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Research Article

Marine mammal bycatch by the industrial bottom trawl fishery at the Río de la Plata Estuary and the adjacent Atlantic Ocean

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ABSTRACT. Fisheries interactions with non-target marine vertebrates are a worldwide problem. The impact of coastal bottom trawl fisheries on marine mammals has never been evaluated before in the Río de la Plata Estuary and the adjacent Atlantic Ocean. Our aim was estimating the bycatch per unit effort (BcPUE) and incidental mortality rates of marine mammals caused by the industrial coastal bottom trawl fisheries fleet. We evaluated the mortality of three species (*i.e.*, franciscana dolphin *Pontoporia blainvillei,* South American sea lion *Otaria flavescens,* and the South American fur seal *Arctocephalus australis*); these species are facing conservation problems either at the regional or local scale. We conducted an onboard data collection program of marine mammals' bycatch involving crew members of 10 vessels (30%) of the Uruguayan coastal bottom trawl fleet between January 2009 and April 2012. A total of 102 marine mammal individuals were bycaught during 490 fishing trips involving 2,398 fishing days. Mortalities estimated for franciscana dolphin were the highest among the species affected, with values adding up to ~100 individuals for year (with scenarios of population decline in the area), followed by South American sea lion with ~77 individuals by year (0.8% of local population) and the South American fur seal with an annual mortality estimate of ~25 individuals (~0.02% of local population). BcPUE showed significant temporal variation, with franciscana dolphin BcPUE varying seasonally and those of otariids according to their breeding season. Our estimates of marine mammal bycatch by bottom trawl fisheries should constitute an important input for the sustainable management of fisheries and the conservation of marine biodiversity in the southwestern Atlantic Ocean.

Keywords: *Pontoporia blainvillei*; *Otaria flavescens*; *Arctocephalus australis*; mortality; bottom-trawl; fisheries, bycatch

INTRODUCTION

Interactions between marine vertebrates and fisheries are a worldwide problem (*i.e.*, Lewison *et al.,* 2004; Read *et al.,* 2006). It is well established that incidental catch (bycatch) in fisheries is one of the major threats for many populations of sharks, seabirds, marine turtles and marine mammals (*e.g.*, Northridge & Hofman, 1999; Hall *et al.,* 2000; Dulvy *et al.,* 2008; Moore *et al.,* 2010; Dmitrieva *et al.,* 2013). Long-lived and low fecundity species are extremely vulnerable to human-caused mortality as the removal of just a few adult individuals may considerably affect population viability (Lewison *et al.,* 2004). The impact of marine mammal

Corresponding editor: Antonio Avila da Silva bycatch is contingent upon the behavioral characteristics of the species involved, the type of fishing gear used, and varies between fishing areas (Lewison *et al.*, 2004; Read, 2005; Read *et al.*, 2006). Therefore, bycatch needs to be evaluated on a case-by-case basis, considering both the species and the fisheries involved (Alverson *et al.*, 1994).

Assessing the magnitude of bycatch is challenging because getting reliable data on incidental captures or mortality rates for species that are not targeted by fisheries is difficult. Different approaches have been used to quantify bycatch, including interviews with fishers, use of logbooks and onboard observer programs (*e.g.*, Franco-Trecu *et al.*, 2009; Dmitrieva *et al.*, 2013; Passadore *et al.*, 2015). An interview-based approach is the recommended method whenever resources are limited (Gavin *et al.*, 2010; Moore *et al.*, 2010; Dmitrieva *et al.*, 2013) and/or no official observer program data is available. The involvement of key stakeholders (*i.e.*, fishers) is then not only essential to access crucial information on incidental bycatch but also for the eventual implementation of further mitigation and management measures (Alava *et al.*, 2017).

In the southwestern Atlantic Ocean, there have been assessments of marine mammal bycatch by artisanal/small-scale (Praderi *et al.*, 1989; Corcuera *et al.*, 1994; Crespo *et al.*, 1994; Bordino *et al.*, 2002; Franco-Trecu *et al.*, 2009) and longline fisheries (*i.e.*, Brasil: Dalla-Rosa & Secchi, 2007; *i.e.*, Uruguay: Passadore *et al.*, 2015), as well as by midwater trawl nets (*i.e.*, Argentina: Crespo *et al.*, 2000; Cappozzo *et al.*, 2007), and bottom trawl nets (Crespo *et al.*, 1997). However, to our knowledge, there have been no systematic assessments of incidental bycatch by industrial coastal bottom trawl fisheries in the Río de la Plata estuary and adjacent Atlantic Ocean since there are only scattered and largely anecdotal records of marine mammal bycatch (Montealegre-Quijano & Neves Ferreira, 2010; Reyes *et al.*, 2012). Studies of coastal artisanal fisheries in southwestern Atlantic Ocean suggest that franciscana dolphins, South American sea lions (sea lion hereafter) and South American fur seals (fur seal hereafter) are the most frequently incidentally caught species (Franco-Trecu *et al.*, 2009). However, in order to understand the overall impact of fisheries on each marine mammal species, it is important to have reliable estimates of the bycatch rates and the impact caused by each type of fishing gear.

