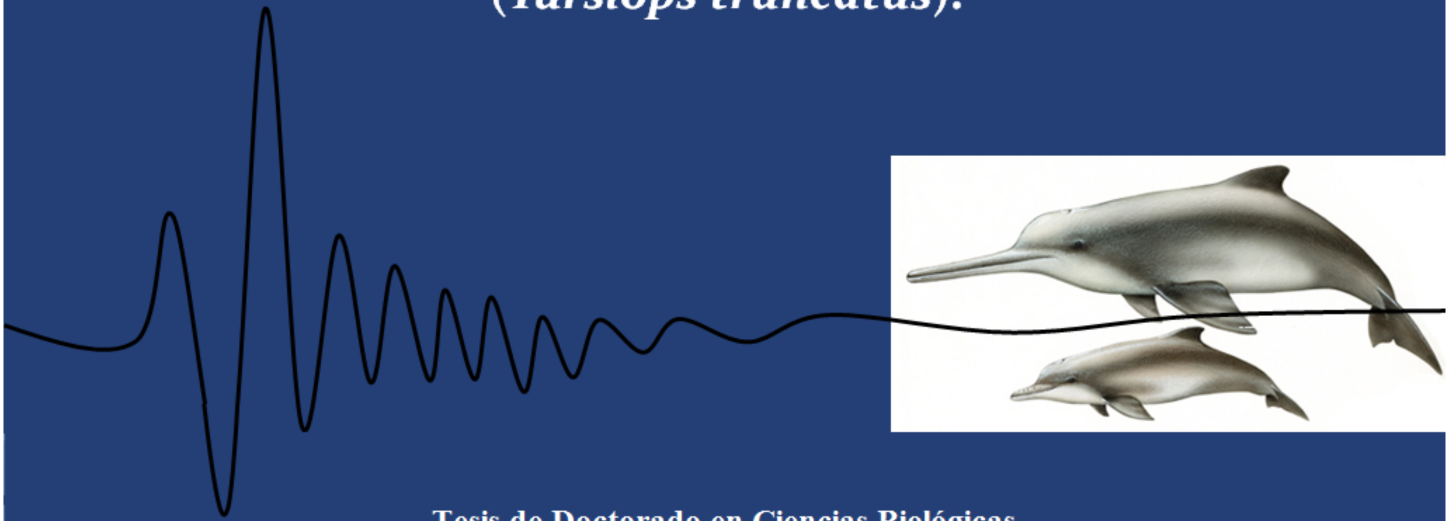
Utilización de la bioacústica como herramienta para la detección de cetáceos en la costa uruguaya: características acústicas de los delfines franciscana (*Pontoporia blainvillei*) y nariz de botella (*Tursiops truncatus*).



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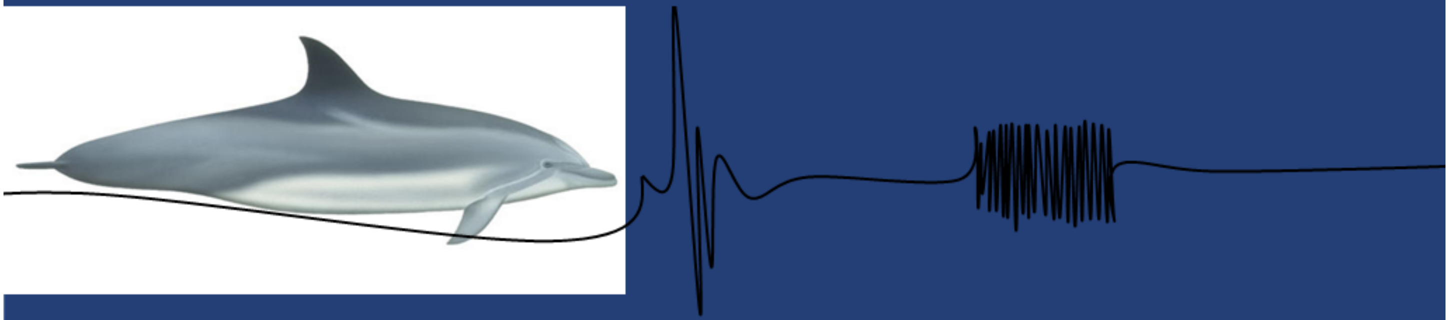

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Agradecimientos:

A mi família, a mi orientador por confiar en mis ideas, a lós amigos que ayudaron siempre y Annabel que me ayudo a relucir esta tesis.

(...) Tan pronto como despegamos sabía que tendría que volar de ahora en adelante...

Amelia Earhart

LISTA DE PUBLICACIONES

La presente tesis esta basada en lós siguientes siete artículos de investigacion, lós cuales seran referidos dentro del texo, lós seis primeros directamente relacionados al a esta tesis, y el ultimo articulo utilizando la misma herramienta, la bioacústica.

Tellechea S. J.,, W. Perez, D. Olsson, M. Lima & W. Norbis. (2017). Feeding Habits of Franciscana Dolphin (*Pontoporia blainvillei*): Echolocation or Passive Listening?. Aquatic Mammals Journal. Aceptado con correcciones.

Tellechea S. J., Ferreira M. & Norbis, W. (2017). Echolocation and burst clicks from Franciscana dolphins (Pontoporia blainvillei) on the coast of Uruguay. Marine Mammal Science. In press.

Tellechea S. J., M. L. Fine, & C., Norbis, W. (2017). Passive acoustic monitoring, development of disturbance calls and differentiation of disturbance and advertisement calls in the Argentine croaker *Umbrina canosai* (Sciaenidae). Journal of Fish Biology. In press.

Tellechea S. J., Daniel Cambon-Tait, Diego Bouvier, & Walter Norbis. (2014). Passive Acoustic Monitoring of Bottlenose Dolphins (*Tursiops truncatus*) on the Uruguayan Coast: Vocal Characteristics and Seasonal Cycles. *Aquatic Mammals Journal* 40(2), 173-184, DOI 10.1578/AM.40.2.2014.173

Tellechea S. J., & Norbis, W. (2014). Sound characteristics of two neonatal Franciscana dolphins (*Pontoporia blainvillei*). *Marine Mammal Sciecne* 30: 1573–1580. doi:10.1111/mms.12122

Tellechea S. J., & Norbis, W. (2012**).** Sexual dimorphism in sound production and relationship between fish size and call characteristics in the striped weakfish *Cynoscion guatucupa.* Zoological Studies- 51(7): 946-955.

