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Abundancia relativa y ocupación del tapir (*Tapirus bairdii*) en cuerpos de agua en la Selva Maya

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Dedicatoria

Dedicado a mi familia Martinez-Chan

A mi esposa Anabel y a mi hijo Daniel

A mis padres Elena y Guadalupe †

A mis hermanos Jane y Norman

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Índice

2.0 Paper submitted "Relative Abundance and occupancy of Baird's Tapir (*Tapirus bairdii)* in waterholes at the Maya Forest"

Wilber E. Martinez, Rafael A. Reyna-Hurtado, Eduardo J. Naranjo, Jose F. Moreira-Ramírez, Marcos A. Briceño-Méndez, Omar A. Figueroa

1.1 Resumen

Se estima que el 25% de las especies de mamíferos del planeta se encuentran en riesgo de desaparecer. Por ejemplo, de las 77 especies de grandes herbívoros del mundo, 44 están en riesgo de extinción debido a cambios de uso del suelo y sobreexplotación. El tapir centroamericano (*Tapirus bairdii*), especie presente en la Selva Maya compartida por Belice, Guatemala y México, no es la excepción. El principal objetivo de este estudio fue evaluar la importancia de los cuerpos de agua (aguadas) para la sobrevivencia de los tapires en la Selva Maya. Usamos cámaras-trampa como unidades de muestreo para determinar el índice de abundancia relativa y modelos de ocupación en 34 aguadas de cuatro sitios de estudio en Belice, Guatemala y México. El estudio se llevó a cabo de enero a septiembre 2015 con un esfuerzo de muestreo de 5,201 cámaras-trampa/noche. Nuestros resultados indicaron que el promedio de abundancia relativa (51.87) en aguadas fue mayor en sitios con menor precipitación y más alejados de infraestructura humana (carreteras y poblados). El estudio resalta: 1) la importancia de cuerpos de agua que requieren mayor estatus de protección; 2) que a mayor distancia de las carreteras, mayor ocurrencia de tapires en los tres países de la Selva Maya.

Palabras Clave: Tapir centroamericano, *Tapirus bairdii*, cámara trampa, índice de abundancia relativa, aguadas, modelo de ocupación, Selva Maya,

1.2 Introducción

Se estima que de las 77 especies de mamíferos clasificados como herbívoros grandes en el mundo, 44 están bajo riesgo de extinción debido a patrones y cambios de uso del suelo y sobreexplotación de las poblaciones (Baillie *et al*., 2010 y IUCN, 2013). Estos cambios repercuten en factores importantes como la disponibilidad de recursos necesarios para supervivencia tales como el alimento, el agua, y las interacciones con otros organismos (Morrison *et al.,* 2006). La disponibilidad de alimento y agua son factores determinantes en los patrones de movimiento, densidad y abundancia de las especies. Cuando estos recursos disminuyen en el paisaje, limitan la ocurrencia y abundancia de las poblaciones (Rautenstrauch y Krausman,1989; Mandujano y Gallina, 1995). Algunos de los grandes mamíferos, como los ungulados, son dependientes de fuentes de agua como parte de sus requerimientos ecológicos y comportamiento (Terwilliger, 1978; Naranjo, 1995; Algers *et al*., 1998, Martínez-Kú *et al*., 2008) y son más sensibles a cambios en su hábitat. Por lo tanto, están obligados a sobrevivir en condiciones más difíciles como hábitats secundarios o paisajes fragmentados (Reyna-Hurtado y Tanner, 2005).

El tapir centroamericano (*Tapirus bairdii*) es el mamífero más grande de Centro y Sur América. Históricamente su distribución geográfica se extendía desde el sur de Veracruz, México, hasta el noroeste de Ecuador y norte de Colombia (Reid, 1997). Su rango altitudinal se extiende desde el nivel del mar hasta los 3,620 msnm (Naranjo, 2009) y exhiben una afinidad a bosques tropicales bien conservados y fuentes de agua (Wainwright, 2007).

Actualmente se reportan 4 especies del género *Tapirus* en el mundo, 3 de ellas en el continente Americano (Centro y Sudamérica) y una en el Sureste de Asia. Las especies del género *Tapirus* son: *T. bairdii* (Gill, 1865), *T. terrestris* (Linnaeus, 1758), *T. pinchaque* (Roulin, 1829) y *T. indicus* (Desmarest, 1819). En 2013 se reportó una posible especie adicional en el continente americano de acuerdo con resultados de análisis de ADN y la morfología; este tapir se nombró *Tapirus kabomani* (Cozzuol *et al*., 2013). Sin embargo, este descubrimiento ha sido desafiado por investigadores y aún no es claro si se trata de una nueva especie o una subespecie de *Tapirus terrestris* (Voss *et al.,* 2014).

