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Title page

# Land-use conflicts between biodiversity conservation and extractive industries in the Peruvian Andes

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## Abstract

The exceptional endemic species richness found in the Tropical Andes is being subjected to high rates of environmental degradation and natural resources exploitation. While many forms of land-cover change and other impacts on species are difficult to control through environmental regulations, governments usually determine how and where extractive industries can take place. This study examines potential conflict between the location of extractive industry activities and biodiversity conservation in the Peruvian Andes. Using geographic information systems, we carry out overlay analyses to determine the spatial congruence between mineral mining, hydrocarbon and logging concessions, on the one hand, and the distribution of protected areas and endemic vertebrate species on the other. The results show that regional protected areas extensively overlap with resource concessions. Furthermore, 16% of endemic species hotspots concur with current concessions, while the geographical distribution of 21 endemic vertebrate species overlap by more than 90% with concession areas. To reconcile conservation and economic development objectives in the future, the geographical distribution of biodiversity, and in particular of endemic species, needs to be considered in natural resources planning and land-use/management activities.

## Keywords

Mineral mining concessions, Timber concessions, Hydrocarbon concessions, Protected areas, Endemic species

## 1. Introduction

The continued expansion of destructive land-use systems throughout tropical regions is the predominant cause of species extinctions (Haddad et al. 2015; Newbold et al. 2015). Fueled by global demands for agricultural commodities, timber and other natural resources, the world's remaining natural ecosystems are increasingly being threatened and exploited by human populations (Rands et al. 2010). Widespread land-cover changes resulting from unplanned agricultural encroachment, illegal timber harvesting and the concomitant development of informal roads represent an important share of the net contribution to tropical habitat degradation (Hosonuma et al. 2012). Many of these land management practices take place in a rapid and uncontrolled fashion, and are driven by a myriad of institutional, socioeconomic and cultural factors that vary in time and space (Lambin et al. 2001; Geist and Lambin 2002; Nelson et al. 2005). Effectively regulating these rampant land-use and land-cover change processes through legislation and other types of government intervention is often difficult (Angelsen 2010; DeFries et al. 2010). In contrast, the geographical expansion of authorized extractive industries usually results directly from the intentions of and decision making by governments (Kohl and Farthing 2012; Ferreira et al. 2014). Most of the world's tropical forests and other natural assets are owned by national governments (FAO 2010). Yet, in the attempt to stimulate economic growth, governments are often strongly inclined to transfer long-term resource exploration and exploitation rights to large corporations through lucrative deals. Given that extractive industry regulations unambiguously favor the interests of private companies over the environment (Gordon and Webber 2008), the privatization of resource extraction rights is commonly associated with increased pollution levels, land-cover change, and other forms of environmental degradation (Bakker 2007; Wang and Chen 2014).

As a megadiverse country with an agriculture and resources based economy, Peru faces the challenge to parallel the preservation of natural landscapes with sustained economic growth and prosperity. Peru's mining and hydrocarbon sectors contributed to over 13% of the gross domestic product (GDP) in 2017 (INEI 2018), while the areas for metal and fossil fuel exploration continue to expand sharply under current levels of investment (Bebbington and Bury 2009; Cuba et al. 2014). Not all concessions become active mines or oil wells, however, resource exploration operations are equally linked to ecological deterioration. In the case of hydrocarbon exploration for example, there is deforestation related to the construction of the basecamp, sub-basecamps, heliports and the clearing of hundreds of kilometers of seismic survey lines, which concurrently opens up areas for agriculture, logging and hunting activities. Further disturbances are caused by exploratory drilling, the influx of numerous crew workers, and the detonation of thousands of seismic explosions (Finer and Orta-Martínez 2010; Harfoot et al. 2018). During the exploitation phase, impacts on biodiversity are usually more severe, causing conversion, degradation and pollution at extraction sites (Finer et al. 2008; Harfoot et al. 2018). Similarly, environmental degradation caused by metal exploration and exploitation in Peru has been related to large-scale deforestation (Asner et al. 2013), water pollution (Bebbington and Williams 2008), bioaccumulation of heavy metals in trophic chains (Bianchini et al. 2015), and socioenvironmental conflict (Bebbington and Bury 2009). In contrast, Peru's timber industry contributes significantly less to the economy (approximately 1% of the Peruvian GDP (FAO 2009)). Yet, the extent of logging concessions has increased significantly as a result of forestry reforms, now covering more than 10% of Peru's forested areas (Salo and Toivonen 2009). Although concessions are supposed to foster sustainable logging practices, in Peru they have been found to enable widespread illegal timber extraction (Finer et al. 2014), which could greatly undermine species conservation and management efforts.

While multiple studies on the expansion of extractive industries in Peru and beyond have examined their potential impact on protected areas (Finer et al. 2008), indigenous territories (Cuba et al. 2014) and forest cover (Elmes et al. 2014), it has been less common to link the location of exploration and/or extraction sites to the geographical distribution of species. Yet, there is urgency to generate knowledge in this regard, since the extent of resource concessions is rapidly expanding while biodiversity continues to degrade at alarming rates. Here, we determine the potential impacts of the mining, hydrocarbon and timber industries on endemic species in the Peruvian Tropical Andes, which is considered one of the world's most critical regions for biodiversity conservation (Myers et al. 2000). We focus on endemic species, as their conservation can only be achieved within the Tropical Andes. Further, we focus on vertebrate species as comprehensive data on the geographical range distribution of plant and invertebrate species is largely unavailable. Following previous studies (Armendáriz-Villegas et al. 2015; Harfoot et al. 2018), we first assess the geographical overlap between the location of concessions and protected areas. Conversely, while protected areas form the single most important biodiversity conservation strategy in the Tropical Andes (Jørgensen et al. 2011), their location is often not in agreement with important ecological features (Rodrigues et al. 2004; Venter et al. 2014). Hence, we additionally determine to what extent the distribution of individual endemic species as well as the location of endemic species hotspots overlap with current concessions.

## 2. Methods

### 2.1 Study area

The study area (Figure 1) includes Peru's Tropical Andes biodiversity hotspot (Mittermeier et al. 2004) and all forested areas along the eastern flank of the Tropical Andes between approximately 500 and 3000 m.a.s.l. (Bax and Francesconi 2018), which are known to harbor many narrow ranged endemic species (Young et al. 2011). This area is located between coordinates 3°4′37 South, 77°56′4 West, 18°2′54 South and 69°47′1 West, and corresponds to about 500,000 km$^2$.

