UNIVERSIDAD REGIONAL AMAZÓNICA IKIAM

Facultad de Ciencias de la Vida

Carrera de Ingeniería en Ecosistemas

Assessment of conflict zones between jaguars (*Panthera onca*) and livestock in Sumaco Biosphere Reserve through a predation-risk model

Proyecto de investigación previo a la obtención del Título de:

INGENIERO EN ECOSISTEMAS

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2022

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que persisten ante los distintos conflictos

y a todas las futuras generaciones que se

interesen en proteger y conservar este majestuoso felino.

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RESUMEN

Los conflictos humano-jaguar se han incrementado en las últimas décadas, especialmente por la depredación del ganado. En la Reserva de la Biosfera de Sumaco (RSB) se reportaron varios ataques de jaguar por parte del Parque Nacional Sumaco Napo Galeras (SNGNP) entre 2018 - 2021. De acuerdo a esto, el primer objetivo de este estudio es generar un modelo de riesgo de depredación con enfoque antropogénico, paisajístico, variables ambientales y de manejo ganadero asociadas a los ataques registrados en la Reserva de la Biosfera Sumaco. El segundo objetivo es evaluar la presencia de jaguares a través de registros de ocurrencia directa e indirecta entre las diferentes clases de riesgo del modelo. El mapa resultante indicó que el 1,04% del área de estudio se categorizó con alto riesgo en un total de 103,69 km^2. Además, con el análisis jackknife obtuvimos que las variables *Distancia a las carreteras*, la *Distancia a las áreas protegidas* y la *Altitud* fueron las tres variables más importantes que contribuyeron a la predicción del modelo. El mapa de riesgo presentó cuatro clases de riesgo: (1) sin riesgo (<=0,1875), (2) riesgo bajo (0,1875 – 0,3750), (3) riesgo medio (0,3750 – 0,5625) y (4) alto riesgo (>0,5625). Registramos la presencia de los jaguares en las diferentes áreas de riesgo utilizando cinco estaciones de cámaras-trampa durante ~79 días con un esfuerzo total de 1341 trampas/noches. Generar un modelo de riesgo de predación es una herramienta fácil y de bajo costo para mejorar el manejo de la vida silvestre y el ganado para mejorar la coexistencia del jaguar y las comunidades locales al reducir las probabilidades de conflicto.

Keywords: Jaguar; Modelo de riesgo; Reserva de Biósfera Sumaco; Predación al ganado; Cámaras-trampa

ABSTRACT

The human-jaguar conflicts have increased in the last decades, especially by the livestock predation. In Sumaco Biosphere Reserve (SBR) several jaguar attacks were reported by the Sumaco Napo Galeras National Park (SNGNP) between 2018 - 2021. According to this, the first objective of this study is to generate a predation risk-model with anthropogenic, landscape, environmental and livestock management variables associated with the attacks recorded in the Sumaco Biosphere Reserve. The second objective is to evaluate jaguar presence through direct and indirect occurrence records among the different risk-classes for the model. The resulting map indicated that 1.04% of the study area was categorized with high risk in a total 103.69 km^2. Furthermore, with the jackknife analysis we obtained that *Distance to roads, Distance to protected areas* and *Altitude* were the three most important variables that contributed to the model's prediction. The risk-map presented four risk-classes: (1) without risk (<=0,1875), (2) low-risk (0,1875 – 0,3750), (3) medium-risk (0,3750 – 0,5625) and (4) high-risk (>0,5625). We recorded the presence of the jaguars in the different risk areas by using five trap cameras stations for ~79 days with a total effort of 1341 trap/nights. Generating a predation risk-model is an easy and low-cost tool to improve wildlife and livestock management to enhance the coexistence of the jaguar and the local communities by reducing conflict probabilities.

Keywords: Jaguar; Risk-model; Sumaco Biosphere Reserve; Livestock predation; trap camera

INTRODUCTION

The swiftly increase in human population and ecosystems fragmentation has intensified the conflict between humans and wildlife around the world, especially with large carnivore populations [1–3] . Large predators have extensive home ranges, often traversed by human settlements, so they coexist and share limited resources [2,4]. For this reason, several rural communities currently maintain this conflict with large carnivores, mainly related to livestock predation [5].

In Ecuador, conflicts have been reported since 2002, [6] increasing in recent years, threatening the large carnivores survival [3,4] considered as endangered species, such as the Andean bear (Tremarctos ornatus), the jaguar (Panthera onca), or vulnerable state such as the puma (Puma concolor) [7,8]. Despite that several case studies have been published on human-carnivores conflict in the Andes region, the Ecuadorian Amazon still remain understudied on the distribution ranges of carnivores and the overlapping with managed pastures for livestock [9]. Predation on livestock can result in significant economic losses for livestock producers and even weakens local support for conservation, leading in many cases to jaguar deaths [10–12].

Predation risk models were originally developed to quantify the ecological interactions between predators and their natural prey [3]. The data used is specific to sites where carnivores successfully kill livestock. Collecting this information reveals associations between these predator-prey encounters and landscape attributes that can be quantified and mapped [3,13]. Since predation risk models are determined from locally associated spatial characteristics, they allow us to manage the territory to propose preventive strategies and solutions [3].

The magnitude of the conflict between jaguars and humans has not been enough studied [9,10,14]. Until 2016, the Wildlife Conservation Society (WCS) – Ecuador Program informally reported in a decade several unpublished cases of conflicts that originated from the attacks on one or more domestic animals among calves, donkeys, dogs, pigs and poultry [15]. On the other hand, in the Sumaco Biosphere Reserve (SBR; north-eastern Ecuador), the entity in charge of collecting information on human-jaguar conflict events are the Sumaco Napo Galeras National Park (SNGNP), which has also recorded several unpublished attacks between 2018 and September 2021. Applying the spatial

risk model to jaguar-livestock interactions will reveal locations and habitat characteristics associated with areas of successful jaguar attacks.
In this context, we aimed to:

1. Generate a predation-risk model based on anthropogenic, landscape, environmental and livestock management variables associated with the attacks recorded in the Sumaco Biosphere Reserve and,

2. Evaluate jaguar presence through direct and indirect occurrence records among the different risk-classes for livestock predation in the Sumaco Biosphere Reserve.

MATERIALS AND METHODS

Study area

The study area is the Sumaco Biosphere Reserve (SBR), located in the north-eastern foothills of the Andes mountains, including the plains of the sub-Andean and Amazonian foothills (00º34'18'S – 77º29'36''W). The SBR have a total surface of ~9319.30 km^2 between the eastern Napo province and western limits of Orellana province where the Sumaco Napo-Galeras National Park (SNGNP) is the core zone of this conservation area [16] as is shown in Figure 1.