Tellechea S. J., & Norbis, W. (2012). Southern Right Whale (*Eubalaena australis*): preliminary recordings of the acoustics emission in coast of Uruguay. *Journal of Cetacean Research and Management*. 12(3): 361–364.

CONTENIDO

CAPITULO 2.- Características de los sonidos del delfín franciscana-*Pontoporia blaninvillei.*

Características de los sonidos emitidos por dos neonatos de *Pontoporia blainvillei*.

CAPITULO 3.- Utilizacion de boyas PAM en la costa de Rocha: detección de acústica del delfín nariz de botella *T. truncatus* por primera vez en ruguay.

CAPITULO 4.- Obtención de sonidos de *Pontoporia blainvillei* salvajes en Santa Lucia del Este, Canelones, caracterización de los clicks.

CAPITULO 5.- Contenido estomacal de *Pontoporia blainvillei,* estudio de presas para dilucidar si la franciscana tiene preferencia alimenticia por los peces productores de sonido.

CAPITULO 1.-INTRODUCCION GENERAL

La bioacustica

El interés científico que suscita el estudio de los cetáceos se ha convertido en los últimos años en necesidad de conservación. El conocimiento de su biología, en términos de aspectos fundamentales de sanidad y de funcionamiento correcto de los aparatos y sistemas vitales de estas especies de mamíferos marinos, no se puede disociar de los factores naturales o antropogénicos que pueden resultar negativos al nivel de un organismo o de una población considerada y traducirse en la aparición de patologías, que rigurosamente analizadas por estudios clínicos y/o post-mortem, cabe interpretar como posible señal inequívoca de un desequilibrio natural de su hábitat. En este contexto, resulta fundamental aproximarse a la percepción del medio en el cual los cetáceos desarrollan sus actividades diarias, no desde nuestra perspectiva como mamífero terrestre que vive en un medio aéreo, sino por medio de los sistemas sensoriales que evolutivamente han desarrollado los cetáceos en su hábitat acuático. Sin descartar la importancia de otros sentidos, la utilización de las señales acústicas, tanto al nivel de su producción como de su recepción, permite vincular gran parte de la información vital que, entre otras funciones, garantiza la coherencia social, la búsqueda de los alimentos y una correcta tasa de reproducción individual o en el seno de una población (Au and Hastings 2008).

La bioacústica es la ciencia que estudia los mecanismos de transferencia de la información biológica por vínculo acústico e incluye el origen morfo-funcional de la producción y recepción de los sonidos, la propagación de los mismos en el medio acuático, el análisis intrínseco de los mecanismos de sonar y de comunicación, la utilización de la herramienta acústica para estudios de poblaciones y las patologías naturales o antropogénicas (i.e. la contaminación acústica) directamente en relación con la capacidad auditiva de los cetáceos. El uso de la escucha pasiva ("Passive acoustic monitoring") ha sido la herramienta que facilito el estudio de cetáceos, muchos de los cuales son mas fáciles de escuchar que de ver (Zimmer 2011).

Emision de sonidos por los cetaceos

Los cetáceos tienen la habilidad de emitir sonidos (Evans 1967, Payne and McVay 1971). Los procesos biológicos utilizados para producir el sonido varían de una familia de cetáceos a otra. Sin embargo, todas las ballenas, delfines y marsopas son mucho más dependientes del sonido para comunicarse.

Las ballenas barbadas (Misticetos) utilizan la laringe, que aparentemente desempeña un papel importante en la generación de los sonidos aunque se desconoce el mecanismo exacto de la generación de los sonidos. La mayor parte de las ballenas barbadas emiten sonidos en una banda de frecuencias entre 20 Hz y 60 Khz (Clark 1990).

Los sonidos de los delfines, marsopas y cachalotes (odontocetos) pueden clasificarse en dos categorías: 1) de variación de frecuencia continua tonal como los silbidos y 2) los "clicks" de banda ancha (ecolocación y burst clicks) (Evans 1967) de alta y baja frecuencia (Figura 2).

Los silbidos son sonidos con componentes de frecuencia de inicio, frecuencia mínima, frecuencia máxima y frecuencia de finalización (Herman and Tavolga 1980; Steiner 1981; Bazua-Duran 1997). Los silbidos pueden ser diferentes en diferentes especies y también en la misma especie (Steiner 1981). La mayoría de los estudios se han llevado a cabo en el delfín nariz de botella o tonina (*Tursiops truncatus*). Se ha determinado que existen silbidos firmas ("signature whistles")

(Cadwell and Cadwell 1965), a partir de los cuales los delfines pueden distinguirse como individuos por su silbido ejecutando siempre esta emisión para ser reconocido o ser llamado.

Los pulsos de ecolocación son pulsos de banda ancha que se caracterizan por tener un gran intervalo entre pulsos, comparados con los trenes de pulsos. Tienen componentes de frecuencias bajas (30 kHz), pasando por frecuencias altas (96 kHz) y frecuencias muy altas (170 o mas kHz) (Evans 1967; Au et al. 1974; Au 1980, Au 1993). Estos sonidos constituyen el biosonar de los cetáceos (Au 1980, 1985; Au 1993; Au and Hastings 2008). Todas las especies de cetáceos producen sonidos pero solo se han podido registrar de unas pocas.

Los trenes de pulsos sonoros (“burst sounds”) son producidos por todos los odontocetos y se reconocen y caracterizan por tener un intervalo entre pulsos muy pequeño, menor a 3 ms (Au and Hastings 2008). Se ha sugerido que estos trenes de pulsos son parte importante de la emisión de sonidos relacionados al comportamiento social de estas especies (Herman and Tavolga 1980).