### 2.2 Data collection and preprocessing

Following Cuba et al. (2014), we used the distribution of legal concessions as indicator for the presence of extractive industry activities. Illicit resource extraction, such as the artisanal goldmining operations in Madre de Dios (Asner et al. 2013) were not considered in this study. Furthermore, other industrialized land claims such as agricultural concessions were not considered, as spatially explicit data were unavailable. Spatial datasets on mineral mining, hydrocarbon and logging concessions were collected from the responsible authorities in Peru (MINAGRI 2017; INGEMMET 2018; PeruPetro 2018). In addition, we collected spatial data on national, regional and private protected areas along with their buffer areas from MINAM (2018), and Important Bird Areas (IBAs) from BirdLife International (2018a).

Geographical range maps for extant vertebrate species (mammals, birds, amphibians and reptiles) in Peru were gathered from IUCN (2017) and BirdLife International and Handbook of the Birds of the World (2016). We mapped in ArcGIS version 10.1 (ESRI 2010) the geographical range of species present in the Tropical Andes, and selected all species whose ranges were at least 90% within the Tropical Andes. This yielded a dataset of 392 vertebrate species endemic or nearly endemic to Peru's Tropical Andes.

Range maps tend to overestimate the presence of species, by covering areas that represent unsuitable habitat (Rodrigues 2011). Consequently, to increase our understanding of the geographical distribution of species, we refined the range maps based on species' elevation and habitat requirements, following Ocampo-Peñuela et al. (2016) and Li and Pimm (2016). Species-specific habitat and elevation information was obtained from the IUCN Red List (IUCN 2016) and BirdLife International (2018b). We buffered the original range maps by a distance of 10 km to reduce potential errors from digitization and georeferencing procedures (Jenkins et al. 2011). Then, we removed all areas beyond species' reported elevational limits using the ASTER 30m Global Digital Elevation Model V2. Elevational limits were rounded to hundreds as it facilitated the systemization of GIS procedures (upper limits were rounded upwards and lower limits were rounded downwards, e.g. the elevation range 970–2130 was rounded to 900–2200 m.a.s.l.). When a single elevation instead of a range was reported, we buffered the elevational value by 100 m on both sides and rounded to the nearest hundred (e.g. the elevation value of 625 was buffered and rounded to a range of 500–700 m.a.s.l.). Finally, we refined the range maps based on species' habitat requirements using a land cover layer produced by Peru's Ministry of the Environment (MINAM 2015). This layer, which consists of 75 land-cover types, was produced based on Landsat 5 TM satellite imagery from 2011 at 30m spatial resolution, in conjunction with RapidEye and Google Earth imagery at approximately 5m spatial resolution. We merged the land-cover types into 7 generalized classes (forest, grassland, shrubland, wetland, agriculture, urban areas and water bodies) and removed all areas that were deemed unsuitable for species' existence according to the IUCN Red List (IUCN 2016) and BirdLife International (2018b).

Based on the refined species-specific range maps, we mapped endemic species richness at 5 $km^2$ resolution using the Hawths Tools ArcGIS extension version 3.27 (Beyer 2004). This resulted in a layer displaying the location of endemic species hotspots in the Peruvian Tropical Andes.

### 2.3 Data analysis

We carried out three overlay analyses to determine the spatial congruence between extractive industries (mineral mining, hydrocarbon and logging), and the distribution of protected areas, endemic species hotspots and individual endemic species. First, to examine potential conflicts between the location and extent of extractive industry activities, and areas assigned for conservation, we overlaid the protected area layer with the industry concessions layer, and calculated the degree of overlap in ArcGIS. Second, we overlaid the industry concessions layer with the endemic species hotspots layer to determine to what extent extractive industry activities coincide with areas of high endemism. Third, we overlaid the industry concessions layer with the refined species-specific geographical range maps to examine the distribution of individual species within concession areas. Species were categorized according to their IUCN Red List status, and binned into 10 categories, ranging from 0% distributional overlap to >90% overlap with concessions.

## 3. Results

Species geographical range maps were refined based on their altitudinal and habitat requirements as reported by IUCN and BirdLife International. Of the 394 endemic or nearly endemic species considered in this study, the geographical range of two species (*Colostethus poecilonotus* and *Dipsas schunkii*) were beyond reported elevation boundaries, while six species (*Erythrolamprus problematicus, Hyloxalus leucophaeus, Pristimantis pardalinus, Pristimantis sternothylax, Psychrophrynella usurpator* and *Telmatobius hockingi*) occured beyond reported elevation boundaries in conjuntion with habitat requirements, reducing the final dataset to 386 species.

