



PHENOLOGICAL DYNAMICS OF MAJOR VEGETATION TYPES AND SEASONAL HABITAT PATTERNS OF WHITE-LIPPED PECCARY IN THE YASUNÍ BIOSPHERE RESERVE



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Gosia Bryja, Galo Zapata-Rios, Victor Utreras and Javier Torres

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1. INTRODUCION:

The Yasuní Biosphere Reserve (YBR) covers approximately 17 570 km² of which Yasuni National Park (YNP) covers 9820 km2 and the Waorani Ethnic Reserve (WER) 7650 km². The Reserve is located in Amazonian Ecuador and it encompasses the Yasuní, Nashino, Cononaco, and Tiputini river basins. The rain forests of the YBR are known for their extreme species richness where palms, being the principal source of food for many birds and mammals, play an important role in the diversity and structure of these forests. As a result, at a landscape scale patterns of palm species richness and their fruiting phenology strongly influence the distribution of wildlife species such as the white-lipped peccary (*Tayassu pecari*). The white-lipped peccary is a key consumer of fruits and seeds of tropical forests and they eat both freshly fallen fruits and seeds, and seeds whose exocarps have been consumed by other frugivores (Fragoso, 1998). Throughout their range, peccaries use fruits and seeds from over 212 plant species belonging to 53 families. However, fruits and seeds from palm species are consumed more frequently (up to 24% more often) than fruits and seeds from any other plant family. Furthermore, analyses of stomach contents of peccaries indicate that palm seeds can account for over 60% of their diet (Beck, 2006). As a result, peccaries have potentially profound effects on palms and palms seasonal dynamics, which in turn, strongly influence the patterns of habitat distribution of peccaries. This interaction can be clearly observed in Yasuní National Park (YNP), which contains large expanses of seasonally flooded forests with a diversity of palm species that are exploited by peccaries mainly during the dry season. During the rainy season, the water level in these forests can reach three to four meters above the forest floor, rendering their fruits inaccessible to peccaries, and thus contracting the species available habitat and shifting their distribution to the upland forest. At the same time, the white-lipped peccary is one of the most hunted animals in the neotropics and its habitat is being lost as the flooded forests and swamps are being cleared and drained to give room for agriculture in the northern parts of YNP. Thus, understanding peccary–palm fruiting interactions is important in determining conservation strategies for this species. The extirpation of white-lipped peccaries can have unknown consequences for the prevalence of palms and the forest community in general (Beck,

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2006) and vice versa. Habitat loss and fragmentation can exacerbate already existing pressure on peccary populations. It is important, thus to better understand how the flooding dynamics of the main palm communities and their fruiting seasonality affect the patterns of white lipped peccaries' habitat use at the landscape scale and how these patterns affect peccary vulnerability to external pressures from hunting and potential habitat loss.

This technical report is the first step towards exploring the peccary-palm fruiting relations in YBR. It shows how remote sensing data coupled with species observation data can serve as the appropriate method to study the interaction between the phenological dynamics of major palm communities and habitat distribution of white-lipped peccaries. However, the report indicates the need for further investigation through careful in-situ measurements and ground verification of the study's findings.

2. DATA AND SITE DESCRIPTION:

2.1 OBSERVATION DATA

For performing the analysis for this work, we used white-lipped peccaries observation data collected by means of a series of track-and-sign, and standardized line-transect surveys from 2005-2009 in three different areas in the Yasuni Biosphere Reserve (Figure 1):

- 1) Control site: Tiputini Area
- 2) Three Kichwa community sites along the River Napo : *Nueva Providencia, Añangu and Sani Isla.*
- 3) Two sites along oil extraction roads: Auca and Maxus roads.

In general, the surveys included the majority of game species of medium-sized and large mammals (> 1 kg) preferred by hunters. In total, there are 26 transects set up with a total length of 755.38 km of surveys conducted through to date. All transects were located randomly but ensuring that the minimum distance between them is at least 1 km. Initially, the length of each transect was 1.5 km, but from December of the 2007 transects located in the communities and in the control sites were extended to 4 km.

All transects have been visited systematically to permit the estimation of the abundance and composition of the fauna by means of the direct observations of animals or of signs of their presence. For each animal detected the observer registered the species and its common name, the distance between the observer and the animal, the angle of deviation of the animal with relation to the line of the transect, and if applicable, the approximate size of the group. Additionally to the direct registrations, the observer registered any signs of animal presence such as tracks, burrows and scats that were found within 1 meter from the transect line. Each study site was visited between five and fourteen times between 2005 and 2009 (in communities 14 times, in the control site 12, and along the Auca and Maxus Roads 5 times).



Figure 1. The main study areas within Yasuní Biosphere Reserve

The purpose of the continuous fauna surveys along the oil extraction roads, within the communities and control sites was to determine the difference in hunting impacts on selected mammal population densities in different human access areas. Furthermore, the observation

data collected along transects provided information about species different seasonal habitat preferences.

Theses observation data were also augmented by the information previously collected in 2002-2003 in 10 sites in the northern section of Yasuní Biosphere Reserve.

