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INTERNATIONAL WHALING COMMISSION

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Marcelo Oliveira Costa[1], Miriam Marmontel[2], Daiane Soares Xavier da Rosa[2], André Coelho[2], Serge Wich[3], Federico Mosquera-Guerra[4,5], Fernando Trujillo[4]

[1] WWF-Brasil, ed. Jade Office, s/n, Guará, sala 421, 71215-650, Brasília, Brazil- – marcelo@wwf.org.br

[2] Mamirauá Institute for Sustainable Development, 2584 Estrada do Bexiga, 69553-225, Tefé, AM, Brazil

[3] Research Centre in Evolutionary Anthropology, and Palaeoecology, School of Natural Sciences and Psychology, Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, United Kingdom and Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands

[4] Fundación Omacha, Calle 84 No. 21 – 64 - Barrio el Polo - Bogotá, D.C, Colombia

[5] Grupo de Ecología del Paisaje y Modelación de Ecosistemas-ECOLMOD: Departamento de Biología, Universidad Nacional de Colombia - Cra 30 No. 45-03 - Bogotá D.C, Colombia

Abstract

Quantifying the distribution and abundance of wildlife is key for developing sound management and conservation plans. Throughout the last decades much effort has been invested into freshwater dolphin surveys in the Amazon and Orinoco basins. However, the large dimensions of the river systems, the complex and expensive logistics required, and the lack of funds limit the replication of such studies across the entire region. As a response, we evaluated the effectiveness of the use of UAVs in the detection of two Amazon dolphin species, *Sotalia fluviatilis* (tucuxi) and *Inia geoffrensis* (pink river dolphin). This study has demonstrated that the use of UAVs can improve population estimates of Amazon river dolphin species that are traditionally carried out through visual surveys. The use of UAVs could provide a less expensive method, be more accurate and record more dolphin groups and individuals than visual surveys.

Introduction

River dolphins are a particularly vulnerable group of exclusively freshwater mammals, distributed in certain South American and Asian deltas and rivers (Vidal *et al.* 1997; Sanderson *et al.* 2002; Smith and Reeves 2012) with the largest populations on the planet living in the Amazon and Orinoco basins. These populations have been threatened by interactions with commercial and artisanal fisheries (Mosquera-Guerra *et al*. 2015*b*; Williams *et al*. 2016), the growing number of hydroelectric dams in Brazil, Peru and Bolivia (Trujillo *et al*. 2010; Pavanato *et al*. 2016; Latrubesse *et al.* 2017), mercury contamination (Rosas and Lehti 1996; Gómez *et al.* 2008; Mosquera-Guerra *et al*. 2015*a, c*; Williams *et al*. 2016), habitat degradation (Utreras *et al*. 2013), and climate change through changes in flood pulse and consequently food availability (Mosquera-Guerra *et al*. 2015*b*).

Although conservation plans have been developed for the Amazon river dolphins (Trujillo *et al*. 2010, 2014; Utreras *et al*. 2013), they have been hampered by the lack of knowledge about ecology, distribution and behaviour of those species. Quantifying the distribution and abundance of wildlife is key for developing sound management and conservation plans (Trujillo *et al.* 2010; Goebel *et al.* 2015; Gonzalez *et al*. 2016; Adame *et al.* 2017). For this reason, throughout the last decades much effort has been invested into freshwater dolphin surveys in the Amazon (Vidal *et al.* 1997; Gómez-Salazar *et al*. 2010, 2011a; Gómez-Salazar 2012; Pavanato *et al*. 2016, *in press*). However, the large dimensions of the river systems in the Amazon, the complex and expensive logistics required, and the lack of funds limit the replication of such studies across the entire region. Current methodology is highly based on distance sampling, originally developed for marine species. However, the specific characteristics of a freshwater river system imposes the need to adapt the traditional method to take into account, for example, the fact that the horizon is not seen, meanders are a common feature of Amazonian systems, and a range of habitats is available for distribution and sampling (*e.g.*, islands, channels, oxbow lakes). Furthermore, distribution of river dolphin species is highly heterogeneous with preferences for specific habitats such as confluences, lakes and channels (Gómez-Salazar *et al*., 2011) requiring different research methodologies.

