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A preliminary multi-country assessment of river dolphin acoustic detections using PODs in South America

Una evaluación preliminar multinacional de detección acústica de delfines de río mediante PODs en América del Sur

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ABSTRACT

River dolphins (*Sotalia fluviatilis* and *Inia* spp.) rely on sound for navigation, foraging, and communication, making passive acoustic monitoring a promising research tool. We present a preliminary assessment of the PODs detections across five South American countries. A total of 486 816 minutes of recordings were collected, with 18% showing positive detections. Detection rates varied among sites and were generally higher in confluences, lakes, and in a dam reservoir than in other habitats. Although PODs cannot reliably distinguish among sympatric species and may miss weak signals, our results show that they can provide useful information on dolphin occurrence in remote freshwater systems, supporting their use as a complementary tool for broad-scale monitoring.

Keywords: Acoustic activity, bioacoustics, echolocation clicks, Odontoceti, passive acoustic monitoring.

RESUMEN

Los delfines de río (*Sotalia fluviatilis* e *Inia* spp.) dependen de sonidos para navegación, forrageo y comunicación, tornando el monitoreo acústico pasivo em una herramienta de investigación relevante. Presentamos una evaluación preliminar de las detecciones con PODs a lo largo de cinco países de America del Sur. Un total de 486 816 minutos de grabación fueron colectados, de los cuales el 18% contiene detecciones positivas. La tasas de detección variaron entre los

sitios, generalmente mayor en confluencias, lagos y en un reservorio hidroeléctrico, que en otro tipo de hábitats. Aunque los PODs no puedem distinguir entre especies de delfines de rio simpátricas y podría perder señales débiles, nuestros resultados muestran que son útiles para establecer información sobre la ocurrencia de delfines en sistemas de agua dulce remotos, lo que refuerza su uso como herramienta complementaria para el monitoreo a mayores escalas.
Palabras clave: Actividad acústica, bioacústica, clicks de ecolocalización, monitoreo acústico pasivo, Odontoceti.

RESUMEN

Os golfinhos de rio (*Sotalia fluviatilis* e *Inia* spp.) dependem dos sons para navegação, forrageio e comunicação, tornando o monitoramento acústico passivo uma promissora ferramenta de pesquisa. Apresentamos uma avaliação preliminar das detecções por PODs em cinco países da América do Sul. Um total de 486 816 minutos de gravação foram coletados, com 18% apresentando detecções positivas. As taxas de detecção variaram entre os locais e, em geral, foram maiores em confluências, lagos e em um reservatório hidrelétrico, do que em outros hábitats. Embora os PODs sejam limitados na diferenciação de espécies simpátricas e na detecção de sinais fracos, nossos resultados mostram que podem fornecer informações úteis sobre a ocorrência de golfinhos em sistemas fluviais remotos, fortalecendo seu uso como ferramenta complementar para o monitoramento em larga escala.
Palavras-chave: Atividade acústica, bioacústica, cliques de ecolocalização, monitoramento acústico passivo, Odontoceti.

INTRODUCTION

Two groups of river dolphins are described in South America: *Inia* spp., which comprises the Amazon river dolphin (*I. geoffrensis*) (Da Silva et al. 2018), the Bolivian river dolphin (*I. boliviensis*) (Banguera-Hinestroza et al. 2002, Hollatz et al. 2011, Gravena et al. 2014, 2015), and the Araguaia dolphin (*I. araguaiaensis*) (Hrbek et al. 2014, Siciliano et al. 2016), and *Sotalia fluviatilis*, commonly referred to as the tucuxi or black bufeo (Rice et al. 1998, Da Silva et al. 2020). These species inhabit highly dynamic fluvial environments characterized by seasonal variations in water level and elevated sediment loads, as well as clearwater systems with relatively low sediment input such as the Guaporé River and others draining the Precambrian Shield (Junk et al. 2011). All these environments are marked by pronounced fluctuations in resource availability, which, although common across aquatic ecosystems, tend to be exceptionally intense in such highly dynamic systems (Mintzer et al. 2016, Paschoalini et al. 2021, Erbs et al. 2023). Although the genus *Inia* exhibits a broader distribution compared to *S. fluviatilis*, both groups occur in sympatry across a large portion of their ranges (Martin et al. 2004, Gómez-Salazar et al. 2012).

