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Estimating Detection Probability and Abundance for the Black Caiman (*Melanosuchus niger*) and the Yacare Caiman (*Caiman yacare*)

Andrea Svalberg

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Supervisors: Karl-Olof Bergman, Linköping University

Luis F. Pacheco, Universidad Mayor de San Andrés

Examiner: Anders Hargeby, Linköping University

Linköpings universitet

Department of Physics, Chemistry and Biology

Linköpings universitet

SE-581 83 Linköping, Sweden

Institutionen för fysik, kemi och biologi

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Författare/Author:

Andrea Svalberg

Sammanfattning/Abstract:

The black caiman *(Melanosuchus niger)* and the yacare caiman *(Caiman yacare)* have in the past been exposed to overexploitation due to the economic profit for their hides, and therefore suffered from great declines in population sizes, especially black caimans. Legal regulation efforts made it possible for these two species to recover and today they are widely distributed in South America. Evaluation of protection and management of populations of top predators like these caimans depend on the ability to detect the animals. The probability of detecting a crocodile, or any animal, is affected by several factors such as habitat complexity and behaviour why it is of importance to acknowledge such matter in order to obtain reliable results for further implications. This study aims to investigate the detection probability and abundances in these two species as a contribution to the monitoring efforts at a local scale. Night counts were performed in Cedral lagoon located in the Beni region in Bolivia. By using the relation between marked animals and resightings of them, as well as the abundance estimate produced by the Lincoln-Petersen estimator, estimates of detection probabilities could be accounted for the total caiman population (black plus yacare caimans) and the black caiman population. Very low sighting probabilities ($p = 0.03$) were obtained when based on marked animals who tend to be more wary after a capture event. Those based on the L-P output were higher (total caiman population $p = 0.15$, black caimans $p = 0.15$). Population sizes were estimated to 25 ± 8.5 black caimans and 34 ± 12 caimans in total. The population size based on marked animals was 12 ± 25.4 caimans.

Nyckelord/Keyword:

Abundance, Caiman yacare, Capture-recapture, Detection probability, Lincoln-Petersen estimator, Mark-resight, Melanosuchus niger

Content

1 Abstract

The black caiman *(Melanosuchus niger)* and the yacare caiman *(Caiman yacare)* have in the past been exposed to overexploitation due to the economic profit for their hides, and therefore suffered from great declines in population sizes, especially black caimans. Legal regulation efforts made it possible for these two species to recover and today they are widely distributed in South America. Evaluation of protection and management of populations of top predators like these caimans depend on the ability to detect the animals. The probability of detecting a crocodile, or any animal, is affected by several factors such as habitat complexity and behaviour why it is of importance to acknowledge such matter in order to obtain reliable results for further implications. This study aims to investigate the detection probability and abundances in these two species as a contribution to the monitoring efforts at a local scale. Night counts were performed in Cedral lagoon located in the Beni region in Bolivia. By using the relation between marked animals and resightings of them, as well as the abundance estimate produced by the Lincoln-Petersen estimator, estimates of detection probabilities could be accounted for the total caiman population (black plus yacare caimans) and the black caiman population. Very low sighting probabilities ($p = 0.03$) were obtained when based on marked animals who tend to be more wary after a capture event. Those based on the L-P output were higher (total caiman population $p = 0.15$, black caimans $p = 0.15$). Population sizes were estimated to 25 ± 8.5 black caimans and 34 ± 12 caimans in total. The population size based on marked animals was 12 ± 25.4 caimans.

Keywords: Abundance, Caiman yacare, Capture-recapture, Detection probability, Lincoln-Petersen estimator, Mark-resight, Melanosuchus niger

2 Introduction

The most basic and crucial variable for an ecologist in general is the information or estimation of the abundance (size of the population) of the population of interest (Kellner et al. 2014, Krebs 2014, O´Donnell et al. 2015). Trends in abundance can then be implemented in population time series, for monitoring, which is one of the fundamental tools in wildlife management (Stokes et al. 2010, Kellner et al. 2014, Lee et al. 2014, O´Donnell et al. 2015). To reach these objectives some kind of count or estimate of population size, or other variables of interest, needs to be performed. Complete counts are nearly impossible to achieve for most animal species, and, therefore a sample of the population (i.e. partial censuses, population indices) is used in order to estimate the variable of interest. One general concern in order to use population indices in long-term monitoring is the probability of detecting the animals in their habitat, because there are several factors affecting detectability, like cryptic behaviour of the species of interest, complexity of the habitat, sampling effort, experience of the observer and the method applied (O´Donnell et al. 2015). To study variables of interest e.g. abundance estimates, one can choose from a lot of available methods in order to obtain a suitable experimental design. For example, simple counts of a species can be used to investigate demographic parameters such as population size (Krebs 2014). Moreover, methods using marked animals and performances of one or several recapture events can use this information to study trends or patterns in populations and evaluate eventual predictions made (Woodward & Moore 1993, Mazerolle et al. 2007, Kellner et al. 2014, Krebs 2014). By the time of the application of some suitable method for population estimation, the general issue concerning detectability, perfect or imperfect, has to be addressed. Perfect probability ($p = 1$) is not often the case (White 2006, Kellner et al. 2014, O´Donnell et al. 2015), especially when working with reptiles or amphibians. Depending on what type of model used one should first try to reduce variability caused by some of the factors likely affecting detection probability for the species being studied. However, identifying and controlling the majority of factors affecting detection probability via protocol (Pacheco 1994) may be a challenging task and rarely succeeds completely. Nowadays there are several software programs designed to assist biologist in their work such as CAPTURE and MARK which can be more flexible regarding assumptions and detectability, but like all analysis the input data needs to be good (White 2006, Thompson 2002, Mazerolle et al. 2007). Kellner et al. (2014) highlights the problem with detection surveys where ecologists base their inferences on data with occurring errors, introducing bias into estimates which of course may have serious consequences.

