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Monitoring of Siamese crocodiles (*Crocodylus siamensis*) in Bàu Sàu Lake, Vietnam.

VƯỜN QUỐC GIA CÁT TIÊN

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Abstract

The Siamese crocodile is a highly threatened species of South-east Asia listed as critically endangered (CR) by the IUCN. During the 1990's, it had totally disappeared in Vietnam, but in the early 2000's a population was reintroduced in the lake of Bàu Sàu, located in the Cat Tien National Park . This population originated from 60 adults that were released between 2000 and 2004. Since this reintroduction, Siamese crocodiles of Bàu Sàu have never been monitored on a regular basis, using a standardized protocol.
In spring 2019, 15 years after this reintroduction, we conducted 11 standardized counting surveys on Bàu Sàu lake to obtain updated information on the local abundance of Siameses crocodiles. Counts were performed at night with a flashlight (spotlighting technique), along a 1.5km transect covering the entire length of the lake. We were able to differentiate adults from juveniles, which provided us with basic but important information on the age structure of the population.
The highest count obtained on a single survey event was 286 crocodiles (58 adults and 228 juveniles), but because detectability is imperfect the population is likely larger than that. We found a significant effect of moon phase and wind strength on the detection of crocodiles. Highest counts occurred during the first and last quarters of the moon (intermediate brightness), and at low wind. Without additional information to disentangle detectability and abundance, we cannot estimate absolute population size. To solve this issue, we recommend using a combination of mark-recapture and double-observer approaches.

I Introduction

The Siamese crocodile (*Crocodylus siamensis*, Schneider 1801) is one of the world's most threatened crocodilian species, currently listed as Critically Endangered by the IUCN (Baillie and Groombridge 1996, IUCN 2019). Until the 1960's, this species was common in the rivers and swamps of Southeast Asia (Smith 1919, 1931), but during the second half of the 19th century, it declined very rapidly mostly due to poaching and habitat degradation (Kanwatanakid-Savini et al. 2012). Siamese crocodiles were also massively captured and taken from the wild to be raised in farms for the trade of their leather and meat (Vassilieva et al. 2016). By the early 1990s, this species was considered extinct in the wild, until a few remnant populations were later rediscovered in Cambodia, Laos and Indonesia (Daltry & Chheang, 2000; Kurniati et al., 2005; Platt et al., 2006; Simpson et al., 2006).

In Vietnam, all known populations of Siamese crocodiles were extinct from the wild by the 1990's. In 1999, a reintroduction program was undertaken by the Cat Tien National Park (CTNP), with the support of the World Wildlife Foundation (WWF; Polet 2006). Between 2001 and 2004, a total of 60 adults, donated by two privately-owned crocodile farms of southern Vietnam, were released in Bàu Sàu lake (Fig. 1), located inside CTNP. Before the collapse of the species in the 1980's-1990's, Bàu Sàu has been known to harbor large numbers of Siamese crocodiles, hence the choice of this particular location. The goal of the reintroduction project was to re-establish a pure-blood wild population of Siamese crocodiles in Vietnam, so before their release, these 60 crocodiles were DNA-tested at the University of Queensland (Australia) to ensure they were not hybridized with the saltwater crocodile *Crocodylus porosus* (Fitzsimmons et al. 2002). Since this reintroduction, occasional surveys and opportunistic observations have provided some information on the growth of the Bàu Sàu population (Polet 2006, Vassilieva et al. 2016), but it has not been formally monitored using a regular and standardized protocol. The first known hatching and breeding event was observed by Cat Tien forest rangers in 2005 (Polet 2006). In 2011, transects surveys provided a minimum known alive number of 150 crocodiles and 46 observed hatchlings (Vassilieva et al. 2016 ; Pahl 2012). No precise information has been released since then. Overall, the Siamese crocodiles remains largely unstudied in the wild, and much about its ecology is still unknown. Given its conservation status, it is highly important to gather more information on that species and ensure that all known populations living in the wild are monitored using robust methods. In this report, we present the results obtained from the monitoring that we performed on the Bàu Sàu Lake between February and April of 2019. We present general results from the raw data, as well as some statistical analyses, and we finish by providing specific recommendations that would help improve the monitoring in the future, if it was to be continued.

