



Understanding the sonar behavior of Franciscana dolphins in response to active pingers

Introduction

The Franciscana dolphin (*Pontoporia blainvillei*) is an endemic species inhabiting the coastal areas of the Southwestern Atlantic Ocean from Itaunas (18 25 S, 30 42 W), Brazil to Golfo Nuevo (42 32 S, 64 48 W), Argentina (Crespo *et al.*, 1998; Moreira and Siciliano, 1991). At present, it is considered the most threatened cetacean species in the region due to a significant level of bycatch in coastal gillnets, and is listed as Vulnerable by the IUCN (Reeves *et al.* 2008). In Argentina, communities of artisanal fishermen based in local towns and in small fishing camps who fish the in shallow waters represent a major threat (Corcuera, 1994). In coastal Buenos Aires, fishermen operating out of these settlements produced an estimated minimum annual bycatch of about 650 individuals (Bordino *et al.*, 2004). The most recent population estimate for this species in Argentinean waters is 14000 individuals (Crespo *et al.* 2010). It is unlikely that current bycatch levels are sustainable, and management measures are, therefore, urgently required to reduce the incidental catch of the species.

The use of acoustic alarms (pingers) has been shown to significantly reduce the bycatch rates of small cetaceans in gillnets (Kraus *et al.* 1997, Trippel *et al.* 1999, Cox *et al.* 2003, Carretta *et al.* 2008, Mangel *et al.* 2013). However, results varied among species, individuals, fishing gear, and location, while in some cases the effectiveness of pingers was controversial and their implementation questionable due to potential concerns about habituation and habitat exclusion (Dawson *et al.* 2013, Dawson *et al.* 1998, Culik *et al.* 2001, Carlstrom *et al.* 2002). Nonetheless, long-term deployment of pingers in several commercial fisheries has not resulted in an increase in cetacean bycatch rates in properly equipped nets (Palka *et al.* 2008, Carretta and Barlow 2011). The use of pingers in experimental trials has significantly reduced the bycatch of Franciscana dolphins in Argentina (Bordino *et al.* 2002, Bordino *et al.* 2004). Although they represent a potential option for reducing Franciscana dolphin bycatch while supporting local gillnet fisheries, several questions remain about how appropriate their use would be within Argentina. For example, potential negative effects of habituation and habitat exclusion have not yet been evaluated.

The Franciscana is one of the smallest cetacean species, and one of the most difficult to observe in the wild because it tends to congregate in small groups. Individuals rarely exhibit aerial behavior, spend relatively short periods of time at the ocean surface, and their coloration is similar to the turbid water in which they are mostly found (Perrin *et al.*, 1989). As a consequence, studies on behavior of the species are scarce (*e.g.* Bordino *et al.* 1998, Bordino 2002, Di Benedito *et al.* 2001,

Cremer and Simões-Lopes 2005, Failla *et al.* 2004), and our knowledge about its sonar behavior limited. Busnel *et al.* (1974) recorded clicks with prevalent signals below 30 kHz on wild individuals. Von Fersen *et al.* (1998) recorded echolocation clicks of around 130 kHz as the dominant frequencies in a captive individual, as well as low frequency and burst signals, with bandwidth of 20kHz. Melcon *et al.* (2012) also recorded similar values with peak frequency at 139kHz and a narrow bandwidth of 19kHz. In all these studies, no whistles were recorded, and it seems Franciscana dolphins employ a similar echolocation strategy to other narrow-band small cetaceans.

The main objective of this project was to investigate the sonar behavior and behavioral responses of Franciscana dolphins to active pingers. The general hypothesis to be tested is that pingers cause changes in sonar behavior that may alter the surface behavior and/or the habitat use by Franciscana dolphins.

Methodology

A blind experiment was conducted in Bahía San Blas (Figure 1) from April 2013 to July 2014. The study area is a coastal marsh zone that includes a group of five islands and sand embankments. In places the coast drops off steeply with depths of up to 15 meters (m) at distances of only 20m from the coastline. The tidal cycle peaks about every 12 hours (hrs), with a mean annual amplitude of about 2.5m. This area was selected because of available baseline information on Franciscana dolphin habitat use (Bordino *et al.* 2000, Bordino 2002, Bordino *et al.* 2008), suitable depth, and because it is relatively easy to observe the species close to shore from adequate platforms. In this study, simultaneous acoustic and visual observations of Franciscana dolphins were recorded from shore.