One group of interest for monitoring and management is crocodilians which commonly are exposed to hunting, for the economic value of their meat and skins, which drove several species to the verge of extinction (Busack et al. 2001, Aguilera et al. 2008). Because most caiman species have experienced significant population losses, many species have been monitored over, at least, the past twenty years (Mourão et al. 1996; Aguilera et al. 2008, Da Silveira et al. 2008, Ten et al. 2008) and in many cases they have been able to regain population sizes (Crocodile Specialist Group. 1996, Ross 2000, Aguilera et al. 2008, Zisadza-Gandiwa et al. 2013). However, monitoring crocodilians can imply some challenges.

First, their habitats tend to change depending on the amount of precipitation, which normally varies seasonally. Flooded areas means larger area available for distribution and occurrence which may have a hampering effect on the probability of observing the animals, even when they are present (i.e. detection probability). Crocodilians can seek for hiding places in the rich vegetation in the water, aggravating for the observer to find them, increasing the proportion of animals that remain undetected (Woodward & Moore 1993, Fujisaki et al. 2011, Fukuda et al. 2013). Wariness can also vary between populations and depends on the size of animals, which can further affect sightability, because some animals are more easily approached than others (Pacheco 1996b), which in turn will affect detection probability for both populations, and size classes. One obvious issue with crocodilians is their ability to swim away under the water making them quite hard to monitor in comparison to terrestrial animals. This applies specifically when estimating body sizes (Woodward & Moore 1993, Fukuda et al. 2013). In contradiction, the possibility to exploit their light reflecting eyes at night facilitates detection of crocodilians at long distances (Woodward & Moore 1993).

The black caiman (*Melanosuchus niger,* Spix 1825) is the largest neotropical caiman and can be found in the Amazon river basin (Da Silveira et al. 1997, Ross 2000). Populations of the black caiman suffered great declines between 1950-1970 primarily due to hunting for its skin and meat. Subsequent actions in the 80-90's like protection via the CITES regulations and further within-country regulations have had a positive effect on the population sizes (Aguilera et al. 2008, Ten et al. 2008). Nowadays the black caiman is widely distributed in Bolivia, Brazil, Columbia, Ecuador, Guiana, French Guyana and Peru (Ross 2000). Similarly, the smaller yacare caiman (*Caiman yacare,* Daudin 1802) was also exposed to great hunting pressure during this period (Coutinho & Campos 1996). Today, however, the species is widely distributed in Argentina, Bolivia, Brazil and Paraguay as a result of regulations regarding hunting etc. (Crocodile Specialist Group 1996, Mourão et al. 1996, Busack et al. 2001). Aguilera et al. (2008) suggest that the greatest threat for the two caiman species today is general disturbance by humans. These two species' have commercial interest in terms of harvesting programs, for both meat and hides (Busack et al. 2001, Aguliera et al. 2008, Caldwell 2015), but there is also an important ecological aspect in their function as top predators (Zisadza-Gandiwa et al. 2013). With proper management interests like these can be satisfied while maintaining stable and viable populations. From here on, *M. niger* will be referred as the black caiman and *C. yacare* as the yacare caiman.

This study aims to investigate the detection probability and abundances in these two species as a contribution to the monitoring efforts at larger spatial scales, using a mark-resight method and the Lincoln-Petersen estimator (Krebs 2014, Lee et al. 2014). The sampling area is Cedral lagoon (ca. 6.5 km shoreline), located within the Beni Biosphere Reserve Estación Biológica Beni where both species occur (Pacheco 1996a, 1996b), which was chosen because of the capture and marking efforts already performed in the area.

3 Material & methods

Ten marked individuals of the black caiman and yacare caiman (seven and three, respectively) were included in the study. I applied a mark-resight method defined as one marking event (performed before this study) and subsequent resightings of both marked and unmarked individuals (Lee et al. 2014). Estimates of sighting probability (probability of detection) were based on the assumption that resightings of marked animals in relation to the total number of marked in the population, represent the detection probability and, if one has a good estimate of the probability to observe an individual, then the total population size can be estimated (Pacheco 1996a, White 2005, MacKenzie et al. 2006).

Because I ended up with only two replicate night counts application of the Lincoln-Petersen estimator was considered as the best option (Nichols 1992, Mazerolle et al. 2007, Krebs 2014). Application of the Lincoln-Petersen estimator was used to estimate population sizes for the whole caiman population (including black and yacare caimans) and the black caiman population separately. This was because of the small sample size for marked yacare caimans (table 2). After I estimated the population sizes, using the L-P estimator, I could make another estimate of detection probability which took into account both marked and unmarked individuals.

The original idea was to establish detection frequencies for each marked individual because we had the advantage of using radio tags with specific frequency for each individual (table 1), which not seldom is a problem when applying mark-resighting models (Lee et al. 2014). However, this was not possible because of the low resighting frequency (table 2). Furthermore, although the best time for crocodilian surveys are during the dry season, which in the study area would be June- November, when animals tend to concentrate in the water bodies (Woodward & Marion 1978, Woodward & Moore 1993, Pacheco 1994), time limitations forced me to conduct the study during the transition between wet and dry season.

Overall, I met a lot of complications with the functions of the motors as well as the availability of them, available boat drivers and canoes, rain and cold temperatures, not optional time of the season and full moon. With three weeks for data collecting, I only completed nine nights of effective sampling which forced us to prioritize the performing of some counts before desired circumstances. The result was a small sample size with large variation.