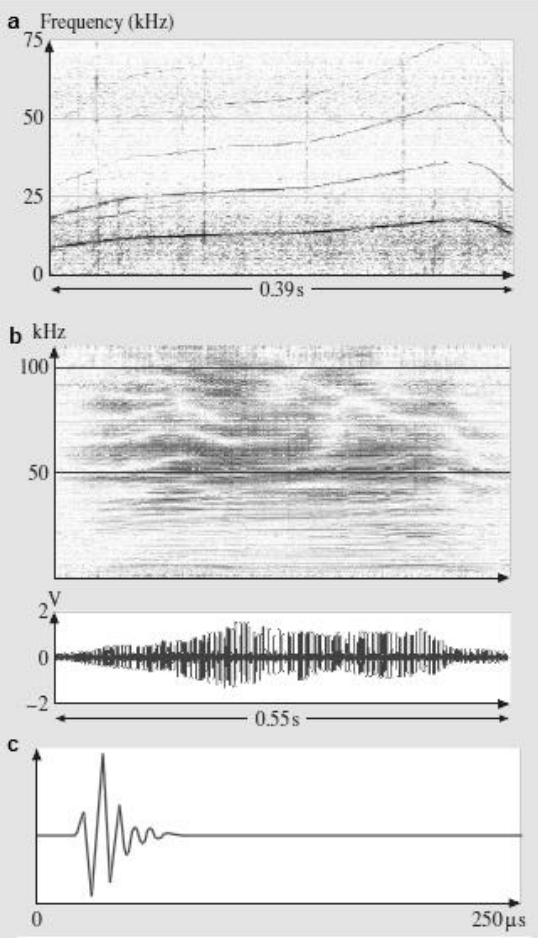

Figura 2. Ejemplos de emisiones de sonido realizadas por delfines, en este caso de *T. truncatus* (a: silbido con sus armónicos; b: trenes de pulsos; c: pulso de ecolocalización) (Tomado de Rossing 2007)

Todos estos sonidos son producidos por un complejo aparato sónico compuesto de labios sónicos (“phono lips”) (Wood 1964, Cranford et al. 1996), los cuales están en interacion con dos sacos vestibulares encargados de la producción de sonido cuando el animal hace pasar aire reciclado a presión por la laringe hacia los labios sónicos siguiendo a los sacos vestibulares (Wood 1964; Purves and Pilleri 1983, Cranford et al. 1996). Los sonidos pasan a través del melón hacia el exterior y en el caso de los pulsos de ecolocación, estos son recibidos directamente por la mandíbula conectada directamente al cerebro por neuroreceptores (Au et al. 2000). Es importante destacar que muchos odontocetos producen silbidos (Au and Hastings 2008) y que unos pocos no (Au and Hastings 2008).

Se ha postulado que la alta frecuencia de las señales de ecolocalización es una estrategia que permite superar el sonido producido por camarones (Au et al. 1985). Además, los delfines pueden emitir clicks de bajo o alto nivel de potencia (210 dB), de acuerdo al nivel sonoro del ambiente (Au and Hastings 2008).

Uso de la escucha pasiva por los cetaceos

Además de la ecolocación los delfines pueden depender de otros sentidos, para encontrar alimento y para orientación, incluyendo la visión, los sonidos generados por sus propios ecos (Au, 1993) y también los sonidos generados por las presas, como señales complementarias para localizarlas (Herzing and dos Santos, 2004).

Los trabajos más relevantes realizados en cetáceos sobre patrones de comportamiento, hábitos de alimentación utilizando la escucha pasiva han sido llevados a cabo con el delfín (*Tursiops truncatus*) (Irvine et al. 1981; Scott et al. 1990; Barros and Wells 1998; Wells et al. 1980, 1987, 2005). Estos delfines considerados residentes en determinadas regiones costeras, tienden a ser exclusivamente piscívoros, forrajean de manera solitaria y se alimentan de peces que no forman cardúmenes (Wells 1999; Barros and Wells 1998) y se ha establecido como hipótesis, que los delfines costeros utilizan la escucha pasiva para localizar los peces que emiten sonido (Barros and Odell 1990; Barros 1993; Barros and Wells 1998). El delfín *T. truncatus* responde de manera consistente a las emisiones de ruidos de peces ("playbacks"), lo que apoya la hipótesis de que los delfines utilizan la escucha pasiva como medio para localizar sus presas (Gannon et al., 2005). Las orcas (*Orcinus orca*) suelen utilizar además de mecanismos de ecolocalización, la escucha pasiva para localizar a sus presas, principalmente peces y otros mamíferos marinos que emiten sonidos (Barret-Lennard et al. 1996). Según los estudios realizados por Johnson (1967), las frecuencias emitidas por el sonido de los peces entran dentro del rango de frecuencias audibles por los delfines (1 Hz a 120 kHz) (Au 1993).

Los delfines franciscana y nariz de botella en la costa de Uruguay

La franciscana

La escucha pasiva es la herramienta ideal para estudiar la ecología del delfin la franciscana *Pontoporia blainvillei* (Gervais & d'Orbigny, 1844), y el delfin nariz de botella *Tursiops truncatus* (Montagu, 1821) por primera vez en la costa uruguaya.

El delfín del Plata o franciscana *Pontoporia blainvillei* (Gervais & d'Orbigny, 1844), es un pequeño cetáceo endémico del Océano Atlántico Sudoccidental, que se distribuye desde Itaunas (18º25′S, 30º42′W), Espirito Santo, Brasil a Golfo Nuevo (42º35′S, 64º48′W), Península Valdés, Argentina (Crespo et al. 1998) (Figura 1), puede vivir indistintamente en aguas dulces o saladas (Ximenez et al. 1972). Tradicionalmente se cree que la distribución de la franciscana se limita a las aguas costeras, a profundidades menores a 30 m (Pinedo et al. 1989), lo que las hace más vulnerables a las actividades antropogénicas, como las redes de enmalle que utiliza la pesquería artesanal (Praderi 1994; Praderi et al. 1989; Secchi et al. 2003; Bordino et al. 2002; Rosas et al. 2002; Franco-Trecu et al. 2009).

A lo largo de su distribución geográfica, experimenta una marcada mortalidad incidental casi continua, como consecuencia de la actividad de la pesca artesanal e industrial (Praderi et al. 1989). Por esta razón es considerada como uno de los pequeños cetáceos más amenazados en el Océano Atlántico Sur (Secchi et al. 2001; Crespo 2002).