The franciscana dolphin is endemic to coastal waters of Brazil, Uruguay and Argentina, that inhabits waters from shore to 55 km offshore and up a water depth of 60 m off (Danilewicz *et al.*, 2010), where it overlaps with the fishing areas of the artisanal and industrial coastal fleets. It is an opportunistic bottom feeder with a generalist diet composed of juvenile demersal fish and some cephalopods (Franco-Trecu *et al.*, 2017). The species is currently considered the most endangered small cetacean in the southwestern Atlantic Ocean and is classified as vulnerable by IUCN (Reeves *et al.*, 2008). For Uruguayan waters (Atlantic coast and Río de la Plata) there are not estimates of franciscana dolphin abundance. However, there are estimations in the adjacent areas. Abundance estimation for the northern Buenos Aires Province was 8,279 individuals (CI = 4,904-13,960), and for southern Buenos Aires Province the number of individuals was 5,896 (CI = 1,928-17,999), and about 3.5-5.6% of the stock may be removed each year by the fishery (Crespo *et al.*, 2010). For Rio Grande do Sul, southern Brazil, abundance was estimated in 6,839 franciscanas (95% CI = 3,709-12,594) concluding that even in the most optimistic scenario, the annual increment of franciscanas is not sustainable with the current levels of bycatch (Danilewicz *et al.*, 2010). The latest mortality estimate of franciscana by the Uruguayan fisheries artisanal fleet was ~300 individuals per year (Franco-Trecu *et al.*, 2009), while only anecdotal bycatch data of 26 individuals killed between 2006 and 2008 is available for the coastal bottom trawl fishery (Franciscana Project, *unpub. data*).

Sea lions and fur seals both occur along the Atlantic Ocean coast from Southern Brazil to the Pacific coast up to Peru (*ca.* 4ºS) (Vaz-Ferreira, 1982). The Uruguayan population of fur seals showed a positive trend between 1956 and 2013 with a 1.5% and a current pups population estimated to be ~31,000 individuals (Franco-Trecu, 2015). In contrast, the smaller Uruguayan sea lion population (estimated to be ~10,000 individuals) is currently decreasing at an annual rate of 2% (Franco-Trecu, 2015). Because the sea lions in Uruguay forage in shallow and coastal waters (Riet-Sapriza *et al.*, 2013), they are likely to interact not only with artisanal coastal fisheries (Szteren & Páez, 2002; Segura *et al.*, 2008; Franco-Trecu *et al.*, 2009), but also with the coastal bottom trawl fleet operating beyond the 7 nm (nautical miles) reserved for the artisanal fisheries (Riet-Sapriza *et al.*, 2013). Contrary, fur seal females used foraging areas of open waters located at (on average) 531 km S-SW from Isla de Lobos (Franco-Trecu, 2015) which would make less likely their interaction with the coastal fleet.

Given the unfavorable conservation status of franciscana dolphins and the declining population trend of the sea lions in Uruguay, we deemed relevant to estimate the bycatch per unit effort (BcPUE) and the bycatch mortality of the marine mammal species captured by the Uruguayan industrial coastal bottom trawl fleet.

MATERIALS AND METHODS

Study area

The study area encompasses the Argentinean-Uruguayan Common Fishing Zone (AUCFZ) and the Uruguayan Exclusive Economic Zone (EEZ), including the Río de la Plata estuary and the Atlantic Ocean coast (Fig. 1). The Río de la Plata (34°00´-36°10´S, 55°00´-58°10´W) is the second largest estuary basin in South America with a large and highly dynamic mixing of seawater and freshwater (Guerrero *et al.*, 1997; Acha *et al.*, 2004). On the coast, the river discharge and the latitudinal shifts of the Brazil-Malvinas Confluence generate seasonal variability in primary productivity, with cold and nutrient-rich sub-Antarctic waters dominating in winter, and warm, nutrient-poor sub-tropical waters during summer (Ortega & Martinez, 2007). The confluence of these two currents produces one of the most energetic and productive regions in the world (Guerrero *et al.*, 1997; Ortega & Martinez, 2007), supporting large fisheries including the white mouth croaker (*Micropogonias furnieri*) that is the most commercially important coastal fish in the region (Macchi & Acha, 2000; Macchi *et al.*, 2003).