In order to address these issues, researchers agreed on the importance of improving survey techniques to estimate the distribution and density of freshwater wildlife species (Perrin *et al.* 1989; Vidal *et al.* 1997), including the adoption of innovative approaches and technologies for data collection (Anderson and Gaston 2013; Mulero-Pázmány *et al.* 2014). Recent developments in the industry of Unmanned Aerial Vehicles (UAVs or drones) have been increasingly recognized as a game changer for environmental monitoring (Hardin and Hardin 2010; Getzin *et al.* 2012; Koh and Wich 2012; Mulero-Pázmán *et al.* 2014; Chabot and Bird, 2015; Linchant *et al.* 2015; Gonzalez *et al.* 2016; Hodgson *et al.* 2016; Adame *et al.* 2017), including surveys on aquatic mammals (Jones *et al.* 2006; Koski *et al.* 2009; Martin *et al.* 2012; Hodgson *et al.* 2013, 2017; Goebel *et al.* 2015; Durban *et al.* 2016). Animal detection is claimed as the first step for accessing the feasibility of the UAVs for studying wildlife species (Hodgson *et al.* 2017). Therefore, the aim of our study was to evaluate the effectiveness of the use of UAVs in the detection of two Amazon dolphin species, *Sotalia fluviatilis* (tucuxi) and *Inia geoffrensis* (pink river dolphin).

Material and Methods

Over six days in November 2016, we conducted river dolphin sampling in the Juruá River, Amazonas state, Brazil (Fig. 1). Two small off-the-shelf quadcopters (DJI Phantom 3 and Phantom 4) were deployed in turns, taking off and landing from the upper deck of a regional Amazonian boat traveling at a constant speed. Drones were positioned at a fixed altitude of 20 m above water level and 50 m from the side of the vessel, in order to monitor a 100-m strip band to the river margin (Fig. 2A).

The UAVs were controlled remotely by the pilot using live video. At least two flights were carried out per hour between 6 am and 6 pm, totalling 41 flights with duration of 10 minutes each. The videos were recorded using 12 megapixel, 35 mm, f/2.8 Sony cameras positioned at an approximate angle of 35º to the water surface. The camera was set up for automatic adjustment of ISO, shutter speed, and diaphragm aperture. In order to access the UAV detectability performance, a boat-based survey was simultaneously performed.

