Spatial modelling of Common Chimpanzees (*Pan troglodytes schweinifurthii*) ecological niche in the western part of Rwanda, using Remote Sensing and global environmental data

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Abstract

In tropical mountainous forests of Africa, Chimpanzees as frugivorous primates are among seeds dispersers. Their humanlike face, fingers and behaviour have made them tourist attracting animals and they have become flagship animals of Nyungwe Forest National Park (NNP) located in the south-western part of Rwanda. However, they are facing many threats varying from environmental conditions, such climate change and natural hazards, to man-induced which lead to the fragmentation of their habitat and the reduction of their number. For this reason, IUCN has recognized chimpanzees as endangered species. During this study, data consisting of chimpanzees' location and their preferred diet were collected at three sites: Mayebe in the main Nyungwe Forest National Park, Cyamudongo Forest Fragment and Gishwati forest Reserve that are located in the western and southern parts of the country. Environmental data consisting of temperature and precipitation were downloaded from World Bioclim (Global Climatic Data: http://www.worldclim.org/bioclim).Altitude was derived for a Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). The land cover was derived from Landsat 8 OLI image of the study area. Data were pre-processed in ArcGis 10.2 to ensure that they have the same spatial extent (projection, pixel size and boundaries). Species location data were integrated with environmental variables (temperature, precipitation, altitude and land cover) in MaxEnt Software for habitat suitability analysis. The results of the analysis showed that chimpanzees prefer high altitudes with moderately low temperature and high precipitation, annual and maximum precipitations being the most determinant of chimpanzees' habitat in the study area. In Rwanda, the Western part is suitable ($0.5<p<0.86$) for chimpanzees while the eastern and central parts that are characterized by low altitude, high temperature and low precipitation are less or not suitable at all ($p<0.5$). For nesting and fruits seeking purposes, chimpanzees prefer dense canopy forest which is dominated by giant tree species such as *Ficus sp.*, *Casporea gumifera* and *Musanga leo-errerae.* The suitability of the western part for chimpanzees is due to the fact that climatic variables have favoured food availability and created a safe microclimate. This research confirmed the hypothesis that through Remote Sensing, global environmental data can be used to accurately model chimpanzees' ecological niche in the western part of Rwanda. The current study recommends that efforts for the conservation of chimpanzees in Rwanda should be concentrated in the western part of the country. Special protection measures should be taken for plant species especially *Ficus sp.*, *Casporea gumifera* and *Musanga leo-errerae* that form the highest proportion of diet sources for chimpanzees.

Key words: Spatial modelling, Chimpanzee, ecological niche, Rwanda

***Theme**: Activities dealing with natural and cultural heritage*

I. Introduction

A key issue in ecology and conservation biology is to determine how species are distributed in space. Since extinction risk is associated with range size (Purvis et al., 2000), a significant reduction of a species range often determines change in conservation status and prime conservation actions. Likewise, protected areas usually focus on biodiversity hotspots in order to conserve efficiently as many species as possible (Eklund et al., 2011; Moilanen et al., 2005).

The current study aimed at modelling chimpanzees (*Pan troglodytes schweinfurthii*) habitat in Rwanda by integrating occurrence data and environmental variables consisting mainly of rainfall, temperature, altitude and land use through a computer assisted species distribution model.

1. Rationale of Species Distribution Models (SDMs)

In the nature, animal and plant species are not evenly distributed. This distribution is mostly determined by environmental factors consisting of climatic, topographic anthropogenic and geologic factors (Stevens & Pfeiffer, 2011). At local scale, human activities are driving forces of species distribution through habitat fragmentation, pollution and exploitation. The basis of biodiversity modelling is to integrate different contributing variables in a computer based model to map the probability of occurrence of a given species at local or global scale (Eklund et al., 2011; Stevens & Pfeiffer, 2011).

According to Moilanen et al. (2005) and Eklund et al. (2011), the following are the reasons explaining why we need to model species: (1)Knowledge about the geographical distribution of species is crucial for conservation and spatial planning; (2) Detailed data on species distribution are usually not available and collecting such data is costly and labour intensive; (2) Conservationists have in many cases to rely on predictive models for estimating patterns of species distribution and for making conservation strategies; (3) SDMs provide one of the best ways to overcome sparseness typical of distributional data, by relating them to a set of geographic or environmental predictors.