Despite their broad distributional range, river dolphins are notoriously difficult to monitor using traditional visual methods (Erbs et al. 2023). Most available information on their distribution is derived from boat-based surveys, typically conducted along river channels (Gómez-Salazar et al. 2012, Mintzer et al. 2016, Paschoalini et al. 2020, 2021, Erbs et al. 2023). However, their inconspicuous surfacing behavior, combined with their frequent occurrence in remote areas, limits the effectiveness of these approaches (Da Silva et al. 2023). In this context, Passive Acoustic Monitoring (PAM) has emerged as a promising alternative, particularly in remote and low-visibility freshwater environments. Cetaceans are vocally active and produce characteristic sounds used in social

interactions, navigation, spatial orientation, and foraging (Au 1993, Amorim et al. 2016, Melo-Santos et al. 2019). Thus, acoustic signals can be used to infer patterns of presence, distribution, and behavior, making PAM a valuable tool for ecological investigations and for assessing anthropogenic impacts (Panicker et al. 2022, Garcia et al. 2023, Patris et al. 2023). Moreover, PAM enables continuous recording of sounds produced by animals and their environment without direct intervention, reducing disturbance and allowing long-term data collection regardless of environmental conditions (Mellinger et al. 2007, Zimmer 2011, Binder and Hines 2014, Tregenza et al. 2016, Andriolo et al. 2018).

Among the technologies applied in PAM, click detectors such as dataloggers in the POD family have been widely used to record echolocation signals from small cetaceans, allowing the inference of patterns of activity, presence, and behavior (Ivanchikova and Tregenza 2023). Studies employing PODs have used the Detection Positive Minute (DPM) metric, defined as the number of minutes containing dolphin click trains, as a quantitative proxy to assess the presence of odontocete species (Filatova et al. 2024, Gauger and Taupp 2025, Giardino et al. 2025), diel patterns (Campbell et al. 2017, Dracott et al. 2022, Ivanchikova et al. 2024, Wang et al. 2024), and seasonal variation in acoustic activity (Dracott et al. 2022, Ivanchikova et al. 2024, Todd et al. 2023, Williams et al. 2023, Wang et al. 2024), as well as habitat preference (Todd et al. 2025a) and the effectiveness of pingers (Paitach et al. 2022, Díaz and García-Cegarra 2025).

Regarding river cetaceans, DPM has been used to describe acoustic activity patterns. For example, it has been applied to *Neophocaena asiaeorientalis asiaeorientalis*, the Yangtze finless porpoise, in the Wuhan region, China, where detection of click trains varied according to month, season, year of data collection, and periods with or without vessel traffic (Wang et al. 2024). For Amazon river dolphins, daily patterns of acoustic activity have been documented in Ucayali, Peru, with higher numbers of positive detection minutes during the morning and early evening, as well as differences among monitoring sites (Campbell et al. 2017).

Although widely applied in marine environments and for small cetaceans, these devices remain relatively underexplored in the context of South American river dolphins, and comparative studies across multiple sites and habitat types are still scarce. Based on this context, the present study provides a preliminary comparison of acoustic detections of South American river dolphins across different sites and habitat types. Specifically, this study investigates whether acoustic detection rates vary among habitats and sampling locations, while also evaluating the efficiency and applicability of PODs as a monitoring tool in freshwater systems.

MATERIAL AND METHODS

This study was conducted in five South American countries – Bolivia, Brazil, Colombia, Peru, and Venezuela – between 2022 and 2024. Each country selected sites relevant to the distribution of river dolphins, where passive acoustic detection devices of the F-POD or L-FPOD type (Chelonia Limited®) were deployed. Both POD models consist of an omnidirectional hydrophone with a frequency response from 20 kHz to 160 kHz and the capacity to detect pulsed sounds (Chelonia, 2025). Deployment of these devices followed a standard setup: an anchor/weight fixed to the riverbed, a line connecting the anchor to the POD and another line connecting the POD to a buoy. The data collection period and the characteristics of each sampling site are presented in Table 1.

