Continuous and automatic estimation of the Amazon river dolphins' populations through acoustic monitoring

Project summary and funding request

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Introduction - Why monitoring dolphins?

In a recent study , R. Bodmer et al. show that climate change has a clear impact on the wildlife of the Peruvian Amazon basin, that might lead to a loss of biodiversity and affect local people's resources [1]. Good indicators of the status of this ecosystem are the populations of two dolphins present in the Amazon river: *Inia geoffrensis* and *Sotalia fluviatilis*, shown in *Fig.1*. If the river suffers from negative changes, such as contamination or overfishing, their populations will quickly decrease. Monitoring these species allows to better understand and preserve them and their habitat.

Figure 1 - Inia geoffrensis (left) and Sotalia fluviatilis (right).

In a nutshell, the data collected by the authors shows that the populations of these dolphins seem to be affected by the strong variation level of the river observed between 2009 and 2012, as shown in *Fig.2*. More details about the impact of this phenomenon on the population dynamics (movements between different type of habitats, adults / juveniles ratio…) can be found in their report. The location of the Pacaya Samiria National Reserve in Peru, where the project took place, is shown in *Fig. 3*.

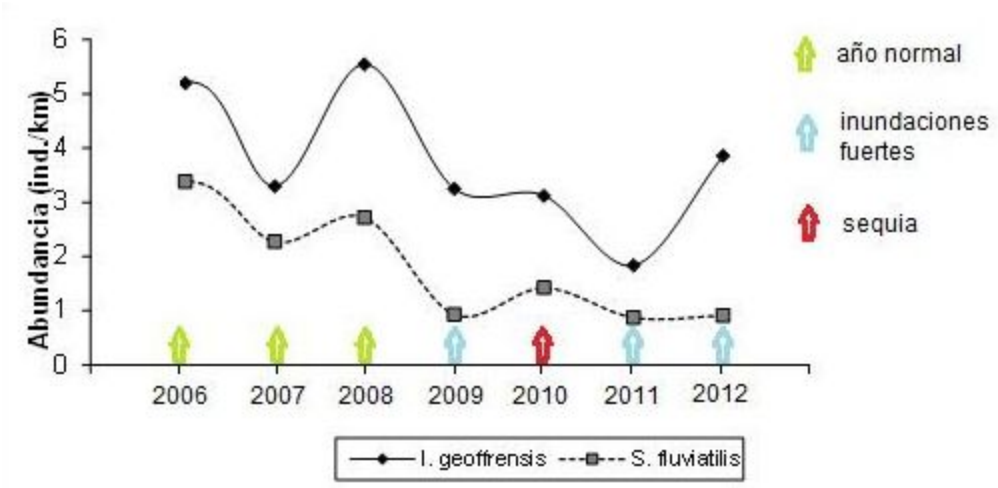

Figure 2 - Population density of Inia geoffrensis and Sotalia fluviatilis in the Amazon river between 2006 and 2012. The color of the arrows indicates the level of the river: green = normal year, blue = flood, red = drought. (Source: [1])

The change in the climate observed during this period in the region seems to be confirmed by an even more recent report published in 2016:

The year 2015 surpassed any warming anomaly observed in the last decade that has seen 'one in a century' extreme events (e.g., droughts of 2005 and 2010). Analysis of long-term temperature records suggests that 2015 is likely the hottest year over Amazonia in the last century. [2]

Both Inia geoffrensis and Sotalia fluviatilis were stated in 2011 as Data Deficient (DD) by the International Union for Conservation of Nature[1] (IUCN), meaning *that inadequate information* (is available) *to make a direct, or indirect, assessment of* (their) *risk of extinction based on* (their) *distribution and/or population status*[2].

The dependency of local communities on the Amazon river ecosystem, the importance of dolphins as indicator species, the correlation between dolphins populations and the level

[1] https://www.iucn.org/
[2] http://www.iucnredlist.org/static/categories_criteria_3_1

of the river, as well as more and more evidence of climate change possibly conducting to even stronger level variations emphasize the need for a better monitoring and understanding of the population dynamics of these species.

