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Effectiveness of pingers to reduce the bycatch of Franciscana (*Pontoporia blainvillei*) in the Uruguayan artisanal gillnet fishery

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Summary
The Franciscana *Pontoporia blainvillei* is the main dolphin species affected by fisheries in the southwest Atlantic. The aim of this study was to test the effectiveness of acoustic deterrents (Banana Pinger) in reducing the bycatch of Franciscana in gillnets. During October 2019 – March 2021 we conducted an experiment under realistic fishing conditions in collaboration with artisanal fishers of seven boats from Montevideo (Río de la Plata) and La Paloma (Atlantic coast), Uruguay. The protocol considered nets with pingers (experimental treatment) and without (control treatment). Data from 428 fishing sets (200 and 228 sets with and without pingers) and 5458 nets (2605 and 2853 nets with and without pingers) were obtained. A total of 25 Franciscana dolphins were captured, 7 of them in the experimental treatment and 18 in the control treatment. After considering relevant ancillary variables (i.e. sea surface temperature, mesh size, soak time) and the fishing boat as random effect, the result of a Generalized Additive Mixed Model (GAMM) indicated a significant reduction in the bycatch of Franciscana in the experimental treatment, in comparison to control nets. We found convincing evidence that Banana Pingers reduces the bycatch of Franciscana in the Uruguayan artisanal gillnet fishery; these results are potentially applicable to other artisanal gillnet fisheries interacting with this small cetacean. Further research needs are discussed.

Introduction

Bycatch in gillnet fisheries represents a serious threat to several small cetaceans (Read et al., 2006; Reeves et al., 2013; Brownell Jr et al., 2019). These species use sound both for communication and echolocation, and therefore acoustic devices have been explored as a tool for reducing bycatch (Dawson et al., 2013). Acoustic alarms, or pingers, are among the most widely used bycatch-mitigation measure to reduce bycatch of small cetaceans (Bordino et al., 2002; Dawson et al., 2013; Mangel et al., 2013).

The Franciscana *Pontoporia blainvillei* is the main cetacean species affected by fisheries in the southwest Atlantic (Secchi et al., 2002; Secchi and Wang, 2002). This small dolphin, distributed in Brazil, Uruguay and Argentina, is currently listed as Vulnerable by the International Union for Conservation of Nature, IUCN (Zerbini et al., 2017). Although its population is still considered large (tens of thousands of individuals (Zerbini et al., 2017)) compared to other small cetacean seriously threatened to extinction (Brownell Jr et al., 2019), it has suffered high levels of incidental mortality in gillnets for eight decades (Praderi, 1997; Ott et al., 2002; Secchi et al., 2003). Several strategies have been tested to mitigate this bycatch (Bordino et al., 2013; Berninsone et al., 2020), including pingers (Bordino et al., 2002). The latter study showed a significant reduction on the bycatch of Franciscana. However, the experimented pingers of 10 Khz produced a "dinner bell" effect on pinnipeds, and hence, an increased fish catch damage over time; This indicates the need of pingers emitting sounds at higher frequencies (Bordino et al., 2002). A subsequent study using 70 Khz pingers showed a significant reduction on the bycatch of Franciscana without producing the mentioned "dinner bell" effect on pinnipeds (Bordino et al., 2004). This was attributed to the inability of pinnipeds to hear the frequency produced by the used pingers (Bordino et al., 2004). Although some studies carried out a few years ago have shown that pinnipeds can perceive frequencies as high as 180Khz (Cunningham et al., 2014; Cunningham and Reichmuth, 2016), the available evidence indicates that pinnipeds are not attracted to pingers emitting at 50–120 Khz (Bordino et al., 2004; Cornwall Wildlife Trust, 2013). Yet, a recent study suggested that sounds at 69 Khz produced a "dinner bell" effect on pinnipeds (Rub and Sandford, 2020).

Emerging pingers randomly moving within the range of 50–120 kHz (Banana Pinger, Fishtek Marine Limited) (Omeyer et al., 2020), could be a solution to reduce the bycatch of small cetaceans and avoid the "dinner bell" effect on pinnipeds. A controlled experiment showed that Atlantic grey seals (*Halichoerus grypus*) were not significantly attracted to these pingers (Cornwall Wildlife Trust, 2013). The randomized ping intervals might reduce an additional concern about these devices; the dolphin habituation to pingers (Dawson et al., 2013) and hence the possible reduction over time in the mitigation measure effectiveness. The proof of concept of these pingers were recently addressed with the harbour porpoises (*Phocoena phocoena*). The results indicated that harbour porpoises did not habituate to the pinger over a period of several months. Furthermore, pinger use did not lead to harbour porpoise displacement over the study period, suggesting an absence of long-term behavioral effects (Omeyer et al., 2020). All these results together suggest that these pingers might be an effective measure to reduce the bycatch of Franciscana in artisanal gillnets.