La distribución y tamaño de la población del tapir centroamericano ha sufrido un descenso dramático desde hace 30 años y en 1996 se consideró como especie Vulnerable por la Unión Internacional para la Conservación de la Naturaleza (UICN) y desde 2002 su estatus cambió a especie en peligro de extinción (UICN, 2013). La fragmentación del hábitat y la cacería son dos de los factores principales que han ocasionado que las poblaciones de tapires disminuyan a través de su rango de distribución (Castellanos *et al.,* 2008). La estimación más reciente de tamaño poblacional es de aproximadamente 5,000 individuos adultos (Castellanos *et al.,* 2008). La amenaza principal en la región de la Selva Maya es la tala de bosques y la fragmentación del hábitat que resulta en fragmentos de bosques cada vez más pequeños y aislados. Consecuentemente, las poblaciones de tapires están más aisladas y los individuos son obligados a sobrevivir en condiciones más difíciles como hábitats secundarios o fragmentados (Reyna-Hurtado y Tanner, 2005).

A pesar que el tapir centroamericano es una especie en peligro de extinción, se ha estudiado poco en la Selva Maya y aún no se conocen completamente aspectos ecológicos básicos como el tamaño de su ámbito hogareño, sus preferencias de hábitat, su abundancia y su densidad. Se ha comprobado que los tapires son los últimos mega-frugívoros vivientes de las Américas que tienen una relación única con las comunidades de plantas, ya que son capaces de ingerir y excretar grandes semillas de frutas y dispersarlas a largas distancias (O´Farrill *et al*., 2006). Además, el tapir centroamericano ha sido catalogado como el número 34 de 4,000 mamíferos prioritarios para la conservación a nivel global (Isaac *et al.,* 2007) y la décima especie más rara del Neotrópico (Dobson y Yu, 1993). Este estudio se realizó en cuerpos de agua de 4 sitos de la Selva Maya. Los objetivos principales fueron: 1) registrar la ocurrencia de tapires en 34 cuerpos de agua en Belice, Guatemala y México; 2) determinar y comparar el índice de abundancia relativa en los cuatro sitios; y 3) modelar la influencia de aspectos de infraestructura humana en la ocurrencia de tapires en los cuerpos de agua.

Title: Relative Abundance and occupancy of Baird's Tapir (*Tapirus bairdii)* in waterholes at the Maya Forest

Wilber E. Martinez, Rafael A. Reyna-Hurtado, Eduardo J. Naranjo, Jose F. Moreira-Ramírez, Marcos A. Briceño-Méndez, Omar A. Figueroa

2.1 Abstract

It is estimated that 25% of the mammal species of the world are at risk of extinction due to land use changes and overexploitation. The Baird's Tapir, an ungulate with part of its distribution within the Maya Forest, is at risk of extinction. Waterholes, a primary source for water and an essential nutrient for the survival of tapirs, were the target of this study design. We used camera-trapping survey to determine relative abundance index (RAI) and occupancy models at 34 survey stations in four study sites within the three countries of the Maya Forest (Belize, Guatemala and Mexico). The survey was carried out from January to September 2015 with a total effort of 5,201 camera trap nights. Our results indicated that average Baird's tapir RAI at waterholes (51.87) were higher at study sites with low precipitation and when further away from human infrastructure (road and village). It highlights (1) the critical importance of waterholes that warrants higher protection for survival of tapirs, and (2) that distance to roads had the highest influence on tapir occurrence across the three countries of the Maya Forest.

Key words: Baird's tapir, camera-trap, relative abundance index, occupancy model, waterholes, Maya Forest

2.2 Introduction

It is estimated that approximately 25% of the world's mammal species and 44 out of 77 large herbivores are threatened with extinction, mainly as a consequence of land use change and overexploitation (Baillie *et al.,* 2010 and IUCN, 2013). Despite great efforts being made on their conservation, the trend prevails as anthropogenic pressures increase. Efforts such as the creation of protected areas and enhanced connectivity are a few mitigation initiatives to curve the demise of endangered mammals (Margules and Sarkar, 2007; Bodin and Norberg, 2007; Kadoya, 2009). Moreover, climate change and prediction of more intense droughts in many areas of the Maya Forest (Mardero *et al*., 2012) pose an additional threat on mammals, especially those that are water dependent. Some ungulate species in particular present ecological requirements and movement behavior that depend on the availability of water resources (Terwilliger, 1978; Naranjo, 1995; Algers *et al.,* 1998; Foerster & Vaugh, 2002; Reyna-Hurtado *et al.*, 2009; Moreira-Ramírez *et al.,* 2016).

The focal species for this study was the Baird's tapir (*Tapirus bairdii)* and the study was conducted in a mosaic of habitat across different sites in the Maya Forest in northern Mesoamerica. The Baird's tapir (*Tapirus bairdii)* (Gill, 1865) is the largest land mammal in Central America. Historically, its geographic distribution extended from southern Veracruz, México, to northeastern Ecuador (Reid, 1997). Its altitudinal range extends from sea level to the mountains (3,620asl) (Naranjo, 2009) and exhibits an affinity to lowlands and sources of water (Wainwright, 2007). It plays a unique role in forest regeneration due to its feeding ecology as a herbivore and seed disperser (Fragoso *et al.,* 2003).

Both the distribution and population size of the Baird's tapir has suffered dramatic reduction in the past decades (IUCN, 2013). It was considered Vulnerable by the International Union for the Conservation of Nature (IUCN) in 1996 but was subsequently uplisted to Endangered in 2002 (IUCN, 2013). Moreover, it was ranked 34th in urgency for conservation among more than 4,000 mammals species of the whole world that were assessed by experts from the institute of Zoology of London due to its level of evolutionary distinctiveness and level of threat (Isaac *et al.,* 2007). It is now considered the 10th rarest forest mammal in the Neotropic (Dobson & Yu, 1993). This alarming status is due to the combined effect of natural rarity, habitat loss, habitat fragmentation, hunting and their vulnerability to cattle-borne disease (Castellanos *et al.,* 2008).

