

# Tapir population patterns under the disappearance of free-standing water

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Baird's tapir is the largest Neotropical tapir species, and it is considered Endangered by the IUCN. The Calakmul Biosphere Reserve (CBR) is the largest protected tropical forest in Mexico. The CBR is at the heart of the Maya Forest, a tri-national forest located in Mexico, Guatemala, and Belize that is the largest tropical forest outside the Amazon River basin. Free-standing water in the CBR occurs in only a few ephemeral ponds. These ponds are rare in the landscape, with a mean density of one pond in every 10 km<sup>2</sup>, and with an average distance among ponds of 3 km. Only some of these ponds have free-standing water in every year. A decreasing trend in water availability from these ponds was detected from 2008 to 2018. Our present objective was to document population of the tapirs during these 11 years, and reveal any relationship to the pattern of water availability. Using the technique of photo-trapping, we monitored from 9 to 15 ponds over a period of 8 years (a total of more than 18,000 camera-days) during the 11-year period. Results showed that although the population remained relatively stable, the index of relative abundance indicated a slight decrease in population abundance and in some sites seemed at least superficially associated with decreasing water availability. Such long-term population studies are becoming more important for estimating the impacts of possible changes and for predicting the future of populations. In turn, they assist the conservation of endangered and sensitive species such as Baird's tapir.

El tapir de Baird es el más grande de las especies de tapires Neotropicales y está considerado como en peligro por la UICN. La Reserva de la Biosfera de Calakmul (CBR por sus siglas en inglés) es el área de bosque tropical protegido mas grande de México y se encuentra en el corazón de la Selva Maya, un bosque tri-nacional localizado entre Belice, Guatemala y México considerado el bosque tropical mas extenso de Mesoamérica. El agua de lluvia en la CBR percola al subsuelo y solamente en pocos sitios (localmente conocidos como aguadas) se almacena agua en el suelo. Estos sitios son raros en el paisaje con una densidad de uno cada 10 km<sup>2</sup> y una distancia promedio de 3 km entre aguadas. Solamente algunos de esos sitios conserva agua durante la época seca de cada año. Se detectó una reducción de la disponibilidad de agua desde el 2008 al 2018. Documentamos la población de tapires durante estos años y examinamos la relación con este patrón de reducción de la disponibilidad de agua. Usando la técnica de foto-trampeo monitoreamos entre 9 a 15 aguadas en 8 años dentro de este periodo de 11 años. Con un total de mas de 18,000 días-cámaras encontramos que aunque la población de tapires de la CBR permanece estable en promedio el índice de abundancia relativa detectó una ligera disminución en la abundancia y en algunas aguadas se asoció con la falta de agua. Estudios de largo plazo de especies en peligro asociadas a cuerpos de agua son importantes porque permiten estimar los efectos de la disponibilidad de agua y predecir futuros escenarios para las poblaciones de fauna silvestre. Esta información es esencial para elaborar planes de conservación de especies en peligro y sensibles tales como el Tapir de Baird.

**Keywords:** Calakmul Biosphere Reserve; ponds; *Tapirus bairdii*; *Tapirella bairdii*; water availability

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## Introduction

Wildlife, especially large mammals and birds, are suffering dramatic reductions across the globe, due mainly to hunting and habitat reduction ([Ripple et al. 2016](#)). Baird's tapir (*Tapirus bairdii*, also known as *Tapirella bairdii*, see: [Alvarez-Castañeda et al. 2015](#) for a review of the species and its taxonomy) is the largest of the Neotropical wildlife and is the only Peris-

sodactyl species living in the Mesoamerican forest ([García et al. 2016](#)). This solitary species lives in well-conserved humid tropical forest from Mexico to Ecuador. Baird's tapir is the largest tapir species in America, and it is considered Endangered by the IUCN (Red List, International Union for the Conservation of Nature; [García et al. 2016](#)). Baird's tapir is ranked 34<sup>th</sup> among species that need conservation attention ([Issac](#)

[et al. 2007](#); [Ripple et al. 2016](#)) and is ranked 10<sup>th</sup> among the rarest Neotropical species ([Dobson and Yu 1993](#)).