2.2 MAJOR FOREST HABITAT TYPES WITH PALM SPECIES

With the exception of the Napo River, which originates in the foothills of the Andean Cordillera, rivers crossing the YBR originate at altitudes from 300 meters to 600 meters above sea level. The topography of the reserve is represented by low plains alternating with the foothills of the Andean chain. Because of its geographic location and relative inaccessibility, YBR is a home to some of the most biodiverse primary tropical rainforest on the planet. The annual rainfall in the YBR can reach 3800 mm with a monthly average rain of 260 mm. The wettest month is, usually, July with 400 mm and the driest is December with 130 mm. The rainfall seasonality in the YBR is bimodal. In other words, there are two wet seasons, one between March and July, and the other between October and November. The mean annual temperature is 25.5 °C with a mean maximum temperature of 30 °C and a minimum of 23°C. November, December and January are the hottest months whereas July is the coldest. The relative humidity is high during the whole year. In the dry season, the annual mean humidity is about 83% while in the rainy season it is almost 90%. This climatic variability coupled with local topography influences the distribution and phenological dynamics of different forest communities within the YBR.

There are four main vegetation cover classes in the Ecuadorian Amazon which white-lipped peccaries are using with different intensity: 1) Upland Forest (*Terra firme*) < 400 m, 2) Lowland Non- flooded Forest, 3) Floodplain forests – *Várzea* and *Igapó* and 4) Mauritia palm swamps (Figure 2).

In the major habitat types of the tropical Ecuadorian Amazonian rainforests, palm communities differ in species composition, having very high levels of palm species and genus richness in *terra firme* forests while in the flooded and swamp forests the palm flora seems to be less diverse,

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even though the contribution of palms to the structure of the forests can be dominant (Asturizaga, 2005).



Figure 2. Main habitat types within the Yasuni Biosphere Reserve.

Upland forest also called *Terra firme* represents the main forest type across the Ecuadorian Amazonian landscape and it supports a high diversity of plants, especially tall trees. *Terra firme* consists of hilly forests that are never flooded by rain or river level fluctuations and the soils in this type of vegetation are red or yellow clays. The average height of the canopy is between 25-30 m with emergent trees taller than 45 m and dense under story layer covered with lianas, epiphytes and herbaceous vines (Sánchez *et.al*, 2002). In general, *terra firme* has very high levels of palm species richness including for example *Iriartea deltoidea, Oenocarpus bataua, Socratea exorrhiza, and Astrocarym chambira* (Beck, 2005)

Floodplain forests, in contrast to upland forests are seasonally flooded. There are two major types of floodplain forests, the ones that are located near white-water rivers like the Napo and

Aguarico and are called *Varzea*, and the ones that are located near black-water rivers like Añangucocha and known as *Igapó*.

Varzea forests ("Varzea" is a term of Brazilian origin that applies to the flooded areas by rivers that charge sediments originating from the Andes) are a lot more fertile than the red clays of upland forest as they are being annually replenishment by nutrients from white water rivers. As a result, even though the diversity of trees in the floodplain forest is lower than in *terra firme* – generally with 200 species of trees per hectare or less, they are more productive in fruits, seeds and nectar and support denser communities of mammals, with higher biomass of animals per hectare. Without doubt, the floodplain forests are extremely important for the populations of mammals and large birds. However, due to their high richness in nutrients, these forests are more suitable for agriculture than typical rainforest and they are disappearing rapidly because of agricultural development (Sánchez *et.al*, 2002).

Soils of *Igapó* forest, on the other hand are acidic, poor in nutrients and not suitable for agriculture (Sánchez *et al*, 2002). Almost all the species of plants in the *Igapó* are endemic to this habitat. One of the palms present in this forest and also important for peccaries is *Astrocarym jauari*.

Lowland non-flooded forest it is found mainly in the northern limits of YNP, between the river Napo and the low basin of the Tiputini river, but far from the influence of the periodic floods of both rivers. In its structure and floral composition, this forest seems similar to the floodplain forest, but since it lacks the periodic enrichment of the floor with the alluvial deposits, the productivity of this forest is probably lower than that of floodplain forest (Sánchez *et al.*, 2002).

Mauritia palm swamps develop in flat areas with stagnant water where the surface is flooded most of the year. It is an "oligarchic" forest dominated by few species of trees among which the most representative one is generally *Mauritia flexuosa* (Sánchez *et al.*, 2002). This fruitproducing palm constitutes the major food source for peccaries.

2.3 REMOTE SENSING DATA – VEGETATION INDICES

During this study, we applied remote sensing data to better understand the general phenological dynamics in four major forest-palm communities to predict temporal white-lipped peccary habitat use. Plant phenology is the study of periodicity in the production of vegetative and reproductive plant structures, most notably the leafing, flowering, and fruiting schedules (Haugaasen and Peres, 2005). Today, one of the important approaches to study the phenological patterns on the landscape scale is remote sensing analysis. Satellite remote sensing data at moderate spatial resolution provide frequent earth observations that may reveal crucial information about vegetation changes. The environmental data layers extracted from remote sensed data cover a range of variables that can provide a measure of above-ground biomass, vegetation cover types, seasonal changes in the greenness of vegetation and vegetation canopy characteristics.