Fishery description

The Uruguayan industrial coastal bottom trawl fishing fleet began operating in 1974 and currently consists of 33 vessels mainly targeting the white mouth croaker and the striped weakfish (*Cynoscion guatucupa*). This fishing fleet operates from the Montevideo harbor and employs 7 to 16 fishermen per vessel with an estimate of 343 crew members. Vessels of this fleet range between 18 and 30 m of length, between 85 and 287 gross register tonnage, and engine power from 290 to 700 HP (DINARA, 2010).

With only one exemption, all vessels of the coastal trawling fleet operated in pairs (*i.e.*, 16 pairs), with the two vessels sailing together in parallel, towing a single trawl, at a distance that maintains the horizontal opening of the net, which can reach 45 m wide and a vertical opening of up to 2.5 m height. The only vessel of the coastal bottom trawl fishing fleet that operates alone uses trawl doors to ensure the opening of the net while being towed. The body of the trawling nets is cone-shaped, the mesh size diminishes towards the bag or cod end with a minimum mesh size of 100 mm. Sometimes the cover is used to protect the cod end, which should have a mesh size at least three times bigger than the reglementary mesh size of the cod end (Art. 42, Decree N°149/997, Ministry of Livestock, Agriculture and Fisheries, Uruguay). Fishing operation depends on the abundance of targeted species and the oceanographic conditions. Fishing trips last on average seven days, and up to three trawls can be conducted each day with trawl events typically lasting about 4-5 h (Domingo *et al.*, 2008). The fishing area includes the AUCFZ and the Uruguayan EEZ covering areas beyond the 7 nm off the coast at depths ranging between 5 and 50 m (Fig. 1).

Data collection

Before systematic data collection, we regularly visited the Montevideo harbor between August and December 2008 to introduce and familiarize fishers with the project goals and to identify those crew members willing to participate in it on a voluntary basis. During this period, we provided to the participating crew with training and material with information concerning species identification, sex determination, and instructions to measure body length of bycatch marine mammals. Data collection took place between January 2009 and April 2012 by crewmembers of 10 vessels (30%) of the fleet. During this period, we visited the harbor fortnightly (before vessels departure or at their arrival from fishing trips) to interview the participating crewmembers and to gather the data collected in the previous trip. For every fishing trip, we thus gathered data for the number of fishing days, the species and number of marine mammals caught per day, the condition of the animal (*e.g.*, dead or alive), date of capture (and occasionally individual length and sex), and the bycatch location was georeferenced.

Data analysis

We compared the bycatch of each marine mammal species by the Uruguayan bottom trawling fleet over time (season and/or year) using Generalized Linear Mixed Models. For franciscana dolphin and sea lion bycatch, the response variable was the number of dead individuals caught in each fishing trip that was modeled using a zero-inflated, negative binomial distribution with a log link function for the count part and a logit function for the zero part (Zuur & Ieno, 2016). Because at most one fur seal was captured per fishing trip, we modeled its bycatch using a binary response variable with a binomial distribution and a logit link function. All statistical models had the number of fishing days per trip as an offset and vessel identity as a random effect to account for the lack of independence of the fishing events for each ship (Zuur & Ieno, 2016). All these statistical models had season (summer: January to March, autumn: April to June, winter: July to September, spring: October to December), year (2009, 2010, 2011 and 2012) and reproductive season (yes/no) as categorical fixed effects. For sea lion and fur seal the reproductive season was considered between December and February (Franco-Trecu *et al.*, 2014, 2015) and for