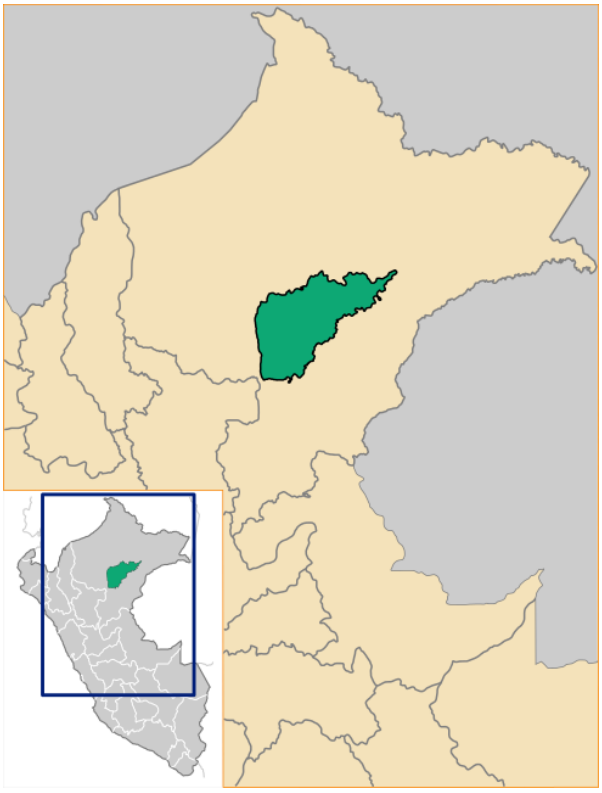

Figure 3 - Location of the Pacaya Samiria National Reserve, Peru. (Source: Wikipedia)

Towards better estimation of dolphin populations through acoustic monitoring

The important work by Bodmer et al. provides a great collection of data and analysis to serve the task of estimating the populations of dolphins in the area. However, estimating the number of individuals from visual observations, as they did, suffers in our opinion from significant drawbacks:

- It is very resource and time-consuming.
- It can only be performed during short periods of time (and during the day).
- It is error-prone, because of inherent problems of observing river dolphins, well described in an experiment on photo identification in the same region [3]: *low surfacing profiles, unpredictable surfacing behavior, indistinct marks, avoidance of boats, and turbid water*.

Like most cetaceans *Inia geoffrensis* and *Sotalia fluviatilis* emit a lot of sounds, both to communicate and to get a representation of their environment through echolocation[3]. These audio signals can be captured and detected automatically via hydrophones and dedicated algorithms, a method called *passive*[4] *acoustic monitoring* (PAM). We believe that a PAM system could allow to better monitor the status of the Amazon river ecosystem through continuous and automatic estimation of the populations of the dolphins. Preliminary experiments have been conducted in 2016 by H. Glotin[5], expert in bioacoustics[6] at the University of Toulon and head of the Scaled Acoustic BIODiversity project[7], during a mission in the Pacaya Samiria National Reserve in Peru. The analysis of the data collected shows that dolphins vocalizations can be automatically detected with good precision (see the dedicated chapter *Preliminary experiments* later in this document).

Expertise of the University of Toulon in bioacoustics

The DYNI (DYNamique de l'Information) team of the University of Toulon is conducting innovations in remote sensing, signal processing and machine learning for bioacoustic data analysis. It is headed by H. Glotin, a world-renowned expert in the analysis of animal vocalizations, Professor of Computer Science, organizer and co-organizer of numerous international conferences, workshops and challenges related to bioacoustics. The DYNI team installed a continuous acoustic monitoring system in biodiversity hotspots of the Port-Cros national park to automatically identify animal species and acoustic anthropogenic disturbances[8], and runs, along with the CIBRA (University of Pavia Italy)[9] and Pr. G. Pavan, the passive acoustic monitoring of integral nature reserves managed by the Italian Forestry Service[10] and related educational expositions. Localization and tracking have also been investigated to assess 3D behavior of flying animals (birds and bats) at night[11]. The team developed a unique low-resource, multi-channel and high sample rate audio acquisition board able to capture the ultra high frequencies emitted by *Inia geoffrensis*.