Figura 1. Distribución de los delfines franciscana (*P. blanivillei)* y nariz de botella (*T. truncatus*) en las costas de Sudamérica (Tomado de Barreto and Weber 2006).

Algunos estudios consideran que la actividad de los pescadores artesanales que viven en asentamientos a la largo de las costas, representan una de las mayores amenazas para la especie, más que las operaciones de pesca que se realizan desde los puertos pesqueros (Corcuera et al. 1998). Esto se debe a que la pesca artesanal se lleva a cabo en aguas poco profundas utilizando redes de enmalle. Actualmente la franciscana está clasificada por la UICN (Unión Internacional para la Conservación de la Naturaleza) como especie vulnerable (Reeves et al. 2008). En Uruguay no se tiene control de las franciscanas que mueren enredadas en las redes de los pescadores artesanales ni tampoco de las que aparecen varadas a lo largo de la costa uruguaya, aunque se considera que la mortalidad puede ser muy alta (Abud et al. 2006) (Datos de varamientos y captura incidental en el periodo de este estudio superan los noventa ejemplares a lo largo de la costa comprendida entre Colonia y Chuy).

El delfin nariz de botella

El delfin nariz de botella tiene una distribucion global, es comunmente avistado en costas llanas, costas en general y en mar abierto (delfines oceánicos) (Leatherwood & Reeves, 1983; Bearzi et al., 2009). En el Oceano Atlántico Sudoccidental el delfin nariz de botella tiene una distribución discuntinua desde el estuario del Rio Amazonas hasta Tierra del Fuego Argentina y las Falkland islands (Islas Malvinas) (Bastida et al., 2007) (Figura 1). La poblacion que habita la costa uruguaya fue inicialmente estimada en aproximadamente cuarenta individuos (Tellechea et al 2014). Existe un decrecimiento substancial en la ocurrencia de esta especie de delfin a lo largo de la costa uruguaya (Lázaro & Praderi, 2000). La causa de esta dismunicion en los avistamientos no es conocida pero podria ser por la sobrepesca o la degradacion del ambiente costero. En la costa uruguya el delfin nariz de botella se observa en la costa atlantica, playas abiertas, y algunos lugares de aparente preferencia (Tellechea et al 2014). Hasta el momento no existian estudios acústicos de esta especie de delfin ni de las características acústicas de la población costera uruguaya.

Comportamiento acústico de la franciscana y el delfin nariz de botella

Los antecedentes sobre el estudio acústico de la franciscana con individuos silvestres son escasos. Los primeros “clicks” fueron registrados por primera vez para la especie por Busnel et al. (1974) en aguas uruguayas. En individuos cautivos, se registraron “clicks” de ecolocalización que rondaban los 130 kHz, como frecuencia dominante (Von Fersen *et al.,* 1998). En Argentina, mediante la utilización de un detector automático de señales y en animales silvestres se registraron “clicks” de 130 kHz (Melcon et al 2012) y por un individuo neonato en cautivero en una piscina de marea se obtuvieron frecuencias de clicks que van de 37 kHz y 160 kHz (Melcon et al 2016). Sonidos de silbidos u otras bajas frecuencias, no fueron registrados nunca en esta especie, sin embargo existen algunas especies de delfines catalogados como delfines de rio que si emiten silbidos como por ejemplo el delfin tucuxi (*Sotalia fluviatilis*) (Norris et al 1972; Nakasai and Takemura 1975) y el delfin boto del amazonas (*Inia geoffrensis*) (Nakasai and Takemura 1975; May-Colladoa and Wartzok 2007).

No existen más datos acerca de las habilidades acústicas de la franciscana, ni si son capaces de producir silbidos o “burst clicks”. En cuanto a sus ecos, no hay registros mas allá de los citados, los cuales no proporcionan un conocimiento suficiente, para analizar a qué tipo de comportamiento están relacionadas dichas emisiones acústicas (por ejemplo si están asociadas a comportamientos sociales o a la búsqueda de alimento). En cuanto a la ontogenia de los sonidos y desarrollo del sonar, no existian datos comparativos entre neonatos y adultos para poder conocer si la franciscana tiene un desarrollado sonar para la comunicación y para detectar objetos como las redes de pesca. Siendo la franciscana un delfin que muere enredada en las redes de los pescadores artesanales, surge la pregunta si el sonar de este delfin es lo suficientemente desarrollado como para detectar las redes o si en realidad podría estar siendo atraído hacia ellas, por el ruido que emiten algunos peces que quedan enmallados en las mismas.

En el caso del delfin nariz de botella, se ha estudiado extensivamente a nivel acústico, y se conoce muy bien sus características acústicas, las cuales difieren en poblaciones en diferentes ambientes (Caldwell et al., 1990; Tyack, 1997; Nowacek, 1999, 2005; Tyack & Clark, 2000; Acevedo-Gutiérrez & Stienessen, 2004; Quick & Janik, 2008; Janik, 2009; Simard et al., 2011). En Uruguay no se han realizado estudios acústicos de esta especie.

Estudios de dieta en la franciscana (presas sonoras)

En general los estudios sobre la identificación de las presas ingeridas por los cetáceos consisten fundamentalmente en la cuantificación de la dieta a través del análisis del contenido estomacal y a partir de individuos obtenidos en general, de manera incidental (Desportes and Mouritsen 1993; Gannon et al. 1997; Barros and Wells 1998). No existe información espacial ni temporal sobre la disponibilidad de las presas que consumen los cetáceos, lo que hace imposible evaluar la selectividad y la electividad de las mismas por parte del predador (MacLeod et al. 2006).

En el caso de la franciscana los estudios realizados sobre la dieta muestran que se alimenta de peces, principalmente de Sciaenidos y Batracodidos, y en menor medida de cefalópodos y crustáceos (Fitch and Brownell 1971; Brownell and Praderi 1974, Brownell 1975; Praderi 1984).