2. Common Chimpanzees Conservation Status and Ecological Niche

In recent years, thousands of species have declined dramatically, and many populations are close to extinction owing to anthropogenic impacts. The effects of this conservation crisis have been particularly severe in tropical regions, which host 50% of animal species including Chimpanzees (*Pan troglodytes shweinfuthii*) (Gross-Camp & Kaplin, 2005; Plumptre et al., 2007; Plumptre et al., 2002).

Common chimpanzees are 'Endangered 'under a strict application of the IUCN Red List Criteria and are listed in Appendix 1 of CITES. In parts of West Africa, their subpopulations have becomes highly fragmented. Therefore, the two most western sub-species can be readily categorized as endangered, especially given the long generation time of the great apes. The central and eastern sub-species are hunted as bush meat in many areas, although in East Africa hunting remains at a relatively low level(Bergl & Oates, 2007; A. Plumptre et al., 2007).

Despite the threats mentioned above, effective conservation requires range-wide on spatial and temporal trends in apes distribution to inform global policy-making and donor decisions, and to foresee and confront emerging threats, such as habitat destruction, large-scale infrastructure development and resource exploitation projects, as well as increasing poaching pressure and climate change impacts (A. Plumptre et al., 2002; REMA, 2009b). Eventually information generated through species distribution models allows evaluating the effectiveness of ape conservation worldwide.

Figure 1. Adult chimpanzee feeding on fruits

Chimpanzees have optimum environmental conditions for their survival and reproduction. The upper limits of temperatures that chimpanzees can tolerate are less well defined, but 29°C and 10°C are the upper and the lower temperature limits that chimpanzees can tolerate(Gross-Camp & Kaplin, 2005). Under extreme temperature conditions, chimpanzees may become inactive. In the wild environment, chimpanzees spend more time on the ground during warm or dry months, which may serve to effectively maintain optimal body temperature and prevent water loss. The humidity should range between 30-70 % (Gross-Camp & Kaplin, 2005).

3. *Chimpanzees in Rwanda*

Nearly all of Rwanda's chimpanzees are found in the Nyungwe National Park in the south west of the country. This 1,020 km² park includes the 4 km² forest patch of Cyamudongo, where there is a small population of habituated chimpanzees. The only other site with chimpanzees is the Gishwati Forest just south of the Volcanoes National park. Wild Conservation Society and Antioch University New England surveyed Nyungwe and Gishwati in 2004 and 2005, respectively, and estimated 380 chimpanzees in Nyungwe and 10–20 in Gishwati as highlighted by figure 2 (Barakabuye, 2005).

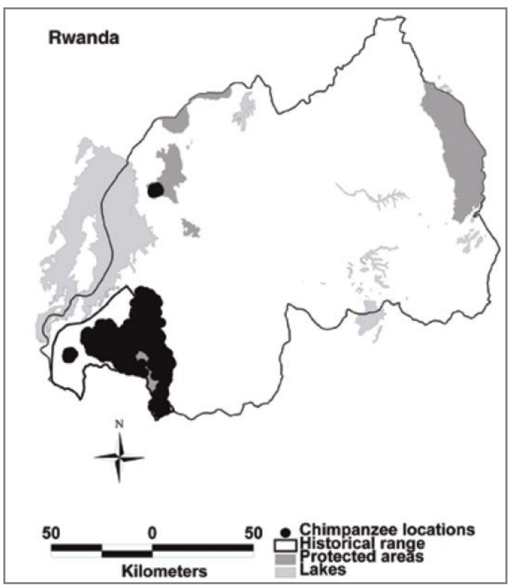

Figure 2. Chimpanzees' distribution in 2004

Nyungwe survey estimated chimpanzee density at eight randomly selected sites across the forest and extrapolated from these to calculate the total population. Preliminary findings from a more robust census in 2009 of 41 transects across the forest indicated that the population size may be lower than the 2004 census, with an estimate of only 306 chimpanzees in Nyungwe. This may be because large areas of the forest were burned in the early 2000s with an estimate of 13% of the forest lost by 2004 (Gross-Camp & Kaplin, 2005; Plumptre et al., 2003).