[3] Location of objects by reflected sound.
[4] As opposed to *active* monitoring, which implies the emission of a signal and the analysis of its reflections on the environment, like in dolphins echolocation or artificial sonars.
[5] http://glotin.univ-tln.fr/
[6] Study of animal vocalizations.
[7] http://sabiod.org/
[8] http://sis.univ-tln.fr/~glotin/sabiod/portcros/
[9] http://www-3.unipv.it/cibra/
[10] http://www-3.unipv.it/cibra/res_soundscapes_uk.html
[11] http://sabiod.univ-tln.fr/media/UTLN_JASON_3Drealtracking_passiveacoustics.mp4

Preliminary experiments and results

During a first mission on the Amazon river in summer 2016, H. Glotin used the JASON audio acquisition board developed internally, and mentioned earlier, and an antenna with 4 hydrophones to collect dolphin vocalizations.

An example of acoustic signal captured is shown in Fig. 4. This signal, here represented both as a waveform and a time-frequency representation (a spectrogram), is a sequence of clicks emitted by (possibly two) Inia geoffrensis for echolocation.

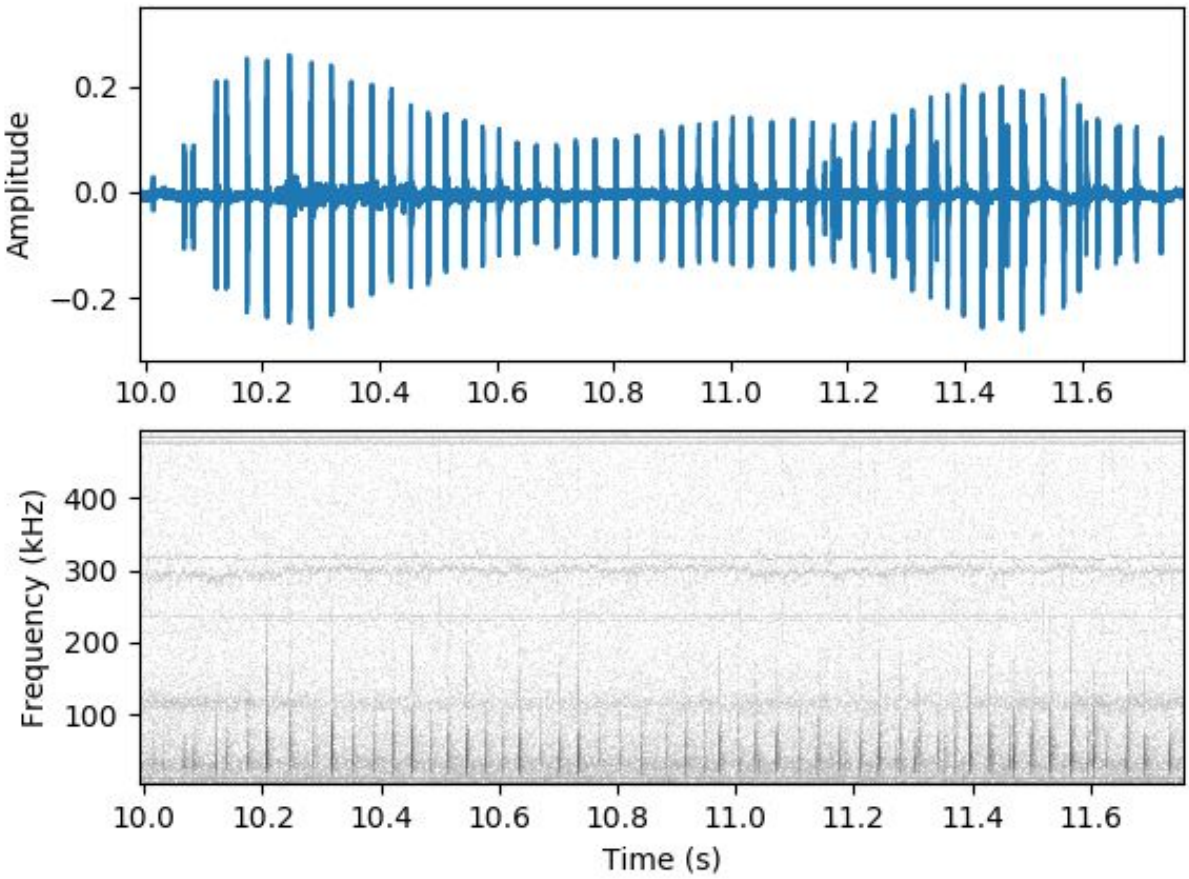