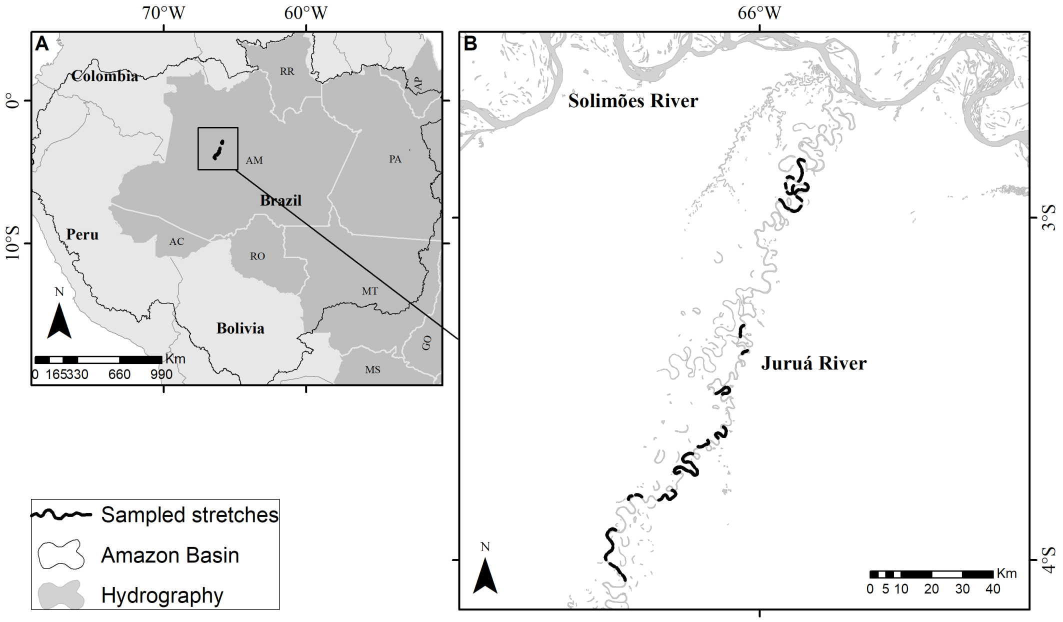

Figure 1. A. Location of site within the Amazon region where field expeditions for dolphin abundance estimation in association with drones were conducted in 2016; B. Detail of study site showing sampled stretches within the Juruá River.

We used a 23-m long, 5.4-m wide double decker with two observation platforms positioned 8 m above water level. There were three observers at the bow and two at the stern of the boat. In both platforms, there was one (additional) data recorder. The observers were actively searching for dolphins from 90° to 10º from their perspectives, positioned at port and starboard sides of the vessel. The vessel navigated at an average speed of 10 km/h, following the line transect sampling protocol (Gómez-Salazar *et al.* 2012) with a combination of 2.5-km long transects, placed 100 m parallel to the river margin (with an equivalent 100 m to the other side of the boat) and cross-channel transects, crossing from one margin to another in a zig-zag pattern (Vidal *et al.* 1997; Martin and da Silva 2004; Martin *et al.* 2004; Gómez-Salazar *et al.* 2012).

For each sighting, the observers reported the species, the group size, presence of calves, the sighting angle related to the trackline, the estimated distance from the observer to the center of the dolphin group and from them to the margin. The type of river margin that the group was associated with (highland, floodplain, floating grass or beach), the type of environment (stratum: main river, tributary, channel, lake, island), and GPS location were registered.

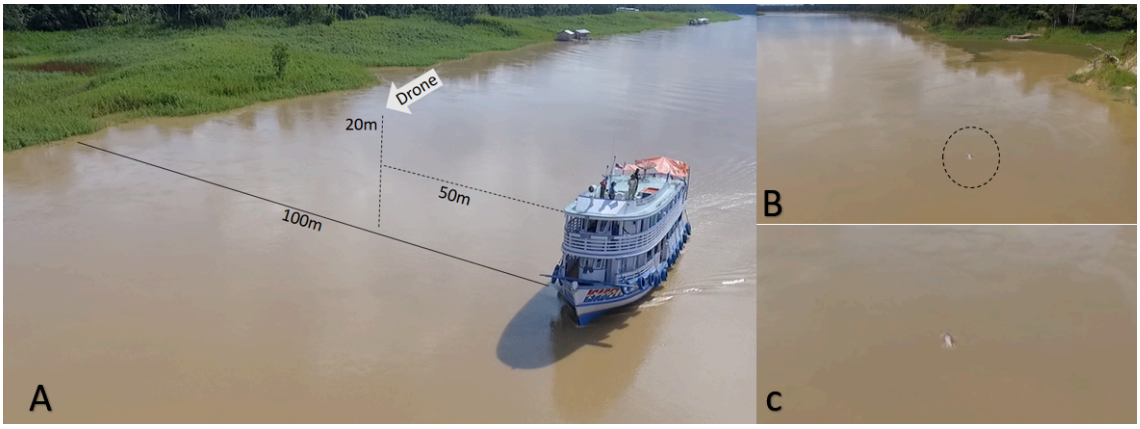

Figure 2. A. Illustrative representation of position of boat and drone under survey conditions (not to scale); B. Pink river dolphin detected by the drone; C. Detail of the animal (*Inia geoffrensis*) detected.