Tapirs are the only species able to disperse some large seeds in Neotropical forest ([O'Farrill et al. 2013](#)), and play the role of the largest herbivores, feeding especially on seedlings and herbs ([Naranjo 2009](#); [Tobler et al. 2006](#)). Baird's tapir populations are decreasing throughout the entire population range due mainly to poaching, habitat loss and fragmentation ([García et al. 2016](#)). Estimations about how many tapirs are in the wild vary from 3000 ([García et al. 2016](#)) to more than 5000 ([Schank et al. 2017](#)).

Calakmul Biosphere Reserve (CBR hereafter) is the largest protected tropical forest in Mexico and is at the heart of the Maya Forest, a tri-national forest located in Mexico, Guatemala and Belize. The CBR is the largest tropical forest outside the forests of the Amazon River basin ([Reyna-Hurtado 2007](#)). In CBR, the forest is seasonal and most of the precipitation percolates underground, and only in a few places have free-standing water ([Reyna-Hurtado et al. 2010](#)). These few ponds (locally known as "aguadas") are the only source of water for wildlife and for some human communities in the dry season. These ponds are rare in the landscape, with a mean density of one pond almost every 10 km<sup>2</sup> and with an average distance of 3 km among them ([Reyna-Hurtado et al. 2009](#)). In addition, these ponds do not contain free-standing water every year ([Reyna-Hurtado et al. 2012](#)). These ponds are essential for the survival of some species, such as the white-lipped peccary (*Tayassu pecari*) that was documented that some groups of peccaries moved as far as 17 km to reach "aguadas". Also, for tapirs, "aguadas" are essential for survival and tapirs visit them frequently ([Sandoval et al. 2016](#), [Carrillo et al. 2015](#)).

Recently, the technique of photo-trapping, or camera traps, is becoming popular among ecologists for estimating parameters of population and behavior of cryptic or secretive species ([O'Connell et al. 2011](#)). Additionally, ecologists have developed theoretical models of animal occupancy (detection or non-detection of the species in a specific site) as a surrogate for animal abundance ([Royle and Dorazio 2006](#); [MacKenzie and Nichols 2004](#)). Occupancy rate estimation is based on the idea that animal detection is imperfect, and every species has some probability of being detected in any given site ([MacKenzie et al. 2006](#)). Thus, occupancy rate is estimated based on the detection probability, and is estimated from a series of repetitive samplings, where detection (1) or non-detection (0) of the species is recorded. It assumes that the population is closed and that the occupancy rate of the species remains stable ([O'Connell and Bailey 2011](#)).

In 2008, a group of conservationists and researchers from several Mexican institutions initiated a monitoring program of a set of ponds that are located in the center of the southern core of CBR, with the aim of monitoring annual changes in wildlife populations that might be associated with water availability patterns. We present the results of this long-term monitoring for the tapir population of the

CBR. This dataset is one of the longest on tapir populations, and water availability was recorded during the same period.

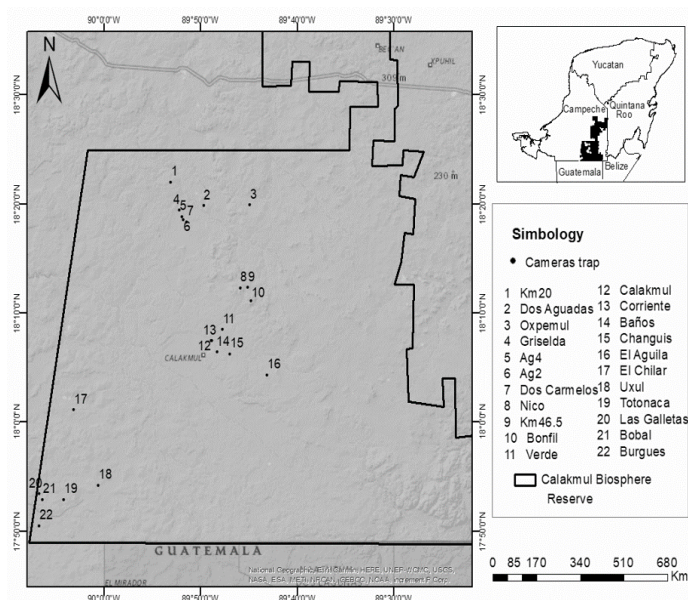
Our research focused on the following questions: What was the trend of the tapir population over 11 years in the CBR, concurrent with pond monitoring? Were the population changes related to water availability changes? Did tapirs favor specific ponds? The general objective was to identify population trends in the CBR over an 11 years period, and any relationship with changes in water availability. Specific objectives were: 1) comparing the population occupancy rate and relative abundance along 11 years in a set of ponds, and 2) examine the relationship of population occupancy and relative abundance of tapir with water availability.