3.1 Study area

The study was carried out at Cedral lagoon (ca. 6.5 km shoreline), located within the Beni Biosphere Reserve Estación Biológica Beni (BBR), Bolivia (14˚30'-14˚50S and 66˚00-6640'W), where both species occur. The BBR spans over 135 000 ha with a spectra of habitat types, like forests combined with swamps and tropical savannas (Miranda 1995; Pacheco 1996a, 1996b). The hydrology of the river Maniqui is known to affect the surroundings, resulting in several stages of succession in the adjacent vegetation (Miranda 1995). The study area is characterized by tropical savannas and forest swamps and with a water depth that varies greatly with season. Cedral lagoon used to be separated from the river Maniqui and have a water depth of 1.5-2 meters[1]. However, in the spring 2016 the river broke into the lagoon resulting in an alteration of the lagoons characteristics, as lower water depth and shape, which in turn affects the distribution and availability of habitats for the caimans. Because of the transition situation heading against dry season, muddy beaches and shallow water were abundant at the time of the survey. The shape of the lagoon was more like a shallow-, irregular river and the risk of getting stuck at the beaches in order to approach individuals made it hard to determine species' and sizes of caimans. During this period of time the study area is frequently exposed to a weather event called surazo, which include cold temperatures and a lot of rain making it unsuitable to conduct night surveys. Some of my surveys had to be conducted under surazo conditions (table 2).

3.2 Spotlight surveys

The study was planned to cover at least 20 sampling nights. However, I could only complete nine because of problems finding a functioning motor, an available boat driver with a canoe, rain and cold temperatures,

[1] Pers. Comm. Luis F. Pacheco, Biology department, Universidad Mayor de San Andrés

the timing of the full moon and the layout of the lagoon creating great problems to just travel with a canoe as well as approaching caimans.

Counts were performed by two observers during nine sampling nights using a motor driven dugout canoe and a headlamp powered by four 1.5 V batteries (Pacheco 1996a), following standardised procedures (Fukuda et al. 2013). Before performing counts intended for analysis's the two observers calibrated their counts and measures of body sizes to increase the accuracy and precision (Woodward & Moore 1993). Every night count followed a predetermined route[2] with a boat driver/guide from the area who had adequate experience in the matter, making the sampling route quite standardized, knowing that distribution of the animals varies over time and space (Fukuda et al. 2013). Survey duration was 4-6 hours.

One person acted as a spotter while another one was recording the data, where one night count constituted one sample, followed by several replicates for increased precision. Ten marked individuals (captured previously to this study) with an individual radio frequency made it possible to distinguish between the animals being tagged and untagged animals during night surveys (table 1). When the spotter observed an eye-shine an attempt to approach the caiman was done in order to determine species and size, exploiting the fact that their eyes reflects light and that they tend to freeze when illuminated (Woodward & Moore 1993). Unidentified animals, as in cases where the animal disappeared or approaching was not possible (e.g. too shallow water with great risk of getting stuck), were noted as "eyes only" and used only for the total number of spotted caimans. Estimation of body size was based on the total length (from snout to distal end of the tail). However, a more common way to estimate body size once in the field is to base the estimation on the size of the head, using the well-known relationship between the size of the skull and the body length, because one will seldom get the chance to observe the animal properly (Magnusson 1983, Aguilera et al. 2008, Fukuda et al. 2013). Night counts were not conducted at rainy, or cold, nights because of the great effect on the probability to detect an animal (Pacheco 1996). Unfortunately, the limited time forced me to perform some counts during cold nights (table 2). Fukuda et al. (2013) highlight the need for regular pauses (e.g. every 90 minute) because concentration of observer and data recorder are

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[2] Pers. Comm. De la Quintana, Biology department, Universidad Mayor de San Andrés

negatively affected by time conducting survey[3]; therefore, we stopped surveys every 90 minutes for about 10 minutes and then resumed the survey.

The layout of the lagoon during the sampling period made it very hard to approach a large fraction of the discovered eye-shines, usually because it was way too shallow to continue with the canoe and too risky (i.e. the risk to get stuck in the mud) to get out of the canoe and continue approaching by foot. Furthermore, although it was desirable to standardize the sampling procedure as much as possible, it was not possible in terms of which kind of canoe we were using, because guides and canoes differed in availability forcing us to use whatever was available at the time to complete a few counts.

Table 1. Sex, species and size distribution within the marked group. Only one of them, 003, was resighted in the survey.

Individual (Marked)	Sex	Species	Size
165	Male	*M. niger*	113
444	Male	*C. yacare*	185
544	Female	*M. niger*	211
505	Female	*M. niger*	331
124	Female	*M. niger*	206
003	Male	*M. niger*	250
245	Male	*C. yacare*	210
223	Female	*C. yacare*	164
483	Male	*M. niger*	161
184	Female	*M. niger*	121

Source: P. De la Quintana, Unpubl. data.

3.3 Data analyses

3.3.1 Detection probability

Detection probability was accounted for by means of using the number of detected marked individuals in relation to the total number of marked individuals. Estimation of abundance was based on a capture-resighting procedure, by comparing between numbers of detected marked animals and unmarked animals using the Lincoln-Petersen estimator (Krebs 2014). The output of the estimator i.e. the estimates of population sizes,

[3] Pers. Comm. Luis F. Pacheco, Biology department, Universidad Mayor de San Andrés

could then be used to obtain another estimate of detection probability. When modelling real world systems and populations some loss of information cannot be avoided. Therefore some assumptions needs to be done for any time-limited capture-recapture study:

1. Closed population. Because target populations are sampled over a short time period I assumed the populations remained closed, which means that during the sampling period there were no births, deaths, immigration or emigration occurring (Krebs 2014, Mazerolle et al. 2007, Fieberg et al. 2015).
2. The sighting probability of the marked individuals are representative of the unmarked individuals (Mazerolle et al. 2007, Fieberg et al. 2015).
3. The marking event does not affect detectability which in this context means resighting of marked animals (Mazerolle et al. 2007, Fieberg et al. 2015).
4. Variation in sightability. Requires resight frequency for each individual (Krebs 2014).
5. Animals do not lose their marks between sampling events (Krebs 2014).
6. All detected marks in the following sampling occasions are reported (Krebs 2014).