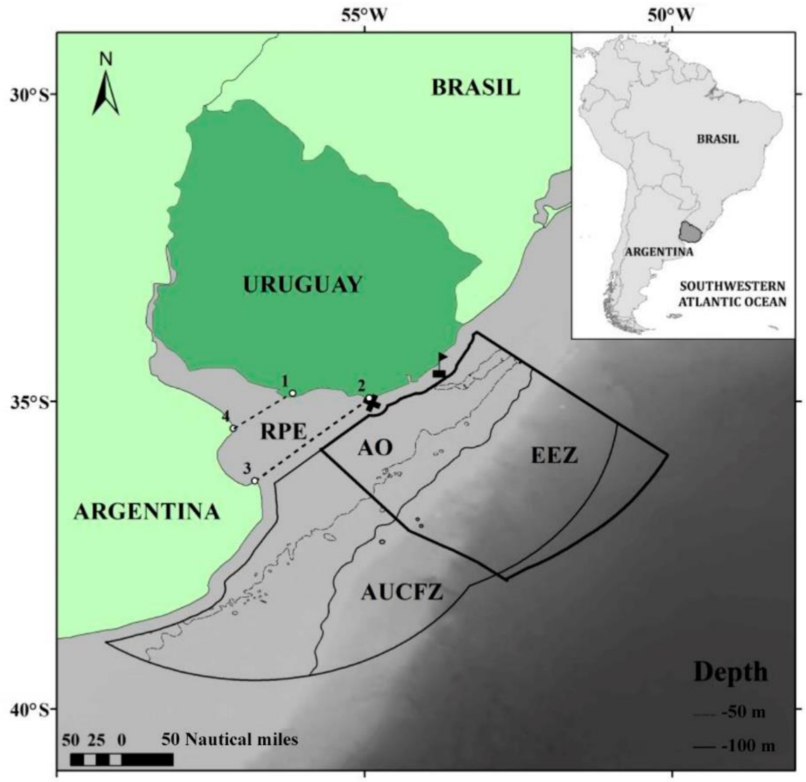

Figure 1. Study area encompassing the Argentinian-Uruguayan Common Fishing Zone (AUCFZ) and the Uruguayan Exclusive Economic Zone (EEZ), including the Río de la Plata Estuary (RPE) and the Atlantic Ocean (AO). The inner and the middle estuary lies above the line between Montevideo (1) -Punta Piedras (4), and the outer estuary is defined as the area between the last line and the line between Punta del Este (2) - Punta Rasa (3). The location of the breeding colonies of sea lions and fur seals is shown: Isla de Lobos (indicated by a cross) and Islas de Torres Group (indicated by a flag).

franciscana dolphins it was considered between October and March accordingly with Danilewicz (2003). All initial statistical models had both the single effects and interaction between either year and season or year and reproductive period as fixed effects and the vessel identity as random effects. We then simplified the initial models by sequentially deleting the term farthest from statistical significance and comparing consecutive models using the likelihood ratio test (Bolker, 2007) until arriving to the minimally adequate model in each case. All final statistical models were validated by residuals analysis by checking the randomness, homogeneity of variance and normality of the deviance residuals (Bolker, 2007).

Based on the output of the selected model for each species, we calculated the mean and 95% confidence intervals of the BcPUE per period (seasons for franciscana dolphin and breeding/non-breeding for fur seal and sea lion) as the inverse of the link function of each coefficient per period. We used the BcPUEs thus obtained to estimate the mean mortality per species due to bycatch by the Uruguayan coastal bottom-trawling fleet by multiplying the BcPUEs by the estimated mean fishing effort of the entire fleet in each period. The annual mortality per species due to bycatch was obtained by simply adding the relevant point estimates per period. Also, we explored the spatial distribution of observed bycatch per species by plotting the cumulative numbers of by-caught animals per species in 15×15 nm grid cells between 2009 and 2012 obtained using ArcGIS 10.1 (ESU759492829) and Spatial Analyst Tools (ESU137593532).

RESULTS

Fishing effort and bycatch

We obtained data for 490 fishing trips with 2,398 fishing days by the Uruguayan bottom trawling fleet between 2009 and 2012. Bycatch events were reported by fishers in 77 of the fishing days monitored. While most capture events involved a single individual, multiple individuals were bycaught in some days (*i.e.*, a total of 40 individuals were captured in 15 effective fishing days).

One hundred and two individuals were bycaught during the study period, corresponding to 49 franciscana dolphins, 43 sea lion, 9 fur seal (Table 1), and one southern elephant seal (*Mirounga leonina*). While all franciscana dolphins and the southern elephant seal bycaught were recovered dead, 30 and 11% of the sea lions and fur seals were captured alive and released afterward (Table 1).

Over one-half of the bycatch franciscana dolphins were measured and sexed, resulting in 13 females and 12 males with a total length ranging from 55 to 152 cm (mean = 125 cm, SD = 22). 19 sea lions bycaught were measured and sexed, 8 were females and 11 males, and their total length ranged from 115 to 210 cm (mean = 169 cm, SD = 27). The fur seal's total length measured (three females and four males) varied between 84 and 135 cm (mean = 113 cm, SD = 21). The southern elephant seal was a female with a total length of 240 cm. In addition to these marine mammals, the bottom trawl vessels also report anecdotally 17 bycatch marine turtles (*i.e.*, five green *Chelonia mydas*, nine logger-head *Caretta caretta*, and three leatherback turtles *Dermochelys coriacea*) during the study period.

The number of fishing vessels surveyed per year and season varied from 3 to 8 (mean = 5.3, SD = 1.6, Table 1, Fig. 2). Seasonal fishing effort observed ranged from 18 fishing days in winter 2010 to 337 days in winter 2009 (season mean = 191 days, SD = 89). It is worth mentioning that a worker's strike in autumn-winter 2010 resulted in the lower winter fishing effort (119 extrapolated fishing days in winter 2010, 1,390 in winter 2009 and 1,172 in winter 2011) (Fig. 2). The entire fleet total fishing effort in autumn 2010 was 820 fishing days; while in autumn 2009 and autumn 2011 was 1,315 and 1,432 days, respectively (Fig. 2, Table 1).

BcPUE and mortality

The selected models (Table 2) showed that the season was the predictor that best explained the variability of BcPUE in franciscana dolphins, whereas the reproductive-non-reproductive season was the most important BcPUE predictor for sea lion and fur seal.