Raw files (.CHE) were analyzed using the FPOD.exe software (v.2025), where

all logged data (.FP1) were processed by the KERNO-F classifier, which identifies dolphins click trains (producing a FP3 file). The methodology described by Ivanchikova and Tregenza (2023) was followed. Only click trains classified as dolphin (or other cetacean) detections of high (Hi) and moderate (Mod) quality were included in the analysis (Fig. 1).

Subsequently, the values of DPM (Detection Positive Minute), each minute containing dolphin click trains of the selected quality (Ivanchikova and Tregenza, 2023), were exported for each detection file.

To ensure equal comparisons across datasets, an acoustic detection rate (*t*), defined as the ratio between DPM and the total recording time in minutes (MinOn), was estimated for each sampled location (main water body).

Table 1. Description of the installation sites of F-POD (or L-FPOD) acoustic acquisition devices in different South American countries for the monitoring of river dolphins. UHE = Hydroelectric Power Plant (Usina Hidrelétrica, in Portuguese); MinOn = time of F-POD data acquisition in minutes; DPM = minutes with river dolphin's clicks detection.

Countr	Main water body	Site Name	Habitat	FPOD ID	UTC	Start Time	End Time	Latitude	Longitude	MinOn	DPM
Bolivia	Pojije River	Municipal Protected Area Gran Mojos	Confluence	6167	-4h	19/09/2022 – 12:23	02/02/2023 – 18:02	-15.4339	-64.8699	228297	53893
	Bravo Lagoon*	Santa Rosa Community	Tectonic Lagoon	6167	-4h	07/03/2023 – 06:41	09/03/2023 – 08:30	-14.0837	-66.8230	2989	705
Brazil	Tocantins River	UHE Peixe Angical	Dam Reservoir	10054	-3h	22/08/2023 – 17:56	26/08/2023 – 09:00	-12.2263	-48.3758	5214	3115
	Branco River	Uraricuera	Confluence	10012	-4h	24/01/2023 – 12:16	13/02/2023 – 19:58	3.0157	-60.4962	29264	1385
		Araraquara	Low-flow Channel Between Islands	10049	-4h	08/02/2023 – 12:30	11/04/2023 – 03:22	2.5471	-60.8279	88725	24011
		Cachoeirinha	Rapids Zone	6166	-4h	19/07/2023 – 11:38	21/08/2023 – 00:22	2.0170	-61.0304	16917	88
		Uraricuera	Confluence	10050	-4h	20/07/2023 – 11:42	02/09/2023 – 08:22	3.0119	-60.4975	16941	413
		Comunidade Itacutu	Main River	10047	-4h	19/06/2024 – 16:15	01/08/2024 – 13:59	3.4348	-60.1816	46894	3
		Boca do Tacutu	Confluence	10052	-4h	21/06/2024 – 10:26	25/07/2024 – 13:07	3.0168	-60.2898	40271	449
Colombia	Amazonas River	Tarapoto Lakes	Lake	10014	-5h	25/10/2022 – 08:08	25/10/2022 – 13:24	-3.8027	-70.4114	318	204
Peru	Imiría Lagoon	-----	Lagoon	10013	-5h	09/06/2023 – 01:45	13/06/2023 – 12:55	-8.8480	-74.2465	2802	148
	Tamaya River	Chauya Confluence	Confluence	10013	-5h	14/06/2023 – 04:53	14/06/2023 – 12:42	-8.8862	-74.1081	276	120
		Imiría Confluence	Confluence	10031	-5h	10/06/2023 – 01:59	17/06/2023 – 12:56	-8.7956	-74.1514	4791	3140
	Yarinococha Lagoon	-----	Lagoon	10032	-5h	07/06/2023 – 04:17	13/06/2023 – 12:02	-8.3406	-74.5913	2951	614
Venezuela	Portuguesa River	-----	Main River	10016	-4h	30/05/2024 – 17:15	30/05/2024 – 19:59	8.1000	-67.6086	166	1