The probability to detect an animal is influenced by the presence or absence of individuals in the study area, because the study was conducted over a short time the assumption of closed populations is safe to apply. Furthermore, the probability of detecting an available individual is affected by factors such as the survey methodology, experience of the observer, and type of habitat (McClintock et al. 2006, O´Donnell et al. 2015). Wary behaviour of caimans depends on sizes, individuals' experiences, and populations' history of disturbance (Pacheco 1996b), making it difficult to approach, or even detect individuals, as they may seek refuge in adjacent vegetation or make diving attempts. As discussed in the previous section, the ability of the observer affects the probability of detecting animals (O´Donnell et al. 2015). Indeed, observers differ in their ability to detect caimans in terms of experience and motivation (Woodward & Moore 1993), as well as the use of equipment can affect counts (Woodward & Marion 1978). The light strength and quality of the lamp used in the survey may also affect the results why we used one kind of flashlight at all night counts performed (Pacheco 1994).

Environmental factors (O´Donnell et al. 2015) generally affects detectability of crocodiles strongly. Caimans are morphologically cryptic, and in addition they have a cryptic behaviour, which clearly makes it difficult to detect them. Given that crocodilians are ectotherms air and water temperature affect their behaviour and spatial occurrence which in turn affects detectability (Zisadza-Gandiwa et al. 2013). This also applies to rainy or windy nights when counts were not performed (Pacheco 1996). For example, wind speed showed a significant effect on observations due to more cryptic behaviour. Environmental conditions like water depth, vegetation cover, wind speed, temperature in air and water and moon phase also affects the probability of detection (Woodward & Marion 1978, Pacheco 1994, Pacheco 1996a, 1996b, Da Silveira et al. 2008, Fujisaki et al. 2011). Calverley and Downs (2014) argue that individual differences in relation to environmental conditions are dependent on size. Da Silveira et al. (2008) discuss the variation in effect intensities by e.g. water level in different water bodies and the need to evaluate the effects for the studying area in order to achieve reliable results (Kellner et al. 2014). Pacheco (1996a) investigated the effect of environmental variables on caiman counts in the same study area but, unfortunately the situation in the lagoon recently changed.

3.3.2 Caiman abundance using the Lincoln-Petersen estimator

The Lincoln-Petersen estimator is a widely applied model used by ecologist to estimate abundance of populations. The limited time for sampling requires an assumption of closed populations and therefore this estimator is suitable (Nichols 1992). Simple estimators based on capture-recapture data like this one assumes the same and constant detection probability for all animals in the population investigated (Fieberg et al. 2015). The model is slightly modified to reduce the biases that otherwise tend to occur in the simpler model suggested by Nichols (1992), and consist of a first sampling event where marking of animals (M) occur, which are then released back into the population. At the second sampling event the total number of captured or resighted animals (C) notes as well as the number of marked individuals (R) within this sample. Based on these counts an estimate of population size can be accounted (Krebs 2014):

$$\tilde{N} = \frac{(M+1)(C+1)}{R+1} - 1 \ (Equation\ 1)$$

By calculating R/C, a value can be obtained and used to find the most proper way to calculate the confidence intervals. All values were less than 1 and therefore a binomial confidence interval was used. The two 95 % confidence limits (Z1 and Z2) can be found in figure 2.2 in Krebs (2014) and then used to provide the confidence intervals for each abundance estimate:

Lower 95 % confidence limit on

$$\tilde{N} = \frac{C}{R}M = \frac{1}{Z1}M \ (Equation\ 2.1)$$

Upper 95 % confidence limit on

$$\tilde{N} = \frac{C}{R}M = \frac{1}{Z2}M \ (Equation\ 2.2)$$

Krebs (2014) discuss how large a sample has to be in order to obtain a good estimate of abundance. Based on the guide in Krebs (2014) the accuracy of the four estimates of abundances could be investigated. If one obtain high accuracy of A= ± 10 % then the result can be implemented in research work in great need for good precision. Less accurate results of around 25 % are suggested to be enough to be used in management plans while 50 % are considered to be acceptable for a preliminary study.

4 Results

A total of 65 caimans were observed over the nine performed night counts. Of these 95.4 % was unmarked animals where 27.7 % could be identified and 67.7 % of the observations consisted of "eyes only". Resighting of marked animals was 4.6 % (figure 1). Mean sizes of the unmarked animals was 161.1 cm and 100 cm, and of the marked animals 199 cm and 186.33 cm (*M. niger* and *C. yacare*, respectively). Out of a total of 10 marked animals only one individual was observed in three of the nine replicate counts (table 2). However, only nights 8 and 9 fulfilled the conditions of a proper night count and were included in the analysis, as two replicates (Fukuda et al. 2013); while cold weather and excess illumination from moonlight made the rest unsuitable for data analysis (table 2).

First, a simple estimate of sighting probability based on the resightings of marked animals with respect to the total number of marked animals in the population (10) was calculated. Because resightings of marked animals were very low, only 3 observations at three occasions, I obtained a mean and SD sighting probability of 3.33 ± 5 % (table 3). Considering all nine night counts, and using this sighting probability, it was possible to estimate the total number of unmarked animals observed, two estimates of population sizes could be obtained with a mean and SD of 12 ± 25.39 (table 3, figure 3).