To test the applicability of remote sensing data in studying phenological dynamics in YBR, we used Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS is an instrument on board NASA's Terra and Aqua platforms for remote sensing of the atmosphere, oceans and land surfaces and it provides two vegetation indices (VIs):the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). In many studies the multi-temporal signatures of the time-series of MODIS EVI and NDVI data were shown to capture essential phenological metrics of various natural land cover types. They represent spectral measures of the amount, relative greenness, phenological characteristics, and biological productivity of observed vegetation types present on the ground. NDVI vegetation indices are sensitive to photosynthetic activity and thus provide an excellent description of spectral aspects of land cover and plant phenology, whereas EVI is designed to minimize the effects of the atmosphere and canopy background and enhance the green vegetation signal. EVI also tends to be more sensitive to variations over high biomass areas of tropical forest (Wallace and Thomas, 2008).

Both VIs time series include errors that are caused by atmospheric and ground conditions (e.g. cloud and snow cover), and sensor problems (e.g. sensor drift, and changes in sensor view angle) that can create irregularly low values or data gaps in time series. The time-series MODIS VI data products are, therefore, composited at 16-day intervals to minimize the degree of cloud cover by substituting a cloud covered pixel with a later uncontaminated pixel within a 16-day period (Wallace and Thomas, 2008).

During this analysis, we used both MODIS NDVI and EVI time series data and examined its contribution to predicting the temporal spatial patterns of habitat use by white lipped peccary. NDVI and EVI are calculated using the following equations:

$$NDVI = \frac{NIR - R}{NIR + R}$$
, (Wallace and Thomas, 2008).

where NIR and R stand for the spectral reflectance measurements acquired in the red and nearinfrared regions, respectively.

2)

1)

EVI =
$$G \frac{NIR - R}{NIR + C_1R - C_2B + L}$$
, (Wallace and Thomas, 2008)

where NIR, R, and B are reflectances in the near infrared, red, and blue bands respectively; C1 and C2 are aerosol resistance coefficients; G is a gain factor, and L is the canopy background adjustment that addresses nonlinear, differential NIR and red radiant transfer through a canopy. The coefficients adopted in the MODIS-EVI algorithm are L = 1, C1 = 6, C2 = 7.5, and G = 2.5. The EVI equation optimizes the vegetation signal, de-couples the canopy background signal, and reduces atmospheric influences to allow for precise inter-comparisons of spatial and temporal variations in terrestrial photosynthetic activity (Wallace and Thomas, 2008).

3. METHODOLOGY:

3.1 Extraction and Smoothing of NDVI and EVI time series data

We obtained the 16-day composite MODIS NDVI and EVI products at 250-m resolution for the four-year period between January 2005 and December 2008 from the EOS Data Gateway. We used ERDAS Imagine 9.1 [Leica Geosystems, Norcross, GA] to import the MODIS time series data and convert them to a float data type. The entire time series of the 16-day MODIS intervals acquired for the four-year period consisted of 92 16-day composite images. Both vegetation indices datasets, NDVI and EVI, were extracted from the MODIS data product, reprojected to the UTM WGS84 and subset to the Yasuni Biosphere Reserve study area.

Despite of the reduction of noise in MODIS data through creating the 16-day composite, a certain level of noise associated with remnant clouds and their shadows always persist in the EVI and NDVI time series. As a result, the TIMESAT package (Jonsson and Eklundh, 2004) was employed to reconstruct a clean, smooth series of EVI and NDVI data from four complete years (n = 92). TIMESAT is a program for analyzing time series of satellite sensor data and provides an adaptive Savitzky-Golay smoothing filter using polynomial functions in the fitting of upper envelope of the vegetation index data (Jonsson and Eklundh, 2004). The most important input parameters for analyzing time-series data are the cut-off spike and the window size for the Savitzky-Golay filter. After running several tests on sample pixels, the cut-off for the spike was set to 4, and the window size was set to 5, 6, 7. Figure 3 shows the sample of NDVI time series profiles for row 2005 and column 500 reconstruction by the TIMESAT.



Figure 3. The sample of NDVI time series profiles for row 2005 and column 500 reconstruction by the TIMESAT with applied with brown line Savitzky-Golay smoothing.

The Savitzky-Golay smoothing filter was applied to all 92 EVI and 92 NDVI images to produce smooth EVI and NDVI series respectively. These smooth EVI and NDVI time series served as inputs for further analysis and the generation of NDVI and EVI stack layers. Both stack layers were generated in acquisition date order for the extraction of seasonal NDVI and EVI signature profiles over a four-year period for each major vegetation type within YBR. The mean values were thus selected from 4 polygons representing four habitat types that were digitized on the base of Landsat TM 7 and vegetation classification. These mean values represent signature EVI and NDVI profiles that were used to capture the phenological dynamics of the four major habitat types within the study area.

