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The Use of Unmanned Aerial Vehicles (UAVs) to Study a Freshwater Turtle Population in the Brazilian Amazon

Camila K. Fagundes[1,4], *Marcos Amend*[2], *and Camila R. Ferrara*[3]

[1]*Sig Mapeamentos, R. Venâncio Aires, 1476, Centro, CEP 97010001, Santa Maria, Rio Grande do Sul, Brazil*
[2]*Mawe Consultoria e Projetos Ambientais, Avenida Adolfo Ducke, 105, Coroado, CEP 69082-653, Manaus, Amazonas, Brazil*
[3]*Wildlife Conservation Society - WCS Brasil, Rua Costa Azevedo 9, sala 403 - Centro, CEP 69010-230, Manaus, Amazonas, Brazil*
[4]*Corresponding author; e-mail: camila.fagundesk@gmail.com*

***Abstract*.—Unmanned aerial vehicles (UAVs) or drones have been widely adopted recently for the conservation, management, and research of a variety of taxa with various purposes and have given good results. This study was the first one to analyze behavioral patterns and to evaluate the disturbance effect of the drone on individuals of a freshwater turtle species in a white river in the Brazilian Amazon. We found no turtles returned to the water during drone flights while nesting. We recorded that a safe altitude for observing Giant South American River Turtle (*Podocnemis expansa*) individuals that were in the water and basking during the nesting period was above 20 m and 40 m, respectively. Different categories of image acquisition had no significant effect on the number of individuals we counted. Also, the number of individuals detected by drones were not significantly different among the sampling times. The interaction of image acquisition type and time was also not significantly different. Data suggest that drones have performed efficiently for studying freshwater turtle populations in the Amazon. The tool can provide information about abundance, distribution, density, and reproductive behavior, which is particularly important in areas with mass nesting and mass hatching.**

Key Words.—chelonians; drone; methods; *Podocnemis expansa*; turtle; unmanned aerial vehicles

Introduction

Historical data indicate that during the pre-Columbian period (730–1,230 CE), *Podocnemis* turtles were the second most consumed bush meat in the Amazon, after fishes, such as *Arapaima* sp. (Prestes-Carneiro et al. 2015). This situation does not seem to have changed much, because thousands of individuals and eggs are still collected every year for sale and illegal consumption (Cantarelli et al. 2014; Pantoja-Lima et al. 2014). The overexploitation has led some populations of the Giant South American River Turtle (*Podocnemis expansa*) to decline (Forero-Medina et al. 2019). Although conservation actions have been developed and implemented for species of the genus (Lacava and Balestra 2019), they are often hampered by lack of knowledge of their ecology and biology.

The complex logistics required to research turtles in remote areas of the Amazon and the time and financial resources to be spent in the field limit the development of scientific studies and monitoring and management activities to obtain data. Most importantly is the fact that population research studies are usually based on the mark-recapture method and because of the large dimensions of the river systems, the recapture rate is very low, even in long-term studies, making it difficult to estimate population parameters (Bernhard and Vogt 2012). In addition, behavioral studies are developed frequently in captivity (Carpenter and Fergusson 1977; Schneider et al. 2010) and do not represent all the complexity found in natural ecosystems. Only a general behavioral pattern has been identified for *P. expansa* during the nesting period in which individuals migrate from feeding areas to the main river channel to nest in the dry season, and it was verified that in some populations adults remain in the vicinity of the nesting site until the hatchlings emerge (Alho and Pádua 1982; Ferrara et al. 2013).

Unmanned Aerial Vehicles (UAVs) or drones have recent been widely adopted to improve the conservation, management, and research of a variety of taxa (Chabot and Bird 2015; Evans et al. 2015; Goebel et al. 2015; Linchant et al. 2015; Kiszka et al. 2016). The technology performs well for evaluating wildlife behavior, distribution, and abundance (Jones et al. 2006; Vas et al. 2015; Bevan et al. 2016; Kiszka et al. 2016) with minimal observer influence (Bevan et al. 2018). In marine turtles, drones have been used for various purposes, such as monitoring turtle abundance and movements, monitoring courtship and mating behavior, detecting operational sex ratios, and verifying temporal variation in fish-cleaning stations (Bevan et al.