The idea was to use an additional approach to these simple estimates of population sizes and sighting probabilities by including outputs of the Lincoln-Petersen estimator in the analysis. Because the resightings of the marked animal were only black caimans (*M. niger),* it was possible to estimate the population size for the species' together (the whole caiman population), and for black caimans separately, given that the number of marked black caimans was known (7 marked). The Lincoln-Petersen estimator generated a population estimate of 31 black caimans and 43 for the total caiman population (black caimans plus yacare caimans) for the 8^{th} night count, with both a quite wide, and not so accurate confidence interval of 41-232 individuals. For the 9^{th} night count, the population size were estimated as 19 black caimans and 26 total caimans, with a confidence interval of 0-66, providing a mean of 25 ± 8.49 black caimans and 34.5 ± 12.02 individuals for the population in whole (table 4). By turning the situation around, and assuming that these were the real population sizes in the lagoon, another estimation of the sighting probability could be assessed by using number of unmarked animals observed for night 8 and 9 with respect to the whole population. The mean sighting probability with relation to the marked individuals (SP, TOT), now took on a higher value of 10 ± 0 % than the initial estimate were it was only based on the marked animals. The detection probability for the caiman population based on the population estimate obtained by the L-P estimator got a mean of 15.5 ± 0.71 %, and the black caiman population accessed a mean of 15.5 ± 7.07 % (table 4). By extracting values from figure 2.3 in Krebs (2014) I could analyze the accuracy of the estimates produced by the L-P estimator, which showed a low accuracy of A = ± 50 % meaning that the accuracy is acceptable given the small sample size, but should not be implemented in work intendent for research or management.

Table 2. Number of individuals observed in each night count and the distribution of marked, unmarked and "eyes only". Out of 10 marked individuals (7 M. niger and 3 C. yacare) only 3 resightings of one individual of M. niger was obtained. Night count 8 and 9 was considered to fulfill the desired conditions for a proper night count.

Night count	Notes	Marked	Unmarked	Eyes only	M. niger	C. yacare
1	Moonlight	0	1	0	1	
2	Moonlight	1	0	0	1	
3	Moonlight	0	0	2		
4	Moonlight	0	2	1		2
5	Cold	0	0	3		
6	Cold	0	2	5	2	
7	Cold	0	2	3	1	2
8		1	7	13	5	3
9		1	4	17	5	1
Sum		3	18	44	15	8

Table 3. Number of observations of marked and unmarked animals in each night count performed which was used to estimate a simple estimate of detection probability (SP, TOT), that in relation to the number of observations was used to estimate population size for the total caiman population (black and yacare caimans) (mean and standard deviation).

Night count	Observations (marked animals)	Total number of marked animals	Detection probability (%)	Observations (unmarked animals)	Population estimate
1	0	10	0	1	0
2	1	10	10	0	0
3	0	10	0	0	0
4	0	10	0	2	0
5	0	10	0	0	0
6	0	10	0	2	0
7	0	10	0	2	0
8	1	10	10	7	70
9	1	10	10	4	40
Mean			3.33		12.22
SD			5		25.39

Table 4. Estimates of population sizes generated by (1) sighting proportion based on resightings of marked animals (2) Lincoln-Petersen estimator for the total caiman population and (3) Lincoln-Petersen estimator for the M. niger population. Based on the population estimates an estimation of detection probability (in %) could be obtained for each group i.e. 1-3 mentioned above.

Night count	Population estimate (S.P, TOT)	Detection probability (S.P, TOT)	Population estimate (LP, TOT)	Detection probability (LP, TOT)	Population estimate (LP, *M. niger*)	Detection probability (LP, *M. niger*)
8	70	10	43	16	31	16
9	40	10	26	15	19	26

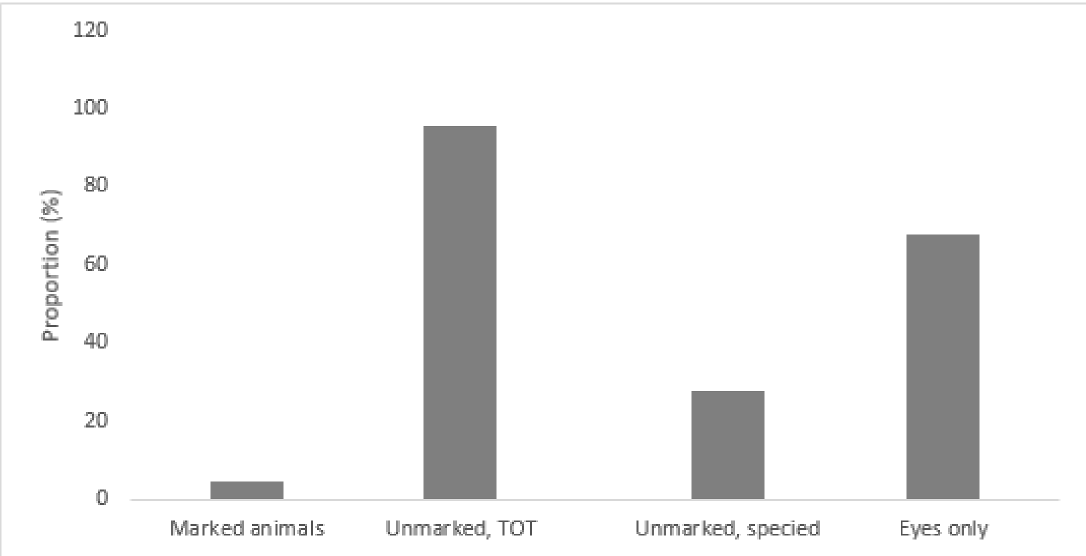

Figure 1. Proportions of observed animals over the nine performed night counts. Marked animals consisted of 7 M. niger and 3 C. yacare. Only one individual, M. niger, 003, was resighted in three occasions. Unmarked, species means animals who could be approached enough to determine species. Unmarked in total consist of all the unmarked animals observed. Eyes only were individuals that could not be approached enough to determine either species, or size.