BcPUE estimates for franciscana dolphins were significantly higher during spring and lower during winter. BcPUE estimates for sea lion and fur seal were lowest during the reproductive season (Table 3). In general, BcPUE was highest for franciscana dolphin, followed by the sea lion and fur seal (Table 3). Considering the entire Uruguayan bottom trawling fleet, the annual mortality of franciscana dolphin was of 99 individuals (IC: 49-210), the average annual mortality of sea lion was 77 individuals (IC: 37-162), and the average annual mortality of fur seal was 26 individuals (IC: 14-51) (Table 4).

Spatial distribution of bycatch

Bycatch of franciscana dolphins, sea lions, and fur seals mainly took place in the outer Río de la Plata Estuary (between the line Montevideo-Punta Piedras and the line Punta del Este-Punta Rasa) (Figs. 1, 3).

While all franciscana dolphins were caught in the outer zone of the Río de la Plata Estuary, in waters of approximately 10 m deep (Fig. 3a), most captures of sea lions occurred in neighboring areas of Isla de Lobos and Islas de Torres Group breeding colonies (Figs. 1, 3b), and those the fur seal took place closer to the coast (Fig. 3c).

DISCUSSION

The results presented herein are the first systematic estimate of marine mammal annual bycatch for the bottom trawl fishery operating in the AUCFZ and the Uruguayan EEZ. These results should help inform decision-makers and fishery managers about the seasonal and yearly rates of marine mammal bycatch in the Río de la Plata Estuary and the adjacent Atlantic Ocean. We chose to work directly with the main stakeholder (*i.e.*, fishers) to estimate marine mammal mortality caused by the bottom trawl fishery because of the persistent lack of an on-board monitoring scheme in the study area. We believe that the mutual engagement of scientists and social actors is essential to obtain scarce information at relevant spatial scales through participatory action research or citizen science schemes (*e.g.*, Brossard *et al.*, 2005; Cooper *et al.*, 2007; Bonney *et al.*, 2009). Although data from onboard scientific observers could be more appropriate to evaluate bycatch than our approach; however, to avoid bias a high coverage of the fishing effort is required. Although fishers bycatch records presented here might contain misreporting and thus negative bias, we could cover a high percentage of the Uruguayan trawling fleet using this approach. In addition, given that there was no scientific onboard observer program in place for this fishery at the time of this study and that values presented here constitute worrisome minimum bycatch levels, we hope that this study should encourage fisheries managers to implement such programs. Estimating bycatch involves an extremely complex interaction between social, economic, political, ethical and ecological dimensions. In this sense, bycatch affect biodiversity through the removal of individuals of non-targeted species, often making an impact on the population, community and ecosystem processes in marine environments (Hall *et al.*, 2000). Dolphins, sea

Table 1. Annual, seasonal, and cumulated fishing effort (total and surveyed days) and the number of bycatch marine mammals by the Uruguayan coastal trawling fishery in 2009-2012. The total catch and the number of dead individuals are shown per species (AA: South American fur seals, OF: South American sea lions; PB: franciscana dolphins) are shown. *Only summer and autumn.

	Fishing effort			Observed bycatch (Number of individuals)						
	Fishing days			AA		OF		PB	Overall	
Year/Season	Surveyed (n)	Total (n)	%	Fatal	Total	Fatal	Total	Total (Fatal)	Fatal	Total
2009	919	5,020	18.3	3	4	8	17	21	32	42
2010	696	3,820	18.2	0	0	9	11	10	19	21
2011	673	5,261	12.8	4	4	11	13	12	27	30
2012*	110	1,815	6.1	1	1	2	2	6	9	9
Summer	576	4,502	12.8	0	0	4	4	8	12	12
Autumn	659	4,045	16.3	3	3	8	14	17	28	34
Winter	497	2,680	18.5	3	4	8	11	3	14	19
Spring	666	4,689	14.2	2	2	10	14	21	33	37
Total	2,398	15,916	15.1	8	9	30	43	49	87	102

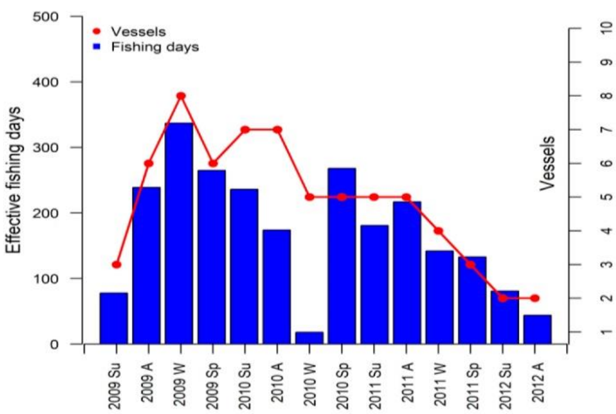

Figure 2. The number of fishing vessels surveyed and the total fishing effort (in days) per season (Su: summer, A: autumn, W: winter, Sp: spring), of the entire Uruguayan coastal bottom trawl fleet, between January 2009 and April 2012.

lions and fur seals are top predators that influence the dynamics and structure of marine ecosystems (Trites, 1997) through their impact on the growth and reproduction of prey and on the growth rates of other predators (*i.e.*, Trites, 1997; Estes *et al.*, 1998). Although only a few fisheries in the world include bycatch assessments on their management plans (Sarda *et al.*, 2015), it is unquestionable that these assessments should be an integral part of ecosystem management schemes.