The Maya Forest is the largest contiguous block of tropical forest in Mesoamerica. It extends through parts of northwestern Belize, northeastern Guatemala and southern Mexico. It is well known for its rich biodiversity, a substantial array of endemic species, and several ancient civilizations (García-Gil & Pat, 2001). It is also highly important for the conservation of wide ranging species that require extensive tracks of intact forest to sustain viable populations, including the Baird's tapir (Naranjo, 2009) and the white-lipped peccary (Reyna-Hurtado *et al.,* 2009). It has been categorized as one of the strongholds for tapir population due to its suitable habitats and unique localization that allows potential connectivity across Yucatan Peninsula with the northeastern Guatemala and Belize (Mendoza *et al.,* 2013; Schank *et al.,* 2015).

Tobler (2002) showed that tapirs in southern Costa Rica were more abundant in areas with limited human presence. These requirements indicate that tapir thrive in large and undisturbed protected areas as oppose to the human dominated landscape.

Despite its level of threat and its ecological and evolutionary relevance, important gaps exist in knowledge of the basic ecology of this species (Garcia *et al.,* 2012). Most ecological studies of tapirs have been carried out in a single protected area and based on camera traps, line transect track surveys, opportunistic observations and a few telemetry data (Reyna-Hurtado & Tanner 2005; Pérez-Cortez *et al*., 2012; Carrillo-Reyna *et al*., 2015; Sandoval-Seres *et al.,* 2016). The fact that water can be a limiting factor to Baird's tapir population (Krausman & Etchberger 1995; Cain *et al.,* 2006; Krausman *et al*., 2006) made that our study focused on assessing its abundance at waterholes across a precipitation gradient and over several protected areas. Our primary objective was to estimate sites specific variables that influence the occurrence of tapirs in these sites by determining the relative abundance index (RAI) of tapirs at four study sites and integrating the data into an occupancy analysis (Mackenzie *et al.,* 2006). We use camera-trap data from waterholes to test the hypothesis that (1) tapir RAI increases where water bodies are seasonal limited; (2) tapir RAI increases in higher protected sites; (3) the probability of tapir occupancy is higher when further away from human infrastructure.

2.3 Study site

The Maya Forest is a tri-national and contiguous tropical forest in Mesoamerica that encompasses the southern Mexican states of Campeche, Chiapas and Quintana Roo, northern Petén department in Guatemala, and northwestern Belize (Fig. 1). Specifically, our study sites in Mexico were located in the southeastern zone of Campeche state in the municipality of Calakmul. The elevation varies from 100 to 380 m above sea level (Garcia-Gil, 2003) with an annual temperature average of 24.6 C (Garcia, 1988) and a precipitation range of 500 to 2500mm. It is characterized as a landscape without a network of superficial hydrology and therefore relying on waterholes as water sources for humans and wildlife (Garcia-Gil, 2003). The two study sites are Calakmul Biosphere Reserve (CBR) a federal reserve and the ejido Nuevo Becal (NB) a community with a system of cooperative land tenure. CBR was established in 1989 with an extension of 723,825 hectares and conserves the largest tract of tropical forest in Mexico. Its location is in the vicinity of latitude 18°07’21’’ N and 89°48’56’’ W with federal highway 186 traversing the reserve via the Escárcega-Chetumal route (García-Gil & Pat, 2001). NB is located on the northeastern section of CBR at geographical coordinates of 18°40’7.7’’ N 89°12’34.3’’ W with an extension of 52,000 hectares of which 50% is designated for sustainable use such as logging and hunting. It is estimated that 80% of the forest is still under forest cover in good stage of conservation (Reyna-Hurtado, 2009). The types of vegetation that exists in CBR and NB includes Medium sub-perennial forest (trees 15-25m), Low-flooded forest (5-15m), Medium-dry forest (8-25m) and secondary vegetation (Pennington & Sarukhan, 1998).

The study site Runaway Creek Nature Reserve (RCNR) is located in central Belize in the Belize district. RCNR, a private nature reserve was established in 1999 with an extension of 2,500 hectares at the geographical coordinates 17°22' N 88°35'W. The elevation ranges from 20-120m above sea level and the area has an annual precipitation of 2000-2200mm. Topographically, RCNR has a range of karstic hills and falls within the watershed of the Sibun river. At the peak of the rainy season the river inundates and supplies the seasonal ponds with water. Geographically, it's one of the few reserves that serve as a biological corridor connecting the Chiquibul Maya Mountain massif in the south to the Maya Forest in northern Belize. The types of vegetation include pine savanna forest, broad leaf forest, riparian forest and lowland forest (Meerman, 1999).