4. *Species Distribution models (SDMs)*

SDMs stand for different techniques that are used to model the suitability of an area to a defined species (Jane et al., 2011; Phillips et al., 2006). Currently, there is a wide range of SDMs including but not limited to environmental envelopes (BIOCLIM), Genetic Algorithms for Rule- set Prediction (GARP), Ecological Niche Factor analysis (ENFA) (Stevens & Pfeiffer, 2011) and Maximum Entropy (MaxEnt) technique developed by Phillips et al. (2006) that will be used in the current study.

According to Stevens and Pfeiffer (2011), all SDMs models are differentiated in the way of integrating the response variable, selection, weighting and fitness of the individual predictors and the interaction of the variables as well as the format of the output. MaxEnt is a presence-only modeling method, which means that no absence data is needed. This modeling approach does not need species absences data which can be biased especially for animals that are always moving(Stevens & Pfeiffer, 2011).

5. Maximum Entropy (MaxEnt)

MaxEnt uses background data as absence data which can also have an inconvenience of predicting absence instead of presence because a species can be there but not seen during the field work. This method integrates species presence data with ecological factors that determine its habitat through a maximum entropy approach for habitat suitability modeling(Phillips et al., 2006).

II. Methods

1. Study sites

Data were collected in Nyungwe National Park; the Rwanda's largest remaining forest and one of the most biologically important rain forests in Africa. It covers about 1000 km^2, in the southwest of Rwanda between 2°15' – 2°55' S, 29°00'– 29°30' E, with an altitude varying between 1600m and 2950m (Plumptre et al., 2002). It is home to 13 species of primates, 260 species of birds, and more than 260 species of trees and shrubs. Nyungwe represents a key area for rainforest conservation in Central Africa and supports an abundance of plant and animal life. The thirteen species of primates known to inhabit the forest include mainly chimpanzees (*Pan troglodytes schweinfurthii*), owl-faced monkeys (*Cercopithecus hamlyni*), blue monkeys (*Cercopithecus mitis kandti*) and white colobus monkeys (*Colobus angolensis ruwenzorii*) (Gross-Camp & Kaplin, 2005; Plumptre et al., 2002).

Our observations on chimpanzee's daily travel distance were made on the semi-habituated Mayebe group of chimpanzees located approximately two kilometres east of the Uwinka Visitor Center. Observations were also done as well in a small patch forest, called Cyamudongo that covers approximately 4.5 km^2 and is much smaller than the main component of Nyungwe forest. Both forest components are separated by approximately 10 km. Similar to the main component forest, Cyamudongo is home to many endangered and/or endemic species of importance to conservationists and ecologists (Plumptre et al., 2002). It is also a high elevation forest, ranging between 1,500 and 2,100m, with similar rainfall and harvest patterns as the main component Nyungwe forest.

Chimpanzees data were lastly collected in Gishwati Forest Reserve that is located in the Northwestern part of Rwanda, from longitude 29^0 21'40" to 29^0 28'50"East and from latitude 1^0 36' 52"to 1^0 52'17" South. Gishwati Forest Reserve was founded in 1933 (REMA, 2009a). The forest constituted the relic of the ombrophyllous montane forests. Its rich natural flora varying from big trees to shrubs and grass has made Gishwati a habitat of different primates such as chimpanzee (*Pan troglodytes schwenfurthii*), mountain monkey (*Cercopithecus l'hoesti*) and golden monkey (*Cercopithecus mitis kandti*)(Barakabuye, 2005). The effects of natural forest conversion and degradation have lead to the reduction of the area of the forest and the threat, if not the extinction of different flora and fauna species (Uwimana, 2007).

2. Data collection and analysis

During the current study, environmental data were integrated with species occurrence data through computer assisted models (Figure 3). Focal samplings (Bates & Byrne, 2009) were carried out on individuals that were easy to recognize by their shape, color, size, sex, and other physical characteristics. During each focal sampling period, the target individual was followed continuously through the forest as long as possible, optimally until the night nest site. The groups were localized before they left their night nest. If the target animal was lost during a focal sample, every attempt was made to regain contact. In general, males occurred to be less disturbed during focal samples than females, and thus were easier to follow(Romero-Calcerrada & Luque, 2006; Secretariat of the Convention on Biological Diversity, 2010; Tsiaras & Domakinis, 2013; Twinomugisha & Chapman, 2007).