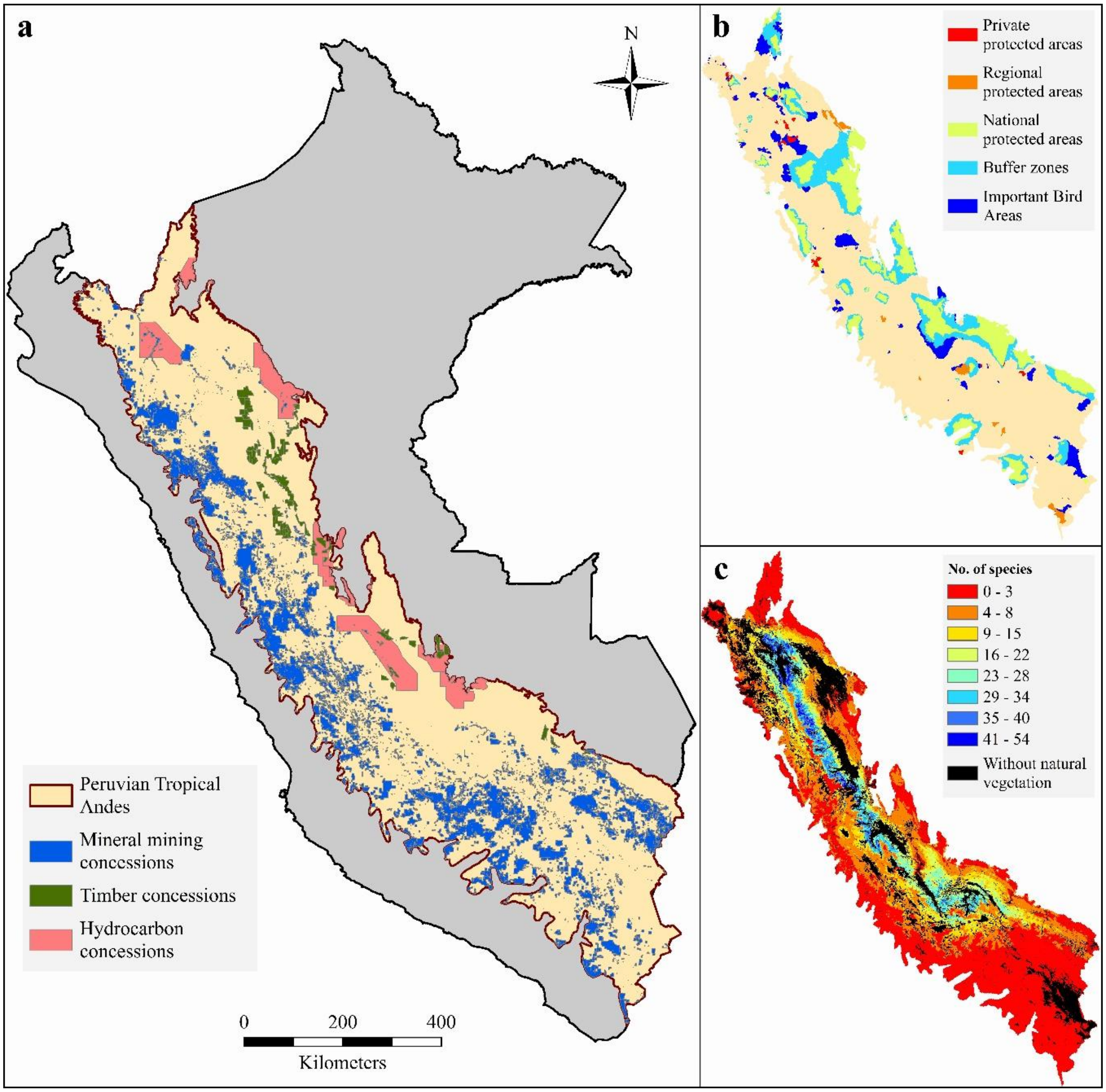

**Fig 1.** a) Distribution of mineral mining concessions, timber concessions and hydrocarbon concessions. b) Distribution of conservation areas. c) Endemic species richness.

The total extent of mineral mining concessions, timber concessions and hydrocarbon concessions within the Peruvian Tropical Andes corresponds to 19%, 2% and 6% of the area respectively, with an aggregated overlap coverage of 26% (Figure 1a). Out of the five conservation area types considered (Figure 1b), the presence of concessions is most extensive within regional protected areas (34% of the total area), followed by buffer zones (25%) (Figure 2). National protected areas are least overlapped by concessions (6%).

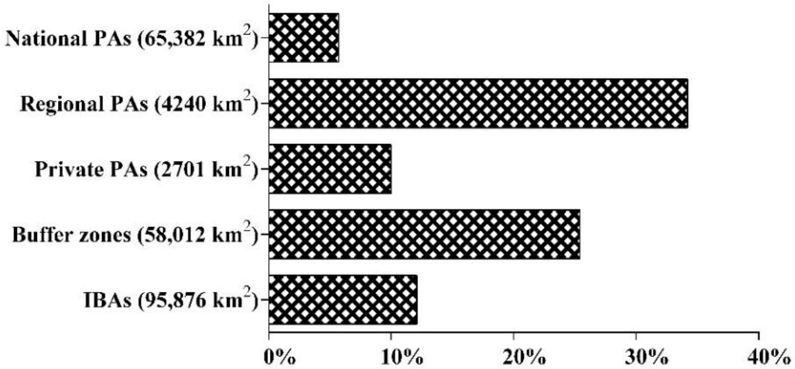

**Fig 2.** Overlap between mining, hydrocarbon and logging concessions and different types of conservation areas within Peru's Tropical Andes. Numbers in parenthesis correspond to the total coverage of each conservation area type. A matrix of the overlaps (in km$^2$ and %) between different types of concessions and conservation areas is provided in appendix A.

The richest areas in terms of endemic species correspond to cloud forest ecosystems at elevations between 1600-3600 m.a.s.l. (Figure 1c). Sixteen percent of areas containing a high number of endemic species (41–54 per 5km$^2$), overlap with concessions (Figure 3). Overlaps with mining concessions are most prominent, which agrees with their higher overall extent compared to the other types of concessions, as reflected in figure 1a.

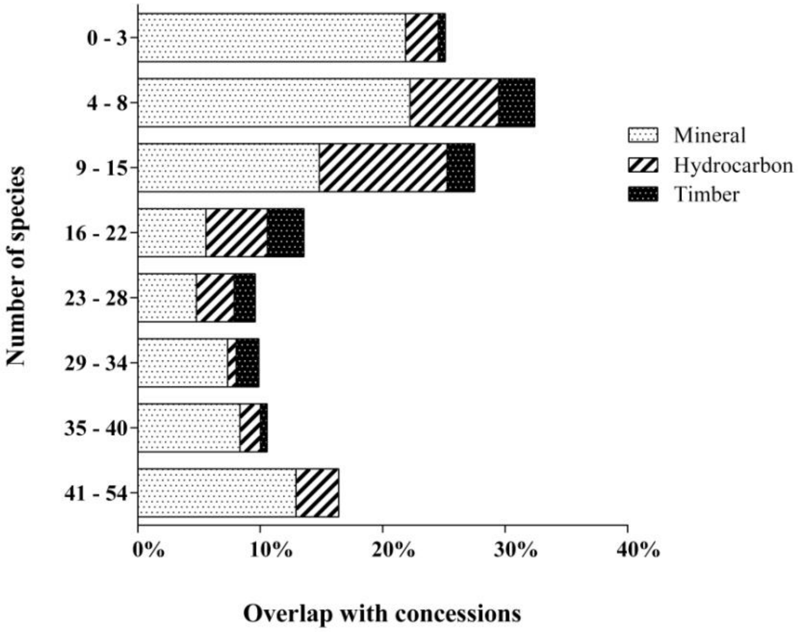

**Fig 3.** Overlap between mining, hydrocarbon and logging concessions, and endemic species richness within Peru's Tropical Andes. A matrix of the overlaps (in km$^2$ and %) between different types of concessions and endemic species richness is provided in appendix A.