*Data were collected during an active attempt to capture and translocate the animals

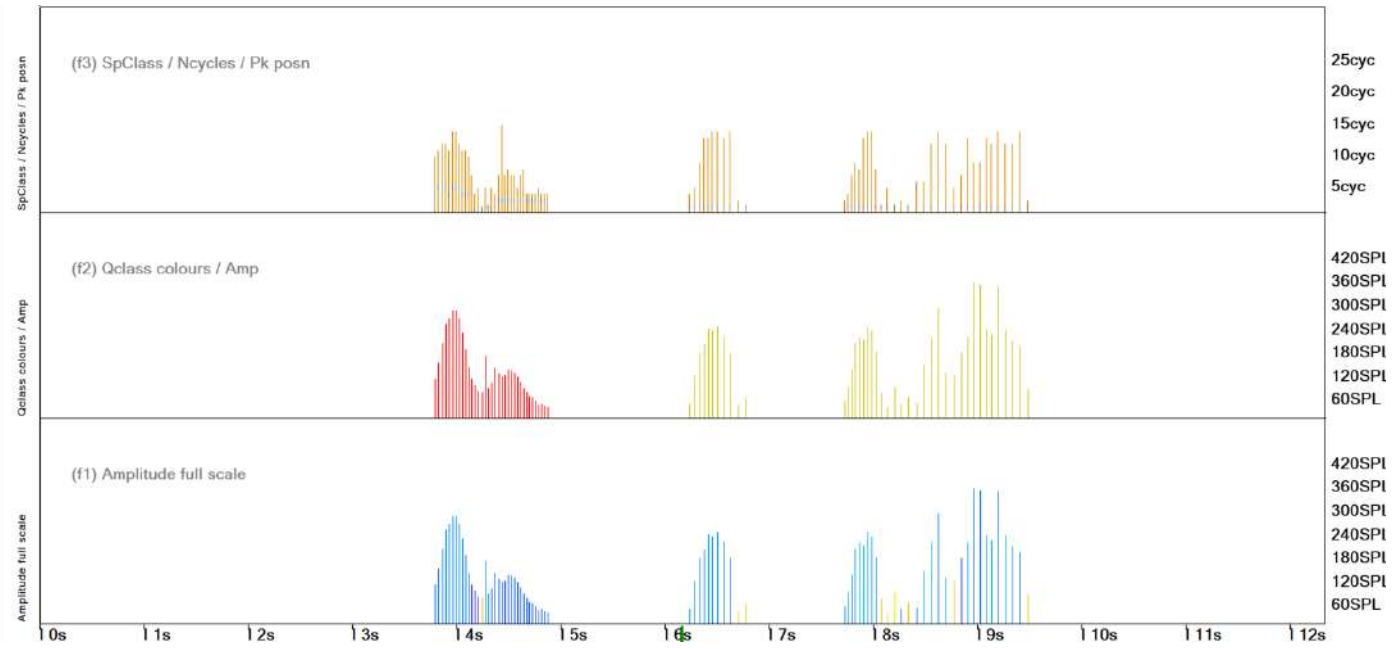


Figure 1. Example of river dolphin click trains. The top panel shows the classification of the trains in the "dolphin" category. The middle panel distinguishes the quality of each train, with yellow indicating moderate quality and red indicating high quality. The bottom panel displays the amplitudes. X axis represents the time in seconds and Y axis represents the click amplitude (SPL) in f1 and f2, and the number of cycles in f3.

RESULTS

A total effort of 486 816 minutes was recorded, of which 88 289 minutes (equivalent to 18% of the total time) contained positive detections. Recording time varied among countries, with the longest data collection period occurring in the Rio Branco, Brazil (239 012 min; 49.10%), followed by the Pojije River, Bolivia (228 297 min; 46.90%). However, the number of minutes with positive detections showed the opposite pattern between these two sites: the Pojije River registered 53 893 (61.04%) minutes with river dolphin click trains, whereas in the Rio Branco this parameter added up to 26 349 (29.84%) minutes.