3.2 Generation of derivatives of NDVI and EVI time series data

To date MODIS data products have not been extensively used in predictive modeling (PDM). As a result, we generated 6 seasonal and 14 annual derivative NDVI and EVI time series layers to test the utility of incorporating MODIS data products as PDM predictors and to determine which layers contribute the most to the final temporal and annual white-lipped peccary habitat models (Table 1 and 2). First, to model temporal changes in the peccaries' habitat quality, the NDVI and EVI time-series data were separated into three seasonal datasets that represent generally defined wet, dry and transition periods. These seasonal datasets corresponded to the dates when the = white-lipped peccary observation data were collected: 1) during the rainy season from March-July, and October – November and 2) during the drier season from December-February, with transition periods in between (Table 1). We created a 'layer stack' for each of the season for each of VIs and then extracted mean NDVI and EVI values for each season over the four year period.

Seasonal NDVI and EVI	
Mean NDVI rainy season	
Mean NDVI dry season	
Mean NDVI transition season	
Mean EVI rainy season	
Mean EVI dry season	
Mean NDVI transition season	

Table 1. Seasonal NDVI and EVI derivatives

Secondly, we applied different approaches to combine all 92 images for NDVI and 92 images for EVI to extract and create different VI derivative layers (Table 2):

- 1) First using TIMESAT software we extracted three annual seasonal parameters from the resulting smooth EVI and NDVI series: annual NDVI, EVI maximum (MAX), the maximum value of the fitted function; annual EVI, NDVI base (BASE), defined as the average value of the left and right minima; and the annual EVI amplitude (AMP), obtained as the difference between the maximum EVI, NDVI and base EVI, NDVI value. There three measures represent the maximum, minimum and the range of phenological activity.
- 2) Secondly, we collapsed the four-year NDVI and EVI profiles down into a single 'standardized' annual profile for that location for each of the vegetation indices separately. This was performed using the mean NDVI value for each 16-day period over the four year period, and then we created one annual collapsed mean, maximum and minimum value for both NDVI and EVI. These data allow quantitative analysis methods to characterize spatial and temporal variations of vegetation indices.

3) Thirdly, we used all 92 time series for NDVI and all 92 time series EVI images to generate a standardized principle components analysis (PCA) for both indices utilizing a correlation matrix. PCA is a commonly used data reduction technique of multitemporal remotely sensed imagery (Hirosawa *et al.* 1996). For the habitat modeling, the first two axes of the PCA were used, as they can be interpreted to represent vegetation structure and temporal dynamics respectively.

Annual NDVI and EVI		
First Approach	Second Approach	
Annual NDVI Maximum TIMESAT parameter	Mean standardized annual EVI	
Annual NDVI Amplitude TIMESAT parameter	Maximum standardized annual EVI	
Annual NDVI Base TIMESAT parameter	Minimum standardized annual EVI	
Annual EVI Maximum TIMESAT parameter	Mean standardized annual NDVI	
Annual EVI Amplitude TIMESAT parameter	Maximum standardized annual NDVI	
Annual EVI Base TIMESAT parameter	Minimum standardized annual NDVI	
	Third approach	
	PCA 1 and PCA 2 for EVI	
	PCA 1 and PCA 2 for NDVI	

Table 2. Annual NDVI and EVI composite layers obtained from smooth NDVI and EVI time series data.

1.3 PREDICTIVE MODELING

First, with respect to temporal dynamics of white-lipped peccaries' habitat distribution, the predictive modeling was applied separately for wet and dry seasons and then an annual model was generated to capture the overall peccaries' habitat availability and relate it with hunting patterns. Location data for each peccary were grouped into seasonal intervals to match general seasonal patterns within YBR.

We developed annual and seasonal white lipped peccary probability distribution models using then software MAXENT (<u>http://www.cs.princeton.edu/~schapire/maxent/</u>). MAXENT utilizes a statistical mechanics approach called maximum entropy to make predictions from presence only occurrence data and to estimate the most uniform distribution (maximum entropy) of the

occurrence points across the study area. What is also important is that MAXENT provides a detailed summary of the model output. The model accuracy is evaluated based on ROC curve (AUC), which is threshold independent. The selection of the threshold that splits the probability surface into presence/absence constitutes another uncertainty so this is why ROC curve becomes increasingly popular as a way of model evaluation. The area under the ROC curve (AUC) is a measure of model success because a curve that maximizes true-positive predictions and minimizes false positive predictions will have AUC values approaching 1.0 and could be considered a good model. A model with an AUC close to 0.5 is considered to be no better than random. MAXENT also provides information about each of the predictor variables and it gives an opportunity to evaluate its contribution to the results of the model. Detailed descriptions of Maxent's methods can be found in Phillips *et al.* (2006).

All probability distribution models were run with generated NDVI and EVI derivative layers to better understand the interaction of MODIS data in the modeling process and its contribution to final results. In addition to the MODIS datasets, the input layers included climatic data and the vegetation layer (TABLE 3).