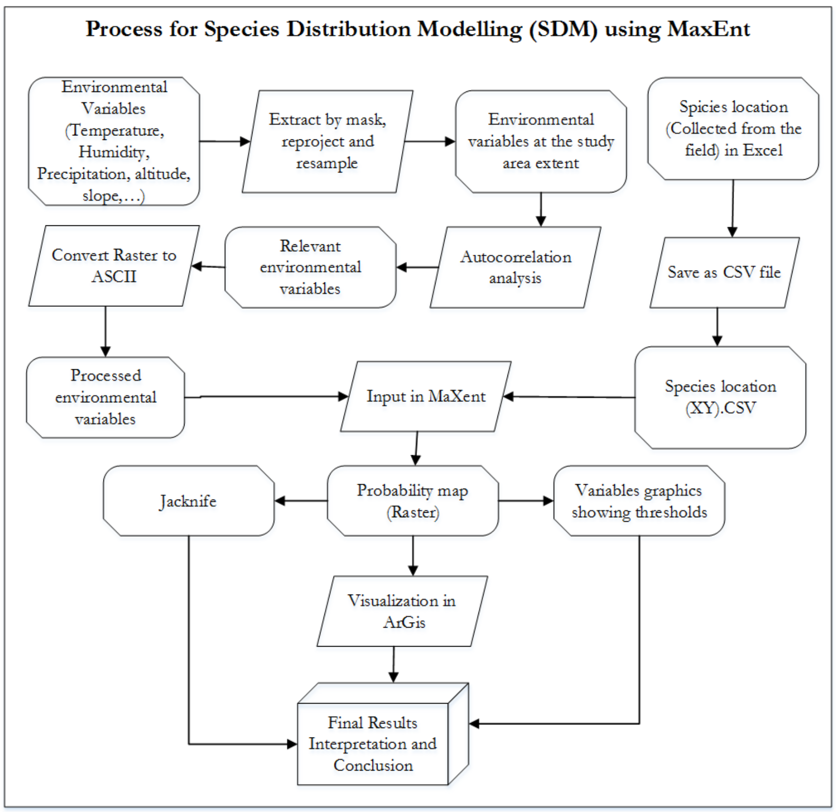

Figure 3. Steps for chimpanzees' home range modelling using MaxEnt model

During a focal sample, we recorded the location of the subject every 15 minutes during travel periods, using a hand-held Garmin XL GPS device with an estimated positional error (EPE) on of less than 9m. (Bates and Byrne, 2009). In areas where the forest cover was too thick to maintain reliable GPS coverage, we moved to a more open location nearby to obtain the GPS reading (Plumptre et al., 2007).

Environmental variables consisting of precipitation and temperature were downloaded from World Bioclim (Table 1) . The altitude was derived from a Shuttle Radar Topography Mission (SRTM) 30 meters resolution Digital Elevation Model (DEM) of the study area. The land cover of the study area was produced through a maximum likelihood classification of the Landsat 8 Operational Land Imager (Landsat 8 OLI) images of the study area.

After performing a collenearity test, correlated variables (r>0.5) were removed from the model as shown in Table 1 (Kayijamahe, 2008). The remaining ones were later converted into ASCII grid format and chimpanzee's GPS location in CSV file in order to be integrated in MaxEnt as summarized in figure 3 (Kayijamahe, 2008; Phillips et al., 2006; Stevens & Pfeiffer, 2011). MaxEnt model was used. For training the model we used only 75% of the observation records while the other 25% of observation records were used to test the model performance. The model was evaluated using the receiver operating characteristic Curve (ROC), which is a graphical plot of the true positive rate (or sensitivity or 1- Omission rate) versus the fraction of the total study area predicted present (or 1 − specificity) (Kayijamahe, 2008; Phillips et al., 2006; Stevens & Pfeiffer, 2011).

The output format was later imported in ArcGIS10.2 Software to produce the Chimpanzee distribution probability map. The response curve and Jackknife test of different environmental variables were carried out and analyzed (Jane et al., 2011; Stevens & Pfeiffer, 2011).