2015, 2016; Schofield et al. 2017a,b). Rees et al. (2018) identified many benefits of drones for the group, such as decreasing the costs and time of project execution and increasing the efficiency in obtaining data over traditional methods for studies on turtle nesting and turtle foraging, movements, a wide range of behaviors, and as surveillance against illegal capture. Furthermore, drones can also provide more accurate population estimation for these animals (Rankin and Kokko 2007; Rees et al. 2016; Dunstan et al. 2020).

Despite the various advantages already verified in the use of drones in ecological and conservation surveys for marine species, only a few studies are available about the use of the technology for freshwater turtles (Biserkov and Lukanov 2017; Escobar et al. 2020; Bogolin et al. 2021). In the Amazon, as far as we know, only one study used drones to perform population estimates of the two species of Amazon river dolphins (Oliveira-da-Costa et al. 2020). A critical component for drone performance is the level of disturbance imposed on the behavioral display of the animal to minimize the effects of their presence and establish an adequate distance for the use of the technology (Bevan et al. 2018). Studies about the disturbance effect of drones on wildlife related to the noise they make are limited (Goebel et al. 2015; Pomeroy et al. 2015; Vas et al. 2015; Christiansen et al. 2016; Smith et al. 2016). In marine turtles, it was verified that drones cause some disturbance on individuals at altitudes below 20 m (Bevan et al. 2018).

We report for the first time the use of a drone to analyze behavioral patterns of a freshwater turtle species, *P. expansa*, in a white river in the Amazon and the potential to accomplish population estimates for the species in these ecosystems. We also evaluated the disturbance effect of this technology on individuals to verify proper flight altitudes that do not interfere with the behavior of these turtles. The species is currently classified as Critically Endangered by the Tortoise and Freshwater Turtle Specialist Group (TFTSG) provisional Red List in 2011 (Turtle Taxonomy Working Group 2021). Our focus here is to provide preliminary information to integrate drones into wildlife studies and conservation resource management in a threatened species and to start to develop protocols for data gathering using drones.

Material and Methods

Study site.—We conducted our study on the Abufari nesting sandbank (5°22'12"S, 63°01'06"W), in the Abufari Biological Reserve (REBIO Abufari), located in the lower Purus River, Brazil (Fig. 1). The Purus River is a white water river, which has a large amount of suspended sediment. The floodplain of REBIO Abufari is subject to profound changes due to the annual variation in the water level, which influences the entire population dynamic of turtles in the region. In the reserve, during the dry period, *P. expansa* exhibits mass nesting in which most of the individuals nest during a few nights

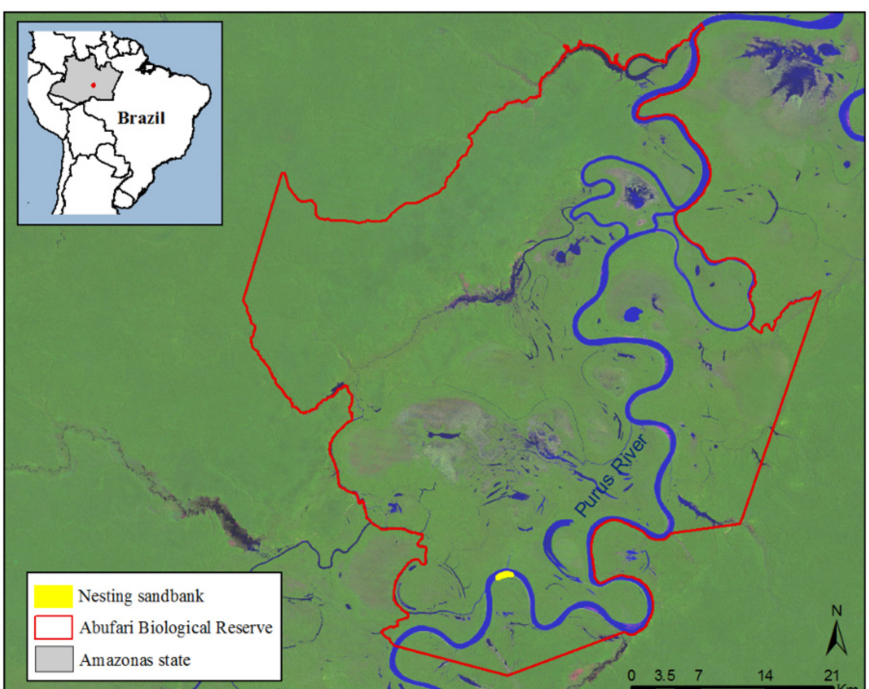

Figure 1. Map showing the location of the nesting sandbank for Giant South America River Turtle (*Podocnemis expansa*) in the Abufari Biological Reserve, Amazon.