During the modeling, we used 25% of our sample training data as testing data to evaluate the model performance based on the ROC curve (AUC). To identify which variables are most important in the model, we also used a jackknife test where each variable was excluded in turn, and a model was created with the remaining variables. Then a model was created using each variable in isolation. The results of jackknife tests allowed us to evaluate an importance of each individual predictor and its interaction with other covariates. Maxent's predictions are 'cumulative values', representing as a percentage the probability value for the current analysis pixel and all other pixels with equal or lower probability values. The pixel with a value of 100 is the most suitable, while pixels closer to 0 are the least suitable within the study area.

Climate and Vegetation data	Source of information
Temperature seasonality (P4)	1 km BIOCLIM
a. Annual Precipitation (P12	1 km BIOCLIM
b. Precipitation of the wettest month (P13)	1 km BIOCLIM
c. Precipitation of driest month (P14)	1 km BIOCLIM
d. Precipitation seasonality (P15)	1 km BIOCLIM
Vegetation and land use cover	EcoCiencia 2002

Table 3. Climatic and land cover data incorporated in the predictive modeling process.

We developed 9 predictive models of white-lipped peccary distribution for dry season, 10 for rainy season and 10 for for combined dry and rainy seasons (annual). First, in all three types of seasonal and annual modeling we tested the climatic variables with the combination of derivative EVI and NDVI MODIS data series without using the vegetation cover. Then we incorporated the vegetation cover excluding some layers that did not contribute much to the final results and we re-ran the modeling process.

4. RESULTS

4.1 SEASONALITY

The seasonal VIs profiles were extracted from 92 NDVI and 92 EVI images from 2005-2008 to monitor the phenology of four major forest-palm communities in the Ecuadorian Amazon. After the visual comparison of EVI and NDVI plots, EVI data plots seemed to perform better in capturing the vegetation seasonality in the selected study. As a result we selected EVI profile plots for the further discussion and analysis (Figure 4).



Figure 4. EVI time series over the period of 4 years (2005-2008)

In Figure 4, the horizontal axis represents the 92 MODIS EVI images in four years where for each year there are 23 image data of 16 day composites. The vertical axis represents the EVI values of the main habitat types from different times of the year. It is important to emphasize that MODIS EVI is primarily the measure of "greenness" phenology and not as much flowering time or fruiting, unless they are closely synchronized. What is thus observed in Figure 4 is related more to leaf phenology driven by leafing and shedding periods. In the graph, we can thus observe big changes in EVI values during different seasons over the period of four years. This

implies that there are clear vegetation phenological responses related to seasonal dynamics among the forest communities of palm swamps, floodplains, lowlands and terra firme. There are, however, marked variations in amplitude of EVI cycle over the study period. They might be related to seasonal climatic variability and the phenological responses of selected tree species to this variability. For all vegetation types, EVI minimum values should correspond to the peak leaf shedding, whereas EVI maximum values to peak leaf flushing. There are differing time lags between fall and flush (Hess et al. Presentation)

According to Haugaasen and Peres (2005) studies, the flooded forest is more deciduous then Terra firme, shedding most of their leaves during the inundation period. They indicated that in Várzea and Igapó forests flooding creates a water deficit in the crown as the anaerobic root conditions lead to greatly reduced root activity. This, in turn, results in leaf shedding in many species and explains the large number of deciduous trees found in these flooded forest environments. Leaf flushing, on the other hand, is usually restricted to the end of rainy season (Haugaasen and Peres, 2005). That pattern suggests that floodplain forest phenology is strongly determined by the seasonality of precipitation. Since we do not have a long term field data about the specific times of leaf flushing, flowering and fruiting dynamics of different palm species, we cannot correlate them with the EVI time series. However, based, on the previous findings by Haugaasen and Peres (2005), we can assume that EVI peaks marked for the flooded forest could be associated with the leaf flushing periods. This general trend can be captured in extracted profile in Figure 4. The selected peak values within floodplain forest occur at the end of rainy seasons . For example – images 21/22 that correspond to November and images 55/56 that correspond to June/July mark the general end of rainy season. As leafing occurs at the end of rainy season the fruiting is concentrated during the inundation period (Haugaasen and Peres, 2005). In fact, Parolin et al. (2002) stated that fruiting in the high-water season is the only homogenous trait among floodplain forest trees and palm species to optimize the chances of seed dispersal.

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For the Upland forest of *terra firme* it is possible observe a slightly different pattern in tree phenology and there is a difference among the leafing, flowering and fruiting times. The general observed tendency is toward community-wide leafing and flowering pulses in *terra firme* at the end of dry season (Haugaasen and Peres, 2005). This suggests that leaf phenology in terra firme is not determined by the seasonality of precipitation as it is in floodplain forests. Instead, leaf phenological process may be driven by availability of solar radiation and/or avoidance of herbivory (Xiao et. Al., 2006). According to Figure 4, the highest peaks for terra firme are observed in images 26-27 that correspond to months of February in 2006. These months probably mark the end of the dry season and thus emergence of new leaves. Fruiting in terra firme tends to occur during early wet season (Haugaasen and Peres, 2005). According to Mendes Pontes and Chivers (2007) study in the Brazilian Amazon in Maraca, the highest fruiting activity in *terra firme* was recorded in the middle of rainy season and fruit availability decreased sharply during the dry season.