The Laguna del Tigre National Park (LTNP) where el Peru site is located is in the western limits of the Maya Biosphere Reserve in the Department of Petén, Guatemala. LTNP as national park was established in 1999 with an area of 337,899 hectares at the geographical coordinates 17°10'30'' N -90°02'44''W and 17°19'49'' N -90°25'22''W with an altitude ranging from 40 to 200 m above sea level and an annual average precipitation of 1,400 to 1,796 mm (CONAP 2007). The national park is divided in three main sub watersheds, namely: Candelaria river, San Pedro river and Escondido river (CONAP 2007). The types of vegetation that exist in LTNP includes Medium sub-perennial forest (trees 15-25m), medium and low semi-deciduous (8-25 m) Low- sub perennial flooded forest (5-15m), (CONAP, 2007) (Fig 1).

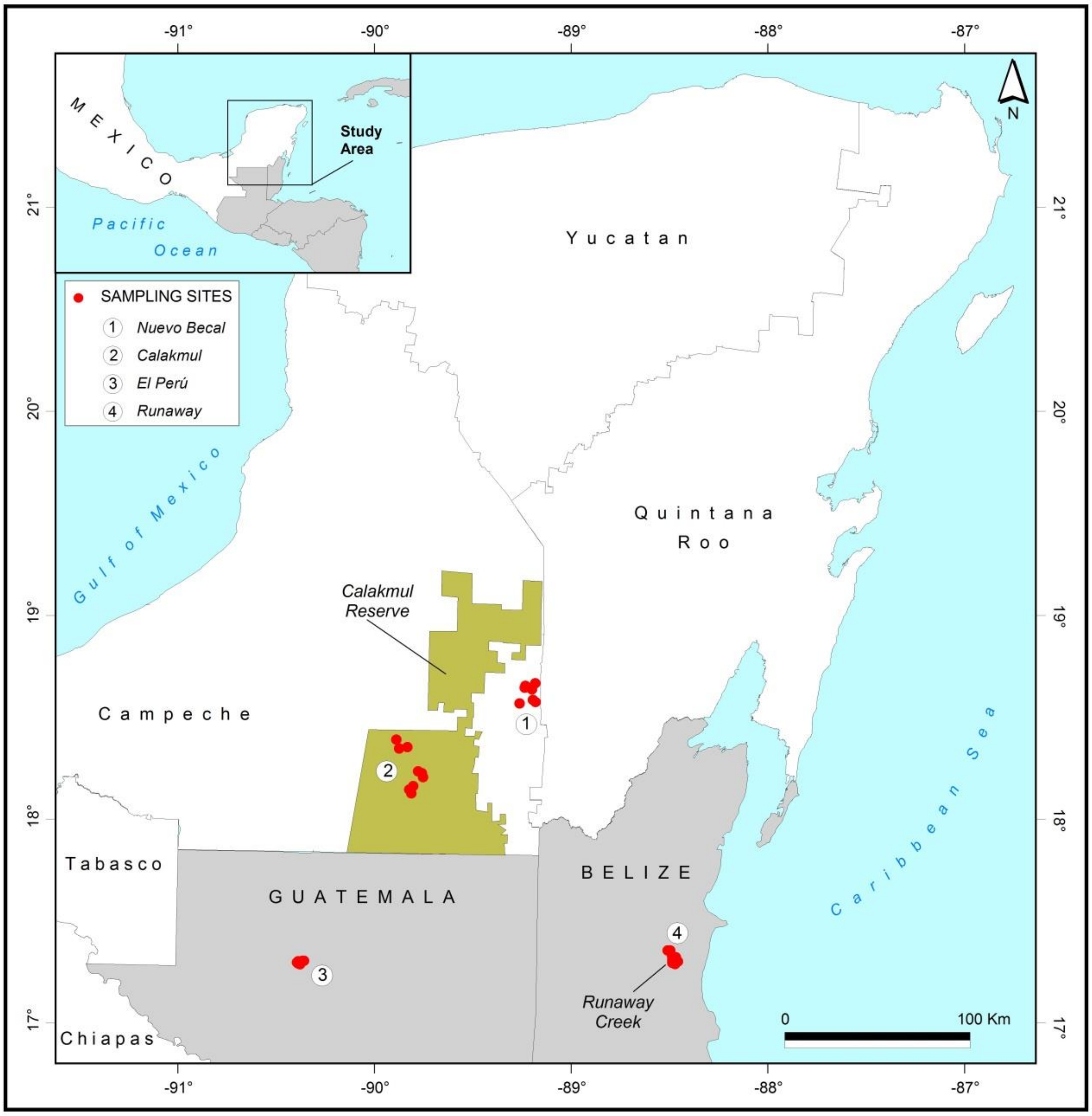

Figure 1. The Maya Forest showing four study sites in Belize, Guatemala and Mexico

2.4 Methods

We conducted camera trap surveys at four study sites in three countries in the Maya Forest. A total of 34 camera-traps (CT) (RCNR-10, CBR-10, NB-7 and LTNP-7) stations were deployed concurrently from January to September 2015 on trails leading to waterholes (*aguadas*) at all four sites. The remote digital camera-traps RECONYX (hyperfire HC600 and HC800) inc and Bushnell (Trophy camera Brown) were interspaced from 0.7 to 3.7km to permit independency of capture event. This distance fits within the reported home range of our target species which has an estimated range of (0.62 - 2.32Km^2; Foerster, 1998). CTs were checked every three weeks to download data and service the cameras.