Las especies de Sciaenidos y Batracodidos se caracterizan por ser especies productoras de sonido. En Uruguay se ha constatado la presencia de siete especies de Sciaenidos (Cousseau et al. 1998), dentro de las cuales cinco, la corvina blanca *M. furnieri* (Tellechea et al. 2010), la corvina negra *Pogonias cromis* (Tellechea et al. 2011a), la pescadilla de calada *C. guatucupa* (Tellechea et al. 2012), la pescadilla de red *Macrodon atricauda* (Tellechea and Norbis en preparación) y el pargo blanco *Umbrina canosai* (Tellechea et al. 2016 in press), producen sonidos (Figura 3). Las antes mencionadas especies sumadas al bagre sapo luminoso del género *Porichthys* (Familia Batrachoididae) son los principales ítems alimenticios de la franciscana (Fitch and Brownell 1971; Brownell and Praderi 1974; Brownell 1975; Tellechea et al. 2016 submitted). Los sonidos de los peces están asociados al cortejo y al desove (“advertisement call”) y también a una llamada de alarma y disturbio (“disturbance call”), asociados a comportamientos de defensa y disturbio (Figura 3) (Fish and Mowbray 1970; Fine et al. 1977; Connaughton and Taylor 1996; Connaugthon et al. 2000; Fine et al. 2001; Connaugthon et al. 2003; Fine et al. 2004; Tellechea et al. 2010, 2011a, 2011b). Se destaca que el sonido de alarma (“disturbance call”) fue registrado cuando ejemplares de *M. furnieri, C. guatucupa, M. ancylodon, P. cromis y U. canosai* fueron capturados con redes de enmalle, como las utilizadas por los pescadores artesanales (Norbis 1995; Tellechea et al. 2010, 2011a, 2016 submited).

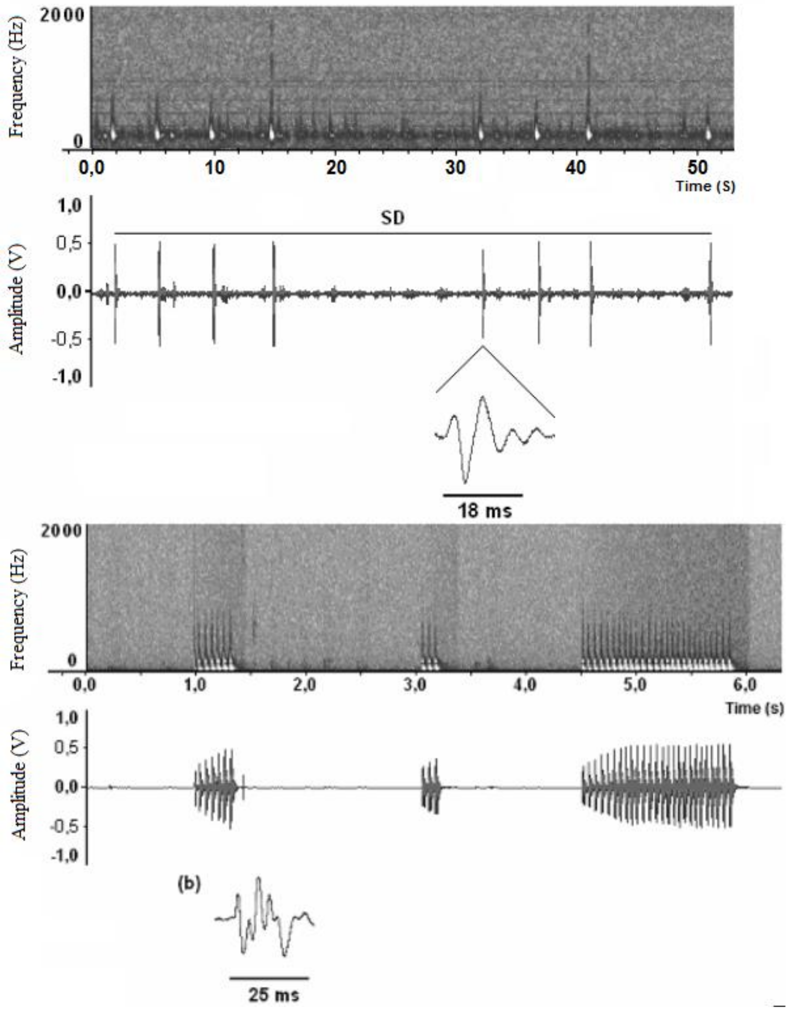

Figura 3. Espectrograma y oscilograma de la llamada de desove ("advertisement call") y un pulso expandido (Figura superior) y de la llamada de disturbio ("disturbance call") y un pulso expandido (Figura inferior) para la corvina blanca *M. furnieri* (Tomado de Tellechea et al., 2010).

Hasta el momento, se ha propuesto que la franciscana identificaba a sus posibles presas mediante ecolocalización y no se ha considerado que la franciscana pueda localizar a sus presas por la escucha de los sonidos producidos por los peces. La franciscana puede identificar sonidos en los rangos de amplitud y frecuencia emitidos por sus presas a través de la escucha pasiva y frecuentemente queda retenida en las redes de enmalle junto con especies de peces que producen sonidos como las mencionadas anteriormente y que constituyen sus principales presas (Fitch and Brownell 1971; Brownell and Praderi 1974; Brownell 1975; Tellechea et al. 2016 submitted).

Hipótesis

1) Se puede utilizar la escucha pasiva para estudiar la ecología de los cetáceos en la costa uruguaya.

2) Los sonidos emitidos por la franciscana se pueden caracterizar y se podrían relacionar a comportamientos sociales, reproductivos y de alimentación.

3) La franciscana utiliza la escucha pasiva más que la ecolocación para localizar y encontrar sus presas, lo cual podría ser la causa de la captura y muerte incidental en las redes de los pescadores artesanales.

4) La fanciscana y el delfin nariz de botella comparten el ambiente pero no interaccionan.

Objetivos

Esta tesis tuvo cuatro objetivos:

1) Utilizar la metodos de escucha pasiva y bioacustia para el estudio de cetáceos en la costa uruguaya, herramientas nunca antes utilizadas.

2) Obtener y analizar las características físicas de los sonidos emitidos por la franciscana, verificar que tipos de “clicks” de ecolocación emite, comprobar si es capaz de emitir silbidos y trenes de pulsos y analizar si existe una relación de la emisión de estos sonidos con comportamientos sociales.