Mauritia-palm (Mauritia flexuosa) swamps' profile seems to follow the terra firme profile exhibiting lower values during the end of the rain season (for example images 33-35 that correspond to May/June, 2006) and higher values during the beginning of wet season (for example images 24-26 that correspond to January 2006). According to Mendes Pontes and Chivers (2007) Buritizal (name originates from buriti - brazilian name for name *Mauritia*-palms) with dominant Mauritia flexuosa species had the highest number of fruiting trees at the beginning of the wet season (and did not show a decline in availability during the last months of the dry season, as occurs in *Terra Firme* forest). Since other studies show that flowering and fruiting in Mauritia palm are irregularly distributed during the year, more field measurements in YBR are required to understand the phenological dynamics of this palm important for whitelipped peccaries.

Finally, according to the EVI profile the lowland non-flooded forest exhibits variability in seasonality from year to year when it either peaks in late dry season and early wet season or late wet and early dry season. These variations again can be caused by specific palm species

and climatic variability but there is little know about this habitat in general. More careful study of its tree species and their phenology has to be undertaken.

4.2 WHITE-LIPPED PECCARY TEMPORAL AND ANNUAL DISTRIBUTION PATTERNS

Twenty-nine annual and seasonal prediction models were run and tested to select the best annual and temporal white-lipped peccary habitat distribution models. The incorporation of climatic variables did not contribute much to the final results, primarily because of the crude resolution that did not accommodate the local variability. As a result, all climatic data were excluded from the final modeling. On the other hand, the vegetation cover turned out to be the most important environmental variable in the prediction for both annual and seasonal models.

In general, to predict dry season habitat patterns environmental layers that performed the best were: 1) Vegetation cover, 2) Maximum Annual EVI, 3) mean NDVI for the dry season, and 4) Maximum annual NDVI value. The final model has AUC for training data = 0.88 and for test data 0.90. On the other hand, for the modeling of habitat during rainy season the best selected layers were following: 1) Vegetation cover, 2) Mean NDVI for transition season 3) Mean NDVI for rainy season, 4) Average annual value for NDVI, 5) Minimum annual value for EVI, 6) Mean EVI for rainy season. The final model has AUC for training data = 0.87 and for test data 0.92, According to the final temporal predictive models, there is a significant difference in the probable distribution of white-lipped peccary between the dry and rainy seasons (Figure 5 and 7). During the dry season, the Figure 5 demonstrates the high probability of occurrence of peccaries in the lowland non-flooded forest as well as floodplains along the major rivers.



Figure 5. The probability of distribution of white-lipped peccary during the dry season

According to the MAXENT model's (Figure 6) logistic prediction curve for the dry season, the probability of white-lipped peccary occurrence is the highest for Lowland non-flooded forest (class 3), and then in decreasing order for floodplain forest of *Igapó* (class 8), flooded forest of *Várzea* (class 2), Mauritia palm swamps (class 9) and Upland forest – *terra firme* (class 1).

Response of Tayassu_pecari to vegetation_tro

4 5 6 vegetation_trc 7 8 9



During the wet season, on the other hand, the pattern of the probable of white-lipped peccary distribution changes. The areas of flooded forest and *Mauritia* palm swamps are not utilized and the highest probability of occurrence is within Lowland non-flooded forest and within scattered patches throughout the upland forest.

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0 1

2 3



Figure 7. The probability of distribution of white-lipped peccary during the rainy season

According to the MAXENT model's (Figure 8) logistic prediction curve for the wet season, the probability of white-lipped peccary occurrence is the highest for Lowland non-flooded forest (class 3 and 5), and then in decreasing order for flooded forest of *Várzea* (class 2) and Upland forest – *terra firme* (class 1).



Figure 8. Logistic white-lipped peccary occurrence prediction curve for major habitat types in the wet season.

In contrast to the dry season, white-lipped peccaries do not occupy either the forest of *Igapó* nor *Muaritia*-palm swamps during the rainy season probably due to high water levels that render these habitats inaccessible.

Well marked flooding dynamics of major forest communities clearly affect the availability of high quality habitat for white-lipped peccaries. We reclassified the annual and temporal probability distribution maps that represent values on the scale of 0-100 into 5 classes representing the general habitat quality. The classes are following:

- 1) 0-20 Very Low Quality,
- 2) 20-40 Low Quality,
- 3) 40-60 Medium Quality,
- 4) 60-80 High Quality
- 5) 80-100 Very High Quality.

According to Figure 9, the dry season offers larger areas of high and very high habitat quality than the rainy season when the important habitats of flooded forest and *Mauritia* palm swamps become inaccessible to the species. This contraction of suitable habitat due to flooding dynamics drives the seasonal differences in the distribution patterns of the peccaries on the landscape scale.



Figure 9. Percentage of probability of utilization of different quality habitats by white-lipped peccary.

In the predictive modeling for the annual probability distribution the most important variables were vegetation cover, NDVI PCA band 1, EVI PCA band 1 and Average standardized annual

NDVI layer. The final AUC for training data were 0.90 and for test data 0.92. This map indicates the annual potential distribution pattern for the white-lipped peccary.