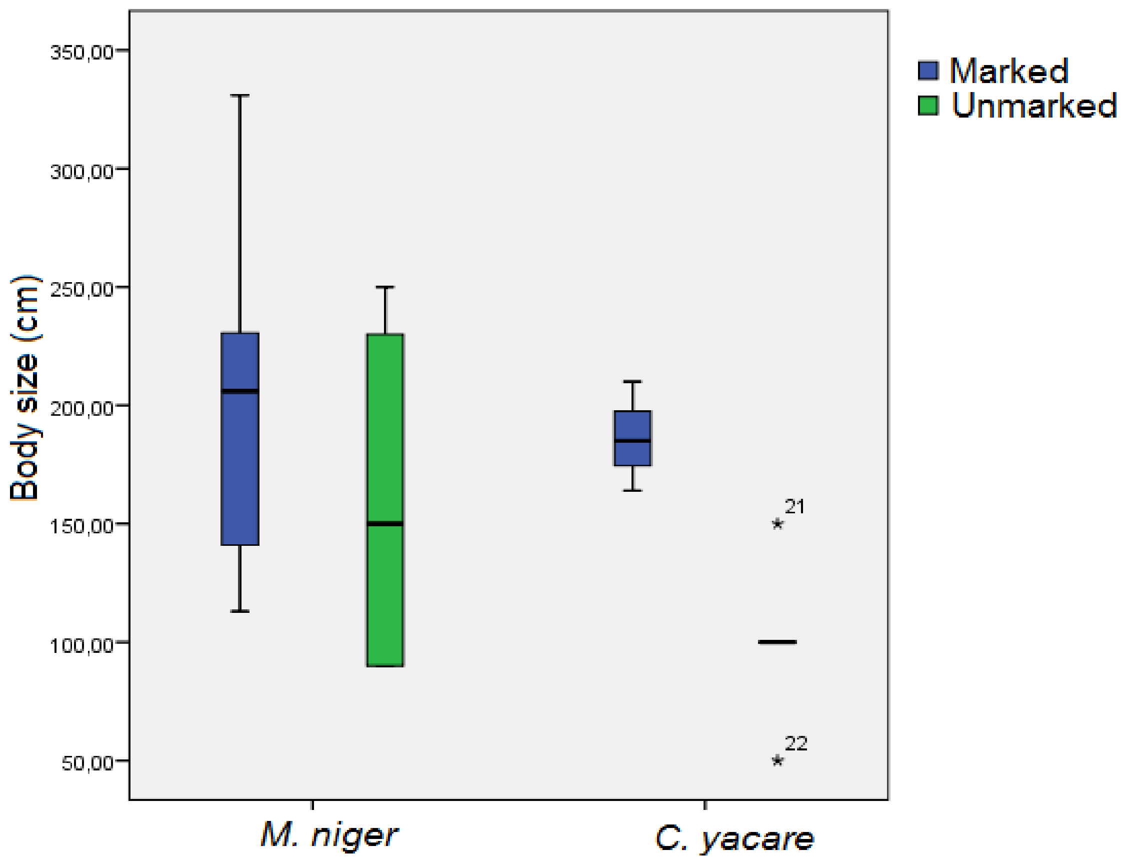

Figure 2. Body sizes of marked animals and unmarked animals that could be approached in order to determine species and body sizes. Body size of the only resighted marked individual, 003, was 250 cm (Median, 1st quartile, 3rd quartile, max- and minimum).

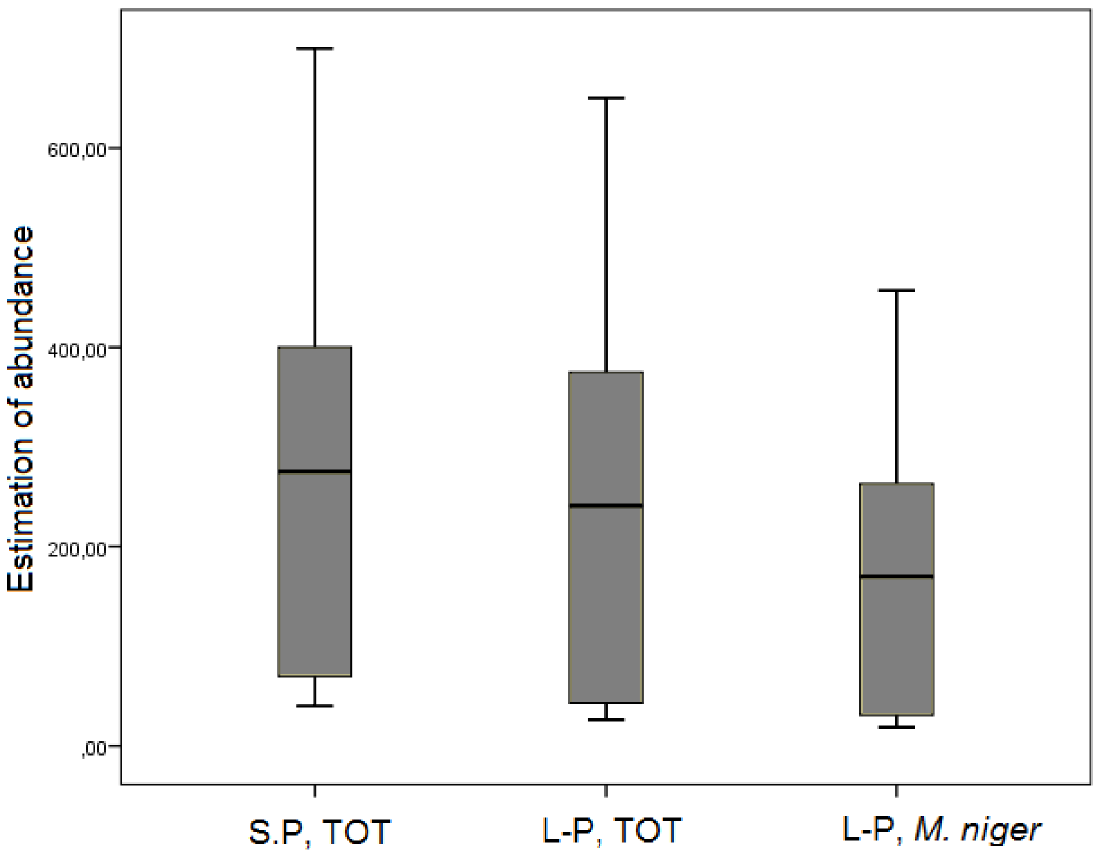

Figure 3. Abundance estimates based on (1) the detection probability generated by resightings of marked animals (2) Lincoln-Petersen estimator for the caiman population (both species') and (3) Lincoln-Petersen using data for only the black caiman population (M. niger) (Median, 1st quartile, 3rd quartile, max- and minimum).

