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Threat Analysis of Forest Fragmentation and Degradation for Peruvian Primates

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Abstract: Peru has 55 primate taxa (including all species and subspecies), a third of which are threatened. The major drivers of habitat loss, degradation and fragmentation are grazing, forestry, agriculture and transport infrastructure. Other activities such as hunting exacerbate these threats. We assessed the threats from degradation and fragmentation facing Peruvian primates to aid in the design and implementation of mitigation strategies. Through GIS-based mapping, statistical modeling and specialist assessments, we evaluated all primate taxa using the IUCN Conservation Measures Partnership Unified Classifications of Direct Threats across five categories (direct threats to primates, threats to habitat, causes of fragmentation, factors exacerbating fragmentation and threats to primates and habitats as a consequence of fragmentation), highlighting which were most common and most severe. Our results showed that all primate taxa were affected by degradation and fragmentation in Peru. The most common and severe direct threat was hunting, whereas housing and urban development, smallholder crop farming, smallholder grazing and large-scale logging were the most common and severe threats across the other categories. The families Cebidae and Atelidae face the highest overall threat. Our analysis showed that the current IUCN listing of *Leontocebus leucogenys* [LC] underestimates the true threat level this species faces and that *Lagothrix lagothricha tschudii* [DD] should be listed under one of the threat categories. In Peru, the need for mitigating the threat of habitat fragmentation is clear. To ensure the survival of Peru's diverse primate taxa, forest connectivity needs to be maintained or recovered through the protection and restoration of key areas considering their biological and social needs.

Keywords: conservation; deforestation; endemic species; GIS; hunting; logging

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1. Introduction

More than 65% of primates are listed as threatened on the IUCN Red List, and over 75% have declining populations [1]. The major worldwide drivers of habitat loss and fragmentation that threaten primates are grazing for livestock (which threatens 38% of species), forestry activities (21% of species) and agriculture (20% of species) [2,3]. Large-scale industrial agriculture, driven by growing global markets, has led to the complete loss of habitat areas throughout the tropics [2]. An estimated 26% of recent (2001–2017) deforestation in the Neotropics has been attributed to commodity-driven production, and

deforestation rates are expected to increase [2]. Harder to assess and control is the threat of small-scale agriculture, livestock farming and selective logging. Fragmentation negatively impacts primates and other species and is correlated with reductions in population numbers and sizes, genetic variability and a greater extinction risk [2–5].

Degradation and fragmentation cause an overall reduction in habitat availability and lead to changes in forest characteristics and dynamics from reduced tree diversity and habitat connectivity. Such changes predominantly affect larger trees, particularly on the forest edge, which are often species animals rely on for food and shelter [6–8]. Increased edge effects and the separation of smaller isolated subpopulations within a fragmented matrix reduces access to resources and dispersal opportunities, and increases the risk of mortality from domestic and wild predators for arboreal species, including many Neotropical primates [9]. Changes in the forest dynamics lead to changes in faunal assemblages and the destabilisation of ecosystems. For example, without primates and other seed dispersers, natural forest regeneration may slow and plant community composition may change [10].

Interrelated intrinsic ecological and biological characteristics, such as body size, dietary preference, home range size and distribution, population densities, the rate of natural increase and social system, determine a given species' susceptibility to the synergistic effects of habitat degradation and fragmentation [11]. Whereas some species can survive and disperse in heavily fragmented habitats, at least for a while, larger-bodied and specialist species (i.e., those with restricted dietary of habitat requirements) are more likely to decline or become locally extinct due to intrinsic factors related to their biology and ecology [12,13]. The ability to use and disperse across the anthropogenic habitat matrix is key to the survival of many species [14]. Even populations of species able to adapt in the short-term will eventually become inviable as fragmentation increases to the point where the remaining areas can no longer support them [11,13], as seen across the Neotropics where the patch size explains the primate species richness and persistence in forest fragments, although this is also strongly affected by hunting pressure [15].

Between 2001 and 2014, Peru lost an average of 118,089 ha of its Amazonian forest per year (Perú, Programa [16]). More recent data from Global Forest Watch show an additional 1.43 million ha of tree cover loss between 2015 and 2019 (>30% canopy cover per pixel; [17]). Small (<5 ha) plots for non-industrial subsistence and commercial farming account for ~81% of forest loss per year in Peru [18]. Since 2007, larger areas (>500 ha) for industrialized agriculture have become more prevalent, particularly for palm oil and cacao in the northern Amazonian regions of Loreto and San Martín [18]. In recent years, illegal gold mining, largely in the southern Amazon, has caused serious environmental damage and human health issues [19]. Nationwide, road construction and urbanization, with their associated infrastructure and migration, have led to increased habitat loss and fragmentation [20,21].

Peru has 55 primate taxa (including species and subspecies), the fourth most of any country [22]. About 30% of these species are listed as "threatened with extinction" by the IUCN, and a further five as "near threatened" and five as "data deficient" (Supplementary Table S1). Peru's primates are predominantly found in the Amazonian lowlands and eastern Andean cloud forests [23], with only two primate species found outside of these areas (*Alouatta palliata aequatorialis* and *Cebus aequatorialis*) in the northern dry forests [24]. Since the threats to primates in Peru are becoming more and more prevalent, we assessed the threat level to Peruvian primates from habitat fragmentation through GIS-based and statistical analyses, and specialist assessments based on first-hand knowledge. This was done as part of an IUCN initiative to create the Best Practice Guidelines for the Stewardship of Primates in Fragments (Marsh et al., in prep.).