Here, we presented the results of an experiment conducted in collaboration with artisanal fishers in Uruguay. The aim of this study was to test the effectiveness of Banana Pinger in reducing the bycatch of Franciscana in gillnets.

Materials and Methods

The Uruguayan artisanal fishery, comprising vessels under 10 GRT, uses mainly gillnets and bottom longlines. The bycatch of Franciscana occurs exclusively in gillnets and mainly between the coast of Montevideo, in the Rio de la Plata, and the Atlantic coast of Rocha (Franco-Trecu et al., 2009; Szephegyi, 2012), comprising current artisanal fishery zones E (from Montevideo to Punta del Este) and L (from Punta del Este to the border with Brazil) (DINARA, 2002). There is a total of 347 small-scale vessels (mean length: 6.8 m, range: 3.5 – 11.5 m; GRT mean: 2.9, range: 0.6 – 10.0) licensed by the "Dirección Nacional de Recursos Acuáticos" (DINARA) to operate in these zones. This number comprises 78 (mean length: 7.9 m, range: 4.5 – 11.5 m; GRT mean: 4.2, range: 0.9 – 10.0), 233 (mean length: 6.5m, range: 3.5 – 10.7 m; GRT mean: 2.6, range: 0.6 – 10.0) and 36 (mean length: 5.9 m, range: 3.7 – 8.7 m; GRT mean: 2.0, range: 0.7 – 4.0) boats licensed in zones L, E and D sub-zone DE, respectively. The latter correspond to boats licensed in the adjacent fishing zone D (from Colonia to Montevideo), with permission to fish over part of zone E (from Montevideo to the mouth of the Solís Chico stream, Canelones; (DINARA, 2004)). It should be noted that not all the licensed boats are active or use gillnets. For example, at Punta del Este, almost all boats operate year-round with demersal longlines (Franco-Trecu et al., 2009). A map with the delimited zones and sub-zones authorized by DINARA to conduct artisanal fishing in Uruguay can be downloaded from: https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/comunicacion/publicaciones/zonas-autorizadas-para-pesca-artesanal.

We conducted an experiment in collaboration with artisanal fishers to test the effectiveness of acoustic deterrents (pingers) in reducing the bycatch of Franciscana in gillnets. The experiment begun in October 2019 and until March 2021 have participated fishers from seven artisanal fishing boats. Three of these boats (length range: 5.3 to 9.0 m) operated in the Atlantic coast from La Paloma port, Rocha, and the remaining four boats (length range: 3.6 to 6.3 m) operated in the Río de la Plata, from Punta Brava and Buceo, Montevideo (**Fig. 1**). All fishing boats usually operated at 0.5 – 2 nm from the coast. The nets were 50 m long and 1.75-3.5 m deep with a mesh size from 14 to 30 cm. They were deployed in strings, usually of 2 – 3 nets in the Río de la Plata and 10 – 40 nets and the Atlantic coast. In these zones, daily effort per boat usually ranged from 8 to 18 nets and 23 to 80 nets, respectively. In Montevideo nets with mesh size of 14 – 16 cm and 24 – 30 cm were employed to target Whitemouth croaker (*Micropogonias furnieri*), and Black drum (*Pogonias courbina*) and Flounder (*Paralichthys orbignyanus*), respectively. In Rocha, nets with mesh size of 18 cm and 24 – 30 cm were employed to catch Whitemouth croaker, and Angular angelshark

(*Squatina guggenheim*) and Flounder, respectively. The soak time of the fishing gear usually was 20-24 hours, but in some circumstances, mainly due to strong winds and storms, nets remained in the water for up to 72 hours.