5 Discussion

This survey was aiming for standardized factors in terms of equipment, weather and season. However, as many researchers are familiar with, time and financial limits may force one to collect data at times where all factors are not standardized. Because of time limitations night counts had to be performed during some cold nights, with full moon and with different canoes and drivers. As pointed out earlier illumination from moonlight can have a negative effect on counts due to the facilitated detection of the approaching canoe by caimans and the decreased effect of the flashlight, which is supposed to be the greatest source of light and therefore make the animal freeze (Woodward & Moore 1993, Pacheco 1996b, Fukuda et al. 2013). Strong effects on counts can be seen at the number of observations obtained during night counts 1-4 when there was a full moon (table 2). This also applies to cold weather, even though we collected a greater sample size in comparison to the first counts conducted, see night count 5-7 (table 2), when the weather event *surazo* brought cold temperatures. Weather factors are crucial, especially, when working with ectotherms because their activity level and behaviour are highly correlated to temperatures (Woodward & Marion 1978, Pacheco 1994, 1996a, 1996b, Fujisaki et al. 2011). As result, only nights 8 and 9 could be included in the analysis, further decreasing the already small sample size. Regarding season, the ideal scenario is to conduct the counts during the dry season, when crocodilians tend to concentrate in the water bodies, which facilitates counts (Woodward & More 1993). However, at the time of the survey, the season was more in a transition state and the shape of the lagoon was more like a river with adjacent smaller lagoons. This created problems approaching eye-shines because of the abundance of sandy beaches which were too muddy to walk on but too shallow to enter with the canoe. For this reason we obtained a high proportion, 67,7 %, of "eyes only". The inability to identify whether these were marked made them unsuited to include in the production of estimates for detecting probability and population sizes. The route and equipment in terms of observers and flashlights could be held standardized meaning that only one lamp was used and two observers with similar experience performed the eye-shine search. In conclusion, even though I aimed for as much standardized factors in my protocol as possible, I failed to reduce much of the variation in the collected data. In contrast, by excluding all samples with low quality I could reduce most severe sources of error for this study, but increased the problems of small sample size. Out of 21 days in the field and 9 performed night counts, I was only able to get two counts that could be used for analyses.

We were unable to approach a large fraction of caimans, and could not include the many "eyes –only" as they could not be identified with risk of disturbing the true number of resightings of marked animals. The result; very few actual observations of caimans that could be interpreted in the analyses. Under better circumstances a better estimate of detection probability would probably be obtained. As so well-pointed out by Kellner et al. (2014), estimates of the probability of detection can be much less than perfect. Furthermore, because I experienced high "invisibility" in my dataset i.e. the inability to include a great number of caimans known to exist (by night counts), there are reasons to suspect an unfair output, given that no estimator can produce reasonable estimates with a poor input (Kellner et al. 2014). At least, higher probabilities were obtained using the L-P estimator output (including unmarked animals) (caiman population $p = 0.15$, black caimans $p = 0.21$) which seems more reasonable than the initial estimate based on marked individuals ($p= 0.03$). MacKenzie et al. (2002) suggest moderate detection probabilities to be ($p > 0.3$) and estimates for other species (e.g. birds $p > 0.5$, e.g. Nichols et al. 2000), why my results seems a little bit low but in reasonable ranges given the special situation this survey was conducted under (e.g. variation in hydrology, wariness of marked animals, difficulties to approach animals due to beaches and separated water bodies). As discussed earlier a lot of factors affecting detectability of crocodiles may have a decreasing effect of detection probability.

Violations of assumptions result in biased estimates of the parameter of interest (Bailey et al. 2004), so it is important to evaluate if these assumptions held in each specific case. Because of the short time of performing this study, assumption 1 regarding closed populations, likely holds true (Krebs 2014, Mazerolle et al. 2007, Fieberg et al. 2015). Variation in sightability (Krebs 2014) could not be evaluated given that it requires a resight frequency for each individual which was not obtained. Concerning the violation of assumption 3, which suggest that the marking event does not affect resightings of marked individuals (Mazerolle et al. 2007, Fieberg et al. 2015), we experienced great "trap-shyness" meaning that we barely ever observed a marked animal. The low sighting probabilities obtained ranging from 3 - 15 % support this observation, where increased wariness likely has arisen in the populations due to captures and continuous resighting events. Aguilera et al. (2008) discuss the post-effects of hunting as a source of changes in habitat selection, which also could affect detectability of them. Higher ranges of probabilities were under greater influence of the unmarked animals who probably were less wary, because these estimates were not only based on data from marked animals who generally tend to be more wary (Pacheco 1996b). I have indications that unmarked animals who were approached or even caught at one night could show greater wariness the next night, since the unmarked animals tended to show up at the same place at several nights. Because of the limited area available for distribution we could detect some patterns in occurrences of some individuals. A general observation were the small home ranges of most caimans observed in the lagoon. I experienced greater wariness with larger animals (~ 200cm) than smaller ones (~ 90 cm), as suggested by Pacheco (1996b). This especially applies to marking events and the wary behaviour of the animals afterwards[4]. Furthermore, assumption 4 that treat the variation in sightability statement, is hard to evaluate because of the low resighting frequency, 10 % out of ten available marked animals considering the two night counts (i.e. night 8 and 9), and those obtained were only of one individual, 003 (figure 1). In reality, variation in sightability do exist given that individuals vary in behaviour and experience of e.g. a capture

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[4] Pers. Comm. De la Quintana, Biology department, Higher University of San Andrés

event (Anderson 2001, White 2006). How representative the detection probability of marked animals is for unmarked, assumption 2, (Mazerolle et al. 2007, Fieberg et al. 2015), is quite violated in this case given the straightforward results suggesting great differences in sightability between marked and unmarked animals.