Franciscana dolphin echolocation activity was recorded with two C-POD units (acoustic click detectors, *Chelonia Limited*, UK). The CPOD is basically a polypropylene case that houses a hydrophone at one end and a removable lid at the other. These passive acoustic monitoring devices are powered with 10 alkaline D-cell batteries, detect echolocation signals between 20-160kHz by recognizing ultrasonic click trains, and use digital waveform diagrams to select clicks, log time, peak frequency, sound pressure level, and duration and bandwidth of each click to 10 μ s resolution. C-PODs identify and record sound characteristics of each click to distinguish them from other ambient sounds, identifying coherent click trains in which the variation in timing between successive clicks is lower than might occur by chance. Information is logged in a single SD card and later processed in a computer using software provided by the manufacturer.

The C-PODs were deployed approximately 25m from shore at about 12-15m depth, parallel to the coastline and anchored arbitrarily at 150m during the first 2 weeks and later during the experiment at 450m from each other. This longer distance was selected to minimize the bias from duplicated records of echolocation signals. The mooring system consisted of a single 5kg Danforth anchor, 5m iron chain, 60m of 10mm polypropylene rope, and a buoy (Figure 2).

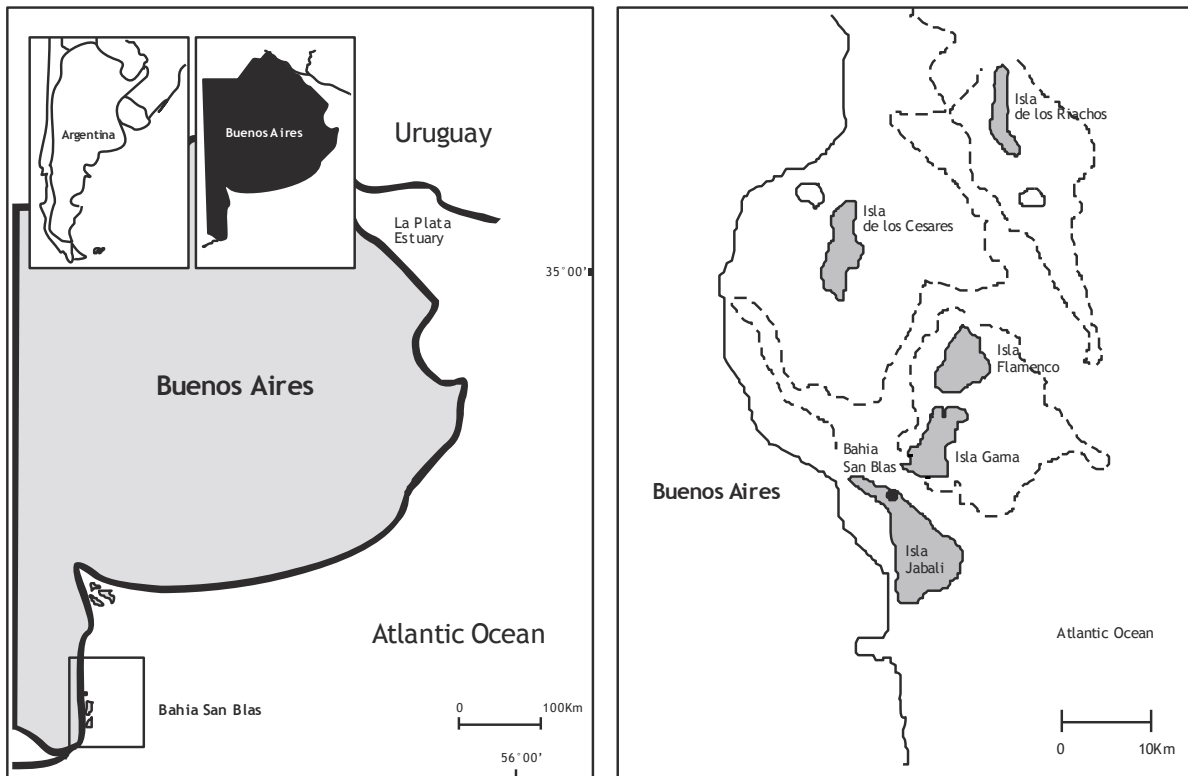


Figure 1. Location of the study area, Bahía San Blas, Northern Patagonia, Argentina. Dotted line indicates outline of sandbanks surrounding the islands.

The C-POD is 0.7kg buoyant when submerged, but in fast currents this is insufficient to have it maintain the hydrophone end up, and it shows lower sensitivity along the long axis in the direction of the lid. The manufacturer's settings have it record clicks up to 70° from the vertical. For this reason, the C-PODs were affixed to the mooring rope with plastic straps at about 5m from the bottom in order to limit their movement during strong tidal currents. The C-PODs also contain an attitude sensor which records the angle from vertical each minute, so that the correct orientation of the C-POD can be verified. The C-PODs were tested in the field prior to launching the experiment. During this test, C-PODs were deployed together with a single anchor at 10m depth for 12hrs over 2 days. Echolocation data recorded in both C-PODs obtained during three dolphin sightings was compared by evaluating the time at which echolocation signals were detected, and the number of clicks and trains at each CPOD. No significant differences were found between C-POD units ($p > 0.05$, t TEST).