When detection rate was assessed, the Tamaya River region in Perú and the Taparoto Lakes in the Amazon River, Colombia, showed the highest values ($t = 0.64$), followed by the Peixe Angical hydropower dam region in the Tocantins River, Brazil ($t = 0.60$). In the remaining sites, the detection rate ranged from 0.006 (in the Portuguesa River, Venezuela) to 0.24 (in the two rivers sampled in Bolivia) (Fig. 2).

DISCUSSION

In the present study, the detection rate showed that river dolphins were present at all acoustic monitoring sites; however, differences were observed in the number of acoustic emissions among countries, as well as among sampling points within the same country. This result may be related to factors that influence the distribution of river dolphins, such as prey availability, seasonality, water current strength (Martin and Da Silva 2004, Martin et al. 2004) and human pressions.

For example, the production of click trains by Amazon river dolphins varies

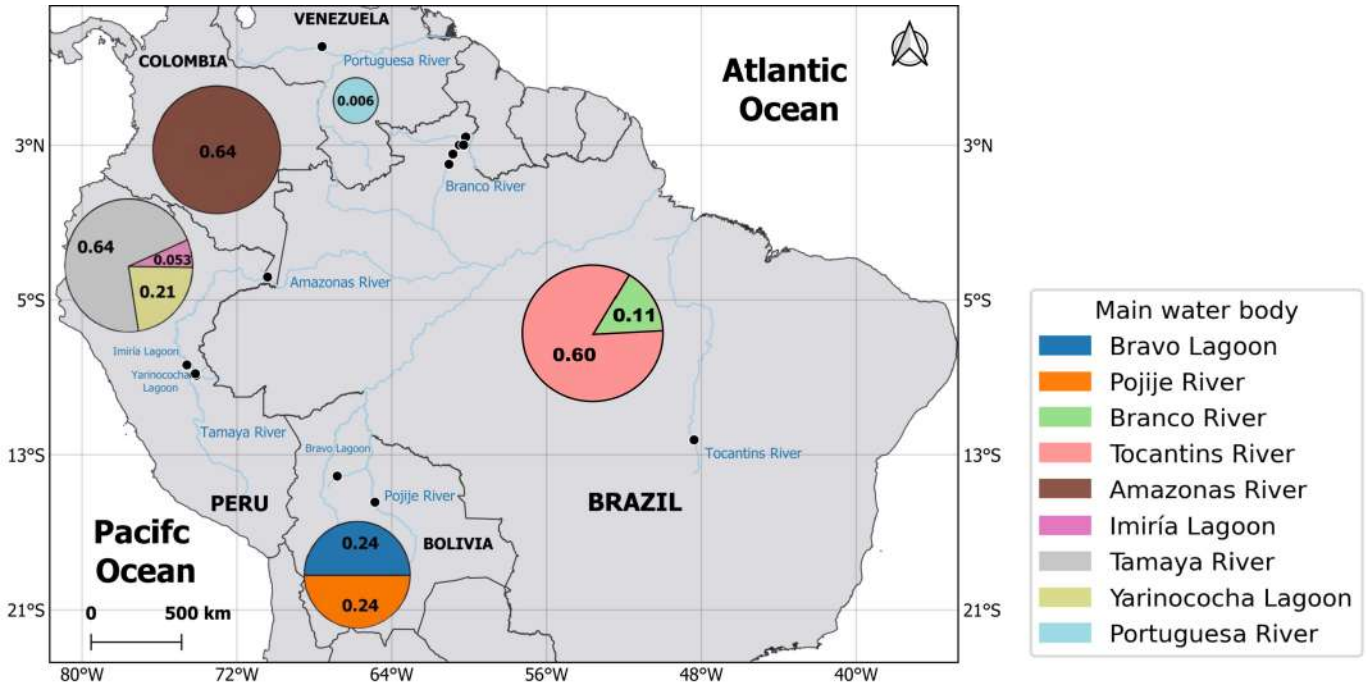


Figure 2. Pie charts showing the proportional contribution of each major water body to the river dolphin acoustic detection rate (DPM/MinOn) within South America countries. Circle size reflects the total detection rate per country, and segment labels indicate normalized values. Black points represent the sampling locations.