The fishing area of the Uruguayan coastal bottom trawl fleet overlaps with the foraging grounds of franciscana dolphins (Franco-Trecu *et al.*, 2017), sea lion (Riet-Sapriza *et al.*, 2013) and partially, fur seal (Franco-Trecu, 2015). Furthermore, the main target species of the bottom-trawl fishery are the white mouth croaker and the stripped weakfish, both of which are important preys for these three marine mammal species (Franco-Trecu *et al.*, 2013, 2017; Riet-Sapriza *et al.*, 2013). Therefore, the bottom trawl fishery in the study area may also have an important indirect effect on marine mammal species through the partial removal of the stock of white mouth croaker on which the three mammal species assessed prey.

The franciscana dolphin was the most frequently bycaught species by the bottom trawl fishery in the study area. Secchi *et al.* (2003) proposed four provisional management units (Franciscana Management Areas, or FMAs) for the whole distribution of the species. FMA III corresponds to coastal waters of southern Brazil and Uruguay. Franciscana mortality was estimated for FMA III only in gillnet fisheries (Kinas, 2002; Secchi *et al.*, 2004; Franco-Trecu *et al.*, 2009). Therefore, mortality in bottom trawls should be added to gillnet mortality to obtain an overall impact of the fishery impact on this species in FMA III. Danilewicz *et al.* (2010) estimated density in FMA III to be about 0.51 ind km^{-2}, but they warned against extrapolating their estimate to areas not covered by their survey (*e.g.*, Ancrenaz *et al.*, 2004). Because the gillnet bycatch is already considered unsustainable in FMA III (Kinas, 2002; Secchi *et al.*, 2004), the bycatch by the Uruguayan coastal bottom trawl fleet (not included in previous assessments of regional population trends) could further impair the persistence of the FMAIII franciscana dolphin population.

Sea lions are considered to be a single breeding stock from southern Brazil to southern Patagonia (Feijoo *et al.*, 2011). However, depending on the trends of local populations and the magnitude of the bycatch, the need for management measures would vary along

Table 2. Set of Generalized Linear Mixed Models fitted for each species showing the probability distribution selected (ZI-NB: zero-inflated negative binomial, B: binomial), the explanatory variables included as fixed effects and Akaike information criterion (AIC) to give an idea of the empirical support given by data to each model. Model selection was carried out using the likelihood ratio test (see main text). The minimally adequate models for each species are shown in both italics and bold. Models are presented separately for *Pontoporia blainvillei*, *Arctocephalus australis* and *Otaria flavescens*.

Species	Model	Distribution	Explained variables	AIC
P. blainvillei	m1	ZI-NB	Season + year	314
	m2	*ZI-NB*	Season	**310**
	m3	ZI-NB	Year	318
	m4	ZI-NB	-	314
	m5	ZI-NB	Reproductive season	315
A. australis	m2	B	Season	93.7
	m4	B	-	91.2
	m5	*B*	Reproductive season	**88.8**
O. flavescens	*m1*	ZI-*NB*	Season + year	**267**
	m2	ZI-NB	Year	265
	m3	ZI-NB	Season	266
	m4	*ZI-NB*	*Reproductive season*	258
	m5	ZI-NB	-	**258**

Table 3. Seasonal byatch per unit of effort (BcPUE, expressed as the number of captures per fishing day) per species estimated for the entire Uruguayan industrial bottom trawl fishery, surveyed between 2009 and 2012. The estimated BcPUE values per period and their confidence intervals (CI) were obtained from the minimally adequate model selected for each species (Table 2). Values are presented separately for *Pontoporia blainvillei*, *Arctocephalus australis* and *Otaria flavescens*.