Figure 4 - Sequence of clicks emitted by two Inia geoffrensis, captured by H. Glotin in the Amazon river during summer 2016 at 1 MHz Sampling rate using JASON. Representations are waveform (top) and spectrogram (bottom) showing dolphin emissions higher than 200 kHz. We can see the overlapped trains of clicks of the two dolphins. The multichannel recording of our system allows to segregate and count the number of individuals.

These clicks are fairly easy to detect automatically, and their cross analysis on the four channels of the antenna allows to estimate the location of their sources, i.e. the dolphins that emitted them, and then to count them, as demonstrated in the experiment depicted in *Fig. 5* and described in further detail in [4].

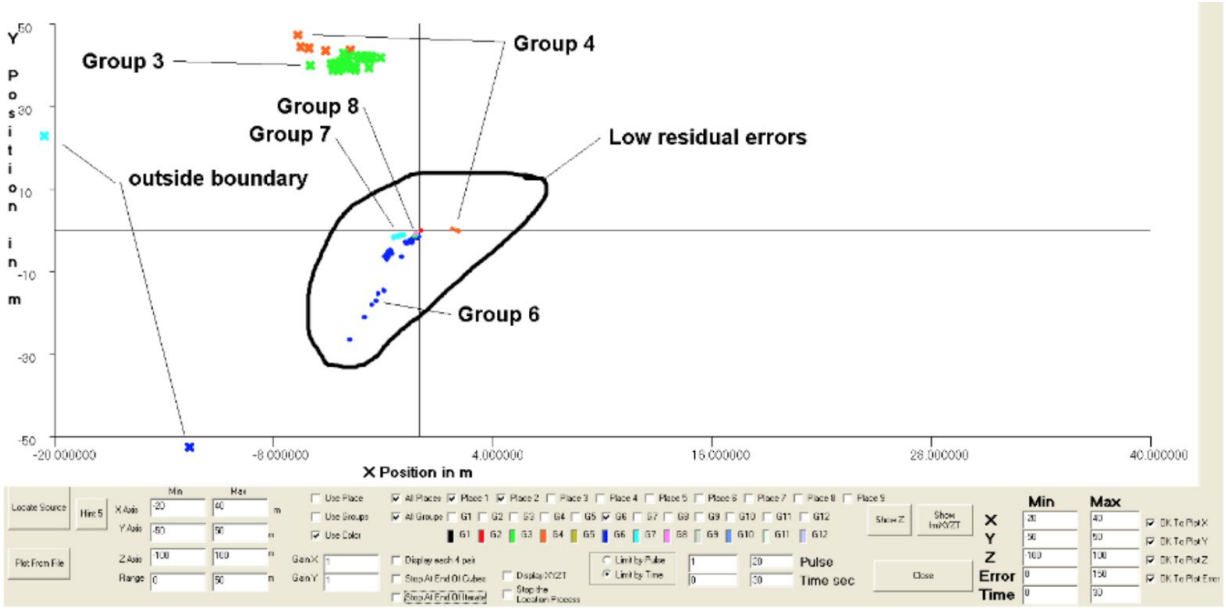

Figure 5 : First automatic localization and counting of Inia geoffrensis individuals recorded on the 16th august 2016 at 5pm. Five INIAs are counted, localized at more than 50 meters away from the 4 hydrophone antenna of only 1 m of aperture. These results demonstrate that high frequency recording on a short array allows to determine the number of individuals and to compute their relative distances, giving information on their group structure, their communication network, the mother / calf interaction, and cues for genre, age or possible individual signature [4].