To estimate relative abundance index (RAI) of tapirs in waterholes, independent photos of tapir were divided by the number of days the cameras were working in the field (sample effort) multiplied by 1,000 (Trolle *et al.,* 2008). Previous and similar studies had used 24 h as the criteria to determine an independent photo or if identified by sex or any particular marks (Perez-Cortez *et al.,* 2012 & Sandoval-Seres *et al*., 2016). We opted to use the criteria of > 2 hour intervals to consider capture independence of an event, which follows the trend of similar studies in Costa Rica and Panama which used >1 hour as an independent event (Cove *et al.,* 2013; Meyer *et al*., 2015). SPSS 19 (SPSS Inc., 2011) was used to conduct a non-parametric test of Kruskal-Wallis to compare events among camera-trap and across study sites. Previously we tested the normality of the data with a Kolmogorov-Smirnov test.

We used the occupancy modeling methodology to evaluate the probability of tapir occupancy at four study sites. Occupancy is an alternative state variable to abundance, that uses the proportion of area occupied by a species and it allows to infer tapir occurrence when detection is lower than 1 (Mackenzie *et al.,* 2006). We partition the detection history in 36 blocks of 7days each and incorporated in a single-season occupancy model in the program Presence 6.9 (Hines, 2009). Six candidate models were evaluated using five site-specific covariates and a survey-specific covariate (Table 3.) The covariates were selected based on known ecology of tapirs and possible factors that influence occurrence and detectability (Wainwright, 2007; Padilla *et al.,* 2010; Licona *et al*., 2011; Cove *et al*., 2013). We measured the nearest distance in km to three human disturbance or infrastructure (village, road and forest edge) with the use of a Garmin GPS (City and Country) and Google earth imagery (City and Country). Rainfall data was acquired by using precipitation data accumulated by researchers for the past five years on each study site. Three types of protected areas were catalogued using the following criteria as the premise: legal protection to perpetuity and existing management plan in action. We categorized the CBR and LTNP a federal reserve as highly protected, RCNR a private reserve was considered as moderately protected, and NB a community reserve as poorly protected. Camera-trap nights (Cove *et al.*, 2013) was the only survey specific covariate incorporated in the analysis and was determined by the total number of days each camera was fully operational. All continuous covariate data were standardized to z scores for further analysis (McKenzie *et al.,* 2002) and the models were averaged using maximum likelihood of occupancy (Burnham & Anderson, 2002).

In this study we assumed that all survey sites have an equal probability of tapir detection (p), so we only allowed occupancy (Ψ) to vary with the covariates. Therefore, we set the detection as the constant. We used six a priori hypotheses for the occurrence of tapirs with five covariates (Table 1; Cove *et al.*, 2013) for later comparison with the PRESENCE results. The models were evaluated using Akaike Information Criterion (AICc) and Akaike weights (w) and all models considered were within 95% CI (confidence intervals). The global model which includes all covariates was run to insure that there is no covariates interaction. The models that were not able to converge were removed from the model ranking.

Table 1. Hypothesis of a priori occurrence (PSI) models for Baird’s tapir, model, model structure and expected results on the four study sites at the Maya forest.

Hypothesis	Model	Model Structure	Expected results
No habitat covariate effect	Ψ(.) p(.)	β0	
Positive effect as distance to village increases	Ψ(village) p(.)	β0 + β1 (village)	β1 > 0
Positive effect as number of trap nights increases	Ψ(Trap nights) p(.)	β0 + β1 (Trap nights)	β1 > 0
Positive effect as distance to Forest edge increases	Ψ(Forest edge) p(.)	β0 + β1 (Forest edge)	β1 > 0
Positive effect as Rainfall increases	Ψ(Avg. Rain fall) p(.)	β0 + β1 (Avg. Rain fall)	β1 > 0
Positive effect as road distance increases	Ψ(Road) p(.)	β0 + β1 (Road)	β1 > 0

2.5 Results

The total sampling effort at the four study sites in the Maya Forest reached 5,201 camera-trap nights (Table 2) yielding 252 independent photos of tapirs. Five out of the 34 camera trap sites yielded no photos of tapir of which 2 were from CBR, 2 at LTNP and 1 at RCNR.

Tapir relative abundance index (RAI) was higher in CBR (62.32) followed by NB (57.66), RCNR (48.43), and was lower in LTNP (39.08; Table 2). The Kruskall Wallis (KW) test yielded significant differences among the sites (T= 15.465, P= 0.001, df=3), therefore the premise of the null hypothesis that the distribution of tapir is the same across sites was rejected. A KW pairwise comparison of sites test showed that the RAI in NB differed both from CBR (T= -17.306,P=0.002) and RCNR (T= -14.35,P=0.014). The analysis at the level of individual study sites showed there was no significant differences in the RAI between waterholes within three of the sites (CBR, KW test T=13.37, P= 0.115 df = 7; RCNR T= 13.739,P= 0.132 df = 9; NB, T= 2.777, P= 0.905 df = 7). In LTNP there was a significant difference of RAI among ponds (T=21.893,P= 0.001, df = 6). The significant difference of LTNP camera trap sites are between Brecha Corta Fuego – C-Idaeh (T= 23.214, P=0.018) and Brecha Corta Fuego – 1FC14 (T= 23.214, P=0.018).