At first, footages were systematically and independently analysed by three experienced river dolphin observers on 15-17 inch computer screens. After this first step, three observers watched the videos systematically and simultaneously on a 50-inch screen. The drone-generated detections were then compared with the data generated by the boat-based survey. Thus, information regarding the time of sighting and dolphin location – both in the footages and in the records from observers - such as angle of sighting, distance from the margin and distance from the boat were fundamental for comparisons.

Results

The UAVs detected 124 animals, while 175 animals were recorded by visual counting (Fig. 3A). Considering the number of observations (groupings of individuals sighted), in total 151 observations were made. On-board observers registered 119 observations of which 76 were confirmed by the UAV platform. On the other hand, the UAV platform registered 108 observations, of which 32 were exclusively made by this platform, with no confirmation by the observers.

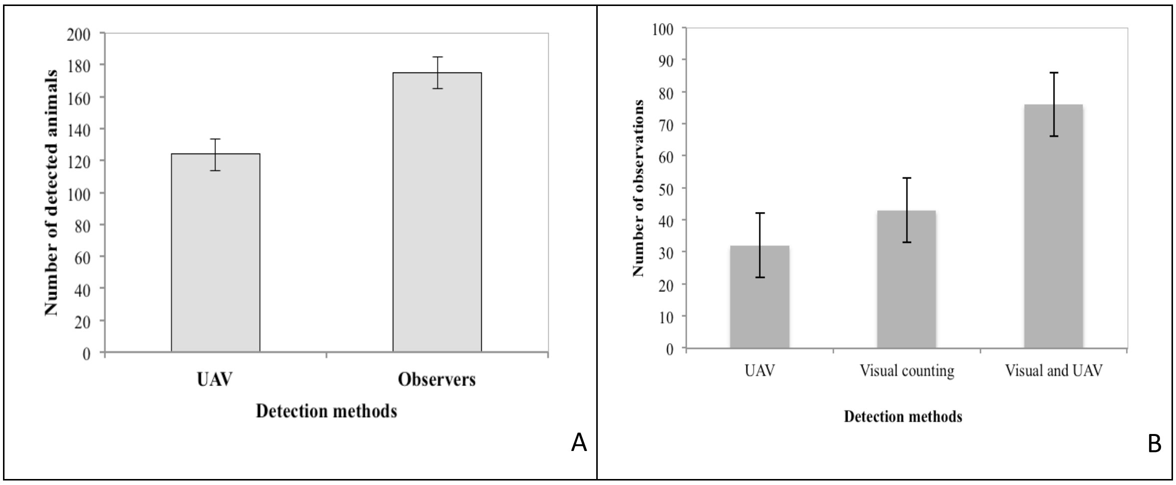

Figure 3. A. Variation between the number of animals detected by each platform; B. Variation in the number of observations made by UAV, Visual counting and both combined.

A total of 68 km of the Juruá River was monitored using the two platforms (visual counting and UAV). Seven hours of footages were recorded and differentiating between species using the analysed images was relatively simple (Fig. 2B, C).

Discussion

Much of the difference in counts between the two methods was due to the limited range of the camera attached to the drone. The maximum distance for animal detection was approximately 100 m, while the sightings by the observers were made up to 300 m from the boat. In the records in which the animals were not clearly visible, identification was based on the behavioural differences between species. Due to the erratic and brief surfacing behaviour (Vidal *et al.* 1997; Reeves *et al.* 2000), many individuals may be missed or else double-counted with either method applied here (Fürstenau Oliveira *et al.* 2017).

There were important variations in the results obtained through the two screens. The large screen not only allows the recognition of groups of individuals with greater acuity, but also facilitates the identification of species through "clues" or behavioural signals, thus increasing the number of observations through the UAV.

The footage UAVs produce constitutes systematic and permanent data, which can be later reviewed for confirmations (Koski *et al.* 2009; Hodgson *et al.* 2013; Linchant *et al.* 2015; Adame *et al.* 2017). The aerial survey provided higher accuracy in counting individuals during the detection of groups. Video analysis was used to confirm and, sometimes, correct mistaken identifications made through visual survey. The images captured by the drones also allowed for the correlation between species and use of habitats with a high degree of precision (Martin *et al.* 2012). The use of UAVs can also reduce the bias caused by responsive movement (Dawson *et al.* 2008).