of the nesting period, and mass hatching occurs with thousands of hatchlings emerging from the same nesting site in a few nights (unpubl. data). Males and females remain aggregated in front of the nesting site during the reproductive period (Pantoja-Lima 2012).

Obtaining aerial images and analysis.—We took photographs and made video recordings in September and November 2019 in 4K at 30fps with the Mavic 2 Enterprise drone (DJI, Shenzhen, China) with low-noise helices during nesting activity and during the incubation period of *P. expansa*. Initially, we performed some tests during nesting activity to verify which altitude is best to record turtles through drone flights and as to not interfere with their behavior. To improve visibility, we adjusted the camera angle to 90° straight down and 45° forward, ensuring that the drone was positioned exactly over the individual. Greater visibility was gained with the drone in front of the turtles, perpendicular to the orientation of the head. We started obtaining turtle images at 150 m height, and then we reduced the altitude to 50, 40, 20, 15, 10, and 5 m. We conducted six flights, totaling 120 min: three flights over the nesting sandbank between 0600 and 1300 for individuals during nesting activity and basking at the nesting site (females bask before and during nesting activity), and three flights over the turtles in the water between 0900 and 1500. We classified the turtle behavior in three categories: (1) no reaction; (2) brief movement of the head and body; and (3) sudden movements to return to the water if the turtle was on the sandbank or diving if turtle was in the water.

During egg incubation in nests, we performed 12 flights of 20 min each (totaling 240 min) over individuals in the water and near the nesting sandbank to verify the best way to obtain standardized images of the individuals to perform population estimates and behavioral analyses. Because of the influence of illumination in the sighting of turtles and due to their behavioral dynamics, we sampled turtles at different times. Thus, in total, we performed three flights for each sampling time: 0700, 1000, 1300, and 1600.

We obtained images in four ways in each portion of a 1,500 m transect located parallel to the nesting sandbank to cover the entire sample area. We categorized image acquisition as: (I) perpendicular to the nesting sandbank, with images taken from 80 m of river channel to the sandbank; (II) perpendicular to the nesting sandbank, with images taken from 200 m of river channel to the sandbank; and (III) a video recording in parallel to the previously defined transect, reaching around 300 m away from the nesting sandbank. All these images were registered at 25 m of altitude, while on video footage, the drone had a constant speed of 6–12 m/s.

We identified and quantified the individuals sampled in the images from each flight and in each category of image acquisition. We used Two-way Analysis of Variance (ANOVA) to verify if there was a significant difference in the number of individuals among different categories of image acquisition and sampling times. We considered a difference significant if $P \leq 0.05$.

Results

We observed no reactions from turtles during flights of 150, 50, and 40 m of altitude (Fig. 2). Turtles on the sandbanks during nesting activity showed a brief head movement during flights between 10 and 5 m of altitude, but none of them showed movements to return to the water (Fig. 3). The turtles that were in the water near the nesting sandbank showed brief movement of the head and body when the drone was 15 m high (Fig. 2), and all turtles dived during flights of 10 m altitude. Most individuals that were basking in the nesting site exhibited movements to return to the water during

(a) (b)