3) Dilucidar si la franciscana se siente atraída por sus presas sonoras mediante el estudio del contenido estomacal de las franciscanas muertas en redes de pescadores artesanales.

4) Obtener y analizar las características físicas de los sonidos emitidos por el delfin nariz de botella por primera vez en la costa uruguaya y discutir si las dos especies de delfines (franciscana y nariz de botella) interaccionana en el mismo ambiente que habitan.

Materiales y métodos

Fabricacion de las boyas PAM (Passive Acoustic Monitoring)

Las boyas PAM utilizadas fueron construidas en el laboratorio y contienen un hidrofono omnidirectional calibrado (-40 dB: re 1 μPa, frecuencia lineal de 20 Hz to 100 kHz), conectado a un amplificador y a una grabadora TASCAM HD-P2 digital recorder (20 Hz and 96 kHz, frecuencia de muestreo = 192 kHz) y un regulador de voltaje que le permite a este sistema grabar por 48 horas seguías ininterrumpidas (Figura 4). La respuesta de este sistema esta limitado a las frecuencias muy altas que pueden emitir los cetáceos que sobrepasan la frecuencia de muestreo del equipo. Dichas boyas se colocaron a lo largo de la costa de Rocha (Capitulo 3) y en la costa del Rio de la Plata (Capitulo 4) para registrar emisiones acusticas de los delfines franciscana y nariz de botella.

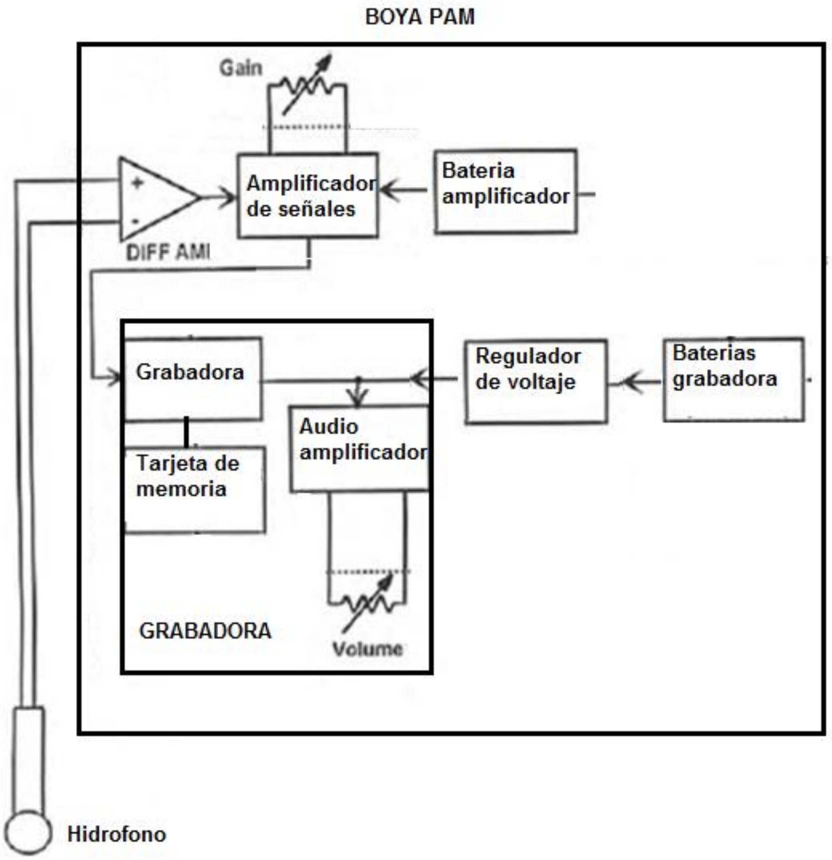

Figura 4. Esquema de una boya PAM utilizada en la costa para registrar los sonidos de las especies de delfines antes mencionadas.

Muestreo de contenido estomacal de la franciscana

Se obtuvieron 50 franciscanas varadas y enmalladas para el estudio del contenido estomacal desde la costa de Montevideo al Chuy. Los cuerpos de los animales sin vida fueron proporcionados por pescadores artesanales, y deportivos de la costa, obteniéndose un muestreo de 41 estomgaos en condiciones de ser muestreados.

CAPITULO 2.- Características de los sonidos emitidos por dos neonatos de *Pontoporia blainvillei.*

Manuscrito publicado en Marine Mammal Science Journal: Sound characteristics of two neonatal franciscana dolphins (*Pontoporia blainvillei*)

Resumen.

Por primera vez se obtuvieron registros acústicos de dos neonatos de *Pontoporia blainvillei* de una semana de edad. Los dos tenían el cordón umbilical al momento de encontrarlos varados en la playa. EL primer neonato fue un macho, y fue encontrado en Jaureguiberry, Uruguay. El segundo se trató de una hembra y fue encontrada en la playa del Buceo en Montevideo. Estos neonatos fueron mantenidos con vida en una ONG donde se pudieron realizar las grabaciones en una piscina de 4 m de diámetro y 1 m de profundidad. Los dos especímenes emitieron "clicks" y no emitieron silbidos. Los "clicks" fueron categorizados como "clicks" de alta frecuencia ("high frequency clicks"), "clicks" de baja frecuencia ("low frequency clicks") y "burst clicks" ("clicks" de frecuencias variables que se caracterizan por tener un intervalo entre "clicks" ("interclick interval") muy pequeño). Los "burst clicks" fueron los "clicks" mas emitidos por los dos neonatos. Los datos aquí presentados sugieren que esta especie de delfín puede emitir diferentes "clicks" a muy corta edad. El presente estudio presentó por primera vez la descripción y caracterización de los sonidos que producen dos individuos (un macho y una hembra) recién nacidos de esta especie, que hasta el momento se desconocía si podían emitir sonidos.