## Methods

**Study site.** The CBR is a seasonal tropical semidry forest located in Southern Mexico in the Yucatan Peninsula. The CBR extends over 7,238 km<sup>2</sup> and was decreed as a protected area in 1989 (Figure 1). The CBR is part of the Great Calakmul Region that includes the Maya Biosphere Reserve in Guatemala and the Rio Bravo-Dos-Milpas conservation area in Belize, which together comprise one of the largest tropical forests in Meso-America with an extent of more than 20,000 km<sup>2</sup>. The CBR is bordered on the west, north and east sides by more than 100 human communities (*ejidos*) with a total population around of 30,000 people ([INEGI 2015](#)). The southern area of the CBR is contiguous with the Maya Biosphere Reserve in Guatemala without any dispersal barrier between them. The Calakmul climate is warm and sub-humid (Aw), with a mean annual temperature of 24.6° C (Köppen modified by [Garcia 1988](#)). There is seasonal rainfall, mainly in summer and early fall, with an annual average of 1076.2 mm. The forest is classified as medium sub-perennial tropical forest ([Pennington and Sarukhan 1998](#)). The area's topography is very flat with some gently rolling hills. Mean elevation is 250 m above sea level with a few hills that reach 340 m. Water in the CBR is obtained through precipitation, since there is no permanent river system. Most of the rainfall percolates through the limestone, but some drains above ground into ephemeral ponds. These ponds constitute the only source for water for wildlife through the dry season ([Reyna-Hurtado et al. 2009](#); [Reyna-Hurtado et al. 2010](#); [Reyna-Hurtado et al. 2012](#)).

**Population Relative Abundance and Occupancy Rates.** Since 2008, a set of 9 to 15 ponds was selected so as to occur at least 1.5 km from each other. All these ponds are in the southern area of the CBR, an area that is isolated from any human community by two checkpoints of the CBR authorities, and have one single road that leads to an archeological site but with very few cars every day (less than 10 on average).

These ponds were monitored by setting up a single camera trap (Reconyx PC800 Hyperfire professional Reconyx, Inc. and Cuddeback Inc) at 50 cm high in each of 15 ponds from April to July of 2008, 2009 and 2010 and in 12 ponds



**Figure 1.** Map of the study area and the ponds monitored in Calakmul Biosphere Reserve.

from February 2014 to December 2018. The cameras were programmed to take five consecutive photos (1 photo per second) each time the sensor detected movement and were checked every 15 days in the period 2008 to 2010 and every 2 months in the period 2014–2018 to change batteries and memory cards.

To consider records independent, we used a 24-hour filter between tapir sequences to avoid having repetitive sequences of the same individual, unless individuals could clearly be distinguished, *e.g.*, female vs male; adult vs juveniles, or individual with unique marks or scars (Lira-Torres et al. 2014; Figure 2). We determined the Relative Abundance Index (RAI hereafter) using classical method with the following equation:  $RAI = N / (SE * 1000 \text{ camera-trap days})$ . Where:  $N$  = Number of independent records and  $SE$  = Sampling effort measured as the number of days multiplied by the number of cameras active. At the same time than cameras were active, we recorded water availability on each pond that was monitored every month and sometimes twice per month. We only recorded water presence or absence and not the amount, or the percentage of it.