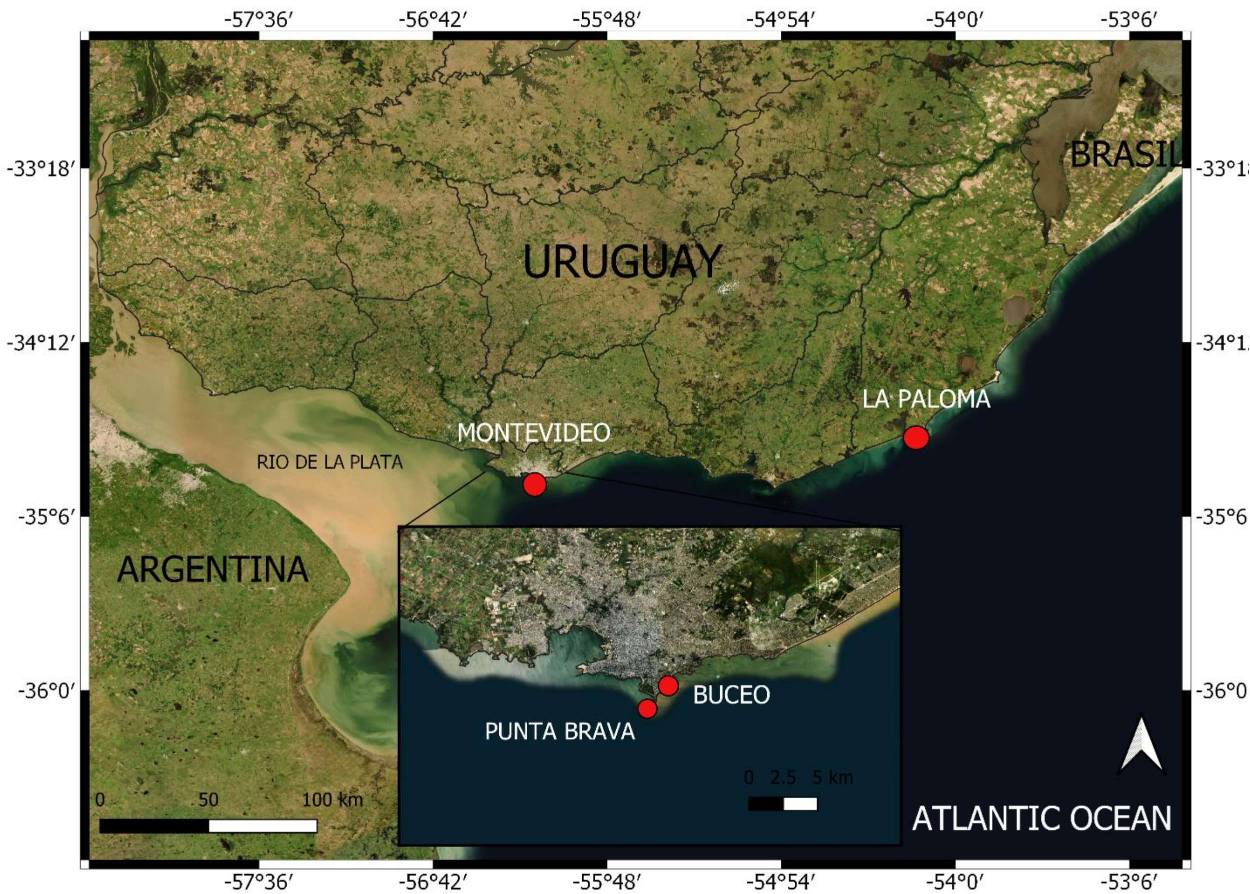

Figure 1. Study area. The map shows the location of La Paloma port, in the Atlantic coast and Montevideo, in the Río de la Plata. Sampled boats in Montevideo operated from Punta Brava and Buceo.

Experimental design

The acoustic devices used are Banana Pingers (Porpoise & dolphin deterrent pinger 50-120 kHz; SPL: 145 dB re 1 µPa at 1 m, ping duration: 300 ms with randomized ping intervals between 4 and 12 s; https://www.fishtekmarine.com/product/deterrent-pinger-50-120/) (Omeyer et al., 2020)) (Fig. 2)). The experiment was conducted during commercial fishing trips under typical fishery conditions. The protocol considered nets with (experimental treatment) and without pingers (control treatment). Both treatments were implemented in agreement with the skipper, considering the particularities of each boat and its fishing gear. Two experimental configurations were applied: 1) one boat deployed the experimental strings with pingers and the other boat deployed the strings with the control treatment, and 2) a single boat deployed both the strings with the experimental treatment and the control treatment. For analyses purposes, the string with the control treatment and that with the experimental treatment were considered as individual fishing sets, even when the two treatments occurred in a single fishing event. The fishing set was considered the sample unit for analyses. The protocol considers a spacing between pingers of 200 m (manufacturer's specification), that is, each pinger would cover a radius of 100 m. In practice, due to differences in fishing gear configurations (i.e. number of nets forming a strings or spacing between strings), the pingers were arranged so that they cover a radius ranging between 65 m and 150 m. On average, the spacing between two pingers was 195 m. In the absence of implemented mitigation measures to reduce the bycatch of Franciscana, the experiment is not considered lethal experimentation (i.e. when an experiment may elevate deaths above the level that would have occurred under normal fishing operations; Pierre and Debski, 2013).