2. Materials and Methods

Following Boonratana [25], we organized the IUCN Conservation Measures Partnership (IUCN-CMP) Unified Classifications of Direct Threats Version 3.2 (https://www.iucnredlist.org/resources/threat-classification-scheme (accessed on 1 September 2021) in a table with the threats listed in rows and columns for the classification of the threats

based on the following categories: (1) direct threat to the primate, (2) threatens the primate habitat, (3) causes fragmentation, (4) exacerbates fragmentation, (5) threatens the primate and the habitat as a consequence of fragmentation ([25], Table 1). The direct threats were considered as proximate anthropogenic activities or processes that act upon or affect the primate being evaluated, for example, the hunting of primates, the loss of habitat or the introduction of pathogens to an environment. The indirect threat categories, or stresses, were considered as non-proximate anthropogenic activities or processes which threaten the primate being evaluated in a secondary manner, for example, whereas logging or harvesting of non-timber forest products may be a direct threat to the taxon being harvested, it may also reduce the habitat quality, thus affecting the primates [26]. The specialists were asked to consider all of the IUCN-CMP threats and categories in their assessments, except for climate change, pathogens and diseases. The threats were assigned qualitative values of zero, possible/probable, low, medium and high based on each experts' professional experience. The primate health specialists, co-authors PM and MEW, assessed the threats to the primates posed by infectious agents based on literature reviews and professional knowledge. These assessments focused on the studies of free-ranging primates, but also took into account the knowledge obtained from captive settings, especially where information from wild populations was lacking [27–29]. When species-specific data were not available, evaluations were made based on the information at the genus level, i.e., there is abundant information on the disease susceptibility of howler monkeys but research efforts are not balanced among the species. Therefore, the threats to Peruvian howler monkeys were assessed considering the knowledge available for *Alouatta* sp. [27,28].

Table 1. Overall threat evaluation of Peruvian primate taxa (n = 55) using decimal threat levels for all categories and subcategories in the IUCN-CMP (# taxa affected/Score). Following the IUCN-CMP version 3.3 (https://www.iucnredlist.org/resources/threat-classification-scheme (accessed on 1 September 2021), the categories were defined as follows. Threatens Primate = the proximate human activities or processes that have impacted the status of the primate being assessed. Threatens Primate Habitat = the proximate human activities or processes that have impacted the status of the habitat of the primate being assessed. Causes Fragmentation = the proximate human activities or processes that have resulted in the habitat of the primate being assessed to fragment. Fragmented habitats are those that are: (a) broken up into smaller distinct patches, exhibiting a reduced total area and isolation between the patches, or (b) dissected, but not isolated, and do not exhibit any significant reduction in the total area, e.g., by a single track road [25]). Exacerbates Fragmentation = the proximate human activities or processes that may or may not have caused habitat fragmentation, but whose impacts have worsened the fragmentation of the habitat of the primate being assessed. Threatens Primate and Primate Habitats as a Consequence of Fragmentation = the proximate human activities or processes resulting from habitat fragmentation that have impacted the status of the primate, or the habitat of the primate being assessed.

	Threat	Threatens Primate	Threatens Primate Habitat	Causes Fragmentation	Exacerbates Fragmentation	Threatens Primate and Primate Habitats as a Consequence of Fragmentation	Row Total (Score Only)
1.	**Residential and Commercial Development**	**29/3.22**	**49/4.05**	**49/4.13**	**45/4.37**	**44/4.19**	**49/3.57**
1.1	Housing and urban	26/5.38	49/6.38	49/6.48	45/6.56	44/6.31	49/5.48
1.2	Commercial and industrial areas	16/4.84	36/5.21	37/5.20	36/5.21	36/5.21	37/4.50
1.3	Tourism and recreation	13/4.81	19/5.00	20/4.88	22/4.89	18/4.86	23/3.91
2.	**Agriculture and Aquaculture**	**22/1.77**	**53/2.57**	**53/2.71**	**47/2.54**	**49/2.36**	**53/2.09**