**Statistical Analyses.** We estimated RAI for each year and for each pond. We estimated average RAI per year and per site, and also per period. We compared RAI between periods by running a T-test and among years and sites by running ANOVA tests. We also estimated occupancy rate ( $Psi$ ) and detection probability ( $p$ ) based on the occupancy theoretical models developed by MacKenzie et al. (2006), that are based on species having different probabilities of being detected at any given site. Thus, once the detection probability was estimated, the model estimated the real occupancy rate of any given site. These models work with a series of repetitive samplings, where the species detection (1) or non-detection (0) is recorded (MacKenzie et al. 2006). Detection and occupancy probabilities were estimated through 72 (monthly) sampling occasions using a single



**Figure 2.** A tapir and a calf recorded in a pond in Calakmul Biosphere Reserve, Mexico.

season model, assuming that tapir occupancy was constant through the sampling period (MacKenzie et al. 2006). We estimated the null models without covariates for the occupancy rate ( $Psi$ ) and detection probability ( $p$ ). These models were estimated in the software PRESENCE V. 12.7 developed by J. Hines based on MacKenzie et al. (2006).

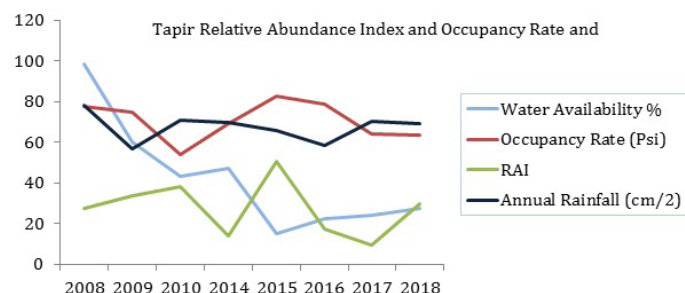
We tested differences between occupancy rate of the two periods and among years and sites using non-parametric statistical methods such as U Mann-Whitney and Kruskal Wallis tests. Finally, we tested the relationships between water availability, average rainfall (obtained at a coarse scale for the Campeche State) and the RAI and occupancy rate separately using regression and correlation analysis. We ran these analyses in R Studio software 3.1.3 (R Core Team 2016).

## Results

The camera trap effort totaled 18,184 days and covered a time lapse of 11 years divided into two periods, one from 2008 to 2010 and the second from 2014 to 2018; there was no sampling from 2011 to 2013. The sampling effort varied from 9 to 15 ponds per year and resulted in 457 independent records of tapir.

**Population trends along years and sites.** The average tapir population RAI from all sites and years was 27.6 (records/1000 camera days) and exhibited a decreasing trend from the first period to the second period with an average of 33.1 from 2008 to 2010 versus 22.5 from 2014 to 2018 although not significantly different ( $t = -1.55$ ,  $P$  value = 0.13,  $d.f. = 26$ ). The highest and smallest RAI per year were found in the second period with 50.7 in 2015 and 9.4 in 2017, respectively (Figure 3).

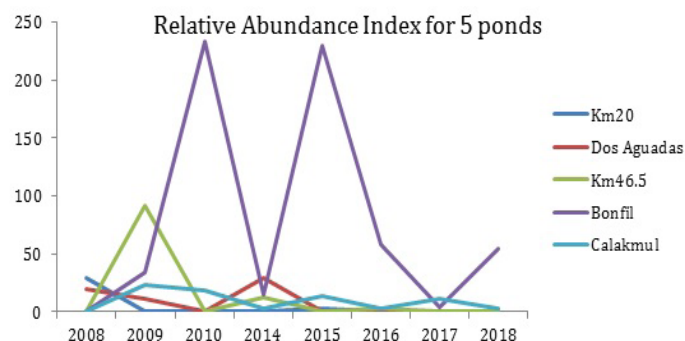
Of all the ponds monitored in the first period the pond “Bonfil” was the one with the largest RAI followed by the ponds “Bobal” and “Totonaca”. There were no significant differences among ponds in the first period (Anova  $F = 1.34$ ,  $P$  value = 0.24,  $d.f. = 44$ ). In the second period, pond “Bonfil” together with pond “Ag1” were the most important for tapirs