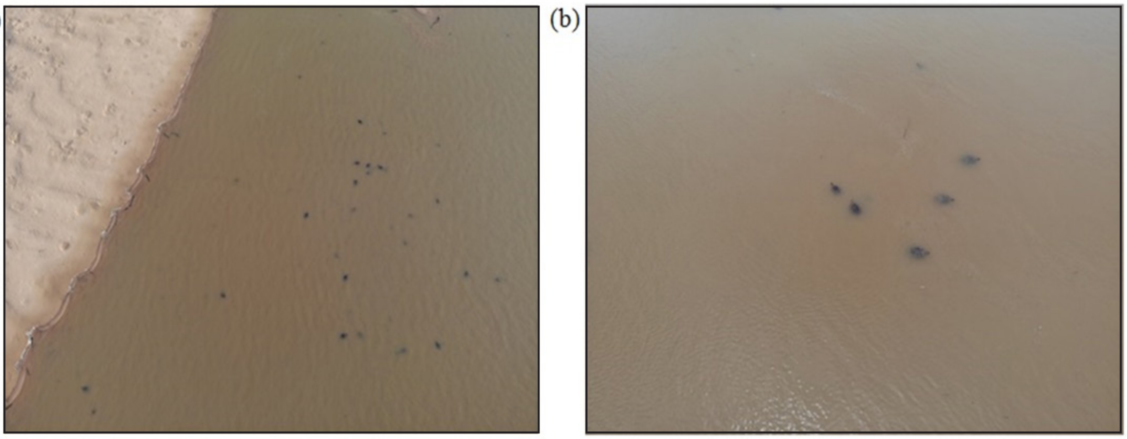

Figure 2. Aerial image of (a) 31 individuals of Giant South America River Turtle (*Podocnemis expansa*) in front of a nesting sandbank in the Abufari Biological Reserve (REBIO Abufari), state of Amazonas, Brazil, obtained during a drone flight of 25 m altitude and (b) five individuals at the minimum altitude (15 m) for recording turtles with drone without disturbing the individuals. (Photographed by Camila K. Fagundes).

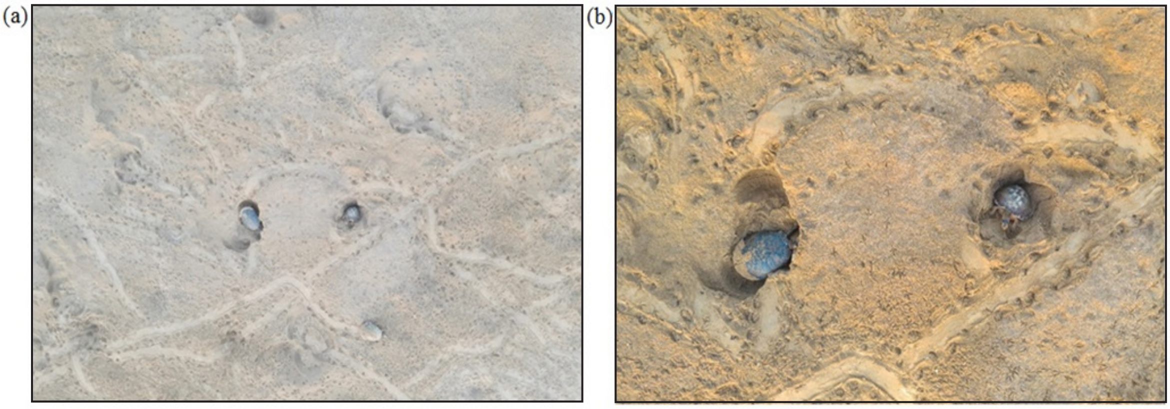

Figure 3. Aerial image of (a) three females of Giant South America River Turtle (*Podocnemis expansa*) in nesting activity in the Abufari Biological Reserve (REBIO Abufari), state of Amazonas, Brazil, obtained during a drone flight of 10 m altitude, and (b) two females nesting during a drone flight of 5 m altitude. (Photographed by Marcos Amend).

flights below 40 m of altitude. At 25 m and 15 m of altitude, we observed individual *P. expansa* in courtship or copulatory behavior on three occasions (Fig. 4) during the incubation period; however, it was not possible to identify the sex of the animals that were in the water.

We counted the smallest number of individuals on flights at 0700 and at 1600, five and eight, respectively, and we registered the largest number of turtles (91) at 1300. The categories of image acquisition that had the largest number of individuals in a single flight were I and III, 91 and 83 individuals, respectively (Table 1). Different categories of image acquisition had no significant effect in the number of individuals counted ($F_{2,18}$ = 0.274, P = 0.764). The number of individuals detected by drones were not significantly different among the sampling times ($F_{3,18}$ = 2.559, P = 0.087). The interaction of image acquisition type and time was also not significantly different ($F_{6,18}$ = 0.403, P = 0.867).