among habitats with different flow characteristics, with a higher number of vocalizations occurring in low current areas such as lakes and confluences (Yamamoto et al. 2015). This pattern is consistent with the higher detection rate values observed in the Tamaya River, where data were collected at confluence sites, and in the Tarapoto Lakes, Amazon River, Colombia, indicating that the physical characteristics of the habitat may modulate the animals' acoustic activity.

The data obtained for Bolivia come from two F-POD monitoring sites: a river confluence and a tectonic lake. Despite their contrasting environmental characteristics, both sites showed similar acoustic emission rates ($t = 0.24$). These sites also differ in their local context, including levels of human activity and the conditions under which data were collected. The confluence of the Pojije River is subject to subsistence fishing activity, whereas data from the tectonic lake were collected during a short-term management intervention involving attempts to capture and to translocate dolphins. The similarity in detection values between sites, as well as differences observed among countries, likely reflect a combination of ecological, environmental, and methodological factors. These results highlight the importance of interpreting passive acoustic detection within the specific environmental and sampling context of each site, and they underscore the need for targeted studies explicitly designed to test the effects of anthropogenic and ecological drivers on river dolphin acoustic behavior.

Despite the small river dolphin population in the Tocantins River (Paschoalini et al. 2020), the high production of echolocation clicks in the Peixe Angical hydropower reservoir may be associated with the opportunistic behavior of these animals (Da Silva and Martin 2018). River dolphins often exploit the high concentration of fish in hydropower dam areas for foraging (Araújo and Wang 2014), a behavior that is associated with the production of a large number of echolocation clicks (Yamamoto et al. 2015). This result indicates that even in rivers with relatively small populations, prey availability

can temporarily increase the acoustic activity detected by PODs, reinforcing the role of feeding behavior and habitat structure in modulating vocalization.

PODs proved to be a promising tool for monitoring the presence, distribution, and habitat use of river dolphins across different environments in the Amazon. Because these regions are difficult and costly to access, this type of acoustic acquisition device is particularly advantageous due to its ease of deployment and its ability to autonomously collect data over extended periods. Additionally, the low data storage requirements and the rapid processing of recorded information further enhance the practicality of these devices. Moreover, the continuous recording of click trains enables the investigation of temporal patterns in habitat use, such as diel and seasonal variations in activity, by quantifying changes in detection rates over time and across habitats, providing insights that would be difficult to obtain through visual or observational methods (Panicker et al. 2022, Garcia et al. 2023, Todd et al. 2023).

However, some factors limit data analyses: differentiation between the echolocation clicks of *Inia* and *Sotalia* remains challenging, and the inability to record whistles and low-intensity pulsed signals restricts a comprehensive understanding of the acoustic repertoire of these animals. Likewise, the lack of compatibility of the files with other analysis software (such as PAMGuard and Raven), as well as the difficulty of comparing the acoustic parameters of click trains detected by PODs with those described in studies using other types of equipment, such as broadband hydrophones coupled to digital recorders or autonomous devices such as SoundTrap (Amorim et al. 2016, Melo-Santos et al. 2019), and the greater possibility of underestimating the occurrence of river dolphins caused by the effective distance of click detection (Todd et al. 2025b), also represent important limitations.

Despite these constraints, the data obtained demonstrate that passive acoustic monitoring is a valuable tool for informing management and conservation actions, enabling the identification of critical areas, improving the understanding of spatial and temporal occurrence patterns, and providing guidance for conservation strategies in complex and difficult-to-access Amazonian environments.

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CONFLICTS OF INTEREST

The authors declare there are no conflicts of interest regarding the publication of this manuscript.

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