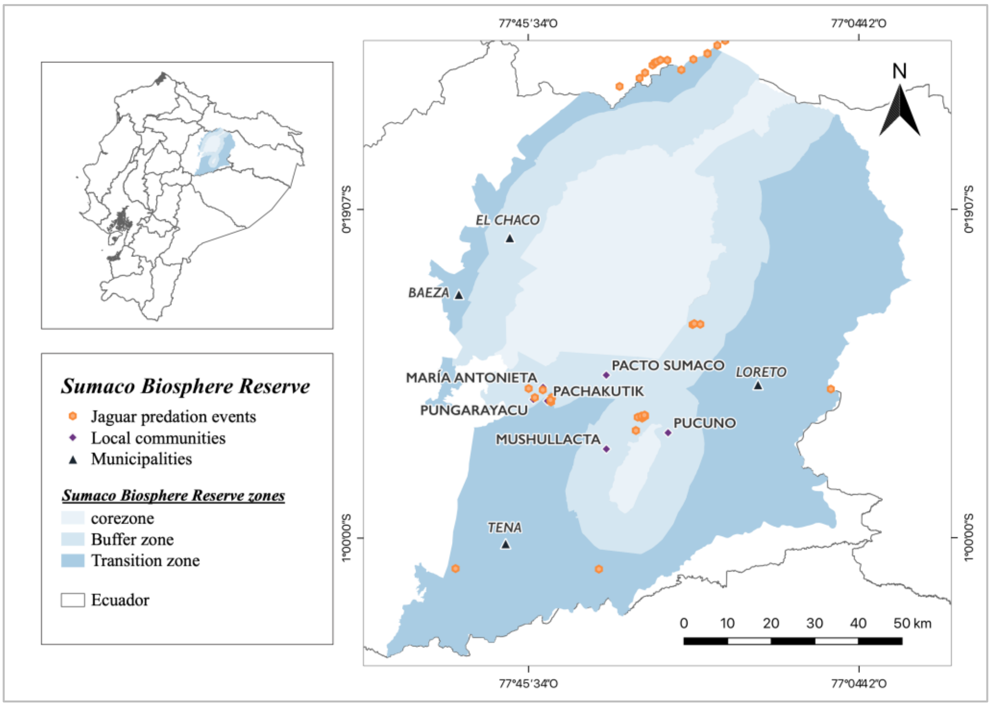

Figure 1. Location of the Sumaco Biosphere Reserve.

The SNGNP was established in 1994 and designed as a Biosphere Reserve (SBR) by UNESCO in 2000 as one of the most outstanding wild areas of the country by its physical, biological and cultural characteristics around the Sumaco, Pan de Azucar and Cerro Negro volcanos. The climatic variation goes from 14ºC to 24ºC, which defines the altitudinal levels as alpine, montane, low montane, foothill and tropical in unique ecosystems as foothill evergreen forest of Galeras, low montane evergreen forest of Galeras, and Grassy and bushy evergreen paramo of Sumaco Volcano [17]. Precipitations are between the 4000 mm to 6000 mm in the lowlands and increase from West to East through the Amazonian plains [18].

SBR vegetation coverage has seven vegetation formations with approximately 6000 species of vascular plants and a great faunistic richness due to the variety of altitudinal levels, ecological niches and habitats of the humid Amazonian tropic. The core zone mainly includes primary forest while the buffer zone contains a matrix of representative patches examples of the country's tropical Andean and Amazonian rainforest ecosystem transitions [19]. Several productive activities are developed in the buffer and transition zones like wood extraction, managed pastures for cattle raising, agricultural production of coffee (*Coffea canephora*), cocoa (*Theobroma cacao*), naranjilla (*Solanum quitoense*) and guayusa (*Ilex guayusa*) along the surroundings of the Hollin-Loreto highway [16,18,19].

Predation events

The predation records were collected by four methods: 1) human-jaguar conflicts reported by SNGNP between 2018-2021, 2) unpublished databases from Wildlife Conservation Society (WCS), 3) published scientific literature, and 4) surveys to local communities (Pungarayacu, Maria Antonietta, Pachakutik, Mushullacta, Pacto Sumaco and Pucuno) located in the buffer and transition zones of the SBR between August and October 2021. After collating the data, a database was made with each predation event including date, coordinates, location, number of murdered animals, and the source of the reported attack. In the final database we had several cases where independent records had the same coordinates but recorded on different years, so we proceeded to deleted the oldest ones to avoid model overfitting (Table 1).

Table 1. Predation data used for the risk model

Source	Records (#)	Year of collected data
Human-jaguar conflict reports (SNGNP)	14	2018 - 2021
Unpublished databases		
Wildlife Conservation Society (WCS)	3	2015
Scientific literature		
Master's thesis	15	2013
Surveys to local communities	7	2021

Environmental data

From other studies of jaguar predation-risk models [1,3,5,20] we selected a set of environmental variables that would identify the areas with higher livestock predation risk. The data layers were separated into continuous and categorical data. The continuous data consisted in: *altitude* [21], *slope*, *distance to water bodies*, *distance to roads*, *distance to protected areas*, *distance to settlements*, *human population density* and *cattle density* (Table 2). Water bodies, roads and settlement layers were obtained from the Geoportal of the Instituto Geográfico Militar – IGM [22]. The protected areas layer was obtained from the Ministry of Environment, Water and Ecological Transition (MAATE). Furthermore, *slope* was extracted from a Digital Elevation Model (DEM) of 30-m resolution and distance layers were created from water bodies, roads, settlements and protected areas layers using the GDAL (Geospatial Data Abstraction Library) and SAGA

(System for Automated Geoscientific Analyses) tools in QGIS v.3.22 software [23]. For the creation of *human population density* variable, the information was obtained from of the last national population census in Ecuador [24]. The information for *cattle density* variable was obtained from surveys by producers uploaded in the Geoportal del Agro Ecuatoriano by the Ministry of Agriculture and Livestock [25].

The categorical data consisted in: *Land cover* (1. Water, 2. Trees, 3. Grass, 4. Flooded Vegetation, 5. Crops, 6. Scrub/shrub, 7. Built area, 8. Bare ground, 9. Snow/ice and 10. Clouds), obtained from a global land use/cover model from ESA Sentinel-2 imagery [26]. All the environmental layers were processed in raster format with a spatial resolution of 30-m, in a square figure that contained the polygon of the SBR. With the resulting raster layer, we made a clip of the SBR extent for the interpretation of the risk-map. Additionally, the variables were analysed through a Pearson's correlation index because the result of the Maxent model did not demonstrated interference with highly correlated variables (r < 0.7 or r < - 0.7) [27]. Even though some variables were correlated, we used all of them in the modelling process because we detected that correlation depended on the topography and human-environment interaction of the study area including important information to the predation-risk model (Supplementary material. **Appendix A**).

Table 2. Environmental variables used for the model of livestock predation risk surface

Name	Year	Source
Altitude	2007	The Shuttle Radar Topography Mission
Slope		
Land cover	2020	Esri Inc.
Protected areas	2020	Ministerio del Ambiente y Agua
Roads	2013	Instituto Geográfico Militar
Settlements	2013	Instituto Geográfico Militar
Water bodies	2013	Instituto Geográfico Militar
Human population density	2010	Instituto Nacional de Estadística y Censo
Cattle population density	2014	Sistema de Información Pública Agropecuaria

Modeling the risk of livestock predation

To predict the risk area of livestock predation by jaguars in the SBR we executed a Maximum Entropy Analysis employing Maxent v.3.3.3 software [28]. We used the area under the curve of the receiver operating characteristics (ROC) curve [29]. The AUC used by Maxent is a modified version for classifying presence versus background points. The performance of the model is classified into five classes according to the value of AUC: 1) fail model (AUC<0.5), 2) poor model ($0.5 \leq AUC < 0.7$), 3) fair model ($0.7 \leq AUC < 0.8$), 4) good model ($0.8 \leq AUC < 0.9$), and 5) excellent model ($0.9 \leq AUC < 1$) [27,30,31].