Table 1. Input environmental data

Variable	**Code in the model**	**Retained after collinearity analysis**
BIO1 = Annual Mean Temperature	temp_mean	Yes
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))	temp_mdr	No
BIO3 = Isothermality (BIO2/BIO7) (* 100)	temp_iso	No
BIO4 = Temperature Seasonality (standard deviation *100)	temp_seas	No
BIO5 = Max Temperature of Warmest Month	temp_max	Yes
BIO6 = Min Temperature of Coldest Month	temp_min	Yes
BIO7 = Temperature Annual Range (BIO5-BIO6)	temp_rang	No
BIO8 = Mean Temperature of Wettest Quarter	temp_wetq	No
BIO9 = Mean Temperature of Driest Quarter	tem_drq	No
BIO10 = Mean Temperature of Warmest Quarter	temp_waq	No
BIO11 = Mean Temperature of Coldest Quarter	temp _coq	No
BIO12 = Annual Precipitation	prec_ann	Yes
BIO13 = Precipitation of Wettest Month	prec_max	Yes
BIO14 = Precipitation of Driest Month	prec_min	Yes
BIO15 = Precipitation Seasonality (Coefficient of Variation)	prec_seas	No
BIO16 = Precipitation of Wettest Quarter	prec_ wetq	No
BIO17 = Precipitation of Driest Quarter	prec_ drq	No
BIO18 = Precipitation of Warmest Quarter	prec_ waq	No
BIO19 = Precipitation of Coldest Quarter	prec_coq	No
Altitude	alt	Yes
Land cover	l_cover	Yes

III. Results

1. Chimpanzee Distribution Probability Map

The suitability map produced with a Kappa of 0.91 and an AUC of 0.89 showed that the areas suitable for chimpanzees are very limited across the whole country. The area of high suitability for chimpanzee was observed in the south and north western parts of Rwanda. The central plateaus, the eastern lowlands and the top north-eastern mountains are characterized by low probabilities of chimpanzees occurrence (Figure 4).

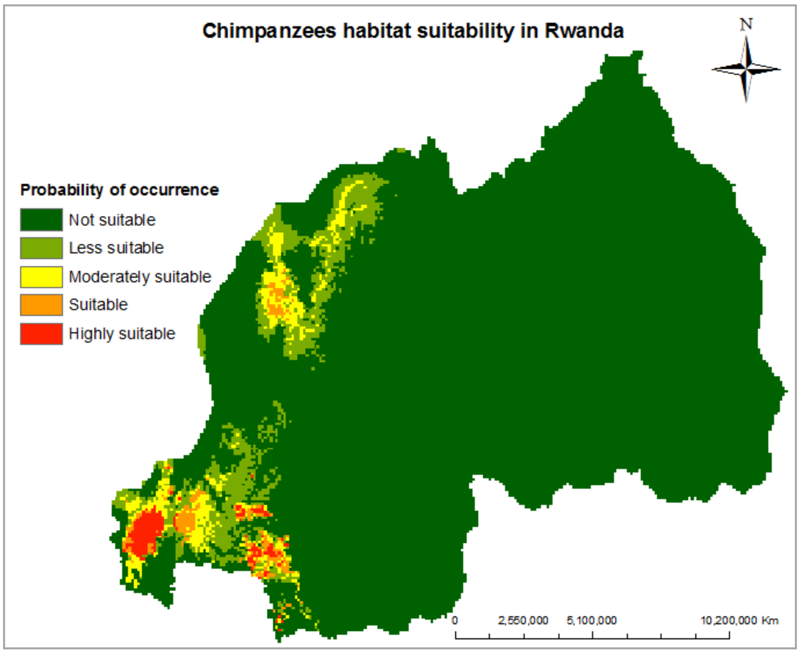

Figure 4. Chimpanzees' distribution probability map

2. Contribution of each variable to model chimpanzees habitat in Rwanda

The model jackknife test was performed to analyze the importance of each environmental variable to the model. The results showed that the environmental variable with highest gain when used in isolation is annual precipitation, followed by the maximum precipitation. The jackknife shows that precipitation is be the most important determinant of chimpanzees habitat in the study area (Figure 5).