The C-PODs were labeled "A" (upcurrent) and "B" (downcurrent), corresponding to observer sites "A" and "B" on shore (Figure 3). The C-PODs were rotated between moorings after each sampling day, and retrieved daily in order to reduce potential drifting and loss of equipment, as well as to conserve batteries.

A 70kHz pinger (*Future Oceans*), was placed below the C-POD "B" at approximately 3m above the sea floor, simulating the position of the float line in a bottom-set gillnet. The pinger weighs less than 200gr and emits a signal at 145db every 4s for 300m/s. Based on the pinger specifications, it

was estimated that its sound covered a radial area of about 200m. It has a LED light that indicates when the pinger is switched on, blinking for the first 15 cycles when the pinger is immersed. Once a pinger is retrieved, the LED light blinks again for another 15 cycles. This feature allows a user to verify that the unit is functioning properly, as the sound emission frequency is outside that of the range of human hearing. The status of the pinger (silent or active) was assigned daily by a random coin toss. Observers were not informed of the pinger status and duct tape was used to cover the LED light. Pinger and C-PODs were deployed only during 6-hr periods of observation (3hrs before and after high tide in order to collect data always during the same tidal period), when environmental conditions permitted. This period of observation was also selected because Franciscana dolphins have shown a pattern of movement associated with tidal flow in the study area, with dolphins coming into the bay during rising and high tide and going out to the mouths of the bays during falling and low tide (Bordino *et al.* 2000, Bordino *et al.* 2008). However, if weather conditions were favorable over a prolonged period, observers occasionally extended observation time beyond 6hrs.

Dolphin behavior was recorded using both the naked eye and binoculars in a limited sampling study area of 150m radius around each C-POD location. Two independent teams recorded behavior after having been trained to estimate distance ranges from the observation sites with the help of buoys and flags. Observations were carried out from sighting platforms approximately 2-4m above sea level. Observations were discontinued when wind speed was greater than 35km/hr or during rain. Each team consisted of at least two observers and one recorder. Observers at each site were rotated daily and shuffled between sites, with no communication between sites during sampling days. Neither team could see the other, its view obstructed by the by the geography of the coast, which helped the teams maintain independence. Observers recorded information in field sheets and tape recorders, and included sighting time, group size (minimum and maximum estimates), presence of calves, behavioral responses to pingers or buoys, initial swimming direction, surfacing-diving sequences when possible, estimated distances to CPODs and pinger, and weather conditions such as Beaufort state and sunlight coverage. Dolphin swimming direction was defined as upcurrent or downcurrent based on the location where it was first sighted. A dolphin group was defined as an association of individuals swimming together within an area of less than 50m and engaged in the same behavioral activity. To maximize independence of sightings data, dolphin groups of equal size sighted in the same area during a one-hour observation period were excluded from the analysis. Surface dolphin behavior was recorded as five behavioral categories--milling, cooperative feeding, traveling, resting, and unknown--as described by Bordino *et al.* (2000), using individual and group focal sampling (Altman 1974, Mann 1999), while C-PODs were simultaneously recording sonar behavior. Estimates of dolphin distance to pinger location, time spent within each range distance from the pingered buoy, and changes in surfacing behavior were recorded for each continuous dolphin surfacing and assigned to previously established 50, 100, and 150m radius ranges from the C-PODs, assuming no differences in the probability of detecting surfacing among the ranges. Dolphin distance to pinger location within the 50m interval from the C-POD was estimated in 10m subintervals. Only consecutive surfacings within a 90s time bin were considered for the analysis. A 90s time bin was used because it is close to the typical maximum dive time reported for the species (Bordino *et al.* 2008). On group sightings, surfacing records were assigned to each of the radius ranges with presence of individuals from the same group, and the average of the time spent at each range was considered for analysis. Visual observations were detected within 150m, suspected to be within the range covered by an active pinger and the detection range of the C-PODs. Based on effects of external disturbances to cetaceans, changes in surfacing behavior were categorized in three levels: a. No change of

behavior recorded, b. Changes in behavior as an increase in swimming speed, and c. Evident change of swimming speed in a direction opposite to the location of the pinger, and/or increase of group size.

The daily sighting-per-unit-effort (SPUE) determined by the number of sightings/hr was calculated and compared for each observer site.

A sampling unit was defined as the daily period of simultaneous recording of acoustic data and sighting from each observation site. Both C-POD data sets were analyzed independently, and compared using non parametric tests.

Echolocation signals recorded simultaneously from different individuals were recognized by overlap of click trains that were sufficiently clear, and it was assumed that the overlap could not have been produced by the same dolphin from a direct path and echo off the sea surface of the same clicks. Signals recorded with no simultaneous sighting were discarded from the analysis.