Table 1. *Cont.*

	Threat	Threatens Primate	Threatens Primate Habitat	Causes Fragmentation	Exacerbates Fragmentation	Threatens Primate and Primate Habitats as a Consequence of Fragmentation	Row Total (Score Only)
2.1	**Annual and Perennial Non-timber Crops**	**16/3.71**	**52/4.12**	**52/4.13**	**45/4.25**	**47/3.99**	**52/3.34**
2.1.1	*Shifting agriculture*	13/5.19	50/5.65	50/5.70	44/5.68	44/5.40	50/4.49
2.1.2	*Smallholder farming*	16/5.78	51/6.57	51/6.57	45/6.61	47/6.28	51/5.31
2.1.3	*Agro-industry farming*	14/5.36	38/6.12	38/6.12	35/6.14	36/5.97	38/5.11
2.1.4	*Scale unknown/unrecorded*	1/2.50	2/3.75	2/3.75	1/2.50	1/2.50	2/2.25
2.2	**Wood and Pulp Plantations**	**10/3.00**	**34/3.38**	**34/3.43**	**32/3.26**	**32/3.10**	**34/2.74**
2.2.1	*Smallholder plantations*	10/5.00	34/5.37	34/5.44	32/5.31	32/5.08	34/4.41
2.2.2	*Agro-Industry plantations*	8/4.69	31/5.16	31/5.24	27/5.19	26/5.10	31/4.08
2.2.3	*Scale unknown/unrecorded*	1/2.50	1/2.50	1/2.50	1/2.50	1/2.50	1/2.50
2.3	**Livestock Farming**	**19/2.34**	**51/2.67**	**50/2.68**	**40/2.89**	**41/2.73**	**51/14.17**
2.3.1	*Nomadic grazing*	2/3.75	3/4.17	3/3.33	3/3.33	3/3.33	3/3.33
2.3.2	*Smallholder grazing, ranching or farming*	17/5.44	49/6.63	48/6.72	38/7.04	39/6.54	49/5.15
2.3.3	*Agro-industry grazing, ranching or farming*	15/5.00	37/5.54	36/5.56	33/5.53	34/5.29	37/4.55
2.3.4	*Scale unknown/unrecorded*	1/2.50	1/2.50	1/2.50	1/2.50	1/2.50	1/2.50
2.4	**Marine and Freshwater Aquaculture**		**5/2.50**	**24/2.50**	**2/2.50**	**2/2.50**	**25/1.65**
2.4.1	*Subsistence/artisanal aquaculture*		5/5.00	22/5.00			23/1.17
2.4.2	*Industrial aquaculture*			2/3.33	2/3.33	2/3.33	3/2.00
2.4.3	*Scale unknown/unrecorded*						
3.	**Energy Production and Mining**	**12/2.71**	**47/4.63**	**47/4.68**	**44/4.35**	**43/3.95**	**47/3.54**
3.1	Oil and gas drilling	4/5.00	39/5.77	41/5.61	34/5.51	31/5.24	41/4.02
3.2	Mining	9/5.00	36/5.83	35/6.00	33/5.91	325.55	36/4.65
3.3	Renewable energy						
4.	**Transportation and Service Corridors**	**18/3.40**	**45/4.94**	**48/5.00**	**41/5.15**	**39/5.03**	**49/3.80**
4.1	Roads and railroads	16/5.31	45/6.33	48/6.51	41/6.65	38/6.45	49/4.90
4.2	Utility and service lines	7/5.36	29/5.52	31/5.40	28/5.36	28/5.27	32/4.14
4.3	Shipping lanes						
4.4	Flight paths						

Table 1. *Cont.*

	Threat	Threatens Primate	Threatens Primate Habitat	Causes Fragmentation	Exacerbates Fragmentation	Threatens Primate and Primate Habitats as a Consequence of Fragmentation	Row Total (Score Only)
5.	**Biological Resource Use**	**55/1.85**	**54/2.03**	**54/2.07**	**47/2.65**	**49/2.27**	**55/2.03**
5.1	**Hunting and Collecting of Terrestrial Animals**	55/3.95	14/2.74	10/2.75	44/3.75	38/3.73	55/2.15
5.1.1	*Intentional use*	55/6.59	12/5.42	9/5.28	44/6.65	38/6.51	55/3.69
5.1.2	*Unintentional effects*	43/5.35	8/5.00	5/5.00	31/5.16	27/5.28	43//2.78
5.1.3	*Persecution/Control*	11/5.45	2/5.00	2/5.00	8/5.31	7/5.00	11/2.86
5.1.4	*Motivation unknown/unrecorded*						
5.2	**Gathering of Terrestrial Plants**	2/1.67	34/1.72	31/1.72	15/1.72	8/1.67	36/1.28
5.2.1	*Intentional use*						
5.2.2	*Unintentional effects*	1/5.00	34/5.00	31/5.00	15/5.17	8/5.00	36/2.49
5.2.3	*Persecution/Control*	1/5.00	1/5.00	1/5.00			2/1.50
5.2.4	*Motivation unknown/unrecorded*						
5.3	**Logging and Wood Harvesting**	25/3.40	54/4.26	54/4.15	44/4.17	47/3.79	54/3.34
5.3.1	*Intentional use: subsistence/small scale*						
5.3.2	*Intentional use: large scale*						
5.3.3	*Unintentional effects: subsistence/small scale*	24/5.21	54/6.57	54/6.39	44/6.31	47/5.85	54/5.10
5.3.4	*Unintentional effects: large scale*	24/5.31	47/7.07	47/6.91	43/6.28	43/5.99	47/5.59
5.3.5	*Motivation unknown/unrecorded*	1/2.50	1/2.50	1/2.50	1/2.50	1/2.50	1/2.50
5.4	**Fishing and Harvesting Aquatic Resources**		1/5.00	18/5.00			18/1.06
5.4.1	*Intentional use: subsistence/small scale*						
5.4.2	*Intentional use: large scale*						
5.4.3	*Unintentional effects: subsistence/small scale*		1/5.00	18/5.00			18/1.06
5.4.4	*Unintentional effects: large scale*						
5.4.5	*Persecution/Control*						
5.4.6	*Motivation unknown/unrecorded*						
6.	**Human Intrusions and Disturbance**	28/2.11	35/3.21	35/3.07	343.19	26/2.88	39/2.37