The advantage for using Maxent algorithm, is the possibility of including continuous and categorical data in the environmental variables, and performing a jackknife analysis to determinate the most important variables by estimating the contribution percentage for the model performance [5,28]. Also, it can run with small samples sizes of records that have relatively widespread geographic distributions, with useful results based on less than 25 occurrences [1,29,32]. We selected the K-Fold cross-validation method with five replicates where randomly the data was divided in 25% of records in training data and 75% in validation data.

The model was built with default values for convergence threshold (10^{-5}), maximum iterations (500), a regularization multiplier of 1, and 10000 background points [29]. Moreover, with the Jackknife test we evaluated the significant environmental predictors with the contribution of the environmental variables and the loss in regularized training gain when each variable was sequentially omitted and the gain when each variable was used alone in the predation-risk model. Furthermore, we generated the responses curves that gave additional information for the most important variables in the model, showing how each environmental variable affects the Maxent prediction [33].

The logistic output was selected so the risk map can be interpreted as a continuous probability of jaguar attacks with values from 0 to 1 [5,34]. Nevertheless, areas with value 1 of probability are not possible to emerge, so we reclassified and divided the risk map into four risk-classes: (1) without risk (<=0,1875), (2) low-risk (0,1875 – 0,3750), (3) medium-risk (0,3750 – 0,5625) and (4) high-risk (>0,5625) [31,35].

Jaguar presence assessment

We incorporated a pilot assessment to evaluate jaguar's presence in the resulting predicted area of the risk map. We selected five sites with different risk-classes to verify jaguar's presence in a short period. The jaguar is an elusive species and to get evidence of its presence we used trap cameras installed in transects of 2.5 km and indirect registration of the predator's presence (footprints, scats and burrows)[36]. For the installation of the trap camera stations, the sites were selected in conjunction with the park rangers, in monitoring trails stablished in the SNGNP, to facilitate that the park rangers can go and verify the installed cameras and their state. We installed simple trap camera stations in each site with 500 m distance between each other and the cameras were placed at a height of 0.5 to 0.75 m from the ground to maximize the capture probability [37,38]. Trap camera stations were left in the forest for a period of 75 days x 20 trap cameras, giving us 1500 trap/night sampling effort.

RESULTS

Predation-risk Model

We used 39 records of jaguar-attack events in the SBR, to develop the model (Table 1). A total of 18 records occurred in the buffer zone and 21 in the transition zone. We selected the average result of five model runs because the results of the same livestock predation-risk areas slightly varied each time. The average test AUC of the model after 5 replicates was 0.953 and the mean standard deviation is 0.029 (Figure 2). The AUC values of all models have an excellent performance in the training data, ranging from 0.979 to 0.987 while the test data ranging from 0.872 to 0.987 (Supplementary material. **Appendix B**).

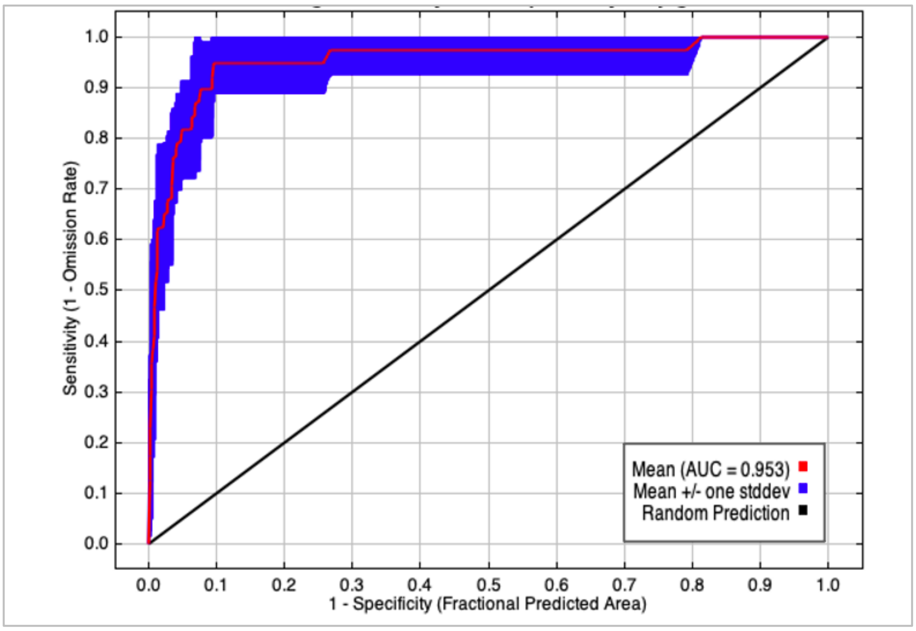

Figure 2. Receiver operating characteristic (ROC) curve and average AUC for 5 Maxent runs across models (the red curve shows the mean of AUC and the blue margins indicated the mean of ± one standard deviation of the predation-risk model, and the black line shows the random prediction calculated in 5 replicates respectively)

The jackknife analysis revealed that the most important environmental variable that contributed to the model building was *Distance to roads* with 41.7% (Figure 3). Other relevant variables were *Distance to protected areas* (20.8%), *Altitude* (15.3%), *Land cover* (9.9%), *Human population density* (5.6%), *Slope* (2.2%), *Distance to water bodies* (2.2%), *Distance to settlements* (2.0%), and finally *Cattle population density* (0.3%).

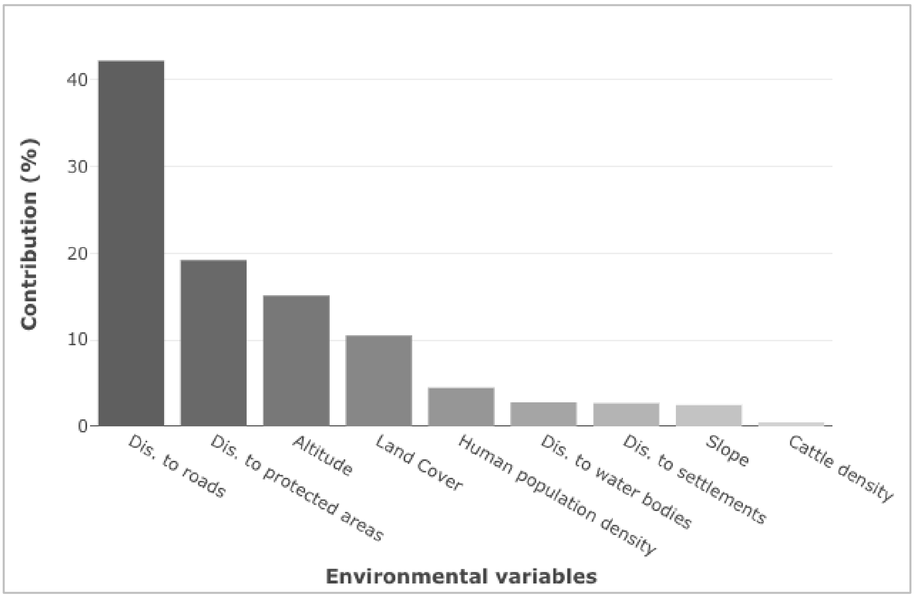

Figure 3. The estimates of percent contribution for 5 maxent runs of the environmental variables to the predation-risk model