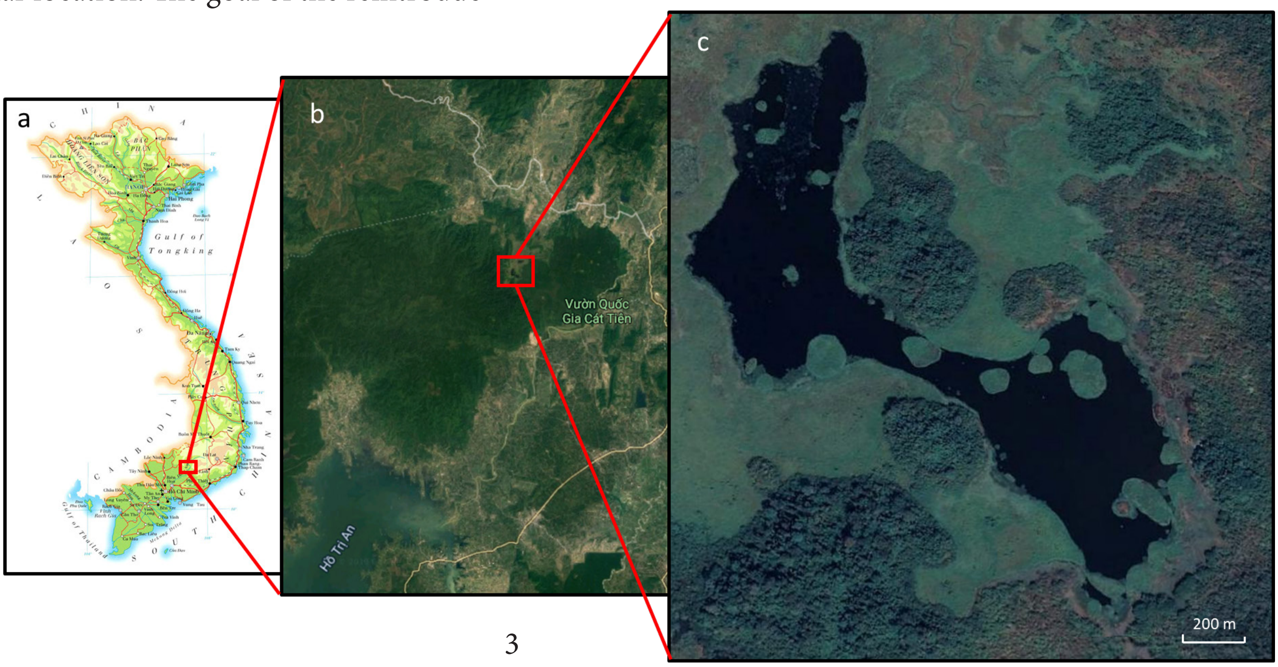

Figure 1: Location of the study area.
a: Map of Vietnam.
b: Satelite photo of Cat Tien National Park in Dong Nai county.
c: Location of Bàu Sàu (Crocodile lake) in the middle of the Cat Tien's jungle.

II Objectives

Our main objective is to provide guidelines for the implementation of a survey protocol that is aimed at gathering basic and essential information on the population of Siamese crocodiles of the Bàu Sàu lake. Currently, none of the basic demographic variables (population size, population growth rate, survival and reproductive rates) are known for this population. The first demographic variables that would need to be estimated to better track the conservation status of this population are :

1. A reliable metric of population size ; this will either be an estimate of real population size (ideally) or an index of abundance. With the current data 2019, we can only get an abundance index.
2. An estimate of annual population growth rate, which provides crucial information about the rate of increase or decline (or stability) of the population.