At the individual species level, the geographical distribution of 47 endemic species, which corresponds to 12% of all species considered, overlaps by more than 50% with concessions (Figure 4). Out of these, 21 species (or 5% of all species) have a distribution range that overlaps by more than 90% with concessions (Figure 4; Table 1). Most of these species occur within the departments of San Martín, Amazonas and Cajamarca located in the north of Peru, have little remaining habitat that is suitable for their existence (<100 km$^2$), and are classified by the IUCN Red List as "data deficient". Furthermore, four species are currently listed as threatened (corresponding to the "endangered" and "critically endangered" categories), while another four species are listed as non-threatened (corresponding to the "least concern" and "near threatened" categories).

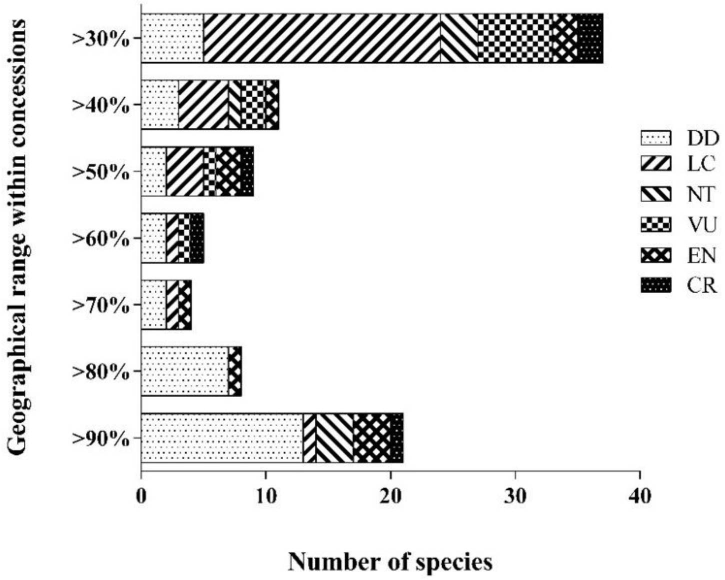

**Fig 4.** Number of species whose distributions coincide with mining, hydrocarbon and logging concessions in Peru's Tropical Andes, according to IUCN Red List status: DD = data deficient, LC = least concern, NT = near threatened, VU = vulnerable, EN = endangered, CR = critically endangered. A matrix of the overlaps (in km$^2$ and %) between different types of concessions and individual endemic species is provided in appendix A.

**Table 1.** Species with >90% of their distribution within current mining, hydrocarbon and logging concessions.

| Scientific name | Taxa | Red List status* | Location | Refined distribution (km$^2$) | Distribution in concessions (%) |
|---|---|---|---|---|---|
| *Allobates ornatus* | Amphibian | DD | San Martín | 50 | 99 |
| *Anomalepis aspinosus* | Retile | DD | Amazonas / Cajamarca | 1513 | 91 |
| *Cochranella croceopodes* | Amphibian | DD | San Martín | 282 | 99 |
| *Enyalioides rudolfarndti* | Retile | LC | Huánuco | 6 | 99 |
| *Espadarana fernandoi* | Amphibian | EN | San Martín | 46 | 98 |
| *Hyloxalus eleutherodactylus* | Amphibian | DD | San Martín | 16 | 100 |
| *Hyloxalus spilotogaster* | Amphibian | DD | Amazonas | 14 | 90 |
| *Incaspiza watkinsi* | Bird | NT | Amazonas / Cajamarca | 795 | 100 |
| *Melanopareia maranonica* | Bird | NT | Amazonas / Cajamarca | 903 | 99 |
| *Nymphargus chancas* | Amphibian | DD | San Martín | 73 | 99 |
| *Pristimantis avicuporum* | Amphibian | DD | Amazonas | 51 | 91 |
| *Pristimantis chimu* | Amphibian | DD | Cajamarca | <1 | 100 |
| *Pristimantis karcharias* | Amphibian | DD | Amazonas | <1 | 100 |
| *Pristimantis pinguis* | Amphibian | DD | Cajamarca | 443 | 94 |
| *Pristimantis simonsii* | Amphibian | CR | Cajamarca | 1 | 90 |

| | | | | | |
|---|---|---|---|---|---|
| *Pseudogonatodes barbouri* | Retile | NT | Cajamarca | 62 | 99 |
| *Psychrophrynella boettgeri* | Amphibian | EN | Puno | <1 | 93 |
| *Rhinella vellardi* | Amphibian | DD | Amazonas / Cajamarca | 137 | 92 |
| *Riama laudahnae* | Retile | DD | Ucayali | <1 | 100 |
| *Rulyrana saxiscandens* | Amphibian | EN | San Martin | 189 | 100 |
| *Rulyrana tangarana* | Amphibian | DD | San Martin | 212 | 99 |

* Based on Red List assessments published before 2018

## 4. Discussion

The Tropical Andes region is a widely recognized priority for conservation efforts, given that its exceptional endemic plant and vertebrate species diversity is confronted by high rates of anthropogenic disturbance (Myers et al. 2000; Brooks et al. 2006). Massive species extinctions in the Tropical Andes are projected under current climate change and habitat conversion scenarios (Brooks et al. 2002; Malcolm et al. 2006). While many of these pressures on biodiversity have proven to be very difficult to mitigate (Jordan et al. 2015), planning and management of industry driven extractive activities is a rather top-down process which takes place under government approval and supervision. This allows for more control over the spatial and temporal allocation of exploration and extraction operations. Nonetheless, ecological considerations may not be properly addressed or have the same weight as potential financial gains from natural resource extraction, which often results in land appropriation for human enterprise irrespective of the spatial distribution of biodiversity across Tropical Andean landscapes.