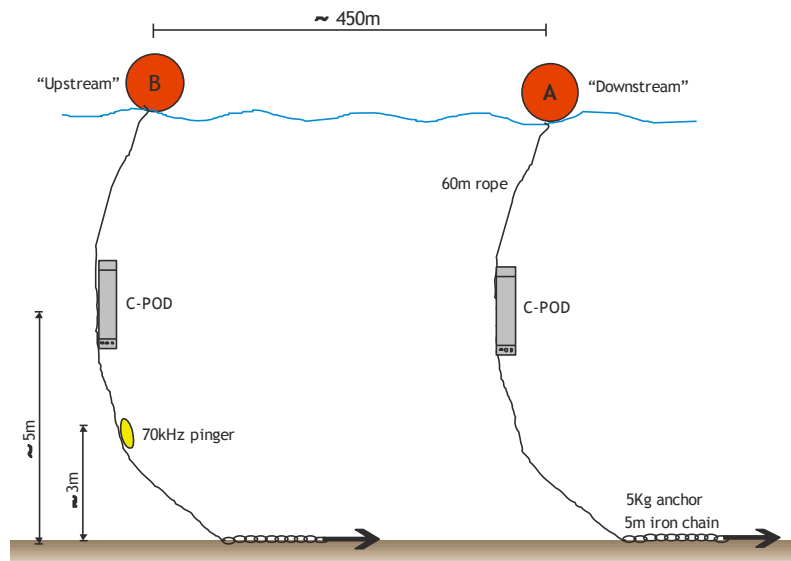


Figure 2. Mooring system (not to scale) for C-PODs and pinger.

The acoustic data set was validated by visual observation of the raw data and run with software *C-POD.exe* (Chelonia Ltd., UK). Only good quality signals were analyzed. Information on signal start and end time, duration, number of clicks-per-train, inter-click duration, and number of click trains were analyzed for each sampling unit. An echolocation encounter was defined arbitrarily as periods with echolocation signals separated by a minimum of 5-minute periods of silence. Each echolocation encounter then consisted of several click trains. The echolocation rate was defined as the number of echolocation encounters/hr. In addition to visual observation of dolphins, changes in behavior were also analyzed considering the ratio of loud clicks to weak clicks only in signals identified from one single individual, assuming that loud clicks indicate dolphins closer to the C-POD. The breakpoint between loud and weak clicks was defined arbitrarily as 50% of the maximum sound pressure scale of a C-POD (25 Pascals peak to peak) as suggested by Hardy et al. (2012).

In order to evaluate habituation to the active pinger during the experiment, first we compared the mean return time of sightings in consecutive daily sampling units in relation to combinations of pinger status considering only records at C-POD "B". The mean return time was defined as the time interval between the last sighting of a daily sample unit and the first sighting of a consecutive daily sighting unit. When possible, photographs of the dorsal fins of dolphins were taken to facilitate the recognition of individuals, and reduce the effect of pseudoreplication (Dawson and Lusseau, 2005).

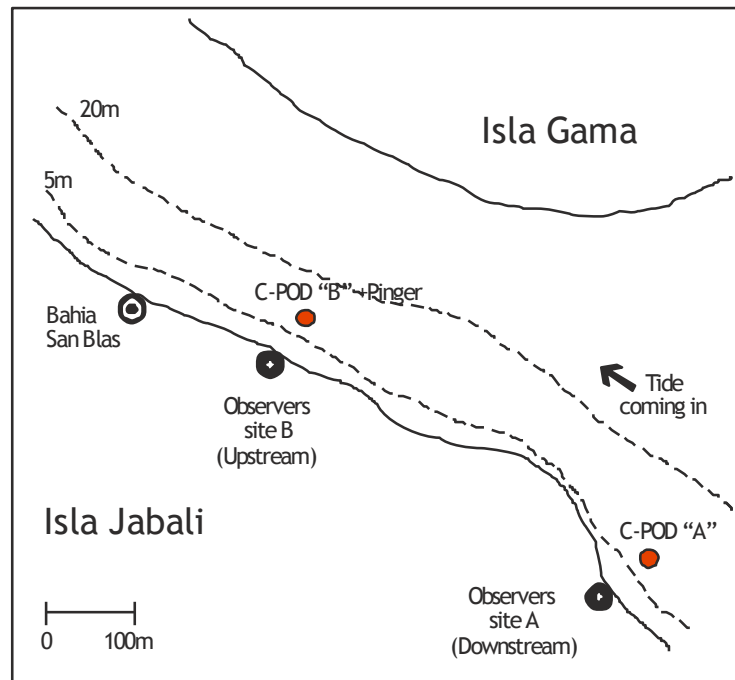


Figure 3. Location of C-PODs, pinger and observation sites in Bahía San Blas indicating the upcurrent and downcurrent sites.