Table 1. *Cont.*

	Threat	Threatens Primate	Threatens Primate Habitat	Causes Fragmentation	Exacerbates Fragmentation	Threatens Primate and Primate Habitats as a Consequence of Fragmentation	Row Total (Score Only)
6.1	**Recreational Activities**	28/5.27	28/5.18	28/5.00	30/5.25	26/5.38	36/4.06
6.2	**War, Civil Unrest and Military Exercises**	3/5.00	13/5.38	13/5.00	13/5.38	7/5.00	16/3.19
6.3	**Work and Other Activities**	3/5.00	23/5.33	22/5.34	18/5.42	9/5.56	23/3.50
7.	**Natural System Modifications**	18/0.83	38/1.60	32/1.91	28/1.37	24/1.39	38/1.10
7.1	**Fire and Fire Suppression**	18/5.00	36/5.90	30/5.83	27/5.93	24/6.04	36/4.35
7.1.1	*Increase in fire frequency/intensity*	18/5.00	36/5.90	30/5.83	27/5.93	24/6.04	36/4.35
7.1.2	*Suppression in fire frequency/intensity*						
7.1.3	*Trend unknown/unrecorded*						
7.2	**Dams and Water Management/Use**		20/1.53	26/1.48	8/1.75	5/2.20	31/1.21
7.2.1	*Abstraction of surface water (domestic use)*		1/5.00	1/5.00			1/2.00
7.2.2	*Abstraction of surface water (commercial use)*		12/5.21	7/5.36	4/5.00	4/5.00	12/2.33
7.2.3	*Abstraction of surface water (agricultural use)*		5/6.00	4/6.25	4/6.25	3/6.67	5/4.00
7.2.4	*Abstraction of surface water (unknown use)*						
7.2.5	*Abstraction of ground water (domestic use)*		1/5.00	4/5.00			4/2.00
7.2.6	*Abstraction of ground water (commercial use)*						
7.2.7	*Abstraction of ground water (agricultural use)*						
7.2.8	*Abstraction of ground water (unknown use)*						
7.2.9	*Small dams*		10/5.00	23/5.22	5.5/00	3/5.00	24/1.75
7.2.10	*Large dams*						
7.2.11	*Dams (size unknown)*						
7.3	**Other Ecosystem Modifications**						
8.	**Invasive and Other Problematic Species and Genes**	52/1.36	2/0.56	2/0.56	52/1.36	54/1.36	55/0.79

Table 1. *Cont.*

	Threat	Threatens Primate	Threatens Primate Habitat	Causes Fragmentation	Exacerbates Fragmentation	Threatens Primate and Primate Habitats as a Consequence of Fragmentation	Row Total (Score Only)
8.1	**Invasive Non-Native/Alien Species**						1/0.00
8.1.1	*Unspecified species*						1/0.00
8.1.2	*Named species*						
8.2	**Problematic Native Species**	2/2.50	2/2.50	2/2.50	2/2.50	2/2.50	2/2.75
8.2.1	*Unspecified species*	2/2.50	2/2.50	2/2.50	2/2.50	2/2.50	2/2.50
8.2.2	*Named species*	2/2.50	2/2.50	2/2.50	2/2.50	2/2.50	2/2.50
8.3	**Introduced Genetic Material**	1/5.00					1/1.00
8.4	**Pathogens and Microbes**	52/2.38			52/2.45	52/2.48	55/1.38
8.4.1	*Unspecified species*	51/2.50			52/2.50	52/2.50	54/1.44
8.4.2	*Named species*	46/2.61			50/2.50	51/2.50	54/1.38
8.5	**Viral/Prion-induced Diseases**	52/2.45			52/2.48	54/2.55	55/1.43
8.5.1	*Unspecified species (disease)*	51/2.50			52/2.50	54/2.50	54/1.44
8.5.2	*Named species (disease)*	51/2.50			51/2.50	53/2.64	54/1.45
8.6	**Disease of Unknown Cause**	46/2.61			46/2.50	48/2.50	48/0.00
9.	**Pollution**	17/0.57	48/1.08	42/0.86	39/0.96	26/0.72	48/0.64
9.1	**Household Sewage and Urban Waste Water**		8/2.81		2/3.75		8/0.75
9.1.1	*Sewage*		8/4.38		2/5.00		8/1.13
9.1.2	*Run-off*		2/5.00		1/5.00		2/1.50
9.1.3	*Type unknown/unrecorded*						
9.2	**Industrial and Military Effluents**	10/2.50	45/3.53	39/3.33	35/3.64	18/3.47	46/2.19
9.2.1	*Oil spills*		37/4.39	30/4.33	27/4.54	12/4.17	37/2.51
9.2.2	*Seepage from mining*	10/5.00	32/4.84	29/4.48	28/4.73	15/5.00	33/3.29
9.2.3	*Type unknown/unrecorded*						
9.3	**Agricultural and Forestry Effluents**	3/1.67	23/2.25	19/1.75	16/1.77	8/1.88	23/1.16
9.3.1	*Nutrient loads*		5/5.00				5/1.00
9.3.2	*Soil erosion*		23/5.22	19/5.26	16/5.31	8/5.63	23/3.04
9.3.3	*Herbicides and pesticides*	3/5.00	2/5.00				5/1.00
9.3.4	*Type unknown/unrecorded*						

Table 1. *Cont.*

	Threat	Threatens Primate	Threatens Primate Habitat	Causes Fragmentation	Exacerbates Fragmentation	Threatens Primate and Primate Habitats as a Consequence of Fragmentation	Row Total (Score Only)
9.4	**Garbage and Solid Waste**	1/5.00	3/5.83	1/5.00	2/5.00	1/5.00	4/0.00
9.5	**Airborne Pollutants**						
9.5.1	*Acid rain*						
9.5.2	*Smog*						
9.5.3	*Ozone*						
9.5.4	*Type unknown/unrecorded*						
9.6	**Excess Energy**	9/1.81			5/1.75	5/1.75	10/1.35
9.6.1	*Light pollution*	6/2.50			3/2.50	4/2.50	6/1.08
9.6.2	*Thermal pollution*						
9.6.3	*Noise pollution*	6/2.92			2/5.00	2/3.75	7/1.00
9.6.4	*Type unknown/unrecorded*						
10.	**Geological Events**	2/2.50	22/2.61	20/2.50	9/2.50	6/2.50	22/1.36
10.1	Volcanoes						
10.2	Earthquakes, tsunamis	2/2.50	3/3.33	2/2.50	2/2.50	2/2.50	3/2.00
10.3	Avalanches, landslides	2/2.50	22/4.77	20/4.75	20/4.44	9/4.17	22/2.45
11.	**Climate Change and Severe Weather**	55/6.41	55/6.49	55/6.42	55/6.49	55/6.48	55/6.46
11.1	Habitat Shifting and alteration	53/7.17	55/7.00	55/7.00	55/7.00	55/7.00	55/6.98
11.2	Droughts	55/5.91	55/6.00	55/5.86	55/6.00	55/5.95	55/5.95
11.3	Temperature excess	54/7.13	54/7.22	54/7.13	54/7.22	54/7.22	54/7.19
11.4	Storms and flooding	54/5.93	54/5.97	54/5.93	54/5.97	54/5.97	54/5.95
11.5	Other impacts						