The jackknife test of regularized training gain is shown in a descending order by its importance to the contribution of the predation-risk model (Figure 4). The environmental variable with the highest gain when is used in isolation is *Distance to roads*, which therefore appears to have the most useful information by itself, like *Distance to protected areas* and *Altitude*, which are the second and third variables that have significant contribution in the model performance. The environmental variable that decreases the gain the most when it is omitted is also *Distance to roads*, which therefore appears to have the most information that isn't present in the other variables. On the other hand, *Cattle density* did not obtained gain and when omitted in the test, their regularized training gain was similar to the average value which means it does not bring useful information for the predation-risk model. The shown values are the average over replicate runs (Supplementary material. **Appendix C)**.

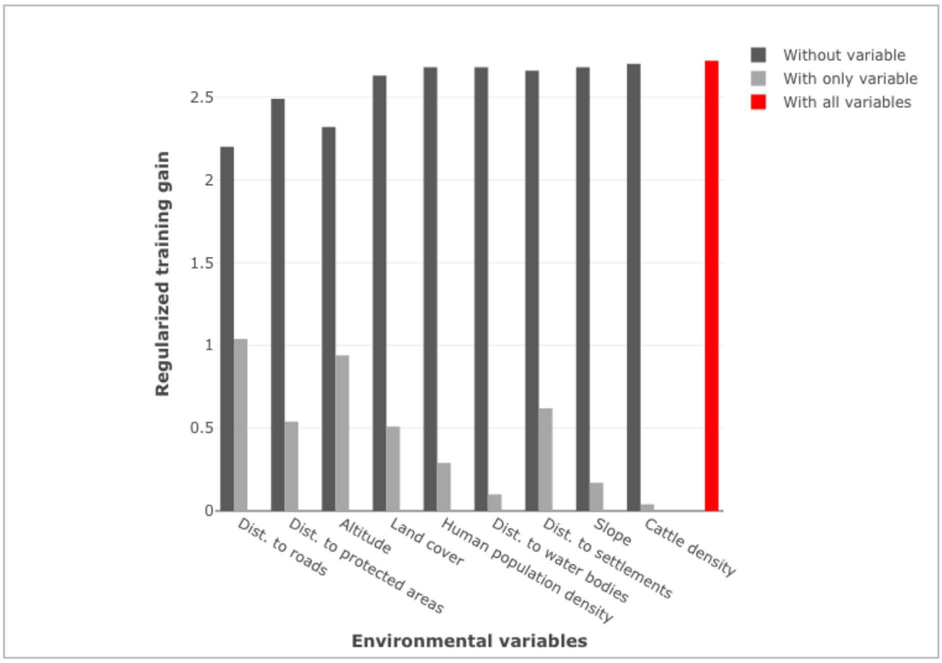

Figure 4. Jackknife test of regularized training gain for 5 maxent runs of variable importance of the predation-risk model variables

The response curves showed how the predicted probability of jaguar predation change as each environmental variable is varied, keeping all other environmental variables at their average sample value (Figure 5). Observing these, we found out when nearest the *Distance to roads* and *Distance to protected areas* the predicted probability of livestock predation will increase. In *Altitude,* the probability will increase until it reaches 1000 m a.s.l. to slowly approach zero at 2700 m a. l. s. Response histogram showed when *Land cover* consisted in built area and scrub/shrub an 81% and 57% of probability of predation events, respectively. In spite of *cattle density* being the least relevant variable for the model, it indicates that the probability of jaguar predation increases as the cattle density reach the maximum value on this variable.

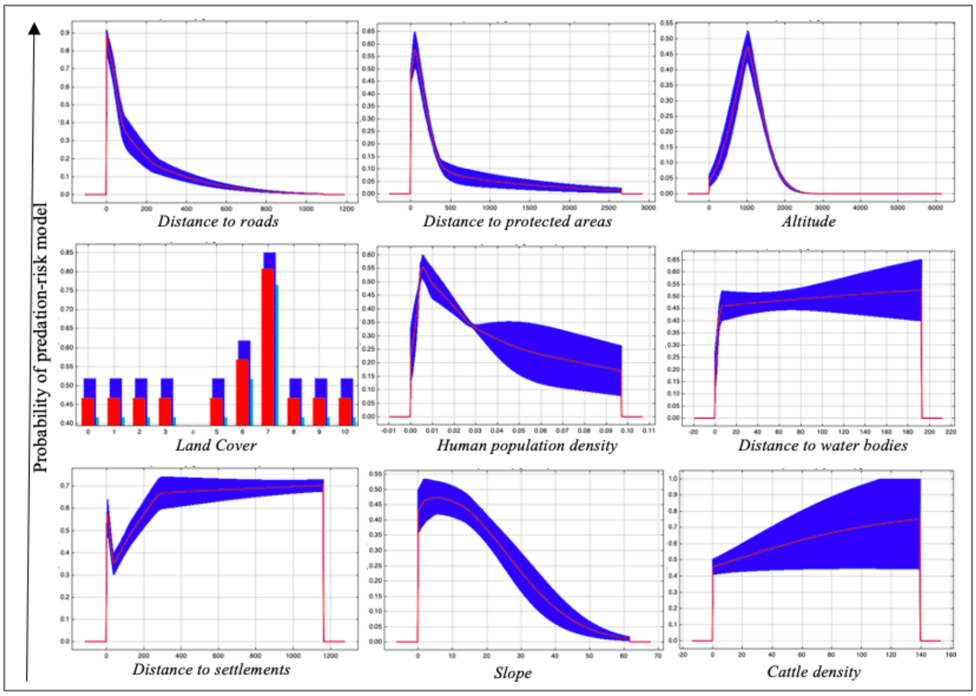

Figure 5. Mean response curves for the continuous variables and histogram for the categorical variable of the predation-risk model for 5 Maxent runs across models (the red line is the mean response and the blue margins indicated the mean ± one standard deviation). Land cover variable categories: 1. Water, 2. Trees, 3. Grass, 4. Flooded Vegetation, 5. Crops, 6. Scrub/shrub, 7. Built area, 8. Bare ground, 9. Snow/ice and 10. Clouds (Jackknife test of regularized training gain for 5 maxent runs of Land cover; red bar is the gain with all the categories, the blue bar is the gain with only the category and the light-blue bar is the gain without the category)

The model of livestock predation-risk surface indicated that 1.04% of the study area was categorized by high-risk (class 4) within 103.69 km^2 between the Buffer zone and Transition zone, 66.30 km^2 and 37.39 km^2, respectively (Table 3). Furthermore, the 1.38% of the study area has medium-risk (class 3) conformed by 137.49 km^2 distributed in core zone (0.37 km^2), buffer zone (81.12 km^2) and transition zone (56.00 km^2). Low-risk (class 2) and No-risk (class 1) areas were covered with 418.90 km^2 (4.21 %) and 9301.72 km^2 (93.37 %), respectively.