Results

A total of 77 days were spent in field activities at Bahía San Blas, with a total of 484hrs of effort. Surface behavioral activity and echolocation signals were simultaneously recorded during 119hrs of direct observation of Franciscana dolphins. A total of 96 sightings were recorded from observation site A, while 54 and 42 sightings were recorded when the pinger was silent and active, respectively, at site B. No significant differences were found in the median SPUE between observation sites and pinger status ($p= 0.99$, KW Test). Sixty-four percent of sightings ($n=96$) were dominated by milling and cooperative feeding behaviors (Figure 4). Fifty-two percent of sightings showed no significant change in behavior during the experiment (Figure 5). However, 73% of sightings ($n=46$) of a significant change in behavior was recorded when the pinger was active. Of these, 47% ($n=34$) showed evident change of swimming speed in the opposite direction to the location of the active pinger (behavioral change b or c) (Figure 5). Additionally, the 43% and 8% of dolphin sightings showed evident downstream movements when the pinger was active and silent

respectively. The analysis of the surface behavioral activity showed significant differences in responses to the active pinger ($p < 0.001$, KS test). Sixty-four percent ($n = 96$) of sightings consisted of single individuals. The mean group size observed was 1.44 ± 0.81 and 1.61 ± 0.58 individuals per group when the pinger was silent and active, respectively. The mean sighting time recorded was 34.3 ± 9.1 min and 38.6 ± 6.5 min when the pinger was silent and active, respectively. No significant differences were observed in group size in relation to observation sites ($p > 0.05$, KW test), and pinger status ($p > 0.05$, MW test).

Significant differences were observed in the number of surface sightings in relation to observation sites and radial ranges ($p < 0.05$, KW test, Figure 6). The analysis showed significant differences in the time spent by dolphins at each radius range when the pinger was active (Figure 7).

A total of 4708 high frequency echolocation signals represented by click trains were selected, out of which 2804 click trains were clearly identified from single individuals. Click trains were characterized by narrow-band frequency clicks at 132 ± 9 kHz, mean click duration of 0.2 ± 0.1 ms, mean inter-click duration of 31 ± 7.9 ms, and mean train duration of 28.4 ± 9.8 s (Figure 8). A summary of dolphin sightings and echolocation signals recorded in relation to pinger status is shown in Table 1. Echolocation signals were recorded in association to sightings within all of the three radial ranges established, although only 13% were recorded within the 150m range from the C-POD locations.

The acoustic data showed that the echolocation rate and the click trains/hr were significantly lower when the pinger was active ($p < 0.05$, MW test). The rate of recording echolocation activity when the pinger was active was approximately 49% of the rate when the pinger was silent. However, a significant lower echolocation activity ($p < 0.05$, MW test) was also recorded at the CPOD "A", placed farther from the pinger location. The ratio of loud clicks to weak clicks was 0.63 and 0.56 when the pinger was silent and active respectively, indicating similar values (Table 2). On three occasions during different daily sampling units, two single individuals and one group of two individuals were observed within 10m from the buoy when the pinger was active. These represented only 7% of the total sightings when the pinger was active, and no echolocation signals were recorded during these three sightings. The sighting records within the same distance range represented 21% of sightings when the pinger was silent, and in all cases echolocation signals were recorded. The mean return time for the initial sighting in consecutive daily sampling units in relation to pinger status is shown in Table 3.

Four Franciscana dolphins were photo-identified during the experiment. All of them were re-sighted, and one was re-sighted two times when the pinger was active during different daily sampling units.