All data were obtained by participating fishers and reported either in fishing logbooks or during frequent visits (1-3 times per week). For each fishing event the available data were boat name, date (hence, month and quarter), location (latitude and longitude), fishing zone, number of strings/nets with and without pingers, the soak time, mesh size and number of bycaught Franciscana. In Montevideo, all bycaught Franciscana were landed for further analysis at the laboratory. Due to logistic reasons, some specimens were not landed in La Paloma.

In addition, we obtained depth (bathymetric data at 15 arc sec resolution) and distance from the coastline using GEBCO dataset (https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2020/), Sea Surface Temperature, SST (NASA/JPL, 2015) near-real-time dataset (dataset ID: nesdisSSH1day) (one day latency) 0.01 degree grid, and Sea level Anomaly, SLA (dataset ID: nesdisSSH1day), with a spatial resolution of 0.25 degree grid (https://coastwatch.noaa.gov/cw/satellite-data-products/sea-surface-height/optimal-interpolation-level-3-sea-level-anomalies-from-multiple-altimeter-missions.html).

Data analysis

The effect of pingers on the capture of Franciscana was evaluated after accounting by ancillary variables. Generalized Additive Mixed Models (GAMMs) with Tweedie error structure were employed to examine the effects of several combinations of covariates on the bycatch rate per unit of effort (BCPUE: dolphins x km of nets $^{-1}$) of Franciscana. The Tweedie distribution is an exponential dispersion model with a variance function $V(\mu)=\mu^p$, where p, the Tweedie index parameter, can take any real value except $0 < p < 1$ (Dunn and Smyth, 2018). The use of the Tweedie distribution has shown better statistical performance than other methods to analyse zero inflated data from bycatch species (Shono, 2008). For 1 < p < 2, the Tweedie distributions are suitable for modelling positive data with exact zeros. This case of the Tweedie distribution is an extension of compound Poisson, non-negative with mass at zero, and is sometime called Poisson–gamma distribution (Dunn and Smyth, 2018). We firstly performed Tweedie Generalized Additive Models (GAMs) with the function tw (library 'mgcv' version 1.8-31 (Wood, 2017)) to estimate p during fitting, setting to 1.01 and 1.99 the lower and upper limit on p for optimization. Then we employed the function Tweedie (library 'mgcv' version 1.8-31 (Wood, 2017)) with the obtained p values to fit the GAMMs. Several covariates were initially considered, including spatial, temporal, environmental and fishing-related variables. **Table 1** provides details in model formulations, including the description of the levels and range of categorical and continuous covariates, respectively. The variables city, port, fishing zone and latitude/longitude were included one at a time. The same procedure was followed with the spatial variable depth and distance to coast and the temporal variables month and quarter. We fitted the GAMMs including the individual boat as a random factor. The model selection process was carried out considering the objective of isolating the effect of the use of pingers. Parsimony and the diagnostic information about the fitting procedure were used in combination to select the final model. The statistical computing environment R (R Core Team, 2020) was used for all statistical analyses.

Table 1. Details of covariates used in the Generalized Additive Mixed Models (GAMMs).

Covariates	Type	Levels / Range	Model terms
Spatial and Temporal			
Spatial (Latitude and Longitude)[1]	Continuous	34.60 – 34.95 ° S; 54.08 - 56.23 °W	s (Lat, Lon)
City[1]	Categorical	La Paloma, Montevideo	+ City
Port[1]	Categorical	La Paloma, Punta Brava, Buceo	+ Port
Fishing Zone[1]	Categorical	5 main fishing zones	+ Fishing Zone
Depth[2]	Continuous	4 - 17 m	s (Depth)
Distance to Coast[2]	Continuous	266 – 5478 m	s (Dist. Coast)
Month[3]	Continuous	1 - 12	s (Month)
Quarter[3]	Categorical	Months 1-3, 4-6, 7-9, 10-12	+ Quarter
Environmental			
Sea Surface Temperature	Continuous	10.46 - 23.76 °C	**s (SST) ***
Sea Level Anomaly	Continuous	-0.46 - 0.97 m	s (SLA)
Fishing Variables			
Treatment	Categorical	Control, Experimental	**+ Treatment***
Soak	Categorical	24 h; > 24 h	**+ Soak ***
Mesh Size	Categorical	14-18; 24-30	**+ Mesh Size***
Effort	Continuous	2 - 40 nets	offset or **included at BCPUE ***
Boat ID	Categorical	7 vessels	**Random effect***

"s" refers to splines and "+" refers to fixed factors in the model formulations. Covariates marked with the same number (e.g. [1]) were included one at a time. Final model includes terms indicated by an asterisk *** and marked in bold**.