If perfect detection is assumed, the cumulative naïve occupancy estimate was 88% for all study sites. Using data from both independent and combined sites, the model that kept both occupancy and detection constant had the highest support to explain the tapir occupancy as it had the lowest AIC value (Table 3). However, distance to road, the number of trap nights and distance to village also had an influence on the occupancy when they were included separately in the analysis. This was supported by the Δ AIC < 2 with the top ranked model (Table 3). These three latter models support the "a priori" hypothesis (Table 1) that there is a positive influence when distances increases from roads and villages and when number of night traps increase on tapir occurrence throughout the four sites in the Maya Forest. Forest edge and average rainfall models presented a negative influence on tapir occurrence and do not support the a priori hypothesis. However, the effect was negligible, as the significance (slope) of the regression coefficient was low for the two variables (-0.09 and -0.07 for distance to forest edge and rainfall respectively). Including the protected area status as a covariate led to the models to fail to converge, therefore this variable was eliminated.

Occupancy modeling was also conducted for each of the four study sites independently. CBR models successfully ran three model candidates; LTNP two, RCNR one and NB data failed to converge and yielded no meaningful results. The road distance model has the highest model support on the three independent study sites: CBR ($\beta = 1.05 \pm 1.49$ SE), LTNP ($\beta = 1.15 \pm 1.47$ SE) and RCNR ($\beta = -0.09 \pm 1.08$ SE) (Table 3) which concurs with the all study sites models. Both CBR and LTNP supported the overall a priori hypothesis that there exists a positive effect in tapir occurrence as road distance increases. However, RCNR results yielded a negative effect but with a non-significant negative slope and NB failed to converge.

Table 2. Relative abundance Index, trapping effort and average precipitation for all study sites

Study Site	Relative Abundance Index	Trapping effort	Average precipitation (mm)
Calakmul- Mexico	62.32	1312	1,076
Nuevo Becal-México	57.66	827	1.076
Runaway Creek-Belize	48.43	1578	2,094
Laguna del Tigre NP- Guatemala	39.08	1484	1,323

Table 3: Model selection statistics for all four sites and a global model with all covariates at the Maya forest of occurrence probabilities for Baird’s tapir and untransformed coefficient.

					Untransformed coefficients of covariates (SE)[1]				
Model	Δ[2]	ω[3]	K[4]	(.)[5]	Road	Trap night	Village	Forest edge	Rain fall
Ψ(.) p(.)	0	0.3099	2	2.23 (0.64)					
Ψ(Road) p(.)	1.09	0.1797	3		0.55 (0.57)				
Ψ(trap night) p(.)	1.52	0.1449	3			0.50 (0.71)			
Ψ(village) p(.)	1.65	0.1358	3				0.36 (0.60)		
Ψ(Forest edge) p(.)	1.98	0.1151	3					-0.09 (0.64)	
Ψ(average rainfall) p(.)	1.99	0.1146	3						-0.07 (0.61)
Ψ (Global)[6] p(.)	30.89	0	6		0.22 (0.38)	0.18 (0.41)	0.16 (0.51)	-0.17 (0.50)	0.03 (0.35)

1 Coefficients are in logit space and corresponds to each model covariate **2** AIC difference

3 Akaike weights **4** number of model parameters **5** model constant **6** All covariates

Table 4: Model selection statistics for each of the four sites at the Maya Forest of occurrence probabilities for Baird’s tapir and untransformed coefficient

				Untransformed coefficients of covariates (SE)[1]			
Model	Δ[2]	ω[3]	K[4]	(.)[5]	Road	F. edge	Village
Calakmul							
Ψ(.)p(.)	0	0.43	2	2.5(2.35)			
Ψ(Road) p(.)	1.39	0.21	3		1.05(1.49)		
Ψ(Forest edge) p(.)	1.69	0.18	3			0.70(1.19)	
Ψ(village) p(.)	1.75	0.17	3				0.66(1.26)
Laguna del Tigre NP							
Ψ(.)p(.)	0	0.49	2	1.79(1.08)			
Ψ(Road) p(.)	1.15	0.28	3		1.15(1.47)		
Ψ(Forest edge) p(.)	1.47	0.23	3			0.83(1.23)	
Runaway							
Ψ(.)p(.)	0	0.73	2	2.21(1.06)			
Ψ(Road) p(.)	1.99	0.27	3		-0.09(1.08)		
Nuevo Becal	None of the models applied were able to converge to produce meaningful results						

1= Coefficients are in logit space and corresponds to each model covariate **2** = AIC difference

3 = Akaike weights **4** = number of model parameters **5** = model constant

2.6 Discussion and Conclusion

This study represents the first attempt to evaluate the occurrence of Baird's tapirs at waterholes at a regional scale in the Maya Forest, a site of global importance for biodiversity. Our results indicated that Baird's tapir abundance at waterholes was higher at study sites with low precipitation and when further away from human infrastructure. This study highlights: (1) the critical importance of waterholes and thus warrants higher protection efforts necessary for the survival of tapirs, and (2) that distance to road had the highest influence on tapir occurrence across the three countries of the Maya Forest.