Table 3. Reclassification of risk classes and areas with continuous probability from the risk-model. Area (km^2) and relative Area (%): Sumaco Biosphere Reserve (SBR), SBR core zone (CZ), SBR buffer zone (BZ) and SBR transition zone (TZ).

Classes	Continuous probability	Area (km²) SBR	CZ	BZ	TZ	Area (%) SBR	CZ	BZ	TZ
1 (Not-risk)	≤ 0,1875	9301.72	2045.87	2641.12	4614.73	93.37	20.54	26.51	46.32
2 (Low-risk)	0,1875 – 0,3750	418.90	12.33	230.68	175.89	4.21	0.12	2.32	1.77
3 (Medium-risk)	0,3750 – 0,5625	137.49	0.37	81.12	56.00	1.38	0.01	0.81	0.56
4 (High-risk)	> 0,5625	103.69	0	66.30	37.39	1.04	0.00	0.67	0.37

Besides that, the risk-map does not reveal high-risk areas in the core zone, medium and low risk areas were predicted inside the SNGNP, especially in the south-eastern part of the protected area and inside the Cordillera Galeras (Figure 6). On the other hand, the low, medium and high-risk categories reach more predicted areas in the Buffer zone instead the Transition zone (Supplementary material. **Appendix E)**.

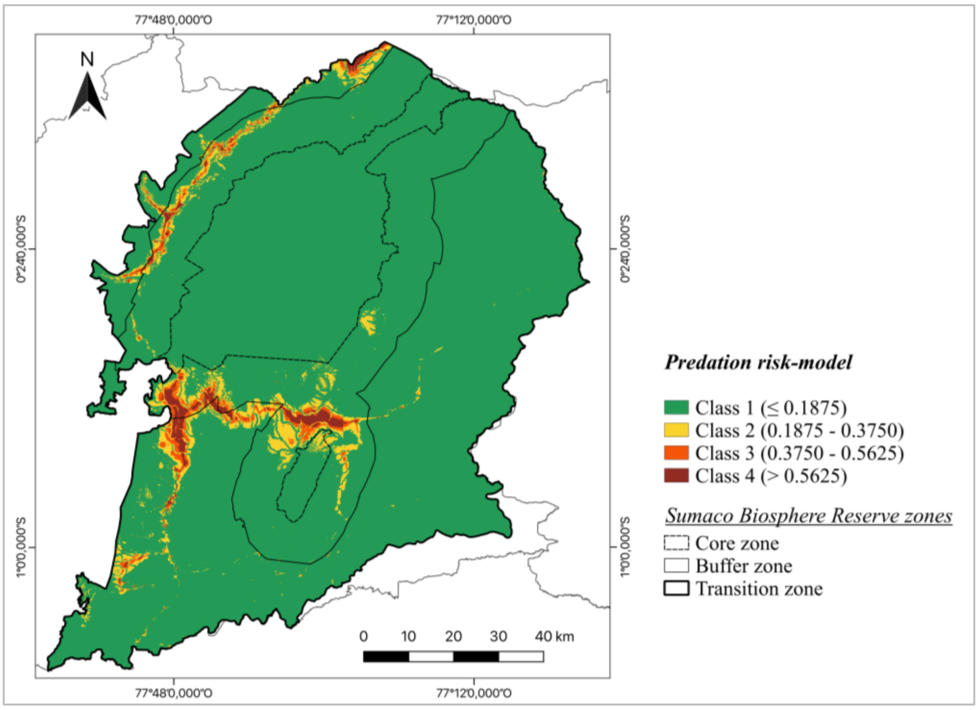

Figure 6. Predation risk-map of jaguar in the Sumaco Biosphere Reserve derived from 5 Maxent runs across models and reclassified into four probability classes

Jaguar presence assessment

According to the model, and the accessibility, five risk-areas were selected to located the trap camera stations for the pilot assessment around the Buffer zone (Figure 7). Four camera traps were installed in Pungarayaku, considered high-risk class (>0,5625), with a sampling effort of 316 traps/night; five cameras in Pucuno, with a sampling effort of 380 traps/night, and four cameras in Mushullacta with 225 trap/night, both considered low-risk class (0,1875 – 0,3750). Finally, five cameras were installed in Sumaco volcano, with 300 traps/night, and two cameras in Pacto Sumaco with 120 traps/night, both considered without risk class (0,1875 – 0,3750). In Mushullacta site, the trap camera station was removed because one trap camera was stolen. On the other hand, the installation of trap camera stations in the Sumaco volcano and Pacto Sumaco sites were delayed because of the COVID19 restrictions and the authorization to mobilize to the selected sites (Supplementary material. **Appendix F**).

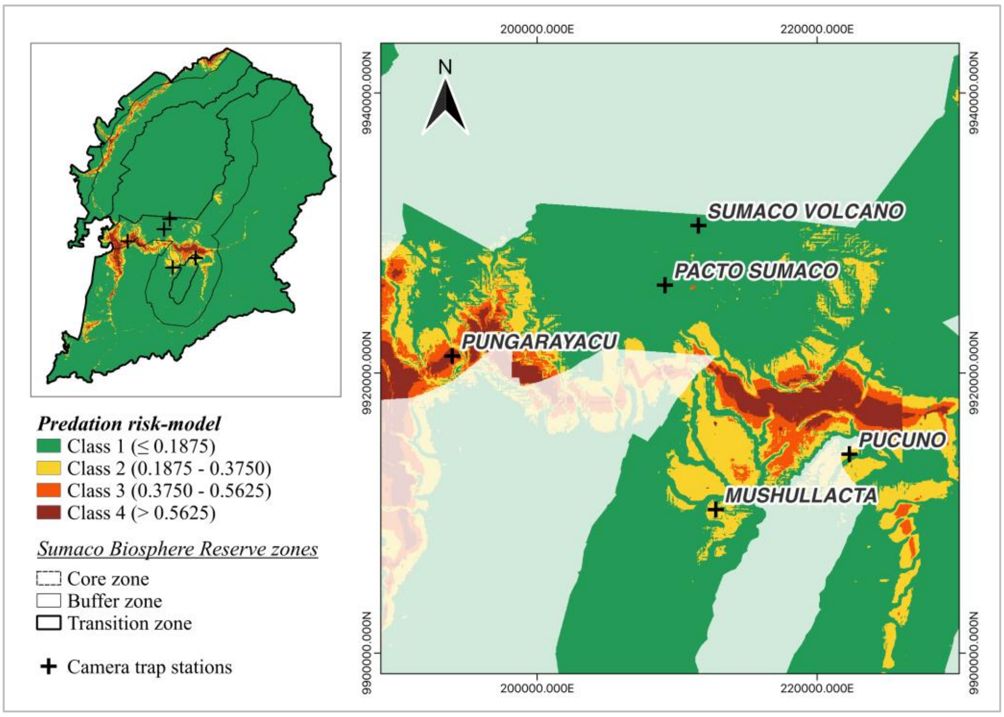

Figure 7. Trap camera stations installed inside the buffer zone of the Sumaco Biosphere Reserve.