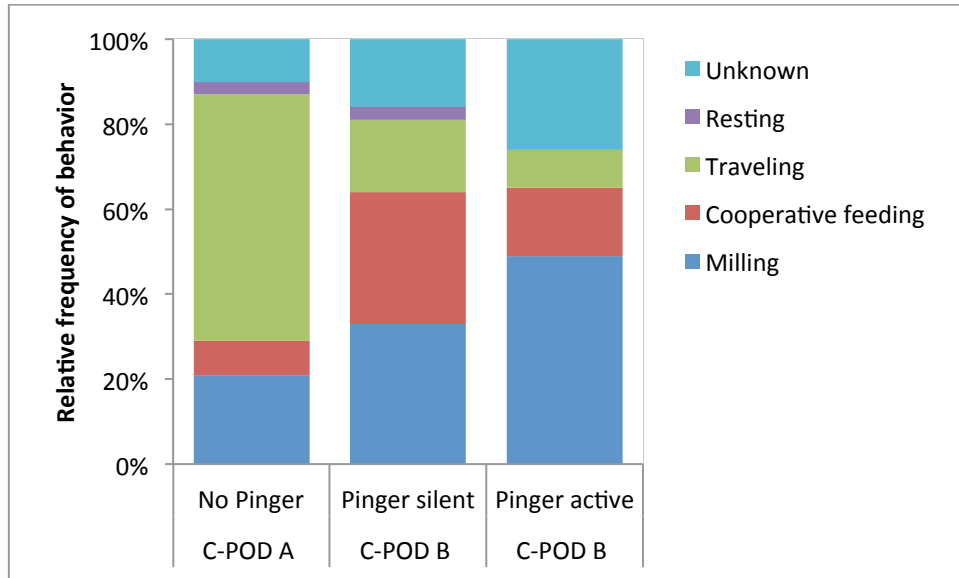


Figure 4. Relative frequency of behavioral categories recorded in relation to the C-POD position and pinger status (n= 246).

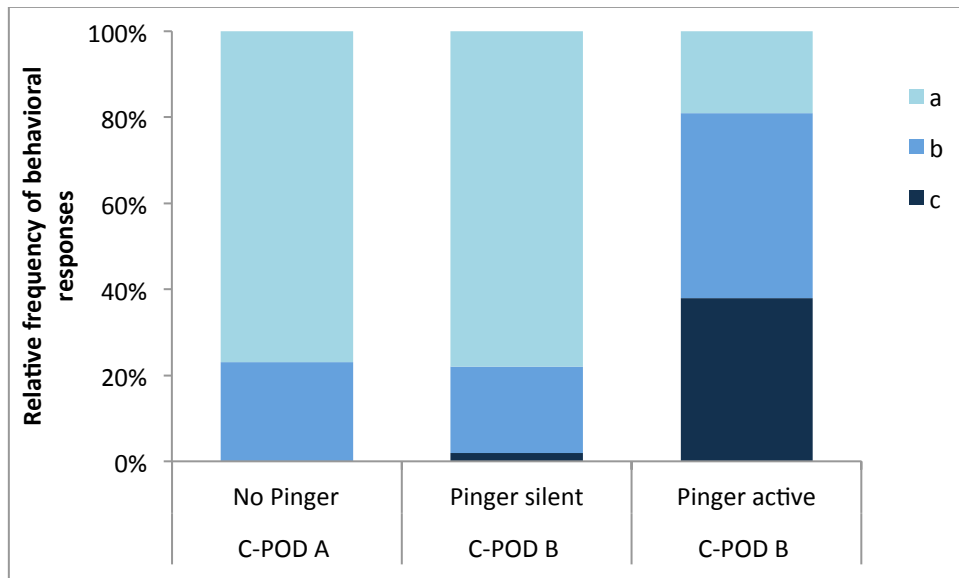


Figure 5. Relative frequency of behavioral responses in relation to C-POD position and pinger status. (a. No change of behavior recorded, b. Changes in behavior by increase in swimming speed, and c. Evident change of swimming speed in opposite direction to the location of the pinger, and/or increase of group size) (n= 192)

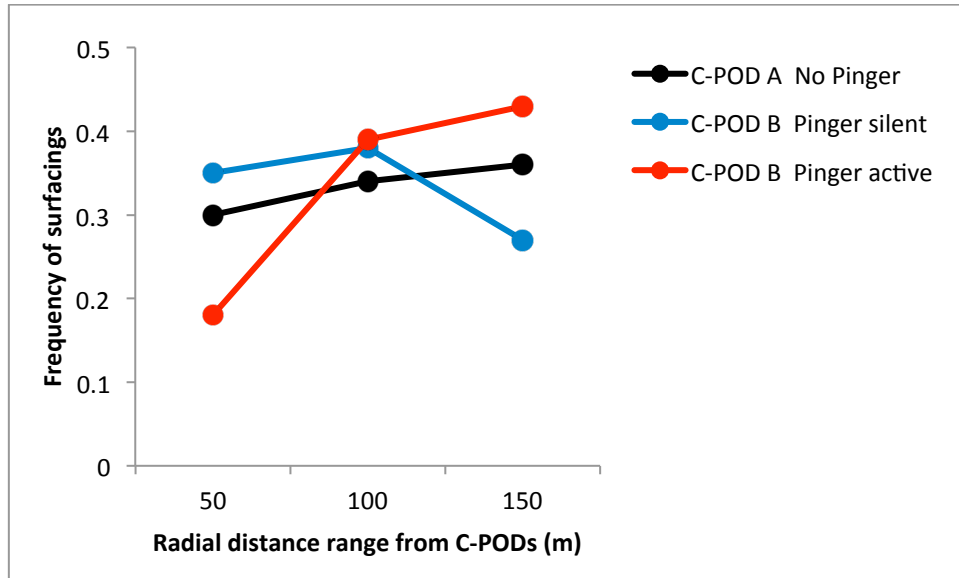


Figure 6. Relative frequency of surfacings by radius distance from C-PODs in relation to pinger status.