To estimate the current levels of habitat loss and fragmentation for each taxon, we conducted a general GIS-based evaluation based on the estimated distributions. We used publicly available distribution maps [1,30] that were overlaid on the latest official government deforestation and degradation layer of Peru (Perú, Ministerio del [31]), removing the areas with more than a 50% level of degradation.

To further evaluate the causes/drivers and the severity of fragmentation, we used the same distribution maps and overlayed them on roads, urban areas, human settlements (rural) and logging, mining, oil and non-timber forestry concession datasets (Supplementary Table S2). Deforestation and forest degradation were used as the proxy measures of the land clearance for agriculture and livestock farming, while nearness to settlements and access routes (e.g., trails, unpaved roads) were the proxies of hunting pressure. When evaluating the severity of each threat, we took into account the species-specific biological and ecological characteristics (i.e., body size, range size, diet, reproductive rate/rate of natural increase).

The climate change analyses were made using models of the predicted changes in the average temperature and precipitation. The climate data came from the International

Panel on Climate Change Fifth Assessment [32] and were downloaded from the WorldClim website [33,34]. We used historical climate data and future models from the NASA Goddard Institute for Space Studies [35]. We calculated the total variation between the historical and predicted temperatures and precipitation across Peru (minimum and maximum pixel values). We then calculated the difference between the current and future values for each pixel, assigning values of zero, low, medium or high based on the equal interval distribution of the pixel value changes. The negative changes, representing reductions in the temperature or precipitation, were converted to positive values as we were evaluating the size of the predicted changes, assuming that any substantial variation from the historic norm would be detrimental to the taxa and/or its habitat.

The assessments were compiled by SS, LFH and NA, reclassifying some threat levels given by other specialists to ensure consistency in the application of the IUCN-CMP methodology. The complete dataset was then sent to all the specialists for review. Once a consensus was reached, threat levels were coded as 0 = no threat, 1 = possible threat, 2 = low, 3 = medium and 4 = high threat. We calculated the number of taxa and categories affected by each threat. To see which threats were most severe on those taxa they affected, we calculated a decimal index based on converting the percentage of the maximum possible score according to the number of taxa affected (Table 1) using the following formula.

$$Severity = \frac{(100/(n\ taxa\ affected * 4)) * sum\ of\ scores}{10}$$

The climate change analyses were evaluated separately as they were based on predictive models and never assigned values of 0 or 1.

3. Results

Of the 55 taxa, 35 were assessed solely with GIS and 20 were assessed by the specialists and supplemented by the GIS analysis (Supplementary Table S3).

The GIS analysis showed that all primate taxa were affected by habitat fragmentation or deforestation to some degree (Figure 1). *Aotus miconax*, *Lagothrix flavicauda*, *Leontocebus leucogenys* and *Plecturocebus oenanthe* were the most affected, each having over 50% of their historical distributions fragmented or lost (Figure 1). The threats varied significantly by family and genus (Figure 2 and Supplementary Table S4). Cebidae and Atelidae, the largest-bodied primates, were the families facing the highest overall threat level, and the endemic *P. oenanthe* was the most severely affected species.

The most common and severe direct threats to the species were from hunting, while the threats to the habitat were from logging and agriculture (Table 1). Housing and urban development, smallholder crop farming, smallholder grazing and large-scale logging were the most common and severe threats (Table 1). All taxa were predicted to be affected by climate change (Supplementary Figure S1). Infectious agents and disease were considered threats for most taxa (n = 52), whether by threatening primates directly or by exacerbating the effects of fragmentation through decreased population size and increased isolation. Few of the IUCN-CMP threat categories were not considered a threat to any primate taxa (Table 1). The full dataset is provided in Supplementary Table S4.