We obtained photographic records in two different risk classes' areas (Table 4). The first set of photographs was recorded in Pungarayacu station, the high-risk class, where also SNGNP human-jaguar conflict team reported an attack event during the collection of the predation data period. The second record was in Pucuno station (one if the low-risk class sites). Through indirect observation, we obtained footprints in the three risk classes (Sumaco volcano, Pucuno, and Pungarayacu) and one burrow in the high-risk class site (Table 4).

Table 4. Indirect records from the trap camera stations installed in the different risk classes on the SBR

Risk Classes – probability of risk attack (%)	Camera trap sites	Indirect records (#)		
		Photographs	Footprints	Burrows
Class 1 (≤ 0.1875)	PACTO SUMACO	0	0	0
Class 1 (≤ 0.1875)	SUMACO VOLCAN	0	5	0
Class 2 (0.1875 – 0.3750)	PUCUNO	1	2	0
Class 2 (0.1875 – 0.3750)	MUSHULLACTA	0	0	0
Class 4 (0.1875 – 0.3750)	PUNGARAYACU	1	1	1

DISCUSSION

This is the first time a predation-risk model is done in Ecuador and in the Andean-Amazon transition zone, making it an important tool for ecosystem management in the country and in the entire region. The statistical validation criteria indicate we acquired an accurate risk-model compared to other spatial models of livestock predation by jaguars [1,5,20]. *Distance to roads* was the most important variable in the contribution of the model, whereas livestock is available to predator as an easily accessible food source by the fragmentation generated by human settlements and roads which are located near to livestock herding areas [5]. On the other hand, *distance to roads* was correlated with *slope*, the Sumaco Napo-Galeras National Park (core zone) is the unique National Park in the country that a highway (Hollín-Loreto-Coca highway) crosses through the middle of the protected area. It was built depending on the slope given that it facilitates connections between the Andean and Amazonian regions in the north of the country passing through 257 m a. l. s. to 1369 m a. l. s. Contrasting with the TransAmazonic highway in Brazil with homogenous slope and elevation given that is located in Amazonian plains [20].

Our work identified *Distance to protected areas* as the second most important variable that contributed to the model and its response curve shows probability predation increases as nearest is the distance from the protected area. This is concordant with a previous study of predation risk index for jaguars in Costa Rica, demonstrated that livestock near to these areas are more likely to have predation events based in national parks protected remaining populations of wild cats and its suitable habitat, as SNGNP does with the jaguar [20,39,40]. This variable was correlated with *Land cover* by the fact that the Core zone is the National Park and it has a category of high restriction, protection and conservation [41].

In the *Altitude* variable (third one most important), the response curve also indicate probability of jaguar attacks increases at 1000 m a.s.l., that contrast with our database where we obtained 21 of the 39-attack records between the 1000 – 1648 m a.s.l. The estimated altitudinal range of the jaguar is located between 600m – 1500m for the premontane forests of Ecuador [15], but new records are located towards the Andean montane forest at 2300 and 2600 m a.s.l. [42], strengthening our hypothesis that the jaguar covers much more area inside the SBR than previously thought in highlands. In this context, we detected an increase on the number of jaguar attacks when managed pastures for livestock are located in high-risk areas, especially if they are in the buffer and transition zones from 240 and 3295 m a.s.l., respectively.

Land cover shows high probability of predation events in two land-use categories, (6) Built area and (7) Scrub/shrub. A jaguar predation jaguar model in Mexico indicates that the most of predation events takes place around human settlements by the fact that domestic animals are close to their suitable habitat and favour the domestic animal's predation by the jaguars opportunistic foraging behaviour [1,5,43]. On the other hand, predation sites in Mexico are characterized by having dense vegetation, especially oaks, shrubs, xeric bushes and mesquites [44]. Additionally, it is reported that montane forests, lowland evergreen forest, dry deciduous forests, mangrove forests, arid scrubs and swampy grasslands are occupied by jaguar around their geographical distribution [45,46].

Surprisingly, the *cattle density* was the variable that contributed the least to the predation-risk model, in contrast to other reviewed risk-models in Mexico [1] and Brazil [5,20], where this variable had a positive effect and was the most important variable to increase attack probability. Despite its contribution, the response curve assessed in our study indicates an increase of the risk probability when the *cattle density* increases (Figure 4). Literature indicates Ecuador is located at the highest level of potential livestock predation worldwide (carnivores present and >300 livestock/km^2) [3]. We hypothesize that *cattle density* variable in our predation-risk model does not have a great contribution because the land conversion is particularly recent (since 1985) in the SBR [19]. Moreover, *distance to roads* locates the cattle at a geographical risk position (livestock located near to roads which are close to dense forests) instead of its density [47] (Supplementary material. **Appendix G)**.

The risk-model indicates the different predation-risk classes for jaguars in the Sumaco Biosphere Reserve, in spite of the limited knowledge of the geographic distributional range inside the reserve. According to *The IUCN Red List of Threatened Species* the geographical range of the jaguar inside the SBR is 5418.38 km^2 but this model was last assessed in 2016 [48]. Moreover, some of the attack events were recorded outside the geographical range proposed, so we can infer the possibly that the jaguar lives within the entire study area. Large carnivores are more susceptible to human disturbances that can alter the relationship between population density and environmental suitability or ecological niches [49]. Moreover, felids highly depend of prey's availability and areas where it decreases, their population size will either decrease, even if climatic conditions are favorable [49,50]. It is required an actualized occupational distribution model for a better management of the species inside the study area.

We expected to find more low, medium and high-risk predicted areas in the transition zone because it is where productive activities are allowed to be promoted and developed. The UNESCO zonation of Biosphere Reserves, buffer zones are identified as fulfilling buffering functions to the core area where only activities compatible with the conservation objective can take place [51]. According to the National System of Protected Areas of Ecuador (SNAP), protected areas with a National Park management category have to maintain their environments with low alteration, a minimum human presence and with a high use restriction level [41]. As we can see, the buffer zone is where low, medium and high-risk areas reach more predicted area despite the fact that 18 of the 39 attacks were recorded in this zone.

Our predation risk-model gave us a resulting model with a different behaviour comparing with the spatial predation models in Mexico and Brazil, especially by the topography and human-environment interaction inside the SBR. Although, an increase in deforestation mainly occurred during the period 1995-200 because of agricultural expansion supported by public and private institutions [19] and it has had a slow development through time, we can still find primary forest patches. Some of the correlated variables as *Human* *population density-distance to water bodies* shows the reality of local communities that do not have potable water and to access to this resource they collect water from nearby rivers moving themselves and the cattle constantly. This is one reason why all the variables were selected for the model performance, trying to keep the actual situation of the SBR socio-productive reality instead of just omitting them for a good fit.