Baird's tapir is intrinsically linked to water bodies for protection against predators, to regulate body temperature, and for resting and defecating (Terwilliger, 1978; Naranjo, 1995; Algers *et al*., 1998). This unique behavior and dependence to water may be altered with ever changing landscape and climate as waterholes in the Maya Forest are ephemeral and fragile ecosystems sensitive to the duration of the dry season (Reyna-Hurtado *et al.,* 2010). If climate change predictions of severe droughts for the Yucatan Peninsula do occur (Magrin *et al.,* 2007), the ecosystem may no longer be able to sustain a functionally connected network of waterholes for endangered species such as the Baird's tapir (O'Farrill *et al.,* 2014). Therefore, studies on waterholes dynamics are imperative and urgently needed so as to learn its importance for endangered wildlife and to implement conservation strategies.

Our study had a high record of independent photos (with an average relative abundance of 51.87 per 1,000 trap nights) on the four sites in comparison to similar camera-trap studies on Baird's tapirs in Mexico and Central America. In Costa Rica at

Cordillera de Talamanca, Gonzales-Maya *et al*., (2009) reported a Relative abundance of 40.28 while in Balam Ka'ax Quintana Roo, México, Perez-Cortez *et al.,* (2012) and Calakmul, Campeche Mexico, Sandoval-Seres *et al*., (2016) reported indices of 37.57 and 37, respectively, and Meyer *et al., (*2016) reported an index of 6.7 in Darien, Panama (cameras were not placed at ponds). Our findings are far above the benchmark reported by authors across the Baird's tapir range. A potential explanation could be that the tapirs use waterholes more frequently in dry sites due to the lack of water in the landscape as suggested by O'Farrill *et al.,* (2014). CBR and NB sites showed a highly skewed number of independent photos on two particular waterholes where 60% of the photos were documented in a camera site in both cases. This suggests that *Bonfil* site at CBR and *Lechugal* site at NB are critical for tapir conservation. These waterholes have increasingly become more important as the drought periods increase in the Yucatan Peninsula which is further exacerbated by a documented decrease of 16% in precipitation in the last 50 years (Mardero *et al*., 2012). In addition, 2015 has been the warmest year ever recorded and unusually high temperature may have favored an increase presence of tapirs by the waterholes compared to previous years. This trend was corroborated by one of the authors personal observations (R. Reyna pers. comm) that from 2008 to 2015 the dry seasons were more severe, leaving *Bonfil* and *Lechugal* as the main if not the only source of water for wildlife during dry season in these two study sites. This could be a reason why CBR ranked the highest in relative abundance indices followed by NB. Another potential reason for overall high tapir abundance in our study sites could be related to tapir movement patterns. It has been documented that *T. bairdii* and *T. terrestris* tend to reduce their core activity areas during dry season and remain near sources of water (Foerster & Vaugh, 2002; Noss *et al*., 2003; Trolle *et al*., 2008). This cluster in movement patterns near water sources thus increased the capture rate at our cameras (Reyna-Hurtado *et al.,* 2016).

On the other hand, RCNR and LTNP study sites showed homogenous events and average number of photos at waterholes across camera-traps and presented a relatively low abundance indices compared to the Mexican study sites. Our occupancy analysis supported the results of the relative abundance indices as occupancy estimation was higher in both CBR and NB followed by el RCNR and LTNP. A plausible explanation is the humidity gradient in the Yucatan Peninsula with rainfall and moisture increasing from north to south (Folan *et al.,* 1983; Gunn & Adams, 1981) and the absence of a free flowing river in the Mexican sites. Unlike the Mexican sites, Guatemalan and Belizean sites count with a river 5km which is within reach of a tapir daily mobility capacity (Foerster, 1998; Reyna-Hurtado *et al.* 2016) from the study sites and have more water sources spread over the landscape. As such, climate and topographic factors have an effect on the abundance and occurrence of tapirs on the waterholes within the Maya Forest region. Tapir population in Mexican sites are more dependent on waterholes and vulnerable to severe droughts therefore relying on waterholes as their sole source of water than their counterparts in the south where water is more available throughout the year.

The influence of human disturbance, especially roads and villages had an effect on tapir occurrence, as showed by our top ranked model where tapir occurrence increased with distance to human infrastructures. This finding concurred with Cove *et* *al*., (2013) who found that increasing distance from villages led to higher tapir abundance in Costa Rica, and with Tobler (2002) who also showed that tapirs in southern Costa Rica were more abundant in areas with limited human presence.

The protected areas in the Maya Forest have different status of protection and each area is managed differently. Results from occupancy analysis at the level of individual study site varied in tapir occurrences as the distances from roads and villages increases. CBR and LTNP who are Federal protected areas and on a higher protected status accord to a positive association to increases in distances to road and village model. On the other hand, RCNR, a private protected area, and NB, a community managed which are medium and poorly protected failed to converge on these models. A potential explanation is that roads and villages were close to the camera stations in both sites. Nevertheless, the relative abundance index rank results place NB as second and RCNR third despite to their protection status which suggest that tapirs may be resilient and adaptive to human pressures across their particular range (Cove *et al.,* 2013). All indications showed that tapir populations are thriving in NB despite anthropogenic pressures and given that they do not suffer heavy human presence and hunting pressures. These findings correspond with Reyna-Hurtado & Tanner (2007), and Sandoval-Seres *et al.,* (2016) in NB, and with R. Cal (pers. comm) in RCNR. Foerster (1998) findings in Corcovado National Park, Costa Rica also confirmed that Baird's tapir thrive and prefer secondary forest.