The survey protocol presented in this document, and as implemented in 2019, provides count data that could be used as a relative index of crocodile abundance on the lake. Such an index, if available each year, could be used to track population changes and estimate the overall population growth rate. The data also provide some information about the age structure of the population (proportions of juvenile vs. adults).

III Material & Method

1. Study Site

Bàu Sàu lake is located in the Cat Tien National Park (CTNP), in Southern Vietnam (fig.1). CTNP, which is mostly composed of tropical forest and wetlands, has a typical tropical monsoon climate (McKnight & Hess, 2000), with two very distinct seasons: the dry season (November to May) and the rainy season (May to November). During the rainy season, Bàu Sàu lake becomes much larger than its typical size during the dry season. The lake is covered by dense neophytic water hyacinth (Pontederiaceae) which provides suitable habitat for crocodiles to hide during the day (Vassilieva et al. 2016).

2. Species

Siamese crocodiles (fig. 2) are nocturnal species. During the day, they stay hidden in the dense vegetation all around the lake where they are very difficult to detect. At night, most crocodiles move to the water to feed, where they become much easier to find. Indeed, crocodiles can then efficiently be detected, using spotlights, thanks to the bright reflection of their eyes. This method of counting has been successfully used on other crocodilian populations (Murphy 2002 ; Simpson 2006).

Figure 2: Adult Siamese crocodile in its natural habitat in Bàu Sàu in Cat Tien National Park (© Guillaume Enot).

3. Study Design Overview

Crocodiles were counted at night using the spotlighting technique described by Webb and Manolis (1989). A powerful flashlight was used to reflect the crocodiles' eyeshine as we moved along a single transect across the lake (fig. 3). The 1.5 km transect crosses the entire length of the lake and, for each survey, it was performed within a time lapse of 30-40 minutes, which corresponds approximately to a speed of 3 km/h.

During the 2019 field season, surveys were carried between mid February and mid April, every quarter of moon phase (New moon [NM], first quarter [FQ], full moon [FM] and third quarter [LQ]) to assess if the moon phase and the ambient brightness on the lake would have an incidence on crocodiles activities and their detectability. On a same survey night (hereafter, "session"), this transect was repeated twice: first at ~7:30 pm and again at ~12:00 am (midnight). With the spotlighting technique, crocodiles cannot be individually identified, witch prevent the use of mark-recapture approaches for the data analysis. However, we were able to distinguish juveniles from adults in our counts.

4. Field protocol

Material required: The most important piece of material required is a boat to do the transect on the lake. To detect crocodiles bright eyes at night, powerful flashlights are required.

Transect implementation: The boat travels in the middle of the lake, such that the distance to shore is approximately equal on both sides (left bank and right bank). The observer counts crocodiles on both sides of the boat (fig. 4) and s/he must differentiate adults and juveniles, based on eye size and brightness (Table. 1)(Nguyen Tuan Anh 2017). It is very important to avoid counting the same crocodiles twice, because double counts will artificially inflate counts and will cause an overestimation of population size. Therefore, only crocodiles located on the sides of the boat must be counted, not those at the front or at the rear of the boat.

Environmental covariates: During the survey, several factors might affect the activity of crocodiles (hence, their availability for detection) and/or their detectability by observers. It is important to measure these factors to adequately account for detectability when we estimate population abundance.

The following covariates should be measured: ambient brightness, wind, fog, as well as air and water temperature. For brightness, wind, fog, we have created an index on a scale from 0 to 3, the value of 0 being the minimum and 3 the maximum. The values are attributed by the observer, based on its best personal assessment. A value of 0 means no fog, no wind and no natural light on the lake, while a value of 3 represents a high level of wind, fog or brightness. These indexes are somewhat subjective but they will provide important information to model detectability and target the best period to count crocodiles on the lake. Air and water temperature were not measured in 2019 because no thermometer was available.