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Sound characteristics of two neonatal franciscana dolphins (*Pontoporia blainvillei*)

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Pulsed and tonal sounds produced by odontocetes are used for navigation, location of prey and communication (Popper 1980, Tyack and Clark 2000). Little is known about the development of sound production in the franciscana (*Pontoporia blainvillei*). The franciscana is a small dolphin endemic to the western South Atlantic Ocean off the coast of South America. Its range extends from Itaunas (18°25′S, 30°42′W), Espirito Santo, Brazil, to Golfo Nuevo (42°35′S, 64°48′W), Peninsula Valdes, Argentina (Crespo *et al.* 1998). Due to continued incidental mortality throughout most of its range (Praderi *et al.* 1989, Crespo 2002, Danilewicz *et al.* 2002, Ott *et al.* 2002, Secchi *et al.* 2004, Franco-Trecu *et al.* 2009), the franciscana is perceived as the most threatened small cetacean in the western South Atlantic Ocean (UNEP/CMS 2000) and is classified as vulnerable by the IUCN (Reeves *et al.* 2008). Limited data on echolocation sounds were obtained for this species during early studies in the wild in Punta del Diablo, Uruguay, by Busnel *et al.* (1974). More recently the additional but limited data on the click patterns of adult individuals were published by Von Fersen *et al.* (1997) from one individual in captivity and by Melcón *et al.* (2012) from animals in the wild in Argentina. As the logistics of recording sounds from wild cetacean calves is challenging, available sound recordings of young individuals from several species have been conducted largely in captivity on calves born in aquaria (Reiss 1988; Killebrew *et al.* 2001; Li *et al.* 2007, 2008). The aim of this work was to describe the echolocation signals of two neonatal franciscana dolphins for the first time in captivity.

The sounds emitted by two 1-wk-old calves, a male calf of 65 cm and a female of 69 cm in total length were recorded. The individuals were found on two beaches (male: 34°47′27″S, 55°24′59″W and female: 34°53′56″S, 56°07′13″W) on the Uruguayan coast in October 2011 and November 2012, respectively. A local marine ani-

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animal rescue center, SOS-Rescate Marino, transferred the animals to a pool and fed them formula for dolphin calves. The male dolphin survived for 3 wk and the female for 5 wk. Recordings were made in a 3 m diameter circular canvas pool of filled with seawater with a calibrated hydrophone built in the laboratory (sensitivity 40 dB re 1 mPa and linear from 20 to 100 kHz). The recordings were made on a digital recorder TASCAM HD-P2, (frequency response: 44.1–192 kHz) sampling frequency: 192 kHz).

The sound files were screened manually for the presence of echolocation signals, and only those with clear signals were selected for further analysis. Sound analysis was performed using Audacity free software, version 1.2.3 (Mazzoni 2006), and Raven Lite 1.0 (Cornell Lab of Ornithology, Ithaca, NY). Power spectra were calculated using a 1,024 point Fast Fourier Transform (FFT) with a Hanning window. For each click train we determined the number of clicks, click duration, click interval, and the peak frequency, even though we could not tell which clicks were on-axis (Au and Hastings 2008).

Eighteen minutes of click sounds were obtained from 4 h of recording for the female, and 15 min from 6 h for the male. Recordings, made a week after transfer to the aquarium, were limited due to the continued stress of the individuals. Tables 1 and 2 summarize the parameters of the analyzed clicks emitted by the two calves and indicate differences in click characteristics. The clicks were categorized as high (Fig. 1), low (Fig. 2), and burst clicks (Fig. 3) (Evans 1967, Au and Hastings 2008). The high frequency click signal consisted of sequences with a mean time of 2 ± 1 s for the male and 3 ± 0.2 s for the female. The mean click duration for the male was 0.20 ± 0.1 ms and 0.18 ± 0.2 ms for the female. The interclick interval for the male was 29 ± 0.9 ms and 27 ± 2.5 ms for the female. Male click trains had a mean peak frequency of 80.63 kHz ± 2.45 kHz, and the female's were 83.71 kHz ± 2.52 kHz (Tables 1 and 2). Figure 1 shows a typical train of high frequency clicks.

Table 1. Characteristics (mean, standard deviation and range) of click sounds emitted by the male franciscana neonate.

Type of click		Mean	SD	Maximum	Minimum
High frequency clicks					
Number of trains	13				
Number of clicks		16.6	12.5	53	1
Click duration (ms)		0.20	0.1	0.29	0.17
Click interval (ms)		29	0.9	48	15
Peak frequency (kHz)		80.63	2.45	90	76
Low frequency clicks					
Number of trains	4				
Number of clicks		18.83	13.11	49	1
Click duration (ms)		0.22	0.16	0.27	0.16
Click interval (ms)		26	0.4	30	18
Peak frequency (kHz)		12.52	1.79	16	11
Burst clicks					
Number of trains	18				
Number of clicks		124	0.5	198	60
Click duration (ms)		13	0.3	19	11
Click interval (ms)		10	1.3	12	9
Peak frequency (kHz)		47.44	1.21	48	44

Table 2. Characteristics (mean, standard deviation and range) of click sounds emitted by the female franciscana neonate.

Type of click		Average	SD	Maximum	Minimum
High frequency clicks					
Number of trains	7				
Number of clicks		16.02	11.07	37	1
Click duration (ms)		0.18	0.2	0.26	0.16
Click interval (ms)		27	2.5	39	13
Peak frequency (kHz)		83.71	2.52	93	87
Low frequency clicks					
Number of trains	3				
Number of clicks		11.19	7.36	32	1
Click duration (ms)		0.19	0.22	0.31	0.13
Click interval (ms)		25	2.1	30	17
Peak frequency (kHz)		10.35	2.18	12	7
Burst clicks					
Number of trains	22				
Number of clicks		138	12.47	241	73
Click duration (ms)		15	0.8	23	13
Click interval (ms)		13	5.3	14	10
Peak frequency (kHz)		30.52	1.54	32	28