**Figure 3.** Water availability on ponds (as percentage of ponds with water), Average Annual Rainfall and Tapir Relative Abundance Index (RAI) and Occupancy Rate (Psi) estimated for all ponds. Occupancy rate was multiplied by 100 times to visualize the trend along the water availability trend. Rainfall in cm was divided by 2 to be on the same scale. Calakmul Biosphere Reserve, Mexico.

and “Bonfil” was the one with the highest RAI of all the ponds (Figure 4). There were statistically significant differences among ponds for this period (Anova  $F = 2.65$ ,  $P$  value = 0.015,  $d. f. = 50$ ) and Tukey post-hoc analyses showed that “Bonfil” differed from “Baños”, “Dos Aguadas”, “Km46.5” and “Nico” ponds. Some ponds were monitored in both periods. “Bonfil” was as the preferred pond in terms of relative abundance for tapirs, although the RAI variability was very large across years (Fig 4). A decreasing population trend was observed among all the ponds with the exception of Bonfil (Figure 4).

The average occupancy rate ( $Psi$ ) for all years and sites was 0.70 (0.14 SE) with a probability of detection ( $p$ ) of 0.40 (0.09 SE) again, for all sites and years. Occupancy rate ( $Psi$ ) showed a slightly different pattern than RAI and remained relatively stable from the first period (0.69) to the second period (0.72), and a U Mann-Whitney test did not show sig-



**Figure 4.** Annual average Relative Abundance Index (RAI) in a set of ponds that were monitored in the two periods. Calakmul Biosphere Reserve, Mexico.

nificant differences among these periods ( $p$  value = 0.82). The year with the highest occupancy rate was, again, the year of 2015, and the smallest was 2010 (Figure 3). A Kruskal-Wallis test did not reveal statistical differences on occupancy rates ( $Psi$ ) across years ( $p$  value = 0.457).

Occupancy rate ( $Psi$ ) of the ponds monitored showed different results than the RAI with “Bobal”, “Uxul”, “Totona”, “Dos Carmelos” and “Aguila” as the most important for tapirs in the first period. “Bonfil” was not identified as the best pond according to the occupancy rate in this period, but, in the second period “Bonfil”, “Corriente”, “Verde”, “Ag4” and “Nico” were the ponds with the largest occupancy rates ( $Psi$ ). A Kruskal-Wallis test on the occupancy rate ( $Psi$ ) among

ponds revealed that the differences were statistically significant ( $p$  value=0.023), with the above-mentioned ponds as the most important and “Changuis” and “Km20” as the least important for the first and second period respectively.

**Population trends and water availability.** Rainfall patterns over the years did not show a decreasing trend state-wide in Campeche (Figure 3) and were not correlated with water availability in the ponds, neither with tapir’s RAI, or tapir’s occupancy rate ( $P = 0.294$ ,  $P = 0.878$  and  $P = 0.450$  respectively according to Pearson correlation test). However, water availability in ponds did show a decreasing trend from 2008 to 2018, with 70 % of ponds being dry from 2008 to 2018. The year with lowest water availability was 2015 where only 15 % of ponds had water (Figure 3). Despite this decreasing trend in water availability of ponds, tapir population on average did not show a decreasing trend and there were not statistically significant relationships between either RAI and water ( $R^2 = 0.001$ ,  $F = 0.007$ ,  $P$  value = 0.935) or the occupancy rate and water ( $R^2 = -0.009$ ,  $F = 0.052$ ,  $P$  value = 0.827) (Figure 3).

## Discussion

We conducted a uniquely long-term study of Baird’s tapir population in a Neotropical forest. The main results indicated that Baird’s tapir populations in the Calakmul Biosphere Reserve were stable but slightly decreasing. At the same time, there was a dramatic decrease in water availability in the ponds. This was an interesting result because water availability on the ground dropped drastically from the initiation of the study through 2018. During this period, however, tapirs appeared to continue to visit ponds in a similar rate. In fact, in-depth analyses of the visitation rate indicated that in the year with lowest water availability (2015) a peak in the population index occurred, counter to our expectations.