This study shows that more than a quarter of Peru’s Tropical Andes has been leased to mineral mining, timber and hydrocarbon companies. Some of these concessions pose a direct threat to biodiversity, as they are spatially congruent with high endemic species richness and areas reserved for conservation. Regional protected areas show the most extensive overlap; for instance the Cordillera Escalera reserve located in the northeast is almost entirely overlaid with a hydrocarbon concession. Also the buffer zones located around protected areas, which are of great importance for sustained ecological health (Laurance et al. 2012), show considerable overlap with concessions. The problem not only lays in the fact that concessions are being granted in areas that are supposed to be protected, but extractive industries have often been found to drive habitat change far beyond operational lease boundaries. Sonter et al. (2017) show that mining related deforestation takes place up to 70 km from concession areas, at a rate 12 times greater than within mining concessions alone. Likewise, Finer et al. (2014) show that Peru’s timber concession system facilitates illicit logging both within and outside authorized areas. This suggests that impacts on biodiversity induced by resource extraction are not restricted to permitted locations, but potentially extend further into conservation areas and epicenters of species endemism.

In their assessment, Bax and Francesconi (2019) exposed severe conservation gaps in Peru’s Tropical Andes protected area system, showing that less than 2% of all endemic mammal, bird, amphibian and reptile species are adequately contained within existing reserves. Alarmingly, the present analysis demonstrates that 5% of all endemic species have geographical distributions that overlap by more than 90% with concession areas. Meanwhile, some of these species display narrow and severely fragmented distributions across suitable habitat areas. This reflects additional threats to their survival, as both species’ geographical distribution and fragmentation are recognized as prime correlates of extinction risk (Di Marco et al. 2014; Crooks et al. 2017).

The outcomes of this study bring forward two recommendations for improved biodiversity management in relation to extractive industry expansion. First, from a conservation planning point of view, it is argued that species subjected to high levels of anthropogenic disturbance, but currently not assessed as threatened based on their Red List status, may require proactive conservation actions to prevent them from becoming threatened or extinct in the future (Baruch-Mordo et al. 2013; Peters et al. 2015). This is particularly true for small-ranged endemic species, which are by definition more susceptible to habitat disturbance and degradation (Myers 2003). Our results show that thirteen endemic species listed as data deficient, and four species listed as non-threatened overlap by more than 90% with concession areas. Although this poses a substantial threat to their long-term survival, they are less likely to be supported through conservation actions. Spatially explicit data regarding the presence of extractive industry activities provides practical information for identifying potential pressures on species, which could be used to enhance extinction risk assessment and the development of precautionary conservation strategies.

Second, as per ecosystem management and natural resource planning from a government perspective, it is recommended to explicitly consider the range distribution of endemic species along with their remaining habitat in resource concession designation processes. While environmental impact assessment (EIA) authorization is legally required for the approval of new projects and expansion of existing projects, it typically fails to thoroughly assess long-term and cumulative impacts on biodiversity associated with resource exploration and extraction operations (Finer et al. 2008). In addition, the hydrocarbon, logging and mining companies contract the firms to carry out the EIA, which generates an evident conflict of interests (Finer et al. 2008; Delgado and Romero 2016).

Likewise, within the context of Peru’s Ecological and Economic Zoning (EEZ) activities, in which regional governments have been designated to define suitable areas for economic activities and conservation, the incorporation of sustainable and efficient resource concession areas should be an integral part of land-use planning. Conversely, in some cases EEZ has been reported to be inadequate for balancing and mediating competing interests in relation to territorial development and conservation of natural resources. Bebbington and Bury (2009) report that concessions have been granted in places irrespective of ecological zoning plans, which evidently undermines effective biodiversity conservation. Furthermore, Jeronimo et al. (2015) show that within gold mining areas in the Cajamarca region in the north of Peru, the EEZ process failed to accommodate the range of economic and ecological values attached to potential mining sites. Instead, EEZ was employed as a strategy to influence the expansion of mining areas (Gustafsson 2017), leading to controversies and extensive conflict between an anti-mining coalition lead by the regional government of Cajamarca, and a pro-mining coalition lead by the central government. This touches upon some of the limitations of current land-use policies and related institutions in Peru (Gustafsson and Scurrah, In press), and emphasizes the need for the development of improved planning strategies and environmental impact assessments that are unbiased toward any given sector.

In addition to spatial planning methods such as EEZ, the temporal scale and significance of extractive industry related impacts on species needs to be considered in land-use planning processes (Papadimitriou and Mairota 1996). This involves a better alignment of the land change trends and processes associated with different types of concession areas (see Scullion et al. 2014), and the time scales in which they operate, to prevent irreversible damages. For instance, current hydrocarbon concessions are subjected to exploration and exploitation activities for at least 30 years (in the case of natural gas) or 40 years (in the case of oil) (Finer and Orta-Martínez 2010). Impacts on biodiversity as a result of these activities are likely to occur within shorter periods, implying that current time scales used in land-use planning are not adjusted to the ecological systems in which they are applied.

Consequently, to reduce conflict between ecological and economic development objectives in coupled human-environment systems, enhanced spatial-temporal planning of resource concessions is needed. Specific attention is required for the potential impacts on endemic species. In this regard, subnational planning authorities and environmental agencies have a key role to play, but they have been found to lack the political power, resources and strategic abilities to enforce sound land-use planning strategies (Gustafsson and Scurrah, In press). By contrast, planning agencies such as the Ministry of Energy and Mines (MINEM) and the Ministry of Economy and Finance (MEF) are more powerful in the sense of having greater access to resources, political influence and technical capacities, but it has been observed they are more likely to prioritize economic interests rather than environmental conservation objectives (Jeronimo et al. 2015). Given these institutional constraints, adequately enforcing sustainable land-use planning to address the current species loss crisis in the Peruvian Andes will be one of Peru's most pressing natural resources and territorial governance challenges in the coming decades.