This mission allowed to specify and test the system needed to capture the dolphins' acoustic signals in the Amazon river, and showed that their sources can be automatically detected and localized through dedicated algorithms. However, the antenna had to be taken by boat to some location for short recording periods (a few hours) and required to be handled manually, and the equipment cost was quite high. In a future experiment, described in the next part of this document, we propose to overcome those issues by using only two hydrophones and by fixing the antenna to the boat used by R. Bodmer to conduct his expedition, which will remain moored to the shore during the whole summer.

Proposal for an expedition in summer 2017

Objective

The main objective of our project proposal is to install an acoustic monitoring system to continuously and automatically estimate the population dynamics of the two species of dolphins present in the Amazon river: *Inia geoffrensis* and *Sotalia fluviatilis*.

This mission requires the knowledge of the field acquired by R. Bodmer through his work, passion and involvement in the area, and we would like to take advantage of his next research expedition to set our audio acquisition system on his laboratory boat in the Pacaya Samiria National Reserve in Peru. In august 2016 H. Glotin visited the headquarter of Fundamazonia[12], an NGO dedicated to issues related to conservation and sustainable development in the Peruvian Amazon and directed by R. Bodmer, who showed great interest in our protocol and agreed to welcome it during his expedition in summer 2017.

In addition to the detection task, further analysis of the signals captured could allow to better understand how these species communicate and perform echolocation, or even to identify acoustic signatures specific to males, females or calves. Similar study will also be conducted on other species living in this ecosystem, such as manatees, fishes and caïmans, to draw a global picture of the aquatic soundscape of the Amazon river. Additional sensors, namely a luxmeter and a thermometer, will allow to analyse possible correlations between dolphins activity and environmental data (light and temperature, respectively).

Experimental protocol

The system has been designed to be cheap, robust and to match the following specifications:

- High audio frequency range, up to 250 kHz to capture the ultra high frequencies emitted by Inia geoffrensis
- 2 audio channels to estimate the direction of dolphins trajectory from the delay between the 2 hydrophones
- Luxmeter with high sensitivity to capture small variations (e.g. due to moon phase or clouds) underwater and in the air.
- Low-power, because we will rely on battery power
- Large amount of storage: sampling stereo audio at 500 MHz generates 160 GB of data every day, or about 15 TB for 3 months (expected duration of the recording in summer)

[12] http://fundamazonia.org

The sensors will be fixed on a rigid structure attached to a boat moored to the shore, as illustrated in *Fig. 6* . The depth of the structure is to be determined according to the depth of the river, but should not be to close to the boat to avoid noise and reflections coming from it.