However, this may have been due in great part to visits to a single pond “Bonfil” (64 %), that had free-standing water during that year while other ponds’ visitation rate decreased dramatically. This fine detail analyses of each pond visitation rate, provides evidence that tapirs are becoming stressed due to water scarcity and that can have important consequences at the population and behavioral level.

This finding agrees with the events that occurred in the first half of 2019 in the Calakmul municipality when several tapirs, in at least 12 separate incidents, were seen near villages, roads or water containers looking apparently for water. Several of them were in very bad physical conditions and several of them died (RR-H, DSP, and NAD pers. obs.). As far as we are aware, that situation has not occurred in these numbers in the area before (RRH pers. obs.).

Occupancy models did not detect a decreasing trend at the general level but the Relative Abundance Index of some ponds that were monitored the whole time did, with the average RAI of each period shows a decreasing trend for the second period. This finding indicates that in spite

of the theoretical expectation that occupancy models are more robust statistically (MacKenzie et al. 2006; O'Connell and Bailey 2011), they miss relevant information because they reduce the estimate of the population to only detection or non-detection of the species. We recommend use of a systematically collected index of relative abundance because it can better indicate changes in the population, especially when these changes are not very dramatic, as in the case of tapirs in the CBR.

Monitoring several ponds in the CBR gave us the opportunity to recognize some of them as very important for the tapir population. "Bonfil" is located in the center of the southern area of the CBR and is a very important area for tapirs. Another important pond is "Ag4" which is located at 22 km north of "Bonfil." Identifying important ponds should allow dedicated conservation efforts. For example, since 2015 the authorities of the CBR are setting artificial ponds (2 meters long x 0.5 meters wide) in some specific areas of the CBR. These efforts should be directed to sites important for tapirs. Additionally, some of these ponds can be treated as wildlife sanctuaries by giving them additional protections from tourists.

Climate change is affecting the CBR as well as the Yucatan peninsula (Magrin et al. 2007; Mardero et al. 2012). It is highly probable that the effects of climate change will intensify in the near future, or will intensify events that appeared periodically such as "El Niño" event that hit the area in 1998, 2003 and apparently between 2015 and 2016 causing less rains in some areas but heavy rains in other areas, or hurricanes that from time to time land in the Mesoamerica region causing damages to the forest and altering tapir behavior as was documented in Nicaragua by Jordan et al. (2019). So continued monitoring of tapir populations is needed to record population changes and to apply adaptive measures when possible.

For example, in the near future, if the population trend continues decreasing, the population of tapir in the area may be increasingly encountered in the communal forest of the municipalities that are outside the CBR as was predicted by O'Farrill et al. (2014). The communal forests have more water and large water bodies due to a natural precipitation gradient of the area (Reyna-Hurtado et al. 2009). If that happens, we will need to work with the communities around CBR to protect tapirs living in their forests.

Long-term wildlife population monitoring is advisable for detecting changes in population trends and relating these changes to environmental or human induced changes. Endangered species such as Baird's tapir need to be monitored closely because their sensitivity to changes in the environment (Naranjo et al. 2015; García et al. 2016). The CBR is the stronghold for the Baird's tapir population in Mesoamerica (Schank et al. 2017), and the dramatic decrease in water availability necessitates detailed monitoring of population and behavioral changes. Additional studies to determine tapir movements are also advisable,

as the species can be resilient. For example, tapir movement abilities were demonstrated by a tapir that in the CBR moved as far as 10 km to visit some ponds (Naranjo 2009). In Nicaragua, in the Indio Maiz region, tapir changed movements in response to a hurricane (Jordan et al. 2019).

Wildlife is being affected by environmental and human induced changes at alarming rates. Long-term population studies are becoming more important for estimating the impacts of these changes and for predicting the future of the populations. Conservation measures are needed for endangered and sensitive species such as Baird's tapir.

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