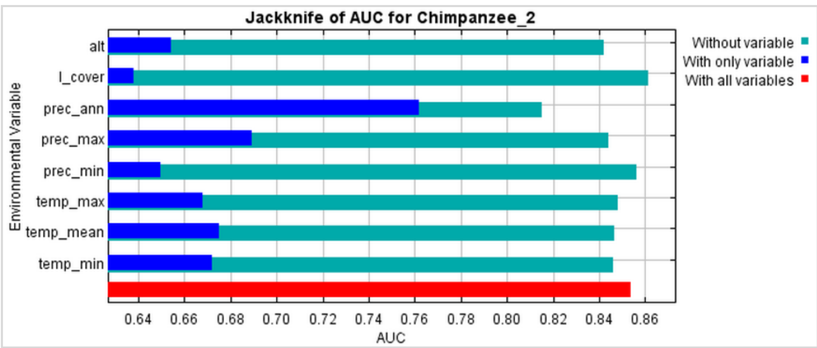

Figure 5. Chimpanzees' distribution model jacknife: The jaccknife shows the contribution of each variable to the model performance

IV. Discussion

1. Chimpanzee Distribution Probability Map

The western part of Rwanda is suitable for chimpanzees while the central plateaus, the eastern lowlands and the top north western part of the country are less suitable or unsuitable to chimpanzees (Figure 4). The high probability of chimpanzees' occurrence in the western part of Rwanda is justified by climatic conditions such as high rainfall, high humidity and low temperature that characterize the western region which is mainly made of mountains of the Congo-Nile Divide. The same microclimate has favoured the proliferation of plants species especially *Ficus sp.*, *Casporea gumifera* and *Musanga leo-errerae* which are the main sources of diet for chimpanzees.

The found distribution is in line with Eklund et al. (2011) and Kayijamahe (2008) who suggested that the distribution of great apes are not only influenced by climatic variables, but also by food availability. The climatic conditions in the central plateaux and eastern lowlands (low humidity, low rainfall and high temperature) and in the top northern-west (extreme high temperature, high humidity and high rainfall) justifies the low probability of occurrence of chimpanzees in these areas (Eklund et al., 2011; Fourcade et al., 2014; Jane et al., 2011; Kayijamahe, 2008; Phillips et al., 2006; Plumptre et al., 2003; Purvis et al., 2000). In addition to climatic conditions, plants species in the central plateaus which are mainly composed of shrubs and crops; and the savannah in the eastern part are not preferred by chimpanzees which are mainly frugivorous (Gross-Camp & Kaplin, 2005).

The fact that the results of the study shows that almost the western part of the country is suitable to chimpanzees could be due to over-fitting (Jane et al., 2011). In fact, MaxEnt was shown to be prone to over-fitting, resulting in inadequate prediction of large unsampled regions at high probability levels (Peterson, 2006). The fact that MaxEnt rely upon presence only data, over-fitting may also result in under-prediction in areas with a lot of occurrences or over-prediction in areas with few occurrences(Phillips et al., 2006; Stevens & Pfeiffer, 2011).

2. Contribution of each variable

Precipitation (annual and maximum) is the most important determinant for chimpanzees' distribution in Rwanda (Figure 5). This is in conformity with Caldecott and Miles (2005) who argued that who argued that African apes are primarily forest dwelling species and many populations occur within the tropical forest belt, which is characterized by a humid climate, high rainfall (which contributes to the total annual precipitation) and low temperature variability. The relatively high temperature in the central plateaus, the eastern lowlands and the north-western highlands has made these areas less suitable or unsuitable to chimpanzees. The top north-western regions made especially of Volcanoes mountains characterized by extremely too low temperature and too high humidity and rainfall are also not suitable to chimpanzees (Kayijamahe, 2008; Moilanen et al., 2005; Phillips et al., 2006).

V. Conclusion

Through the use of MaxEnt as a species distribution model, suitable areas for chimpanzees were modeled in Rwanda. The output of the model showed that the western part of Rwanda is suitable while the central plateaus and the eastern lowlands are not suitable. This unequal probability of occurrence is defined by climatic conditions especially rainfall and temperature; and land cover which have a direct influence on chimpanzees food availability. However, the fact the model uses presence only data may influence the results of the study and lead to over-prediction or under-prediction. Thus, in future it may be necessary to compare these results with those from other models such as GARP. Nevertheless, the use of Maxent modelling in this study has resulted in delineating more detailed chimpanzees ecological niche beyond the administrative boundaries as previously described which could be useful while making policies and implementing biodiversity conservation measures.

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