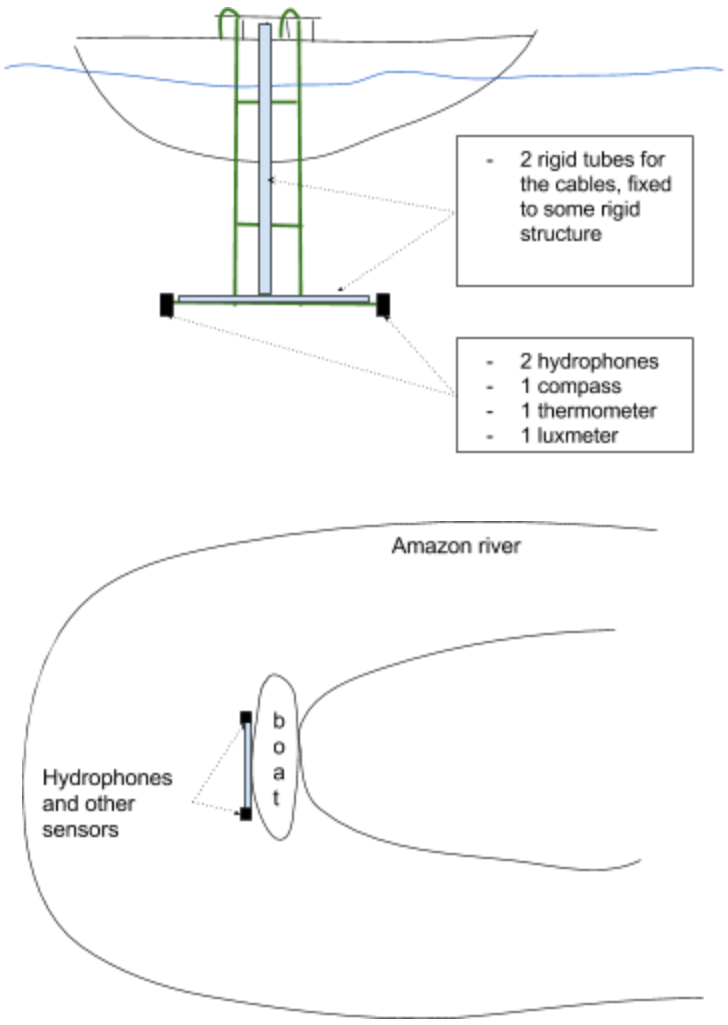

Figure 6 - System setting from the side (top) and from above (bottom) (scale is not respected).

The restored boat used to welcome Bodmer's expedition in the flooded forest of the Amazon is shown in *Fig. 7*.

Figure 7 - The boat, permanently moored to the shore, used as a base during R. Bodmer's expeditions.

A picture of a similar system, designed by the DYNI team and currently used by F. Sarano, Cousteau's long-time scientific advisor and professional diver, to record sperm whales near Mauritius in the Indian Ocean is shown in *Fig. 8*.

Figure 8 - Ultrasonic and environmental data acquisition system including 2 hydrophones (here not fixed) a luxmeter, a compass, a JASON board and batteries. The system can be powered during days by an external car battery.

Cost

The equipment used during the preliminary mission has been installed on the BOMBYX submarine platform[13] and is then not available for other uses.

The complete list as well as the total cost is given in *Table 1*.

Description	Price (EUR)
Equipment	
Digital audio acquisition board JASON[14]	1,600
2 hydrophones CRT C57	2 x 1,000 = 2,000
Cables (2 x 15 m)	2 x 350 = 700
5 Silicon Power Armor A60 2TB	5 x 100 = 500
1 luxmeter Darkjasor (with included thermometer)	500
PVC Pipes and little furniture	100
Travel and accommodation	
Return ticket (Toulon - Iquitos)	1,500
4 nights in hotel (2 on departure and 2 on arrival in Lima and Iquitos, because there is no direct connection)	4 x 100 = 400
10 days on R. Bodmer's expedition boat	10 x 50 = 500
TOTAL	7700

Table 1 - Cost of the project

[13] Multimodal submarine platform for bioacoustics, fauna video acquisition and the study of streams. http://glotin.univ-tln.fr/BOMBYX/.

[14] http://sabiod.org/SMIoT

Funding request

The mission, which will provide new insights on the population dynamics and acoustic communication of the Amazon river dolphins is well-specified and welcome in R. Bodmer's expedition. Most of the resource would be provided by the DYNI team as human resources for the analysis of the data collected. The only cost left includes the equipment, the travel costs for J. Ricard, bioacoustic and computer science expert in the DYNI team, and some cost related to the stay on the laboratory boat of R. Bodmer's foundation.

The amount of funding requested is 7700 €.

The sponsor will appear on all the future publications related to the project as well as on the dedicated website that will be hosted in the well established sabiod.org domain. The terms can be discussed by contacting the authors of this document at glotin@univ-tln.fr and julien.ricard@gmail.com.

References

[1] Bodmer, R. E., et al. "Cambio climático y fauna silvestre en la Amazonia peruana." *Impacto de la sequía y de las inundaciones intensas en la Reserva Nacional Pacaya Samiria. Fundación Latinoamericana para el Trópico Amazónico (Fundamazonia). Lima* (2014).

[2] Jiménez-Muñoz, Juan C., et al. "Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015–2016." *Scientific Reports* 6 (2016).

[3] McGuire, Tamara L., and Thomas Henningsen. "Movement patterns and site fidelity of river dolphins (Inia geoffrensis and Sotalia fluviatilis) in the Peruvian Amazon as determined by photo-identification." *Aquatic Mammals* 33.3 (2007): 359.

[4] Glotin, H. et al. "Inia rostrum rotation dynamics tracking: beam pattern and precise on axis estimation". LSIS Research Report (2017).