Figure 4. Aerial image of two individuals of Giant South America River Turtle (*Podocnemis expansa*) in courtship behavior in the Abufari Biological Reserve (REBIO Abufari), state of Amazonas, Brazil, obtained during a drone flight of 15 m altitude. (Photographed by Camila K. Fagundes).

Table 1. Number of individuals of Giant South America River Turtle (*Podocnemis expansa*) quantified on drone flights for each category of image acquisition and sampling time during the incubation period in the Abufari Biological Reserve, Amazon. Category is the type of image acquisition: I = perpendicular to the nesting sandbank, with images taken from 80 m of river channel to the sandbank, II = perpendicular to the nesting sandbank, with images taken from 200 m of river channel to the sandbank, and III = a video recording in parallel to the previously defined transect, reaching around 300 m away from the nesting sandbank.

		Time			
Day	Category	0700	1000	1300	1600
1	I		69		14
	II		41		13
	III				
2	I	8	12	91	25
	II	5		20	
	III		48	83	22
3	I	6	10	20	6
	II	35	50	53	15
	III	39	11	50	15
4	I				
	II		18	21	
	III	18	22	23	

Discussion

Our study is the first to show that drones can be used to count individuals and detect behaviors in populations of freshwater turtles in the Amazon. It is necessary, however, to analyze and understand the impact of drones on wildlife to minimize the effects of their presence and make the appropriate use of this tool. We found that when individual *P. expansa* were on the sandbank during nesting activity, they only showed a brief head movement in response to the lowest tested drone altitudes. Similarly, for three marine turtle species, Green Sea Turtle (*Chelonia mydas*), Flatback Sea Turtle (*Natator depressus*), and Hawksbill Sea Turtle (*Eretmochelys imbricate*), females were not perturbed by drones at 10 m altitude during nesting activity (Bevan et al. 2018). For *P. expansa* that were in the water, turtles showed brief movements of the head and body at 15 m drone flight and there was no reaction at 20 m altitude. So, we conclude that 20 m is a safe altitude to observe *P. expansa*. Altitudes at or above 20 m were acceptable for studying marine turtles (Bevan et al. 2018). Greater care with a drone should be taken when turtles are basking before and during the nesting period. Flights over these individuals must be above 40 m altitude.

The auditory sensitivity in sea turtles varies between 100 to 1,000 Hz (Martin et al. 2012; Piniak et al. 2012). For *C. mydas* and the Loggerhead Sea Turtle (*Caretta caretta*) peak auditory sensitivity in air occurs between 300 and 400 Hz, and underwater between 50 and 400 Hz (Martin et al. 2012; Piniak et al. 2012). Thus, these species can detect noise levels of commercial drones at altitudes between 5 and 10 m (50 ± 200 [standard deviation] Hz, 57.8 ± 80 dB; Goebel et al. 2015; Vas et al. 2015; Cabell et al. 2016; Christiansen et al. 2016). If they are not perturbed by the drone during their nesting activity, it is because the noise is not sufficient to provoke changes in their behavior (Bevan et al. 2018). *Podocnemis expansa* also can detect commercial drones because the auditory sensitivity of the species is from 30–6,000 Hz, with peak sensitivity higher than that observed for sea turtles, between 1,000 and 1,500 Hz (Wever 1978). The nesting sandbank we studied was located in a river channel, which is an important waterway for commercial and human-transporting boats. The sandbank also is an important habitat for many species of aquatic birds; thus, drone sounds may be lost against background noise. *Podocnemis expansa* could also be disturbed by visual detection of the drone and its shadow, but because turtles only showed avoidance behavior at lower altitudes, we believed they did not perceive the drone as a threat (Bevan et al. 2018).

The ability to identify turtles may be affected by the depth they are in the water, the water color, wind conditions, the brightness and reflection of the sun on the water, as well as a combination of these factors. At 0700 and 1600, in general, there was a greater reflection of the sun on the water, hindering the visibility of the individuals; however, the interaction of different methods of image obtaining with drone and sampling times did not affect the number of detected individuals. Thus, any of these methods and sampling times can be used to make population estimates and for monitoring purposes.