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# Land-use conflicts between biodiversity conservation and extractive industries in the Peruvian Andes

## APPENDIX A

**Table A1.** Overlap between mining, hydrocarbon and logging concessions and different types of conservation areas in the Peruvian Tropical Andes.

| Conservation area type | Total area ($km^2$) | Overlap with mineral mining concessions in $km^2$ (%) | Overlap with hydrocarbon concessions in $km^2$ (%) | Overlap with timber concessions in $km^2$ (%) | Total overlap ($km^2$)* | Total overlap (%)* |
|---|---|---|---|---|---|---|
| National PAs | 65382 | 607 (0.9) | 3106 (4.8) | 10 (0.0) | 3694 | 5.7 |
| Regional PAs | 4240 | 88 (2.1) | 1363 (32.1) | 0 (0.0) | 1450 | 34.2 |
| Private PAs | 2701 | 221 (8.2) | 48 (1.8) | 0 (0.0) | 269 | 10 |
| Buffer zones | 58012 | 4260 (7.3) | 6693 (11.5) | 4099 (7.1) | 14741 | 25.4 |
| IBAs | 95876 | 4139 (4.3) | 7369 (7.7) | 576 (0.6) | 11630 | 12.1 |

* overlap between concessions is aggregated

**Table A2.** Overlap between mining, hydrocarbon and logging concessions, and endemic species richness in the Peruvian Tropical Andes.

| Number of species | Total area ($km^2$) | Overlap with mineral mining concessions in $km^2$ (%) | Overlap with hydrocarbon concessions in $km^2$ (%) | Overlap with timber concessions in $km^2$ (%) | Total overlap ($km^2$)* | Total overlap (%)* |
|---|---|---|---|---|---|---|
| 0 - 3 | 203949 | 44609 (21.9) | 5511 (2.7) | 1685 (0.8) | 50127 | 24.6 |
| 4 - 8 | 107953 | 23997 (22.2) | 7854 (7.3) | 3581 (3.3) | 35089 | 32.5 |
| 9 - 15 | 50770 | 7533 (14.8) | 5456 (10.7) | 1395 (2.7) | 13889 | 27.4 |
| 16 - 22 | 20454 | 1137 (5.6) | 1040 (5.1) | 700 (3.4) | 2783 | 13.6 |
| 23 - 28 | 14946 | 717 (4.8) | 458 (3.1) | 268 (1.8) | 1434 | 9.6 |
| 29 - 34 | 13115 | 962 (7.3) | 94 (0.7) | 243 (1.9) | 1301 | 9.9 |
| 35 - 40 | 7448 | 622 (8.3) | 127 (1.7) | 40 (0.5) | 790 | 10.6 |
| 41 - 54 | 2659 | 344 (12.9) | 101 (3.8) | 0 (0.0) | 427 | 16.0 |
| Anthropogenically disturbed areas | 82355 | 13270 (16.1) | 9652 (11.7) | 1736 (2.1) | 22740 | 27.6 |
| Total | 503647 | 93189 (18.5) | 30292 (6.0) | 9648 (1.9) | 130480 | 25.9 |

* overlap between concessions is aggregated

**Table A3.** Overlap between mining, hydrocarbon and logging concessions, and individual endemic species in the Peruvian Tropical Andes.