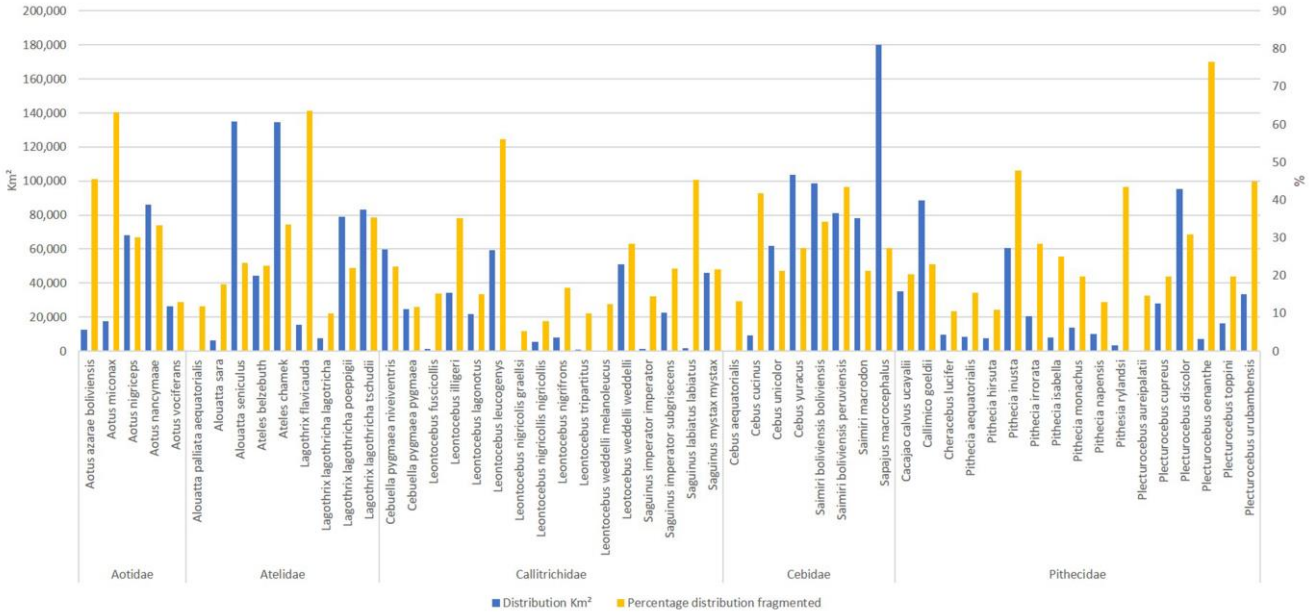

Figure 1. Estimated distribution size and percent distribution fragmented and/or deforested for Peruvian primate taxa (n = 55).

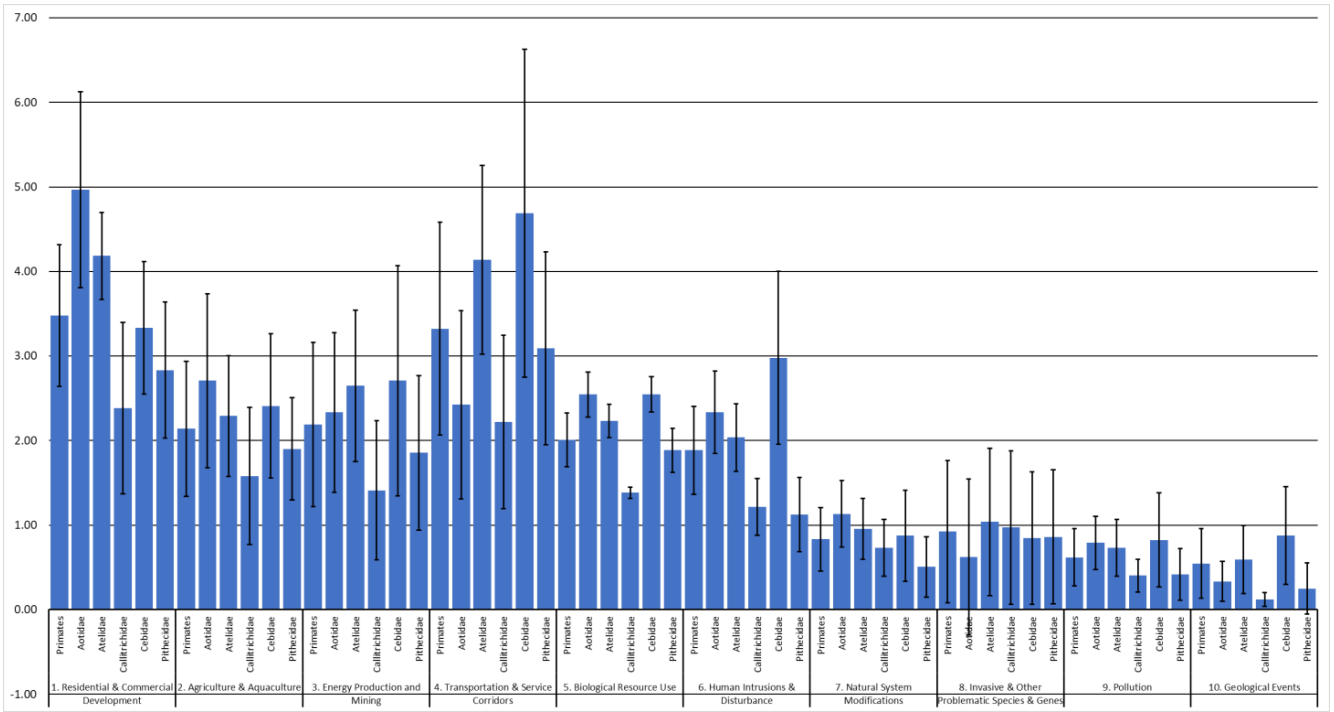

Figure 2. Predicted threat score to Peruvian primates at the family level, by major threat categories.

4. Discussion

The IUCN-CMP classification scheme allowed us to identify trends similar to those of primate conservation assessments worldwide [1,3]. Housing and urban expansion, smallholder farming and large-scale logging were the most common and most severe threats and were identified across all threat categories. Hunting was the most common and severe direct threat to individual taxa (Table 2). By conducing evaluations on the subspecific level, we were able to account for the differences in primate responses to the threats, which will not be the same across taxa living in sympatry. This was particularly

important considering that Peru has one of the highest numbers of primate species of any country, and many areas with a very high level of sympatry, with some sites having as many as 12 to 13 sympatric primate species [36,37].

Table 2. Most important causes of fragmentation-related threats to Peruvian primates. Based on the most common and highest scoring threat (excluding climate change). The columns show the threat category and the number of taxa threatened/decimal score.