The Maya Forest, one of the last strongholds of the endangered Baird's tapir in Mesoamerica (Mendoza *et al.,* 2013) is under constant anthropogenic pressures despite its protection status and management levels. CBR is the largest block of forest on southern Mexico for flora and fauna needs calibrated and refined intervention on specific zones for the protection of this emblematic and endangered species. On a fine scale, particular and urgent attention is needed on specific waterholes that cater for large records of tapir occurrence during the peak of the dry season. Community and privately owned areas such as NB and RCNR showed their value for tapir conservation, and therefore need special attention on their protection status and their role as potential corridors to larger massifs of forest. This highlights the potential that community forest may have for tapir conservation. At RCNR and LTNP sites, attention is needed on regulating the agricultural and ranching expansions on the periphery of the reserves and possible wildlife-human conflicts in the future.

This study represents a snapshot of the current status of the Baird's tapir on waterholes on three different countries and management levels. Apart from habitat loss, hunting, land use changes and increased infrastructures as main threats to the species, severe and prolonged dry season and their impact on the availability of water at ponds are also eminent threats (Magrin *et al.,* 2007). More collaborative efforts on a systematic research design are essential not only for the conservation of tapirs' habitat but also for an understanding of waterhole usage dynamics. This study sets the path for future and similar studies in the Maya Forest where strategic research is needed to enhance survival and viability of the Baird's tapir population in the region.

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3.0 Conclusión general

Este estudio presenta un panorama del estatus actual del tapir centroamericano en cuerpos de agua de los tres países de la Selva Maya. A pesar de las amenazas evidentes tales como la deforestación, la fragmentación del hábitat, la cacería y las enfermedades bovinas transmisibles, este estudio mostró que la disponibilidad de agua es importante para los tapires y que la sequía prolongada es también una amenaza eminente. Se determinó que la abundancia relativa de tapires es mayor en sitios con menor precipitación y con mayor distancia a obras de infraestructura como los poblados y carreteras.

La Reserva de la Biosfera de Calakmul (RBC) es el bosque tropical más extenso de México y el sitio con mayor índice de abundancia relativa de tapires entre los cuatro sitios de estudio. Esto demuestra la importancia de las aguadas en esta reserva durante tiempos de sequía para la conservación del tapir. Además, sitios tales como Nuevo Becal (NB) y Runaway Creek (RC) con estatus limitados de protección, demostraron su importancia para la conservación del tapir al tener índices de abundancia relativa en segundo y tercer lugar de entre los cuatro sitios de estudio. Por lo tanto, se requiere atención a sus estatus de conservación y sus roles como corredores potenciales que favorecen la conectividad entre grandes fragmentos de bosques. Esto puede ser debido a la mayor disponibilidad de agua en las aguadas y un rio a 5 km de los sitios. No obstante, se necesita mantener el estatus de conservación de El Perú que es uno de los más altos en la región y con un manejo activo. Además, en estos dos sitios se necesita atención para regular la expansión de la ganadería y la agricultura en las periferias y evitar así conflictos emergentes entre humanos y fauna silvestre. Tampoco no hay que olvidar que los cuatro sitios en general presentaron un índice de abundancia relativa más alto que otros sitios donde se ha estudiado (Gonzales-Maya *et al*.,2009; Perez-Cortez *et al.,*2012; Sandoval-Seres *et al*.,2016; Meyer *et al.,* 2016).

Los modelos de ocupación demostraron que la infraestructura humana tiene un efecto negativo en la ocurrencia de tapires. RBC y el Perú son sitios con mayor estatus de protección y tuvieron un efecto positivo en la ocurrencia de tapir mientras las carreteras y los poblados se encuentren lejos de las cámaras-trampa. Es evidente que estas áreas protegidas están jugando un rol en la conservación de los tapires. Por otro lado, NB y RC, áreas protegidas con menor estatus de protección, no presentaron efecto alguno en la ocurrencia de tapires debido a que los modelos no convergieron. Esto puede ser debido a que los poblados y carreteras están cerca de las áreas protegidas. Esta evidencia trae a la luz que aunque estos sitios cuentan con menor protección, mostraron altos índices de abundancia relativa en comparación con el Perú. Lo anterior demuestra que los tapires son resilientes y adaptivos a presiones antropogénicas tales como la presencia de carreteras, poblados y bosques secundarios (Cove *et al*., 2013; Tobler, 2002).

Las iniciativas de protección de hábitat y declaración de áreas protegidas no son suficientes para la conservación del tapir. Es importante realizar estudios en las aguadas de las áreas protegidas para entender la dinámica del uso de este recurso y así recomendar mayor protección para las que presentan un mayor uso, como es el caso de las aguadas *Bonfil* en Calakmul y *Lechugal* en Nuevo Becal. Es esencial impulsar esfuerzos colaborativos transnacionales en estudios sistemáticos para tener un panorama más amplio de la ecología del tapir. Este estudio sugiere la necesidad de estudios colaborativos en la Selva Maya donde las investigaciones estratégicas son necesarias para la sobrevivencia y crecimiento de las poblaciones de tapires en la región.

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3.2 Resumen Curricular

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