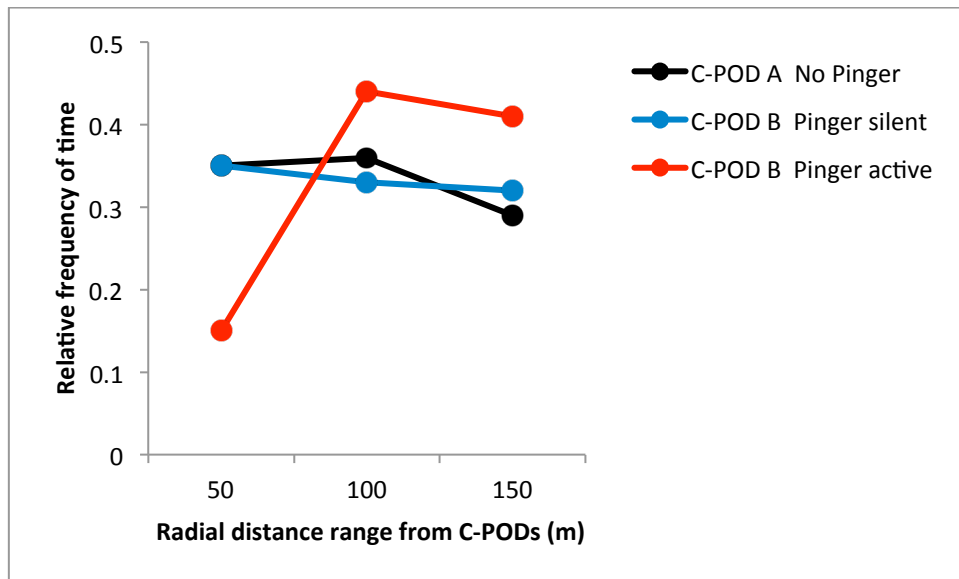


Figure 7. Relative frequency of time spent by radius distance from C-PODs in relation to pinger status.

Table 1. Summary of number of sightings and echolocation signals recorded during the experiment.

C-POD +			Effective	# Eco	Encounter			Click		
Pinger status	Effort (hr)	# of sightings	SPUE	effort (hr)	encounters	rate	# Clicks	Clicks/hr	trains	Click trains/hr
A + No pinger	484	96	0.198	59.5	12	0.2	43005	722.8	1350	22.68
B + Pinger silent	261	54	0.206	31.8	44	1.4	78893	2480.9	2355	74.05
B + Pinger active	223	42	0.189	27.8	11	0.4	22891	823.4	1003	36.07
							144789		4708	

Table 2. Ratio between loud and weak clicks in relation to the pinger status.

Pinger status	Loud clicks	Weak clicks
Silent	769	1221
Active	291	523
	1060	1744

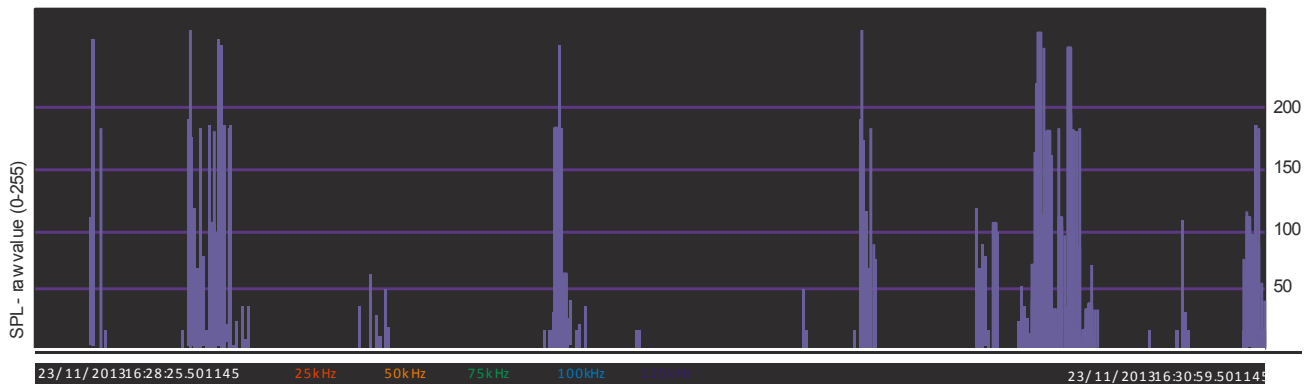


Figure 8. Franciscana dolphin high click trains recorded at C-POD “B” on November 23, 2013.

Table 3. Average return time in relation to pinger status for combination of consecutive daily sampling units.