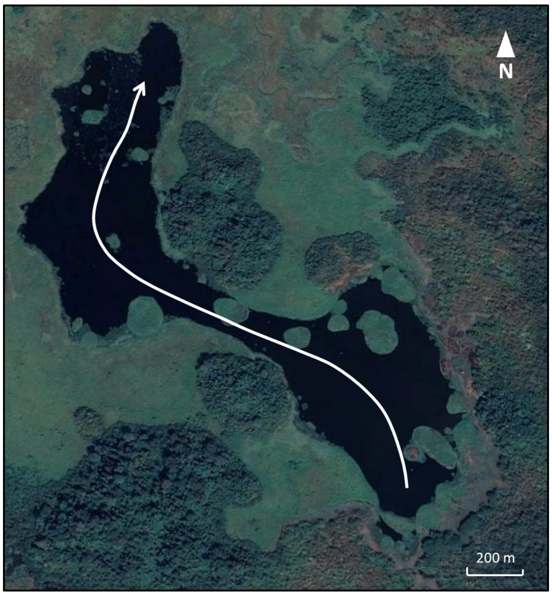

Figure 3: Line transect (1.5 km) used for every survey. It starts from the south end of the lake and ends on the north end.

Figure 4: The observer counts crocodiles on each side of the boat. If the observer illuminates and counts crocodiles in front of the boat, the crocodiles will be disturbed by the light and dive to move somewhere else. The chance of double counting will increase substantially. To avoid this issue, only crocodiles located on both side of the boat should be counted as the boat moves forward.

Identification	Diameter of eye orbit (cm)	Diameter of eye (cm)	Brightness	Distance between 2 eye orbits (cm)
Juvenile	< 2	< 1	Low to Middle	2 - 4
Adult	2 – 5 cm	1 – 1.5	High	6 - 10

Table 1 : Criteria used to differentiate the two age classes (adult vs juveniles) of crocodiles during spotlighting surveys. Three criteria were used: the size of the eyes, the distance between them and their brightness. This table was adapted from Nguyen Tuan Anh (2017).

5. Data analyses

We provide a summary and some statistical analyses of the data collected during the 2019 field season. The analyses of the count data were done using a Poisson regression, under a generalized linear modeling (GLM) approach. The primary purpose of the statistical analyses was to assess the effect of the moon phase, as well as the other environmental covariates, on the detectability of crocodiles during surveys. With only one year of data, this is all that can be done at this point.

IV Results

1. Data summary

Out of 12 surveys planned (6 nights, 2 surveys per night), we were able to perform 11. The very last survey had to be cancelled because of an excess of fog on the lake, rending the visibility close to null (fog index = 3). On average, transect duration was 34.1 min (SD = 4.6 min), with a the longest survey lasting 43 min and the shortest 29 min. For standardization purposes, we recommend keeping survey duration within a 30-40min window.

The maximum number [of crocodiles] observed in Bàu Sàu during a single survey was 286 : 58 adults and 228 juveniles. These values provide a minimum number [of crocodiles] known alive (MNKA) for 2019. This might be used as an index for abundance, for comparison with future years. This observation was made during the first quarter of a moon cycle [FQ]. During that survey occasion, other environmental factors were: Wind [0] ; Brightness [1] ; Fog [1].

The average number of crocodiles observed during surveys was 205.5 (SD = 49.9), with age-specific mean values of 46.4 (SD = 8.6) for adults and 159.1 (SD = 44.9) for juveniles. These data reveals the presence of many more juveniles than adults in this population. From the maximum counts, we estimate that there are 3.9 times more juveniles than adults (juvenile-to-adult ratio: mean = 3.5, SD = 0.86).