| Scientific name | Refined geographic range (km$^2$) | Overlap with mineral mining concessions in km$^2$ (%) | Overlap with hydrocarbon concessions in km$^2$ (%) | Overlap with timber concessions in km$^2$ (%) | Total overlap (km$^2$)* | Total overlap (%)* |
|---|---|---|---|---|---|---|
| *Aglaeactis aliciae* | 274.13 | 192.47 (70.2) | 0.00 (0.0) | 0.00 (0.0) | 192.47 | 70.2 |
| *Allobates alessandroi* | 1523.75 | 532.50 (34.9) | 0.00 (0.0) | 47.96 (3.1) | 540.75 | 35.5 |
| *Allobates ornatus* | 50.48 | 0.00 (0.0) | 49.79 (98.6) | 0.00 (0.0) | 49.79 | 98.6 |
| *Ameerega bassleri* | 5718.09 | 10.36 (0.2) | 2169.37 (37.9) | 170.52 (3.0) | 2321.9 | 40.6 |
| *Ameerega planipaleae* | 2.11 | 0.00 (0.0) | 0.65 (30.7) | 0.00 (0.0) | 0.65 | 30.7 |
| *Amphisbaena polygrammica* | 8380.21 | 738.65 (8.8) | 3218.55 (38.4) | 183.15 (2.2) | 3932.71 | 46.9 |
| *Anomalepis aspinosus* | 1512.51 | 124.98 (8.3) | 1380.89 (91.3) | 0.00 (0.0) | 1380.89 | 91.3 |
| *Arremon nigriceps* | 481.14 | 75.77 (15.7) | 151.86 (31.6) | 0.00 (0.0) | 198.88 | 41.3 |
| *Asthenes usheri* | 2985.71 | 1141.38 (38.2) | 0.00 (0.0) | 0.00 (0.0) | 1141.38 | 38.2 |
| *Atelopus dimorphus* | 53.35 | 0.00 (0.0) | 8.52 (16) | 29.33 (55) | 30.74 | 57.6 |
| *Atelopus erythropus* | 169.42 | 89.86 (53) | 0.00 (0.0) | 0.00 (0.0) | 89.86 | 53.0 |
| *Atelopus reticulatus* | 60.98 | 0.00 (0.0) | 33 (54.1) | 23.22 (38.1) | 42.01 | 68.9 |
| *Bachia barbouri* | 2474.08 | 168.64 (6.8) | 2009.50 (81.2) | 0.00 (0.0) | 2010.51 | 81.3 |
| *Bachia intermedia* | 2052.82 | 147.42 (7.2) | 1820.73 (88.7) | 0.00 (0.0) | 1820.73 | 88.7 |
| *Callicebus oenanthe* | 3406.21 | 4.64 (0.1) | 681.16 (20) | 579.02 (17) | 1263.1 | 37.1 |
| *Cochranella croceopodes* | 281.96 | 0.00 (0.0) | 278.21 (98.7) | 0.00 (0.0) | 278.21 | 98.7 |
| *Enyalioides rudolfarndti* | 5.86 | 0.04 (0.7) | 5.76 (98.3) | 0.00 (0.0) | 5.81 | 99.0 |
| *Espadarana fernandoi* | 46.35 | 0.00 (0.0) | 45.61 (98.4) | 0.00 (0.0) | 45.61 | 98.4 |
| *Eubucco glaucogularis* | 13360.68 | 423.87 (3.2) | 4087.03 (30.6) | 523.92 (3.9) | 4719.8 | 35.3 |
| *Euspondylus caideni* | 43.58 | 16.17 (37.1) | 0.00 (0.0) | 0.00 (0.0) | 16.17 | 37.1 |
| *Euspondylus josyi* | 12.23 | 4.82 (39.4) | 0.00 (0.0) | 0.00 (0.0) | 4.82 | 39.4 |
| *Euspondylus oreades* | 21.11 | 9.67 (45.8) | 0.00 (0.0) | 0.00 (0.0) | 9.67 | 45.8 |
| *Gastrotheca atympana* | 6.38 | 2.10 (32.8) | 0.00 (0.0) | 0.00 (0.0) | 2.1 | 32.8 |
| *Gastrotheca griswoldi* | 3942.89 | 1365.99 (34.6) | 0.00 (0.0) | 0.00 (0.0) | 1365.99 | 34.6 |
| *Gastrotheca peruana* | 17194.68 | 8598.50 (50) | 0.00 (0.0) | 0.00 (0.0) | 8598.5 | 50.0 |
| *Geositta saxicolina* | 32712.02 | 11829.46 (36.2) | 0.00 (0.0) | 0.00 (0.0) | 11829.46 | 36.2 |
| *Gonatodes atricucullaris* | 438.67 | 14.31 (3.3) | 347.97 (79.3) | 0.00 (0.0) | 347.97 | 79.3 |
| *Grallaria andicolus* | 60096.61 | 18175.13 (30.2) | 2.04 (0.0) | 8.56 (0.0) | 18175.13 | 30.2 |
| *Grallaria capitalis* | 4578.60 | 215.67 (4.7) | 1029.55 (22.5) | 266.29 (5.8) | 1384.2 | 30.2 |
| *Hyloxalus eleutherodactylus* | 16.05 | 0.02 (0.1) | 16.05 (100.0) | 0.00 (0.0) | 16.05 | 100.0 |
| *Hyloxalus spilotogaster* | 14.43 | 0.00 (0.0) | 13.03 (90.3) | 0.00 (0.0) | 13.03 | 90.3 |
| *Incaspiza watkinsi* | 794.78 | 68.25 (8.6) | 794.53 (100.0) | 0.00 (0.0) | 794.53 | 100 |
| *Liolaemus ortizii* | 36.84 | 12.69 (34.4) | 0.00 (0.0) | 0.00 (0.0) | 12.69 | 34.4 |
| *Liolaemus pachacutec* | 5062.40 | 1930.57 (38.1) | 0.00 (0.0) | 0.00 (0.0) | 1930.57 | 38.1 |
| *Liolaemus polystictus* | 947.35 | 288.10 (30.4) | 0.00 (0.0) | 0.00 (0.0) | 288.1 | 30.4 |
| *Liolaemus robustus* | 2868.52 | 1097.65 (38.3) | 0.00 (0.0) | 0.00 (0.0) | 1097.65 | 38.3 |
| *Liolaemus thomasi* | 444.21 | 299.81 (67.5) | 0.00 (0.0) | 0.00 (0.0) | 299.81 | 67.5 |
| *Liolaemus walkeri* | 4147.04 | 1427.49 (34.4) | 0.00 (0.0) | 0.00 (0.0) | 1427.49 | 34.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Marmosops juninensis* | 2678.47 | 182.03 (6.8) | 655.35 (24.5) | 69.78 (2.6) | 846.49 | 31.6 |
| *Melanopareia maranonica* | 902.98 | 124.57 (13.8) | 895.61 (99.2) | 0.00 (0.0) | 896.38 | 99.3 |
| *Microlophus stolzmanni* | 5858.25 | 691.50 (11.8) | 1578.68 (26.9) | 0.00 (0.0) | 2116.06 | 36.1 |
| *Nannophryne cophotis* | 6481.19 | 3190.91 (49.2) | 0.00 (0.0) | 0.00 (0.0) | 3190.91 | 49.2 |
| *Nannophryne corynetes* | 275.99 | 116.48 (42.2) | 0.00 (0.0) | 0.00 (0.0) | 116.48 | 42.2 |
| *Nymphargus chancas* | 73.47 | 0.00 (0.0) | 72.73 (99) | 0.00 (0.0) | 72.73 | 99.0 |
| *Oreobates saxatilis* | 175.38 | 0.22 (0.1) | 140.32 (80) | 6.98 (4.0) | 145.28 | 82.8 |
| *Oreotrochilus stolzmanni* | 17938.52 | 6282.75 (35) | 0.00 (0.0) | 0.05 (0.0) | 6282.75 | 35.0 |