Results

During August 2019 – March 2021 data from 428 fishing events and 5458 nets were obtained. A total of 2605 and 2853 nets distributed on 200 and 228 fishing sets were sampled for the experimental (pingers) and control treatments, respectively. Fifty-nine and 45% of the fishing sets and nets, respectively, were sampled in Río de la Plata (Montevideo), and the rest of the effort corresponded to the Atlantic coast (Rocha). A total of 25 Franciscana dolphins (12 females, 8 males and 5 undetermined; all were dead) were captured in the experiment, 18 (0.13 dolphins km^{-1}) of them in the control treatment and 7 (0.05 dolphins km^{-1}) in the experimental treatment, indicating a reduction of 61% in the nominal BCPUE. After considering relevant ancillary variables (i.e. SST, mesh size, soak time) and the fishing boat as random effect (**Table 1**), the result of the GAMM indicated a significant reduction in the bycatch of Franciscana in the treatment with pingers, in comparison to nets without pingers (**Fig. 2A**). This model predicted that the mean BCPUE decreased by 92% on the presence of pingers (0.016 dolphins km^{-1}), compared to the mean BCPUE on the strings without pingers (0.211 dolphins km^{-1}). A secondary result to this study, and expected, was that bycatch rates were significantly higher during those fishing events with extended soak time (**Fig. 2B).** Bycatch rates were higher with large mesh size (24 – 30 cm) than those observed in medium size (14 – 18 cm; **Fig. 2C**). Finally, bycatch rates significantly increased towards colder waters.

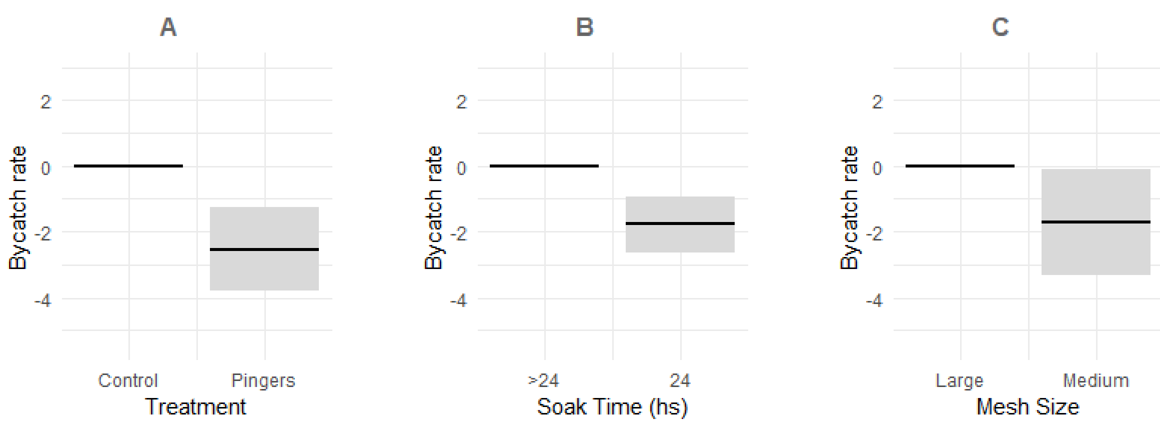

Figure 2. Results of GAMM on the effect of (A) pingers on the bycatch rate of Franciscana dolphin taking into account ancillary variables (Soak Time, Mesh Size and SST) and fishing boat as random effect. The effect of two relevant covariates is also shown: (B) soak time and (C) mesh size. Each plot illustrates the relative bycatch rate effect size (on the scale of the linear predictor) between levels, setting to 0 the reference category. Bands represent the 95% confidence intervals.

Discussion

Our study founds convincing evidence that Banana Pingers reduces the bycatch of Franciscana in the Uruguayan artisanal gillnet fishery. These results are potentially applicable to other gillnet fisheries interacting with this dolphin in the southwest Atlantic, and even other small cetaceans affected by this type of fishing gear elsewhere.

Further research needs 1) to discard any potential "dinner bell effect" on South American sea lion (*Otaria byronia*) and South American fur seal (*Arctocephalus australis*); 2) to confirm the absence of Franciscana habituation over time to Banana pingers, and hence a possible reduction in the efficacy of this mitigation measure; and 3) to determine if pinger effect is localized and has not long-term displacements from favourable habitats.

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