2. Statistical Analyses

We first tested the effect of the different moon phases on the detectability of crocodiles. We used the full moon as the baseline covariate for these tests. During full moon surveys we counted 171.5 crocodiles (SD = 55.8) on average. During all other moon phases, more crocodiles were detected, but this effect was statistically significant only for FQ and LQ, not for NM (fig. 5), and only for juveniles, not for adults (fig. 6).

During the FQ and LQ surveys, we counted 48% and 33% more crocodiles than during the full moon. These differences were highly significant ($P < 0.001$).

During the new moon, we counted only 12% more crocodiles than during the full moon, and this effect was close to be significant at the $\alpha = 5\%$ level, but not quite ($P = 0.08$).

We also tested the effect of wind and fog on detectability. Brightness being highly correlated to the moon phase, we do not provide test results for it, as it would be redundant with the moon phase results. Given the small sample size available, we only tested single covariate effects. Additive and interactive effects might exist, but it would require more data to estimate additional parameters.

When the wind was weak (wind index = 0 or 1), more crocodiles were counted (mean count (C) = 215 and 205, resp.) than when a stronger wind prevailed during surveys (for wind index = 2: mean C = 139, $P < 0.001$). This result was expected because crocodiles, which are ectotherms, tend to hide (e.g., in the vegetation) to stay warm when the wind is blowing, and they are thus less available for detection. There was no data for a wind index of 3, but we expect that even less crocodiles would be available for detection, and would not recommend doing surveys during such days.

The effect of fog as estimated from the data was not so easily interpretable, despite being highly significant ($P < 0.001$). Indeed, the test results indicated that detection was highest at a fog index of 1 (mean C = 250), and much lower when there was either no fog (index = 0, mean C = 193) or more fog (index = 2, mean C = 201). No data were available at fog index = 3, because the only day this occurred the survey had to be cancelled due to the lack of visibility. The estimate obtained at fog index = 0 is probably biased low because it is highly confounded with days of full moon. Indeed, out of six days with no fog, four occurred during a full moon (thus, low detectability). We would need more combinations of fog indexes and moon phases to get more reliable conclusions. On the field, it was evident that, on days with more fog, our ability to detect crocodiles was lower. We expect the effect of fog to mostly affect our own detection ability. It might also have an effect on crocodiles' activity, and thus their availability for detection, but at this point, it is impossible to draw any conclusion on that latter point.

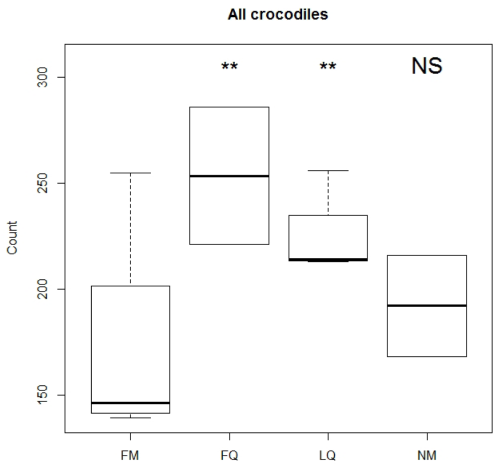

Figure 5: Effect of the different moon phases on the total number of crocodiles detected during surveys. FM was used as a baseline to assess the effect of the other moon phases. The statistical significance (at α = 5%) is provided as follows: a double-star (**) indicates a highly significant p-value ($P < 0.001$), while NS indicates a non-significant test result ($P > 0.05$). There was no intermediate p-values ($0.001 < P < 0.05$).