Threat	Threatens Primate (1)	Threat	Threatens Primate Habitat (2)	Threat	Causes Fragmentation (3)	Threat	Exacerbates Fragmentation (4)	Threat	Threatens Primate and Primate Habitats as a Consequence of Fragmentation (5)	Threat	Total
Hunting intentional use	55/ 6.59	Logging unintentional effects: subsistence/ small-scale	54/ 6.57	Logging unintentional effects: subsistence/ small-scale	54/ 6.39	Housing and urban	45/ 6.56	Smallholder farming	47/ 6.28	Logging unintentional effects: subsistence/ small-scale	54/ 5.10
Hunting unintentional effects	43/ 5.35	Smallholder farming	51/ 6.57	Smallholder farming	51/ 6.57	Smallholder farming	45/ 6.61	Logging unintentional effects: subsistence/ small-scale	47/ 5.85	Smallholder farming	51/ 5.31
Housing and urban	26/ 5.38	Housing and urban	49/ 6.38	Housing and urban	49/ 6.48	Hunting intentional use	44/ 6.65	Housing and urban	44/ 6.31	Housing and urban	49/ 5.48
Logging unintentional effects: large-scale	24/ 5.31	Smallholder grazing, ranching or farming	49/ 6.63	Smallholder grazing, ranching or farming	48/ 6.72	Logging unintentional effects: subsistence/ small-scale	44/ 6.31	Logging unintentional effects: large-scale	43/ 5.99	Smallholder grazing, ranching or farming	49/ 5.15
Smallholder grazing, ranching or farming	17/ 5.44	Logging unintentional effects: large-scale	47/ 7.07	Roads and railroads	48/ 6.51	Logging unintentional effects: large-scale	43/ 6.28	Smallholder grazing, ranching or farming	39/ 6.54	Roads and railroads	49/ 4.90
Smallholder farming	16/ 7.78	Roads and railroads	45/ 6.33	Logging unintentional effects: large-scale	47/ 6.91	Roads and railroads	41/ 6.65	Roads and railroads	38/ 6.45	Logging unintentional effects: large-scale	47/ 5.59
		Agro-industry farming	38/ 6.12	Agro-industry farming	38/ 6.12	Smallholder grazing, ranching or farming	38/ 7.04	Hunting intentional use	38/ 6.51		
						Agro-industry farming	35/ 6.14	Agro-industry farming	36/ 5.97		

In our assessments, some commonly cited threats in the literature were not found to be present, including renewable energy production, large dams and fire suppression activities (Table 1). However, Peru currently has plans to build several large dams for energy production in the Amazon and Amazonian Andes, which would affect many primate

species, as such this could become a threat in the future [38]. Increasing temperatures and changes in rainfall patterns due to climate change, firebreaks, controlled burns and the use of surface water to control wildfires could lead to fragmentation and habitat degradation.

Due to housing and the increase in new settlements, the growth of the existing urban areas in Peru has generally followed global trends. In the Neotropics, growing urbanization (1.44% annually) has resulted in the majority of the population (78.3%, [39]) concentrated in large cities [40,41]. Although the Andean foothills and Amazonian lowlands remain relatively sparsely populated, starting in the 1970s the Peruvian government implemented programs of colonization, building and paving new highways and providing economic and technical incentives for migrants [42,43]. In Peru, ~75% of forest disturbance and deforestation in the Amazon has occurred <20 km from roads, with similar concentrations of deforestation along rivers with no road access [20]. With unprecedented plans for the expansion of the road network in the Peruvian Amazon [44], this must be considered one of the greatest indirect threats to deforestation and fragmentation in the future. This also increases the dangers to wildlife from death or injury due to power lines or crossing roads [45–47].

Our analysis highlights the impact of settled smallholder farming on primate habitats. The aggregate effect of these individual farms has an enormous impact on remaining forests, contributing to ~81% of yearly forest loss in Peru [18]. People follow roads into new areas, quickly settling and clearing forest, either for cultivation or for land trafficking [43]. This causes deforestation and fragmentation but also exacerbates these threats through increased rates of human–wildlife conflict [47]. Industrialized agriculture is a growing threat globally, with increases in oil palm and soy megafarms [41,48,49]. Previous studies found that an estimated 72% of palm plantations in the Peruvian Amazon are on cleared primary forest [50,51]. Approx. 80% of new deforestation in the Neotropics has been for grazing lands [48] and accounts for an estimated 40% of deforestation in the Peruvian Amazon [52]. Although some attempts have been made toward more sustainable production, these have been beset by issues such as social conflicts with local communities and a lack of transparency, enforcement and accountability, but these are beyond the scope of this discussion (c.f., [50]).

We found that logging was a common threat to the habitat and species. Industrial logging is a threat globally and affects large areas of primary forest, with companies interested in a number of tropical hardwood species [41]. While some remote logging activities may have a limited effect on primates [53], it is a principal cause of degradation, and in the lowland Peruvian Amazon, illegal loggers regularly enter official concessions and other areas (including protected areas), making proper management of forestry operations extremely difficult. Loggers in these remote areas hunt regularly, often for subsistence, but in many cases also to extract fauna for sale in local and regional markets [54]. Selective logging occurs throughout Peru and is one of the major causes of forest degradation [55]. Individual small-scale operations may not threaten primates, as loggers are often only interested in a single marketable species, individually extracting logs, but in many cases these are connected to larger, more organized operations [55]. The widespread and incipient nature of selective logging has the most effect, reaching all parts of Peru, and is not limited to designated concessions.