Figure 10. The probability of distribution of white-lipped peccary within the Yasuni Biosphere Reserve

According to the annual MAXENT model's (Figure 11) logistic prediction curve, the probability of white-lipped peccary occurrence is the highest for Lowland non-flooded forest (class 3 and 5), and then in decreasing order for Mauritia palm swamps (class 9), flooded forest of *Várzea* (class 2), and Upland forest – *terra firme* (class 1).





4.3 MEASURING WHITE-LIPPED PECCARY HUNTING RISK

Since white-lipped peccaries are heavily hunted it is important to evaluate the risk of hunting of these species on the landscape scale. The seasonal probability distribution maps indicate that high quality habitats for peccaries are also located in areas that are highly threatened by human activities. As a result, in order to evaluate this risk, we combined the annual habitat white-lipped peccary distribution probabilities with the commercial hunting model generated by Bryja (2009). The commercial hunting model represents the relative hunting severity/risk values ranking from 0-100, where 0 signifies lack of risk (white color) and 100 (dark red color) signifies the highest risk (Figure 12).



Figure 12. The relative risk of commercial hunting within the YBR

According to Figure 12, the high intensity of commercial hunting is concentrated in the northwestern portion of YNP within the area of the Maxus Road where operates REPSOL, the major oil company in Ecuador. Due to the provided by the oil company transportation subsidies as well as the emergence of a wild meat market in Pompeya at the entrance to the YNP, the

local hunting patterns have changed significantly. The study carried our but the WCS team that resulted in *WCS Equator Bulletin, 2007* and the publication by Suarez (2009) indicates that the transportation subsidy provided by the oil companies along the Maxus Road had three important consequences: (1) it provided an access to a much larger hunting area along the road for the fauna exploitation; (2) it facilitated the transportation of the hunted animals and (3) it considerably reduced the costs that the Waorani hunters would incur in order to bring the wild meat to the market. As a result, the transportation subsidy caused significant intensification of the commercial hunting in the area by changing the patterns of hunting from subsistence to trade. The supply of gasoline by the oil companies to the local communities also expanded the opportunity for local Waorani to traverse the areas along the rivers of Yasuní and Tiputini increasing the hunting impact in those areas as well.

For the purpose of the evaluating of hunting risk within YBR, we assumed that the value of 100 in our commercial hunting model represents the highest impact of hunting with probability of killing as many as 99% of the peccaries. Then the risk of hunting scales linearly down until reaches the value of 0 (Figure 13).





To calculate and visualize the hunting impact on the landscape scale we applied the following formula:

([Annual Habitat Quality] * (100 - ([hunting_risk] * 0.99)))/100

Where 0.99 represents 99% of peccary hunting risk.

The results can be easily observed in Figure 14, where figure C represents the reduction of habitat quality for white-lipped peccaries and that reduction is most noticeable in the area of the Maxus road and rivers. In other words, the highest species hunting risk occurs around to the oil exploration road and main rivers where human accessibility is facilitated by the local subsidies.



Figure 14. The impact of commercial hunting on the white-peccary population : A) the habitat quality, b) the commercial hunting model and c) the reduction of the white-lipped peccaries habitat quality or species hunting risk

The results of the model are confirmed by Zapata (2009) in his evaluation of the detection probability of white-lipped peccaries along the roads (Figure 15).



Figure 15. White-lipped peccary detection probabilities (and 95% confidence intervals) along major road systems (Maxus and Auca) in YNP (and a control site) calculated from track and sign data.

Overall detection probabilities of the white-lipped peccaries in the vicinity of the Auca and Maxus road were approximately 0% and 30% in comparison of detection probability in the control sites with the value higher than 70%. The results of this analysis evidently indicate the highest hunting impact on this species in the areas close to the roads.

5. DISCUSSION:

This study confirms that the highly diverse Ecuadorian Amazon landscape could be monitored and analyzed with MODIS vegetation index (VI) time series data. The MODIS enhanced vegetation index (EVI) seasonal profiles were found useful in characterizing the spatial and temporal variability in landscape phenology and the Normalized Vegetation Index (NDVI) proved to contribute significantly to the final white-lipped distribution predictive models. Even though the interpretation of the EVI values for major forest communities depends on many assumptions due to lack of field data that link the precipitation information with the phenological activity of forest species, we can still demonstrate that leafing, flowering and fruiting in Ecuadorian tropical forests is subject to periods of highs and lows. This confirms the phenological studies in other tropical wet forests that exhibit a wide range of fruiting patterns, including unimodal or bimodal fruiting peaks. Some tropical dry forest plant phenology studies describe a single fruiting peak related to the dry season or several peaks in the wet and dry seasons (Haugaasen and Peres, 2005). In our analysis, some variations within the EVI profile might be due to the noise of image data caused by the presence of clouds especially during the rainy season. As a result, careful ground, in-situ measurements on fruiting, leaf flushing and falling and flooding dynamics have to be undertaken to exclude the noise and to better understand the seasonal phenological dynamics of major palm species and forest communities.