It has been reported that the efficiency of drones in estimating population parameters of marine turtles is better compared to traditional methods, because drones integrate information about individuals from both sexes and with different size and age classes (Rees et al. 2016, 2018). For most traditional studies, it is only possible to obtain the number of nesting females, limiting predictions of population size estimates and the development of effective conservation actions (Rankin and Kokko 2007; Rees et al. 2016; Dunstan et al. 2020). Unlike sea turtles, however, it was not possible for us to easily identify sex of turtles with drone images when *P. expansa* were in the water. Male sea turtles can be easily distinguished from drone images because they have a much longer tails in proportion to the body compared to females (Bevan et al. 2016). In addition, the water in our study area was muddy, making it difficult to classify sex.

In summary, our study provides some information to address the use of drones in turtle monitoring and research for freshwater turtles. With flights above 20 m of altitude, drones have the potential to provide good information about abundance, distribution, density of individuals in water during the dry season, even in muddy rivers. This altitude is also good for studies about reproductive behavior during the nesting and incubation periods. To evaluate parameters of reproductive females during the nesting period, flights should be carried out below 40 m of altitude when turtles are basking. We found that nesting females are not disturbed by flights above 10 m. The use of drones is particularly important in areas with mass nesting and mass hatching emergence, such as in REBIO Abufari. In these habitats, drones can be useful to quantify nesting and hatchling production, even if they occur at night.

It is important to highlight that the noise level of drones varies widely with different equipment. The drones we used in our study had low-noise helices. Other drones can be much louder and show different disturbance patterns (Schäffer et al. 2021). Thus, we recommend that the behavior of *P. expansa* with respect to different kinds of drones be evaluated in other populations and in different river and habitat types in the Amazon. The altitude limit tolerated before individuals exhibited evasive behavior varied with the study area and equipment used. This likely was due to the auditory sensitivity of the species, its visual detection ability, the sound signature of the drone, and the association of the sound of the drone with a local threat (Bevan et al. 2018). It would be useful also to measure at which decibel-level and at what altitude turtles begin to react to drones, so that the minimum height for each drone type can be calibrated.

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Camila K. Fagundes produces maps and spatial analysis for academic works and for environmental licensing services as a consultant. She received her Bachelor's degree in Biology from the Universidade Federal de Santa Maria, Brazil, and a Master's degree in Animal Biodiversity at the same University. She completed her Ph.D. in Aquatic Biology at National Institute for Amazonian Research (INPA) in Manaus, Brazil. Camila has developed studies about biology and ecology of turtles and also about spatial conservation planning in relation to the impacts of habitat loss in Amazon, producing maps that show priority conservation areas for turtles. Her research activities are also focused on vulnerability of organisms to land use/land cover changes and species distribution modeling aimed at management practices. (Photographed by Camila R. Ferrara).

Marcos Amend currently develops economic studies focusing on the sustainability of the Amazon as a consultant. He is also a professional nature photographer and drone operator, both for image production and research. He received his Bachelor's degree in Administration, his specialist degree in Administration from the Pontifícia Universidade Católica do Paraná (PUC-PR), Brazil, and his Master's degree in Forestry Economics and Policy from the Universidade Federal do Paraná (UFPR), Brazil. Marcos was co-founder and Executive Director for 10 y of Strategic Conservation, a non-profit institution dedicated to the use and teaching of economics as a tool for nature conservation. (Photographed by Marcos Amend).

Camila R. Ferrara works at Wildlife Conservation Society in Brazil as an Aquatic Wildlife Ecologist. Her responsibilities include creating a conservation plan for freshwater turtles in Amazonas State, training professionals, students, and local community members in wildlife monitoring techniques, and coordinating WCS monitoring and conservation efforts aimed at aquatic wildlife (especially turtles) priority areas. Camila is a Veterinarian and completed her Master's and Ph.D. in Aquatic Biology, with a focus on turtle ecology and conservation, at the Instituto Nacional de Pesquisas da Amazônia (INPA) in Manaus, Brazil. She also participated for 2 y on the project Tartarugas da Amazonia (Turtles of Amazonia), managing field-based monitoring efforts, working with local communities to protect nesting beaches, and on environmental education activities. (Photographed by Camila R. Ferrara).