V Discussion

The counts performed in 2019 indicate a minimum population size of 286 siamese crocodiles (58 adults, 228 juveniles) in the Bàu Sàu lake. There are actually more crocodiles than that, as we inevitably missed some crocodiles during any survey, as highlighted by the variance between the repeated counts we did (SD of 49.9, for an average of 205.5 crocodiles counted per survey ; Min = 139, Max = 286). This lake thus homes a large population of Siamese crocodiles, relative to the world population size for that species, which is estimated at ca. 500-1,000 mature individuals (IUCN red list). This lake, which holds at least 58 adults, thus

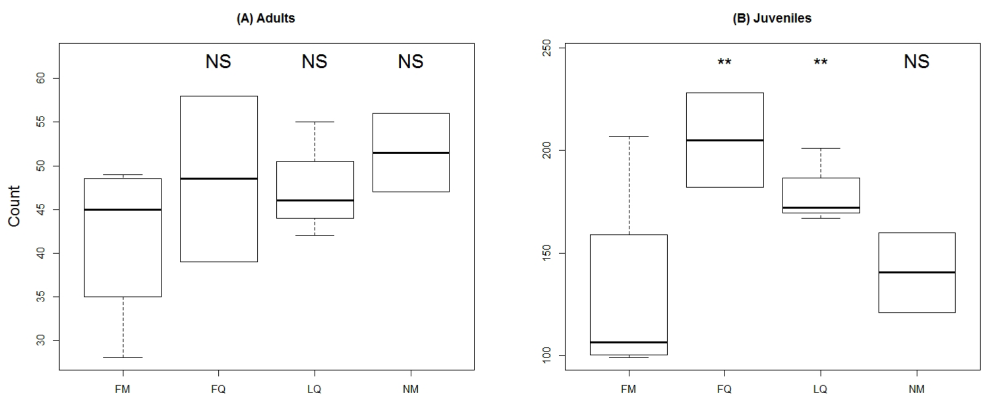

Figure 6: Effect of the moon phases on the number of (A) adults and (B) juveniles detected during surveys. FM was used as a baseline to assess the effect of the other moon phases. The statistical significance (at α = 5%) is provided as follows: a double-star (**) indicates a highly significant p-value ($P < 0.001$), while NS indicates a non-significant test result ($P > 0.05$). There was no intermediate p-values ($0.001 < P < 0.05$).

represents about 5 to 12% of the world's known population.

We also found that the population is heavily biased towards juveniles, in comparison to adults. Previous studies have suggested that this age structure is a sign of a depleted population (Webb et al. 2000; Fukuda et al. 2011, Nair et al. 2012). Given that the species was reintroduced to the lake 15 years ago, this population has probably not yet reached its equilibrium. If it keeps growing, the age structure should shift towards higher numbers of adults (and subadults), and low numbers of juveniles.

1. Population size estimation

Simple count data like these, collected under a standardized protocol with constant effort, can only provide a relative measure of population size (Slade and Blair 2000). Over multiple years, such counts can be used as annual indexes of abundance to assess population changes from one year to the next, but they do not allow estimating absolute population size because detectability remains unknown (Nichols 1992). Indeed, for any wild species, count data is always a product of two components: (1) the total number of individuals (N) in the population, which we seek to estimate, and (2) the detectability of these individuals (p). Getting reliable estimates of real population size requires estimating detectability. With count data collected at a single site, these two components remain confounded.

To estimate real population size and detectability separately, other survey methods must be used. The most reliable approach is the capture-mark-recapture (CMR) approach (Williams et al. 2002, Nichols 1992), which allows distinguishing individuals with some kinds of marks. This method is the most reliable because, unlike other methods, it takes into account the two components of detectability: (i) the availability of crocodiles for detection and (ii) the detection ability of the observer given that a crocodile is available (Diefenbach et al. 2007). For crocodile surveys, two other methods, less reliable than CMR, could be considered: (1) distance sampling (Buckland et al. 2001) and (2) the double-observer counting approach (Nichols et al. 2000, Forcey et al. 2006).

With distance sampling, the detectability of animals is modeled as a function of their distance to the observer. This method thus requires measuring the distance-to-observer of every animal counted during a survey. Although this method works well for some species, it would be difficult to accurately measure the distance of an eye shines detected at night with a flashlight. In addition, distance sampling would only partially solve the issue of imperfect detectability, because it would only account for crocodiles that are emerged in the water or on the lake banks. Any crocodiles that is under water during a survey would not be available for detection, which would bias estimates of population size (Diefenbach et al. 2007).