| *Osteocephalus leoniae* | 7215.32 | 19.80 (0.3) | 1023.97 (14.2) | 1769.23 (24.5) | 2590.18 | 35.9 |
| *Oxyrhopus erdisii* | 33413.06 | 108.46 (0.3) | 9461.85 (28.3) | 1269.75 (3.8) | 10138.56 | 30.3 |
| *Oxyrhopus marcapatae* | 1764.62 | 423.38 (24) | 0.00 (0.0) | 143.36 (8.1) | 544.88 | 30.9 |
| *Petracola labioocularis* | 0.04 | 0.00 (0.0) | 0.01 (34.5) | 0.00 (0.0) | 0.01 | 34.5 |
| *Phacellodomus dorsalis* | 2713.26 | 1013.04 (37.3) | 0.00 (0.0) | 0.00 (0.0) | 1013.04 | 37.3 |
| *Phrynopus bufoides* | 158.70 | 79.68 (50.2) | 0.00 (0.0) | 0.00 (0.0) | 79.68 | 50.2 |
| *Phrynopus pesantesi* | 97.95 | 62.33 (63.6) | 0.00 (0.0) | 0.00 (0.0) | 62.33 | 63.6 |
| *Polychrus peruvianus* | 2899.41 | 204.84 (7.1) | 1421.94 (49) | 0.00 (0.0) | 1481.52 | 51.1 |
| *Pristimantis ardalonychus* | 2173.59 | 4.84 (0.2) | 1090.10 (50.2) | 0.10 (0.0) | 1094.95 | 50.4 |
| *Pristimantis avicuporum* | 50.60 | 0.00 (0.0) | 45.93 (90.8) | 0.00 (0.0) | 45.93 | 90.8 |
| *Pristimantis chimu* | 0.31 | 0.31 (100.0) | 0.00 (0.0) | 0.00 (0.0) | 0.31 | 100 |
| *Pristimantis cruciocularis* | 638.44 | 90.27 (14.1) | 88.54 (13.9) | 66.17 (10.4) | 244.46 | 38.3 |
| *Pristimantis cuneirostris* | 31.98 | 0.00 (0.0) | 23.68 (74.1) | 0.00 (0.0) | 23.68 | 74.1 |
| *Pristimantis karcharias* | 0.50 | 0.37 (73.6) | 0.26 (51.3) | 0.00 (0.0) | 0.5 | 100.0 |
| *Pristimantis lirellus* | 493.80 | 1.40 (0.3) | 435.50 (88.2) | 0.00 (0.0) | 436.9 | 88.5 |
| *Pristimantis petrobardus* | 199.43 | 83.03 (41.6) | 0.00 (0.0) | 0.00 (0.0) | 83.03 | 41.6 |
| *Pristimantis phalaroinguinis* | 150.86 | 47.11 (31.2) | 0.00 (0.0) | 0.00 (0.0) | 47.11 | 31.2 |
| *Pristimantis pinguis* | 443.27 | 415.27 (93.7) | 0.00 (0.0) | 0.00 (0.0) | 415.27 | 93.7 |
| *Pristimantis seorsus* | 0.24 | 0.00 (0.0) | 0.21 (86.4) | 0.02 (9.7) | 0.21 | 86.4 |
| *Pristimantis simonsii* | 1.19 | 1.08 (90) | 0.00 (0.0) | 0.00 (0.0) | 1.08 | 90.0 |
| *Pristimantis tanyrhynchus* | 0.44 | 0.00 (0.0) | 0.34 (78.5) | 0.13 (30.7) | 0.35 | 80.6 |
| *Pristimantis vilcabambae* | 0.32 | 0.00 (0.0) | 0.27 (83.9) | 0.01 (2.2) | 0.27 | 83.9 |
| *Pseudogonatodes barbouri* | 61.69 | 8.01 (13) | 60.85 (98.6) | 0.00 (0.0) | 60.85 | 98.6 |
| *Psychrophrynella boettgeri* | 0.30 | 0.28 (93.1) | 0.00 (0.0) | 0.00 (0.0) | 0.28 | 93.1 |
| *Punomys kofordi* | 643.98 | 239.07 (37.1) | 0.00 (0.0) | 0.00 (0.0) | 239.07 | 37.1 |
| *Ramphocelus melanogaster* | 30141.99 | 195.56 (0.6) | 5419.17 (18) | 4737.56 (15.7) | 9857.1 | 32.7 |
| *Rhinella iserni* | 2616.98 | 0.95 (0.0) | 1806.96 (69) | 93.19 (3.6) | 1836.08 | 70.2 |
| *Rhinella vellardi* | 137.36 | 19.11 (13.9) | 125.96 (91.7) | 0.00 (0.0) | 126.03 | 91.8 |
| *Rhipidomys modicus* | 30555.90 | 179.66 (0.6) | 5410.30 (17.7) | 4469.75 (14.6) | 9577.46 | 31.3 |
| *Rhipidomys ochrogaster* | 237.11 | 87.31 (36.8) | 0.00 (0.0) | 0.00 (0.0) | 87.31 | 36.8 |
| *Riama laudahnae* | 0.43 | 0.00 (0.0) | 0.43 (100.0) | 0.43 (100.0) | 0.43 | 100.0 |
| *Rulyrana saxiscandens* | 189.25 | 0.00 (0.0) | 189.25 (100.0) | 0.00 (0.0) | 189.25 | 100.0 |
| *Rulyrana tangarana* | 212.37 | 0.16 (0.1) | 209.40 (98.6) | 0.00 (0.0) | 209.56 | 98.7 |
| *Scytalopus affinis* | 6821.94 | 3677.78 (53.9) | 0.00 (0.0) | 0.00 (0.0) | 3677.78 | 53.9 |
| *Scytalopus unicolor* | 1572.67 | 667.73 (42.5) | 0.00 (0.0) | 0.00 (0.0) | 667.73 | 42.5 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| *Stenocercus huancabambae* | 922.27 | 77.01 (8.4) | 279.15 (30.3) | 0.00 (0.0) | 326.98 | 35.5 |
| *Stenocercus melanopygus* | 3449.87 | 1461.86 (42.4) | 0.00 (0.0) | 0.00 (0.0) | 1461.86 | 42.4 |
| *Stenocercus orientalis* | 805.29 | 187.42 (23.3) | 118.29 (14.7) | 0.00 (0.0) | 304.24 | 37.8 |
| *Stenocercus torquatus* | 987.67 | 40.25 (4.1) | 539.34 (54.6) | 40.24 (4.1) | 594.97 | 60.2 |
| *Taphrolesbia griseiventris* | 5194.36 | 1756.50 (33.8) | 0.00 (0.0) | 0.00 (0.0) | 1756.5 | 33.8 |
| *Telmatobius brevipes* | 5531.58 | 2767.49 (50) | 0.00 (0.0) | 0.00 (0.0) | 2767.49 | 50.0 |
| *Telmatobius carrillae* | 4565.75 | 2069.41 (45.3) | 0.00 (0.0) | 0.00 (0.0) | 2069.41 | 45.3 |
| *Telmatobius colanensis* | 29.83 | 0.00 (0.0) | 13.34 (44.7) | 0.00 (0.0) | 13.34 | 44.7 |
| *Telmatobius macrostomus* | 7275.33 | 2188.08 (30.1) | 0.00 (0.0) | 0.20 (0.0) | 2188.08 | 30.1 |
| *Telmatobius thompsoni* | 6.93 | 5.91 (85.2) | 0.00 (0.0) | 0.00 (0.0) | 5.91 | 85.2 |
| *Thamnophilus shumbae* | 4620.49 | 242 (5.2) | 1454.51 (31.5) | 0.00 (0.0) | 1543.43 | 33.4 |
| *Thlypopsis inornata* | 2173.34 | 141.87 (6.5) | 1138.84 (52.4) | 0.00 (0.0) | 1165.23 | 53.6 |
| *Truebella skoptes* | 17.07 | 10.76 (63.1) | 0.00 (0.0) | 0.00 (0.0) | 10.76 | 63.1 |
| *Turdus maranonicus* | 7630.23 | 829.79 (10.9) | 1664.51 (21.8) | 0.00 (0.0) | 2335.56 | 30.6 |

* overlap between concessions is aggregated