VU | 24,467,578 | 3,566,639 | 647,525 | 121,549 | 2.6 | 3.4 |
| *Spizaetus isidori* | | EN | 6,101,548 | 2,418,046 | 173,057 | 52,399 | 2.8 | 2.2 |
| *Buteogallus coronatus* | | EN | 27,146,927 | 7,649,742 | 10,591,525 | 2,790,425 | 39.0 | 36.5 |
| *Ramphastos culminatus* | | VU | 30,316,449 | 6,721,245 | 3,227,174 | 323,894 | 10.6 | 4.8 |
| *Capito dayi* | | VU | 2,707,614 | 1,553,855 | 322,225 | 116,975 | 11.9 | 7.5 |
| *Touit huetii* | | VU | 2,853,776 | 608,629 | 385,650 | 39,400 | 13.5 | 6.5 |
| *Myiopsitta luchsi* | X | | 2,403,318 | 363,260 | 3600 | 475 | 0.1 | 0.1 |
| *Amazona tucumana* | | VU | 2,315,790 | 216,696 | 94,414 | 8972 | 4.1 | 4.1 |
| *Pyrrhura perlata* | | VU | 3,940,722 | 1,750,782 | 621,375 | 119,750 | 15.8 | 6.8 |
| *Pyrrhura snethlageae* | | VU | 8,847,518 | 2,639,075 | 1,531,900 | 263,225 | 17.3 | 10.0 |
| *Anodorhynchus hyacinthinus* | | VU | 1,136,000 | 949,652 | 836,650 | 726,600 | 73.6 | 76.5 |
| *Primolius couloni* | | VU | 10,607,473 | 1,409,521 | 824,775 | 75,125 | 7.8 | 5.3 |
| *Ara glaucogularis* | X | CR | 5,044,030 | 1,903,458 | 3,731,300 | 1,493,325 | 74.0 | 78.5 |
| *Ara rubrogenys* | X | CR | 2,581,914 | 392,616 | 10,675 | 3975 | 0.4 | 1.0 |
| *Ara militaris* | | VU | 7,620,889 | 2,553,029 | 185,668 | 41,286 | 2.4 | 1.6 |
| *Euchrepomis sharpei* | | EN | 1,871,754 | 812,665 | 28,146 | 17,747 | 1.5 | 2.2 |
| *Hypocnemis ochrogyna* | | VU | 8,006,115 | 2,381,660 | 1,485,550 | 208,050 | 18.6 | 8.7 |
| *Hylopezus auricularis* | X | VU | 49,808 | 25,050 | 5050 | 3175 | 10.1 | 12.7 |
| *Geositta poeciloptera* | | VU | 323,179 | 320,467 | 209,825 | 208,775 | 64.9 | 65.1 |
| *Cinclodes aricomae* | | CR | 307,113 | 141,392 | 32,025 | 15,700 | 10.4 | 11.1 |
| *Asthenes berlepschi* | X | | 95,063 | 31,942 | 2675 | 1250 | 2.8 | 3.9 |
| *Asthenes harterti* | X | | 548,323 | 158,629 | 44,400 | 23,200 | 8.1 | 14.6 |
| *Asthenes helleri* | | VU | 146,117 | 107,656 | 18,575 | 14,850 | 12.7 | 13.8 |
| *Cranioleuca henricae* | X | VU | 180,629 | 47,958 | 1725 | 700 | 1.0 | 1.5 |
| *Cranioleuca curtata* | | VU | 2,692,172 | 1,163,412 | 23,021 | 10,102 | 0.9 | 0.9 |
| *Phibalura boliviana* | X | EN | 420,463 | 228,057 | 18,650 | 14,700 | 4.4 | 6.4 |
| *Lipaugus uropygialis* | | VU | 1,007,525 | 443,049 | 31,053 | 10,205 | 3.1 | 2.3 |
| *Cnipodectes superrufus* | | VU | 110,997 | 20,461 | 2,825 | 350 | 2.5 | 1.7 |
| *Zimmerius cinereicapilla* | | VU | 550,336 | 128,573 | 2300 | 200 | 0.4 | 0.2 |
| *Phyllomyias weedeni* | | VU | 1,245,022 | 432,825 | 6094 | 1232 | 0.5 | 0.3 |
| *Anairetes alpinus* | | EN | 295,573 | 195,260 | 31,580 | 24,832 | 10.7 | 12.7 |
| *Culicivora caudacuta* | | VU | 6,443,013 | 1,792,394 | 5,086,225 | 1,398,475 | 78.9 | 78.0 |
| *Alectrurus tricolor* | | VU | 4,531,974 | 1,335,363 | 3,760,300 | 1,128,375 | 83.0 | 84.5 |
| *Agriornis albicauda* | | VU | 7,009,968 | 338,221 | 49,734 | 20,117 | 0.7 | 5.9 |
| *Cinclus schulzii* | | VU | 451,414 | 46,929 | 23,425 | 4150 | 5.2 | 8.8 |
| *Turdus haplochrous* | X | | 4,489,831 | 302,390 | 1,800,100 | 131,000 | 40.1 | 43.3 |
| *Atlapetes rufinucha* | X | | 2,525,452 | 836,952 | 75,275 | 25,275 | 3.0 | 3.0 |
| *Oreopsar bolivianus* | X | | 3,128,908 | 443,207 | 7625 | 2825 | 0.2 | 0.6 |
| *Diglossa carbonaria* | X | | 1,580,198 | 270,379 | 62,525 | 35,825 | 4.0 | 13.2 |
| *Sporophila nigrorufa* | | VU | 525,873 | 336,433 | 319,975 | 196,625 | 60.8 | 58.4 |
| *Sporophila maximiliani* | | EN | 9,974,039 | 2,583,537 | 6,923,925 | 2,004,725 | 69.4 | 77.6 |
| *Coryphaspiza melanotis* | | VU | 4,663,450 | 1,103,558 | 3,828,675 | 921,700 | 82.1 | 83.5 |
| *Poospiza garleppi* | X | EN | 647,396 | 100,099 | 18,500 | 7150 | 2.9 | 7.1 |
| *Poospiza baeri* | | VU | 78,810 | 14,824 | 2925 | 1675 | 3.7 | 11.3 |
| *Stilpnia argyrofenges* | | VU | 2,987,003 | 1,546,496 | 71,652 | 30,056 | 2.4 | 1.9 |

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