The double-observer approach requires two observers to count animals at the same time and same place during each survey. This provides a form of replicated counts which allows estimating detectability, using adequate statistical methods (Nichols et al. 2000). This method could easily be implemented on crocodile surveys, but like the distance sampling approach, population estimates would only be corrected for the detectability of crocodiles that are available at the time of a survey. Any unavailable crocodile (e.g., hidden, under water or deep inside the vegetation) would not be accounted for, thus biasing abundance estimates (Diefenbach et al. 2007).

2. Recommendations

Material: In the future, it would be necessary to get some material to measure air and water temperature (thermometers), as well as brightness (light meter). Those pieces of material would provide better data to quantify environmental covariates than the subjective indexes we used to measure the covariates discussed above (cf. environmental covariates part).

Abundance index protocol: Based on the results of our first survey season, we suggest some ways of improving the sampling design of the count protocol used for abundance indexes. First, the survey period could be changed from February-April to January-February to avoid the beginning of the rainy season. In 2019, we cancelled some late-season surveys because of tropical rains. Such rains decrease the lake temperature, causing the sudden appearance of a lot of fog, which strongly decreases the visibility on the lake. In 2019, the first tropical rains appeared at the end of March, so it would be better to carry all surveys before that time of year.

We also recommend carrying multiple surveys sessions (nights) per week, instead of just one as we did in 2019. We think that 3 sessions per week, with two transects per session, would be an efficient way to quickly accumulate survey repetitions. For instance, instead of doing a single survey on the on the night of Last Quarter moon [LQ], we would carry surveys on 3 consecutive nights in a row, on [LQ - 1], [LQ] and [LQ + 1]. By following this recommendation, a total of 24 surveys could be done within only 4 weeks, which would likely be enough.

3. Future directions

In our opinion, documenting and tracking the dynamic of this population over time should be a high priority and it would be feasible with a bearable amount of effort and investment.

First, repeated count surveys, as we did in 2019, should be continued every year. Although they cannot provide precise estimates of absolute population size, they can be used as annual indexes of abundance to track population changes over time. In addition, by providing knowledge on the juvenile-to-adult ratio, this type of monitoring will also inform us on the current status of the population, in relation to its expected equilibrium.

Second, monitoring options allowing the estimation of absolute (real) population size and detection probability should be explored. As explained in section V.1, a capture-mark-recapture approach would provide the most reliable data. In addition, we recommend using the double-observer method, also described in section V.1, which would improve the accuracy of counts and allow estimating the observers' detectability.

Finally, it would be very interesting to collect information on crocodile demographic rates, which includes reproduction and annual survival rates. For reproduction, specific surveys could be implemented during the nesting (April-May) and the hatchling (June-July) seasons. For survival, if long-lasting marks can be applied to crocodiles, this would provide the required data to estimate annual survival probabilities, using CMR analytical methods.

If these different pieces of information become available after several years, it would then be possible to perform accurate viability population analyses, which would prove highly useful for the conservation of that species in the future.

VI Conclusion

- Our 2019 survey revealed that lake Bàu Sàu is home to ca. 5-12% of the world's known population of Siamese crocodiles.
- However, the current age class ratio of this population suggests that it has not reached its equilibrium, yet.
- The monitoring of that population should be a high priority to help the conservation of that species.
- The standardized protocol, presented here, to count crocodiles and get abundance indexes is fairly easy to implement and should be pursued in the future to track population changes.
- Additional survey methods (CMR, double-observer) should be tested to gather more precise information.
- Because of its structure and ease of access, the Bàu Sàu lake would surely prove to be an excellent site to monitor and study this cryptic species in more details (demography, reproduction, behavior, etc.).

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