Despite the fact that Pucuno trap camera station was installed in a low-risk area, it is near the Core zone where the model predicted low-risk areas. Actually, in Pucuno community a new road is under construction, which in the near future will intensify productive activities like wood extraction, cattle ranching and wildlife hunting (hunting evidence obtained during the rapid pilot assessment). Although we did not record cattle ranches in this community, the opening of a new road increases the possibility of cattle introduction in the area and as we predicted in our model, *Distance to roads* was the most relevant variable indicating a highly probable predation risk of predation in the area.

In the jaguar presence assessment around the Buffer zone, we obtained remarkable indirect records of jaguars in a short period through trap cameras, a burrow and several footprints. With less than 300 traps/nights a jaguar was recorded in high-risk class area (Pungarayacu) and also in one of the low-risk class (Pucuno); in both areas we also found jaguar footprints. With this data we can infer that the presence of the jaguar in both areas is representative, compared to the higher effort involved in jaguar detection (1000 traps/nights) according to literature [37,52]. Considering that our objective was not to estimate jaguars' density, we inferred the possibility of presence of at least three different individuals detected in our pilot assessment.

Although the risk-map showed low-risk areas through the north-eastern of the SBR and we found footprints in not-risk classes, we can hypothesize that jaguars' population flow is not interrupted across the Core and Transition zones. In the case of the south-eastern of the SBR, monitoring the Buffer zone is an important immediate task in the entire Biosphere reserve, so we can know how conflict areas can affect jaguar population, home-range, population flows and prey availability. Nevertheless, for an assertive analysis of prey availability in predation areas we recommend to incorporate wildlife occurrences into the model, to know the influence of wild prey density on the frequency of livestock predation events [5].

We faced some limitations related to an outdated distribution of cattle ranches and livestock distribution from the national databases of the Ministry of Agriculture (2014) which could reduce the predictive power of the risk-model. Another possible limitation is that livestock owners may not report attacks inside the core zone given that the activity is forbidden in the protected area, as has been reported in other studies that assess *Felidae* attacks and protected areas [53]. On the other hand, our model predicts a small geographical area at risk at one of the limits of the core zone, where the protected area is closer to the main roads and towns, allowing the jaguar and cattle to range freely between the inexistent borders of the SBR. To tackle this limitation, this study complemented the model with fieldwork assessment using trap cameras (Table 4) and community surveys that corroborated the free movement of the livestock (Supplementary material. **Appendix H-I**) and helped us comprehend the actual anthropogenic pressures inside the SBR. Fortunately, the nature of the ecological modelling allows rerunning it with new data without difficulty, calibrating updated conflict areas across all the zones of the SBR.

Finally, this risk-model proved to be an easy-to-use, cost-effective tool that can be applied to other Biosphere reserves or protected areas in the country, to manage human-large carnivores' conflicts [5,20]. Predation-risk models can help mitigate the conflict as livestock owners can apply preventive non-lethal techniques (night pens, olfactory repellents, livestock carcass removal programs, etc.) to reduce jaguar attacks [3,11,54]. Furthermore, splitting the risk-map into risk-classes can effectively help the managers of the SBR to enhance the coexistence of the jaguar and work with local communities to reduce conflict probabilities and unnecessary jaguar deaths, informing to the people about the risk level that they are exposed to, and how they can prioritize management alternatives.

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ANEXOS

Anexo 1. *Environmental variables analyzed through a Pearson's correlation index (r < 0.7 or r < - 0.7). Grey shaded cells indicates highly correlated variables*

	Altitude	*Slope*	*Human population density*	*Cattle density*	*Distance to roads*	*Distance to water bodies*	*Distance to settlements*	*Distance to protected areas*	*Land cover*
Altitude		0,0014613	0,014737	0,23648	0,31445	0,067477	0,44546	0,011726	0,22086
Slope	0,49809		0,042231	0,8192	0,99424	0,23157	0,10771	0,30086	0,14498
Human population density	-0,3927	-0,33121		0,80881	0,26311	0,93345	0,0023583	1,45E-05	0,0072556
Cattle density	0,19673	-0,038348	-0,040591		0,64413	0,33765	0,55486	0,53575	0,54142
Distance to roads	-0,16763	0,0012123	-0,18617	-0,077409		0,41826	8,34E-05	0,72266	0,20695
Distance to water bodies	0,29977	0,19877	0,014013	-0,15988	-0,13522		0,29886	0,29342	0,48323
Distance to settlements	0,12753	0,26511	-0,4788	0,098859	0,59435	-0,17303		0,66193	0,0044778
Distance to protected areas	-0,4047	-0,17233	0,64109	0,10365	0,05951	-0,17496	0,073284		0,89067
Land cover	-0,20331	-0,24099	0,42862	-0,10222	-0,20944	-0,11726	-0,45108	0,023066	

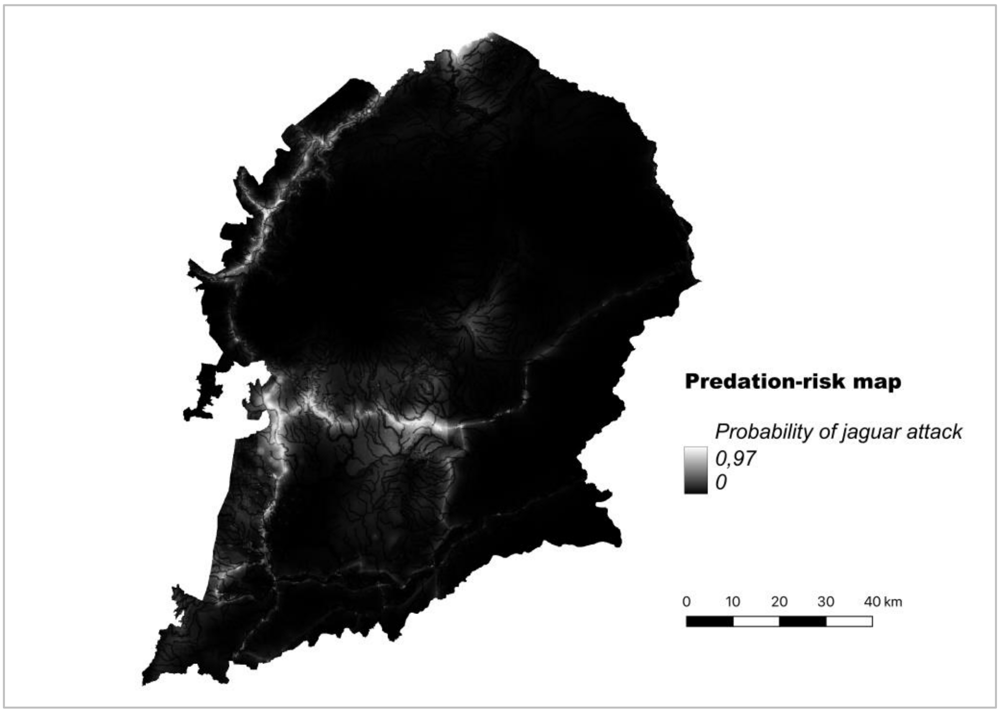
Anexo 2*. Training AUC, Test AUC, AUC Standard deviation values from the 5 replicates of the predation-risk model.*