In addition, I wanted to evaluate if there was a size difference between unmarked (who could be approached) and the marked animals, with respect to both the effect on wariness by the marking event, and the wariness correlated to size. Body size have been showed to have an effect of detectability in terms of variation in wariness (Pacheco 1996b), providing the prediction that larger animals should be harder to approach. To compare body sizes each group i.e. unmarked black caimans, marked black caimans, unmarked yacare and marked yacare caimans, were divided by the number of individuals included in each group. Unmarked yacare caimans were generally smaller than the marked animals, making it likely that a combination of size-correlated wariness and the inexperience of a capture event, may affect and result in a higher detectability for this group. There were less difference in sizes of marked and unmarked black caimans, but still unmarked animals tended to be smaller keeping in line with the predictions (figure 2). The fact that one of the largest marked black caiman was spotted at three occasions needs to be taken into account, as well as the variation in behaviour of individuals, may explain this observation.

Aguilera et al. (2008) argue that density of black caimans may affect the distribution of yacare caimans which could explain the less frequent encounters, especially with the pressing space as the lagoon is shrinking further into the dry season. In conclusion, there may be reasons to suspect that body size actually may affect sightability in this case, given the low sighting frequency of yacare caimans.

The Lincoln-Petersen estimator with application of the assumptions of closed populations and equal detection probabilities (Nichols 1992, Krebs 2014, Fieberg et al. 2015) was used to generate an abundance estimate of the caiman population inhabiting Cedral lagoon. A modified equation of the estimator was used to get an estimation of the theoretical population sizes and in extent a perception of the real population sizes (Nichols 1992; Krebs 2014). Unfortunately, the small sample size reduces the power of the L-P estimator which leaves me to hardly make any inferences (Nichols 1992, Krebs 2014). Krebs (2014) discuss and offers guidance into the question of how large a sample have to be to obtain a good estimate of abundance. All estimates where within A = ± 50 % and thereby could be considered as suitable for a preliminary study, but not for more precise work that requires higher accuracy like research for management plans and similar (Krebs 2014). A small sample can in extent be a source of bias as precision and accuracy decreases with less animals marked (Lee et al. 2014). Bailey et al. (2004) discuss the assessed low probabilities (usually $p < 0.1$, as in this case) of effective capture estimates with population estimates with large confidence intervals as a result.

There were negligible differences between estimates of population sizes produced by the two models (S.P and L-P estimator). Furthermore, the relation between these estimates seems fair as well, given that black caimans might constitute a larger fraction of the total caiman population (figure 3) following suggestions of competition of the two species' (Da Silveira & Thorbjarnarson 1999, Da Silveira et al. 1997). Even though the mean output of the two models for the total caiman population (L-P: 34 ± 12 and S.P: 12 ± 25.4 individuals) were different, their large standard deviations provided an overlap suggesting that the true population size should lay within this interval. If this holds true then the population of black caimans (L-P: 25 ± 8.5) should constitute the major part of the total caiman population in Cedral lagoon. Aguilera et al. (2008) detected well-distributed and high abundances of yacare caimans probably due to their faster reproduction and less selective choice of habitat, making it possible for them to distribute widely while black caimans suffers from slower reproduction, and also seems to prefer more clear water and remotely located lakes. Because Cedral lagoon used to be a separated from the river Maniqui, the high proportion of black caimans in the abundance estimate I obtained, could be fair given that black caimans might outcompete yacare caimans in remote lakes as suggested by Da Silveira & Thorbjarnarson (1999) and Aguilera et al. (2008). The limited availability of open water to travel on by the indigenous people in Cedral lagoon may result in an accumulation of human disturbances as only a few recently formed small rivers are possible to travel on by canoe. As discussed earlier, both drought and the shifted course of the river Maniqui, making it connect to Cedral lagoon, may have contributed to this situation. As a result detectability of the caimans may be affected further with continuous disturbances during this period of time with special characteristics regarding hydrology.

Anderson (2001) argues that "indexes" or demographic variables such as abundance estimates based on raw counts, are inappropriate to apply given that the index is a function of a lot of factors (e.g. environmental factors, equipment etc.) as well as a function of the true abundance. It is clear that a variety of factors influence, which makes the estimates weak in this case. However, marked individuals tend to be more wary than unmarked animals greatly affecting estimates of population sizes and other variables based on some kind of count of animals. This is important to consider in the work with crocodilians, as well as other species.

5.1 Societal and ethical considerations

Biodiversity is of general concern for the society as it is one of its most important foundations providing us with oxygen, food, water, medicines and other resources we heavily depend on. Furthermore, because interactions occurs within, and between ecosystems and species, biodiversity is of importance in order to maintain functional systems that can provide the society with such services. In this matter, estimating population size is one of the most basic and fundamental variable implemented in the management work, as this provide information of how to proceed with investigations and actions (Kellner et al. 2014, Krebs 2014, O´Donnell et al. 2015). Top predators are known to have a great impact on their system, and changes in population size resulting in loss of their functional role or disappearance usually tend to alter the whole system or food web where they interact (McPeek 1998).

Ethical considerations implies the exposure to stress and disturbances when approaching and eventual capturing of animals occur (Fukuda et al. 2015). However, this stress is considered to be minimal with known effects like increased wariness of the individual after encounter (Pacheco 1996b), but with small effects on their well-being in general.

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