Species	Variable	BcPUE		
		2.5% CI	mean	97.5% CI
P. blainvillei	Winter	0.003	0.008	0.027
	Autumn	0.011	0.022	0.043
	Spring	0.018	0.033	0.061
	Summer	0.005	0.012	0.031
A. australis	Reproductive season	0.000	0.000	0.000
	No reproductive season	0.007	0.013	0.025
O. flavescens	Annual	0.007	0.015	0.028

the species geographical range. For instance, the annual mortality rate in trawl fisheries represents around 1-2% of the northern and central Patagonia sea lion population (Crespo *et al.*, 1997, 2012), but this population is currently increasing at an annual rate of ~5.6% (Dans *et al.*, 2004; Grandi *et al.*, 2014). In contrast, the Uruguayan sea lion population is declining at an annual rate of 2% (Franco-Trecu, 2015). The bycatch by bottom trawl fisheries would be causing a mean annual mortality of 0.8% of Uruguayan sea lion population (IC: 0.4-1.6%). Thus, the overall incidental sea lion mortality caused by the bottom trawl fishery in Río de la Plata estuary and Atlantic ocean and by the incidental capture in artisanal gillnets (Franco-Trecu *et al.*, 2009), might be considered to be relatively high and unsustainable for the small and declining Uruguayan sea lion population. The management implications of the estimated fur seal bycatch differ from of sea lions. Although the fur seal is also considered a single breeding population along the southwestern Atlantic (Crespo *et al.*, 2015) and bycatch is almost nonexistent in Patagonia (Crespo *et al.*, 2015), the annual mortality reported in the present study represents about 0.08% of the last pups abundance estimate of Uruguayan population of ~31,000 individuals (Franco-Trecu, 2015).

Finally, it is worth mentioning the single capture of a southern elephant seal during the surveyed period, a rare event because southern elephant seals reproduce in higher latitudes and feed in deeper waters out of the continental shelf (*i.e.*, Vergani & Stanganelli, 2001; Lewis *et al.*, 2006). Only a few individuals occasionally visit Uruguayan waters during the feeding migration

Table 4. Seasonal and annual mortality estimated for the entire Uruguayan industrial bottom trawl fishery. Mean mortality values are presented with their confidence intervals (CI) at 2.5% and 97.5%. Values are presented separately for *Pontoporia blainvillei*, *Arctocephalus australis* and *Otaria flavescens*.

Species	Variable	Annual mortality		
		2.5% IC	mean	97.5% IC
P. blainvillei	Winter	3	11	34
	Autumn	12	24	46
	Spring	28	52	95
	Summer	5	14	35
	Total	49	99	210
A. australis	Reproductive season	0	0	0
	Non-reproductive season	14	26	51
	Total	14	26	51
O. flavescens	Total	40	80	157