Hunting was the most commonly reported threat to Peruvian primates, directly affecting all taxa, and had the highest overall score of any threat (Table 1). Larger-bodied primates are the most targeted by hunters for consumption or sale as food, particularly the species of *Ateles* and *Lagothrix*, which have been extirpated from large areas across the Amazon due to hunting pressure [56]. Although smaller-bodied species are less desirable to hunters, they are commonly targeted for consumption in areas where larger-bodied species are no longer available. Some of the smaller-bodied species are amongst the most popular for the illegal pet trade, such as those of the genera *Cebuella*, *Saimiri*, *Leontocebus* and *Saguinus* [57,58]. Hunting is a common threat to primates globally, affecting up to 90% of primate species in Africa, Madagascar and Asia [3,49]. Most global evaluations

list hunting in the Neotropics as a less serious threat than in other regions [1,3], but this is contrary to our results and personal experiences working in Peru and across South America. Due to its clandestine nature, the studies of wildlife trafficking are difficult and our best estimates are based on extrapolations from imperfect data. In one study, a single market in Peru had a turnover of over 40 live primates sold each week, only counting animals visibly displayed for sale [58]. Shanee, Mendoza and Shanee [58] estimated the numbers in excess of 35,000 primates killed and consumed as bushmeat annually in Loreto and Ucayali regions, and thousands more are killed or trafficked live as pets nationally. As the human population has steadily increased in the Peruvian Amazon, hunting for bushmeat and the illegal pet trade have also increased [59]. Unfortunately, the enforcement of wildlife laws in Peru is still severely lacking [58,60,61].

Infectious agents and disease scored as moderate threats (threat score = 2.51) and could exacerbate the effects of fragmentation for most taxa. It was not considered to be a cause of fragmentation or a direct threat for the primate habitat (Table 1). Fragmentation increases forest edge, and reduces overall habitat areas, tending to increase animal densities and opportunities for interspecies interactions, enhancing pathogen transmission [62]. Although species diversity decreases in human-modified landscapes, those that adapt to these modifications also tend to carry more pathogens due to the proximity to humans and domesticated animals coupled with increased stress and immunocompromised physiologies [63]. Disease outbreaks and pathogen loads in natural populations remain largely undocumented, hence it is difficult to quantify the direct impact of disease on animals within fragmented habitats and/or the impact of fragmentation on disease circulation [64]. Models show that once an outbreak is established, fragmentation leads to larger and longer epidemics if the density of the affected species is high or the course of the disease is long [65]. Vector-borne diseases such as yellow fever, zika and malaria may have a greater impact on susceptible species if deforestation and fragmentation increase the prevalence of vectors and intermediate species [66]. The effects of diseases also go beyond direct mortality events. Smaller patch sizes, the frequent incursion of non-native species and resource scarcity caused by fragmentation and habitat degradation can result in increased parasitism and lower fitness [67,68]. Climate change is also expected to expand the range of vectors and infectious diseases in both humans and non-human primates [69].

Our mapping showed climate change affecting all primates in Peru to some degree (Supplemental Figure S1). *Plecturocebus oenanthe* was predicted to be the most affected species, and the western Amazonian lowlands was predicted to face the greatest threat (Supplemental Figure S1). Previous studies have shown that the current levels of anthropogenic climate change are increasing in line with worst-case scenarios and have led to changes in rainfall patterns, temperatures and seasonality [70]. It is predicted that for some species, ecological niches could expand. However, it is unlikely that primates will be able to migrate apace with these changes as the human activities which fragment habitats may block the migration routes needed for arboreal species to reach these new areas, and as areas which would have had a suitable habitat may already be reduced or lost [71–74].

5. Conclusions

The adapted IUCN-CMP classification scheme [25] provides a useful tool for the evaluation of the fragmentation threat. When evaluating the results, especially across such a large number of taxa, specific threats and trends can become diluted when looking at higher-level category groupings for the threats and/or taxa. For example, hunting was the most common direct threat to species, while the overall biological resource use (which includes hunting and logging, but also plant use and fishing) was not found to be a severe threat. As different species will be unevenly affected by different threats, even when present in the same geographic area, evaluations should be made to the smallest taxonomic or geographic unit to consider the species-specific traits, such as body size, diet and behavioral ecology, to ensure threats and their severity are properly identified and that the results are as applicable and specific as possible.

The development of the IUCN Best Practice Guidelines for the Stewardship of Primates in Fragments (Marsh et al., in prep) will provide an important tool for conservation practitioners and policymakers at all levels. Once completed, they can be applied to mitigate the impacts of activities that negatively affect primates and provide a framework for other taxonomic groups as well as national and regional guidelines. In Peru, habitat connectivity needs to be intentionally and proactively maintained or recovered. The planned expansion to the road network in the Peruvian Amazon should not be overlooked as a driver for habitat loss, fragmentation, hunting and other threats to primates. The impact of individual infrastructure projects is likely to be very large. The restoration of key areas could help avoid future extinctions and provide a high return on conservation investment [75,76]. These initiatives need to be based on policies that take into account not just the biological considerations, but also the effects on the potential income of the surrounding human populations [77]. The need for a systematized approach to mitigating habitat degradation and fragmentation is clear, and we hope the current evaluation will help this process.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15020276/s1, Figure S1: Predicted threat score to Peruvian primates from future climate change; Table S1: Estimated fragmentation of Peruvian primate taxa distributions; Table S2: Details of layers used for GIS based assessments; Table S3: Taxa and specialists primarily responsible for non-GIS based assessments; Table S4: Full data set including individual, genus and family level assessments.

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