Being a frugivorous species, the white-lipped peccary habitat preferences are strongly influenced by the regional flooding dynamics and fruiting seasonality of the major palm species. In Vaupés, Colombia, it was observed that white-lipped peccary herds remained in the highlands during the rainy season but moved to lowlands in the dry season (Carrillo et.al, 2002). According to some studies, the movement and foraging ecology of white-lipped peccaries is primarily driven by mast fruiting events of several palm species, including *Astrocaryum murumuru, Astrocaryum tucuma, Attalea maripa, Lepidocaryum, Mauritia flexuosa, Orbygynia phalerata*, and *Raphia taedigera* (Beck, 2006) The predictability of the palm mast, as a result, provides a relatively reliable cue to the location of superabundant food and may help in defining the direction and timing of peccary movements. The study of Fragoso (1998) of the

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relationship between the densities of white-lipped peccaries and palm phenology on the Ilha de Maracá indicated that greatest densities of peccaries coincides with the masting of the inajá palm (*Maximiliana maripa*) and the period of greatest fruit abundance in the forest. For example, on Ilha de Maracá during the dry season the buriti palm (Mauritia flexuosa) which fruits thought the year, appears to act as the key resource influencing peccary movements (Fragoso, 1998). This pattern is confirmed by our study where during the dry season, the vast areas of flooded forest or Mauritia palm swamps in the YBR seem to be highly exploited by the peccaries. This concentration of the peccaries in the areas of the floodplain forest might be caused by food scarcity in terra firme as indicated in the study of Mendes Pontes and Chivers (2007) where fruits are most abundant during the wet season. This is also confirmed by Fragoso (1998) and Pontes and Chivers (2007) that indicate that during the dry season fruit scarcity, peccaries tend to increase their range by expanding into seasonally flooded forests and monopolizing Mauritia-palm swamps, the only habitat with considerable amounts of fruit on the forest floor. In contrast, during the wet season the white lipped peccary probably reduces its range since fruit availability in terra firme and lowland forest is greatest (Fragoso 1998) and the areas of floodplain forest and swamps are inaccessible. Our seasonal predictive models evidently support the seasonal habitat shifting patterns in the peccaries distribution and demonstrate this expansion of medium to very high habitat quality during the dry seasons and its contraction during the wet season over the period of 2005-2008. Out of all habitats, according to our seasonal predictive models, lowland non-flooded forest seems to offer the best quality habitat both during the wet and dry season. It would be thus important to collect field data on the potential food sources for white-lipped peccary in this habitat.

6. CONSERVATION IMPLICATIONS

The variation in fruiting patterns between terra firme, palm swamps, and lowland non-flooded and floodplain forests provides the white-lipped peccaries with a food macro-mosaic in both space and time. Our analysis even though it should be further explored and supported with more field based data, indicates clearly that peccaries exhibit seasonal habitat preferences due to the flooding and fruiting patterns. Evaluation of the potential of forest habitats to support white-lipped peccaries should thus consider both spatial and temporal components. This suggests that in order to best conserve the frugivorous vertebrate community of the YBR region, conservation planning at a landscape scale must be considered. However, the preservation of large areas of the good quality habitat might not be sufficient to ensure the long-term conservation of white-lipped peccaries. Because of their large group sizes, foraging ecology, and area requirements, white-lipped peccaries are much more susceptible to extirpation by anthropogenic disturbance. It is also important to take into account the vulnerability of species during different seasons and their habitat use patterns. For example, as peccaries expand their range during the dry season and are found in higher densities in the areas of flooding forest and swamps, they might be more vulnerable to hunting than during the wet season when they are more scattered throughout *terra firme*. According to the study conducted by WCS biologists white-lipped peccaries detection probability was less in the areas close to the roads than in undisturbed areas principally due to high hunting. Stricter hunting regulation efforts coupled with large areas of full protection probably need to be implemented to ensure that peccaries in the Yasuni Biosphere Reserve do not suffer reduced numbers and distribution.

7. FUTURE RESEARCH NEEDS

This study demonstrates the first step towards the investigation of seasonal habitat dynamics of white-lipped peccaries and the utility of remote sensing data in exploring the spatial and temporal variability in forest communities phenology. Still, in order to clearly demonstrate the seasonal patterns of white-lipped peccary distribution, and their interaction with flooding and forest phenology, careful species observation data have to be collected and coupled with insitu measurements of phenological dynamics of selected tree and palm species. This information then can be used to strengthen the interpretation of the remote sensing data on the landscape scale.

Specific research needs:

- 1. Need to couple MODIS phenology with field indices of phenology.
- 2. White-lipped peccary observation data have to be correlated with different wet and dry seasons.
- Since flowering time and fruiting times are clearly different from the "greenness" phenology that the MODIS product measures, it is important to better understand the dynamics among leafing, flowering and fruiting of palm and tree species that are important for peccaries.
- 4. Explore further MODIS data indices, especially Leaf index and verify the applicability of NDVI data.
- 5. Collect field data on food sources and on white-lipped peccary densities in the habitat of lowland non-flooded forest that according to the seasonal models offers the best habitat both during the wet and dry season.

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