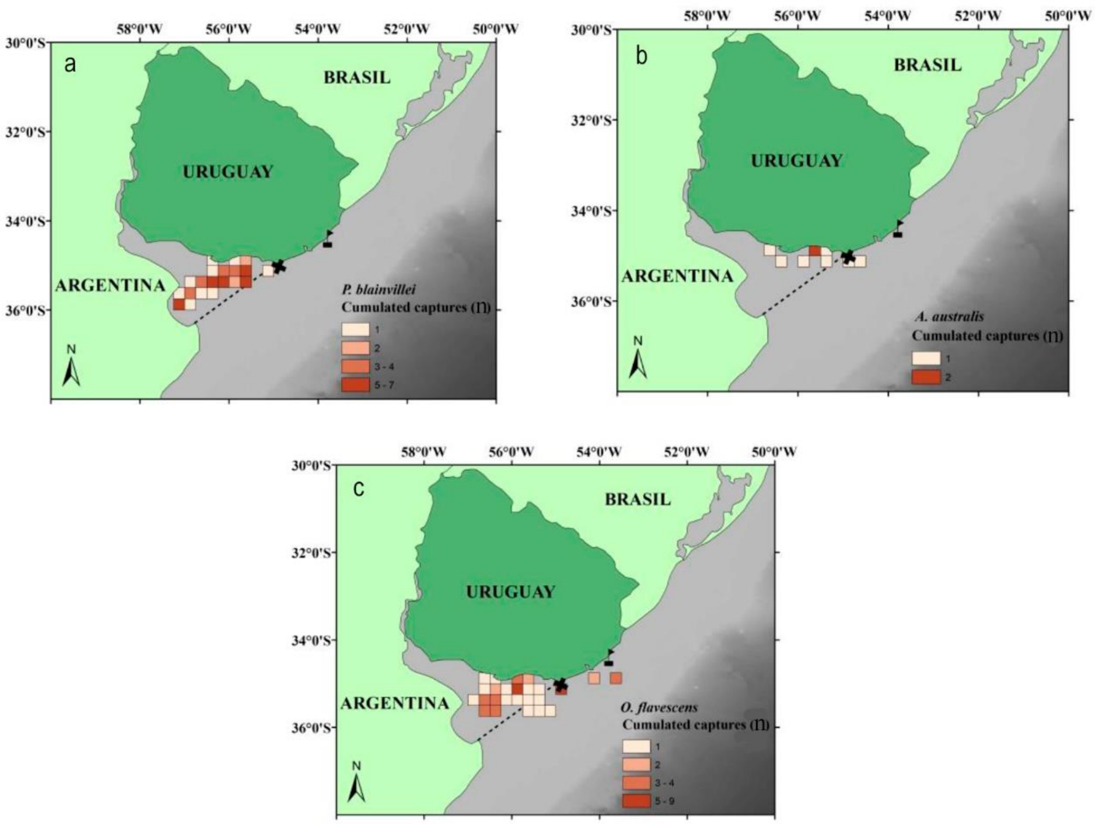

Figure 3. Spatial distribution of marine mammal bycatch of the industrial bottom trawl fishery; data are presented as the accumulated number of individuals in areas of 15×15 nm for the period 2009-2012: a) *Pontoporia blainvillei*, b) *Otaria flavescens* and c) *Arctocephalus australis*).

right after the reproductive season (Lewis *et al.,* 2006). Nevertheless, elephant seals have never been recorded entangled in fishing gears in the southwestern Atlantic.

BcPUE and mortality estimates for franciscana dolphins, sea lions, and fur seals are consistent with the direct encounter probability in relation with their feeding habits. Franciscana dolphins and the sea lions forage in coastal waters (Riet-Sapriza *et al.,* 2013; Franco-Trecu *et al.*, 2017) and hence these species have substantial spatial overlap with the area of operation of the Uruguayan bottom trawl fishery in the study area. In contrast, the fur seal mainly feeds at the shelf break 200-500 km off the coast (Franco-Trecu, 2015), which reduces the chances of spatial overlapping with the bottom trawl fleet. However, the spatial distribution of bycatch may be related to a different fishing effort among areas, but because we do not have this information, this should be taken with caution.

Regarding the seasonal variation in the capture, franciscana dolphin BcPUE was higher during spring, when the species approaches the coast to breed (Bordino *et al.,* 1999). These seasonal distributions of franciscana dolphins BcPUE values match with what was found in the artisanal fisheries (Franco-Trecu *et al.,* 2009). The BcPUE for pinnipeds in the study area were lower during summer (or reproductive season: December to February) when both the fur seal and sea lions breed (Franco-Trecu *et al.,* 2014, 2015). During their breeding period, adult males of both species remain on the rookeries to defending their breeding territories (Franco-Trecu *et al.,* 2014, 2015). On the other hand, females of both pinniped species must meet the high energetic costs of lactation throughout the whole year, and for sea lion the additional cost of foraging up to 150 km from the coast (Riet- Sapriza *et al.,* 2013). The remaining portion of the year, sea lion males must produce the necessary energetic reserves to endure fasting during the reproductive season and to migrate to other foraging areas (Rosas *et al.,* 1994; Drago *et al.,* 2015) where they are not susceptible to be bycaught by the Uruguayan bottom trawl fleet.

Worldwide fishing fleets are under pressure to mitigate the incidental bycatch of non-targeted species (Sarda *et al.,* 2015). A variety of conservation actions are deemed necessary to decrease their impacts on species with “slow” life-history such as marine mammals that are particularly vulnerable to added adult mortality (Fischer *et al.,* 2012). When it comes to threatened species, of which there is little information, the use of it should be maximized in order to obtain results that allow us to delineate management measures in line with the local reality and intensify conservation efforts. In this study, we quantified the industrial coastal bottom trawl fishery bycatch, for the first time, in our study area. This assessment suggests that the current conservation status and prospects of the franciscana dolphins, and possibly of the sea lion, are affected by their interactions with coastal fisheries. Thus, actions should be taken to reduce the bycatch mortality, including the introduction of fishing gear modifications, and spatial shifts or seasonal closures of fishing grounds, to minimize bycatch in the study area, according to the life cycles of the most affected species. Area closures to fisheries and the designation and enforcement of marine protected areas would contribute to the recovery of these marine mammal species as well as of some fish stocks declared fully exploited or with signs of overexploitation (Milessi *et al.,* 2005; Defeo *et al.,* 2009; Defeo, 2015), eventually benefiting the fisheries on a long-term basis. However, good quality information about the impacted species distributions is needed (mainly for franciscana dolphins) to achieve both fishery management and conservation objectives (Molina & Cooke, 2012; Rassweiler *et al.,* 2012). The gathering of data by local actors is increasingly becoming a useful method to gather the otherwise hard-to-collect evidence necessary for decision-making and ecosystem management (Bonney *et al.,* 2009). This paper has shown the importance of the commitment of informed fishers to obtain key information collected during their daily work that could decisively contribute to nature conservation efforts. We recommend that any measure, particularly those involving management efforts to mitigate the effects of incidental bycatch, should involve the active participation of bottom trawl fishers whose involvement should be encouraged through bottom-up approaches, including proactive fishers engagement and fisheries governance with fishing communities (Alava *et al.,* 2017), to develop and implement effective management and mitigation measures.

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