The small multi-rotor off-the-shelf UAVs were chosen because of their vertical take-off and landing capability required to operate from a boat in movement, and their stability in flight. which allows for stable image capturing (Jones *et al.* 2006; Goebel *et al.* 2015; Linchant *et al.* 2015). However, under strong wind situations, the take-off and landing operations with the moving boat were challenging. Experienced pilots are thus a necessity and this should be taken into account in future studies. In addition, it is recommended that waterproof aerial vehicles be tested, as sudden rainfall or any equipment failure during operation could compromise data collection should a system need to make an emergency landing on the river.

Other limitations to this emerging technology becoming a viable alternative are related to their short flight endurance, sensor resolution and legislation (Linchant *et al.* 2015; Vincent *et al.* 2015; Hodgson *et al.* 2017). However, recent off-the-shelf multi-rotors already have increased flight duration and the rapid advances we are seeing in sensor, battery, and communications technology make it clear that neither data quality nor flight extent should be assumed as limited by where we are now (Jones *et al.* 2006). Regarding the legislation, in Brazil flights below 400 ft carried out in remote areas using aircraft duly registered on the national UAV system, and which are controlled manually through visual line-of-sight do not require any specific authorisation. This means that the use of UAVs within the flight parameters established for this study would be simple.

The use of UAVs during the study followed well-defined operational protocols, including the best practice described in the literature (Hodgson and Koh 2016), in order to ensure minimal disturbance to wildlife and the safety of operators and researchers. Experimental flights were carried out in areas around the confluence of rivers. These areas have high population densities of both species, enabling any interference in the behaviour of the animals to be evaluated. No signs of disturbance were observed among the animals as a result of the operation of the UAVs at altitudes varying from 30 to 10 meters. During the flights at the standard altitude of 20 m, some bird species demonstrated defensive territorial behaviour and followed the aircraft for varying amounts of time, although no incidents were registered. Our study also confirmed the use of drones as an outstanding behavioural observation technique, from which very detailed information can be extracted (Linchant *et al*. 2015; Hodgson *et al.* 2017) for river dolphin studies.

The use of emerging technology for wildlife abundance surveys generates a large quantity of data. Manual processing and revision of the collected data is time consuming and susceptible to human error. Nevertheless, this can be overcome through automated counting of animals in imagery (Hodgson *et al.* 2017; Seymour *et al.* 2017), which can provide better precision and accuracy (van Gemert *et al.* 2014; Hodgson *et al.* 2016). As yet there is no universal solution for automatically detecting and counting a wide variety of wildlife species (Chabot and Bird, 2015), requiring solutions to the particular species surveyed. Furthermore, with the adoption of novel survey approaches, new statistical methods will be required for population studies (Linchant *et al*. 2015). Moreover, because of the thermal signature that mammals have there is also potential in evaluating whether thermal cameras can capture large river mammals such as dolphins and whether counting can be automated (Longmore *et al*. 2017).

Our study has demonstrated that the use of UAVs can improve population estimates of Amazon river dolphin species that are traditionally carried out through visual surveys. The use of UAVs could provide a less expensive method (Kudo *et al.* 2012) when compared to the traditional method of collecting demographic data.

We suggest that further studies are performed to evaluate the use of UAVs and develop an alternative method to estimation studies in narrow waterways (<200 m), where visual surveys are held from canoes and cross-channel transects are not feasible, hampering the use of the distance model (Buckland *et al.* 2001). Therefore, detection of river dolphins through aerial survey could be more accurate and record more dolphin groups and individuals than visual surveys (Fürstenau Oliveira *et al.* 2017). In addition, comparison of full counts of UAV with distance sampling estimates is critical to understand the effectiveness of the technology, perhaps even contributing for the development of a new method to estimate populations of Amazonian river dolphins with the use of UAVs to be used by small teams to overcome the huge gaps remaining in the Amazon.

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