Pinger status combinations	Silent/Silent	Silent/Active	Active/Silent	Active/Active
Mean return time \pm SD (hr)	24.3 \pm 1.8	23.1 \pm 1.7	24.4 \pm 2.8	23.6 \pm 1.8
Range (hr)	21.1 - 27.9	20.8 - 26.7	21.5 - 28.2	20.3 - 25.9
N	9	8	10	9

Discussion

Analysis of the data suggests that Franciscana dolphin responses to active pingers include changes in surfacing, sonar behavior, and spatial distribution. The similar median SPUE at both observation sites indicates that most dolphins within the scanned area were sighted by both observer teams. The predominant behavior at site “A” was traveling, while milling and cooperative feeding were the most recorded at site “B”. Such a difference in behavioral activity composition indicates that during this observation period site “A” was predominantly a traveling area, and site “B” a feeding area for Franciscana dolphins at Bahía San Blas. Site “B” is well known by local sport fishermen and tourists as one of the best areas for shore fishing in the bay. At Bahía San Blas, the movement pattern for the species is strongly influenced by tide and location of prey (Bordino 2002, Bordino *et al.* 2008). Additionally, when the pinger was active at site “B”, milling and unknown behavior increased while traveling decreased. Milling is a behavior associated with feeding and foraging (Bordino *et al.* 2000). No pattern could be discerned in the unknown behavior category so it was not possible to assign it to a known behavioral category recorded for this species. Changes in dolphin behavior were clearly associated when the pinger was active, as indicated by the increase in swimming speed and change in swimming heading away from the pinger. When the pinger was active, Franciscana dolphins were mostly sighted farther away from the it and remained for a longer period if time at distances greater than 50m, suggesting a potential spatial response to the pingers.

Additionally, Franciscana dolphin echolocation rates decreased when the pinger was active. The reduction of echolocation rate in response to pingers was also recorded in Harbor porpoises (*Phocoena phocoena*) (Cox *et al.* 2001, Carlstrom *et al.* 2009) and Bottlenose dolphins (*Tursiops truncatus*) (Leeney *et al.* 2007). Four main hypotheses have been postulated to explain why pingers have been effective in mitigate the bycatch of some small cetacean species (Dawson *et al.* 2013). Among them, the “alerting” hypothesis suggests that pinger sounds encourage echolocation and alert the dolphins to the presence of a fishing net, and the “aversive” hypothesis in which pinger sound produces displacement of dolphins from the pinger location. The higher occurrence of downstream movements when the pinger was active observed during this trial would be most aligned with aversive behavior. The absence of echolocation resulting when the pinger was active in this trial is not consistent with the “alerting” hypothesis, further arguing that for Franciscana dolphins pingers may be prompting an aversion response.

However, the lowest echolocation rate was recorded at site "A". This would be a direct consequence of the highest occurrence of traveling at site "A", since there is strong evidence that dolphins and porpoises do not constantly need to interrogate their environment with echolocation signals (Wood and Evans 1980), and it has been suggested that entanglement of Franciscana dolphins in gillnets could indicate that dolphins are not using echolocation while traveling between feeding areas (Bordino *et al.* 2002).

The three sightings with no simultaneous echolocation signals recorded within 10m from an active pinger may indicate variation in individual response to a pinger, and it could partially explain why a few Franciscana dolphins were bycaught in pingered gillnets during earlier field trials (Bordino *et al.* 2002, Bordino *et al.* 2004).

The ratio of loud to weak clicks was not useful to explain aversive response to the active pinger. The analysis of returning time showed no evidence of habituation to pinger throughout this experiment. The number of photos that could be used to identify individuals and resightings was too low to perform an analysis to evaluate habituation considering that exist individual responses to pingers. Nevertheless, additional data collection can yield a sufficient sample size to carry out this analysis.

The results from this experiment focused on behavioral response to a single pinger. Questions remain regarding the responses of Franciscana dolphins to pingered nets. However, the results showed evidence of variable aversive responses to a 70kHz pinger, useful for determining appropriate and effective pinger spacing within a real fishing scenario. The interpretation of the sonar behavior in small cetaceans and how they perceive their environment is by itself a challenge. To our knowledge, this is the first study simultaneously recording surfacing and sonar behavior of wild Franciscana dolphins, and the first one investigating the spatial response of the species to pingers. Behavioral studies of this kind can assist in answering critical questions pertaining to how pingers actually create aversion responses in some species of small cetaceans, and inform the most effective deployment of units in actual fishing conditions so as to maximize bycatch reduction levels.

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Observation site at Bahía San Blas.



Observers during a training session at Bahía San Blas.



Attachment system of the C-POD units and 70kHz pinger showing the LED light.



Franciscana dolphin sighting in Bahía San Blas, October 2013.



Checking a C-POD mooring in Bahía San Blas, July 2013.