Model	Training Sample	Test sample	Training AUC	Test AUC	AUC Standard deviation
1	30	8	0,9867	0,8717	0,0908
2	30	8	0,9790	0,9597	0,0300
3	30	8	0,9733	0,9869	0,0070
4	31	7	0,9726	0,9769	0,0080
5	31	7	0,9747	0,9693	0,0111
Average	304	76	0,9773	0,9529	0,0294

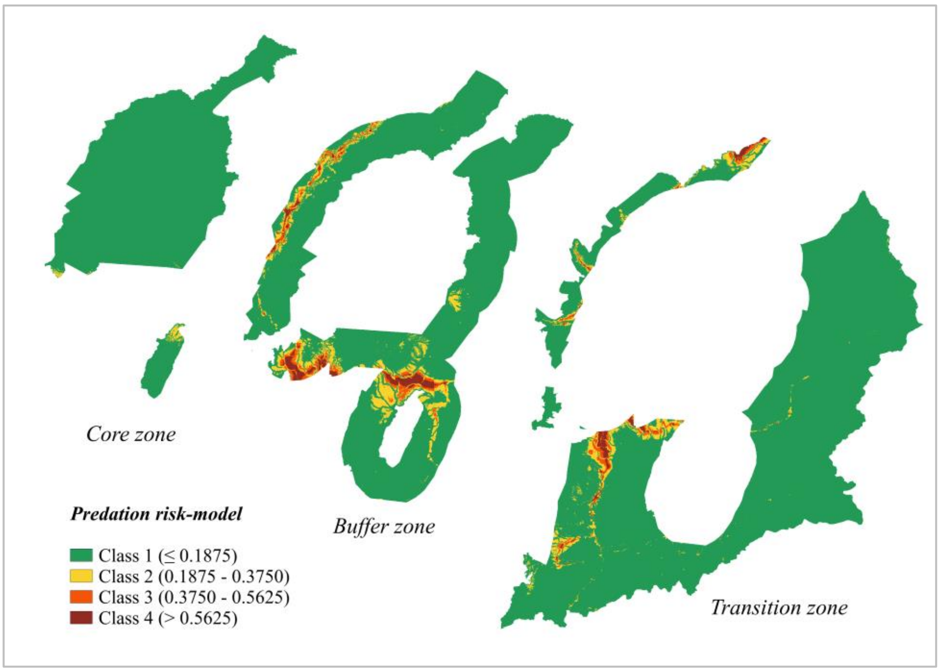
Anexo 3. *Regularized training gain without the variable, with only the variable and with all the variables of regularized training gain from the 5 replicates of the predation-risk model.*

	Regularized training gain		
Environmental variables	***Without the variable***	***With only the variable***	***All the variable***
Distance to roads	2,20	1,40	
Distance to protected areas	2,49	0,54	
Altitude	2,32	0,94	
Land cover	2,63	0,51	
Human population density	2,68	0,29	
Distance to water bodies	2,68	0,10	
Distance to settlements	2,66	0,62	
Slope	2,68	0,17	
Cattle density	2,70	0,04	
Average model			2,72

Anexo 4. *Predation-risk map with continuous probability of jaguar attacks in the Sumaco Biosphere Reserve*



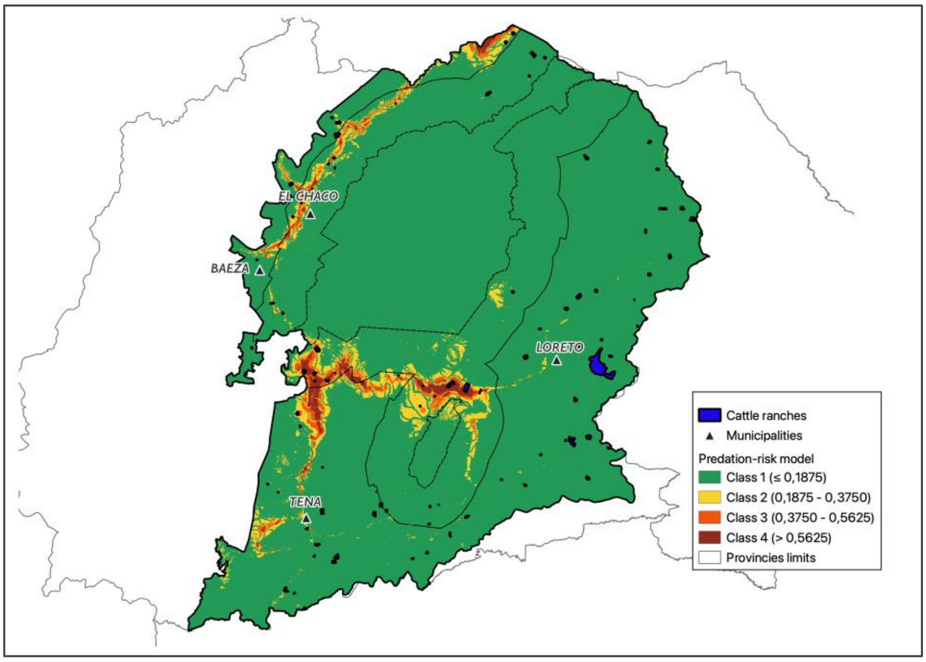
Anexo 5. *Predation-risk map divided in the core, buffer and transition zone with reclassified into four probability classes*



Anexo 6. *Name location where the camera trap stations were installed, each code, state, days installed and trap/night information of each camera trap for the monitoring*

Name location	Trap cameras (CODE)	State	Days installed	Trap/Night
1 - Pungarayaku	PUN01	Operative	79	316
	PUN02	Operative	79	
	PUN03	Operative	79	
	PUN04	Operative	79	
2 - Pucuno	PUC01	Operative	76	380
	PUC02	Operative	76	
	PUC03	Operative	76	
	PUC04	Operative	76	
	PUC05	Operative	76	
3 - Mushullacta	MUSH01.	Stolen Sd Card	75	225
	MUSH02	Stolen camera	75	
	MUSH03	Removed	75	
	MUSH04	Removed	75	
4 - Sumaco Volcano	VOL01	Operative	60	300
	VOL02	Operative	60	
	VOL03	Operative	60	
	VOL04	Operative	60	
	VOL05	Operative	60	
5 - Pacto Sumaco	PAC01	Operative	60	120
	PAC02	Operative	60	

***Anexo 7**. Cattle density shapefile overlapped our predation-risk model*



***Anexo 8.** Cattle recorded pasture freely inside the Pungarayacu site during the Jaguar presence assessment.*

Anexo 9. *Answers obtained from the questions asked during the process of gathering information within the territory through the survey "People-livestock conflict within the Sumaco Biosphere Reserve"; A) Type of grazing. B) What measures did you take to protect your livestock?*