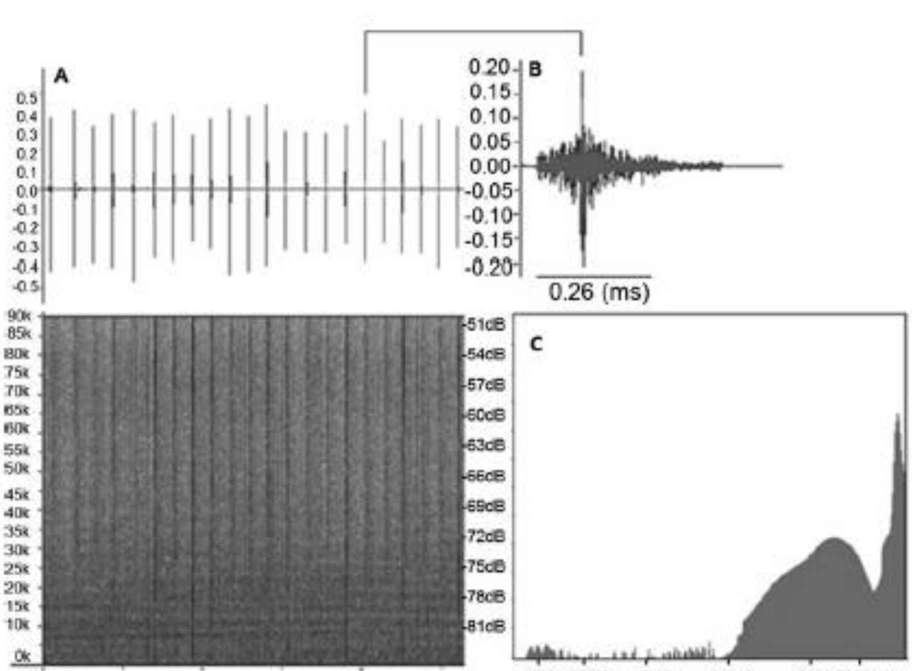

Figure 1. An example of high frequency click sequences of a click train emitted by the male neonate franciscana; (A) oscillogram and spectrogram (Hanning window FFT: 1,024), (B) single expanded pulses, (C) spectrum of the expanded pulse showing the peak frequency.

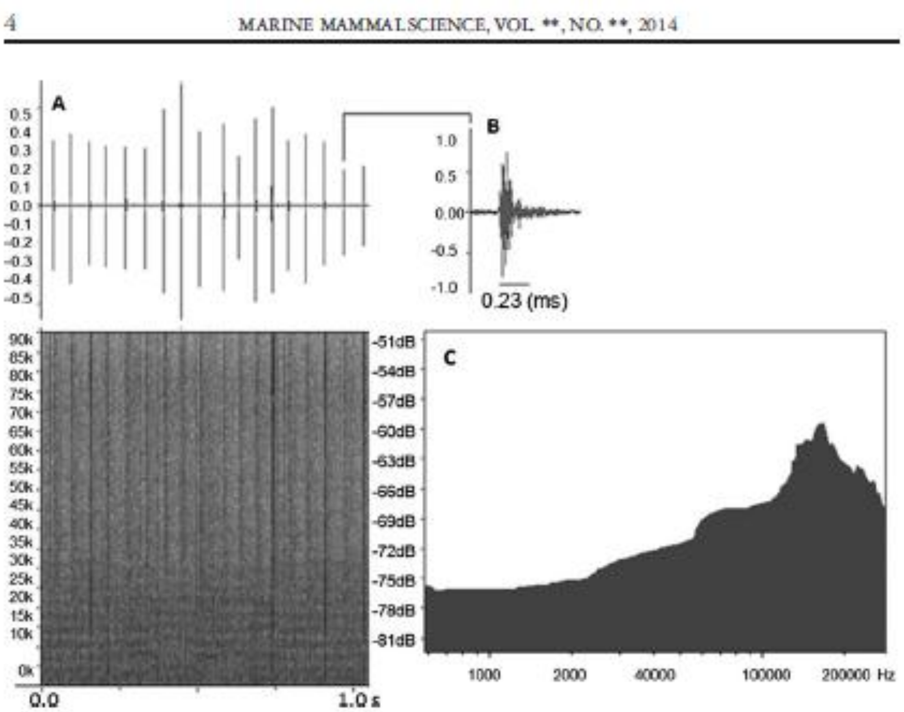

Figure 2. An example of low frequency click sequences of a click train emitted by the female neonate franciscana; (A) oscillogram and spectrogram (Hanning window FFT: 1,024), (B) single expanded pulse, (C) spectrum of the expanded pulse showing the peak frequency.

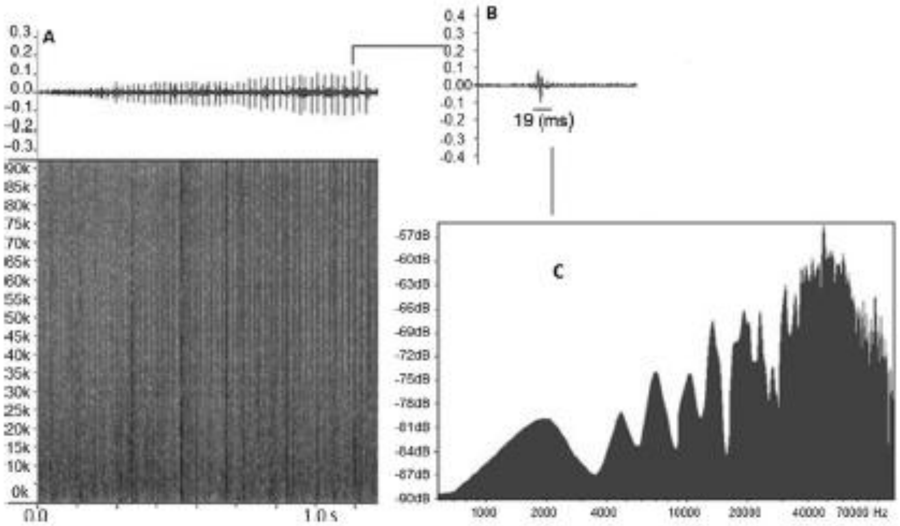

Figure 3. An example of a burst click emitted by the male neonate franciscana. Representative burst click (A) oscillogram and spectrogram (Hanning window FFT: 1,024), (B) single expanded pulse, (C) spectrum of the expanded pulse showing the peak frequency.

Low frequency clicks consisted of train sequences with a mean time of 3 ± 1 s for the male and 2 ± 1 s for the female, a mean click duration of 0.22 ± 0.16 ms for the male and 0.19 ± 0.22 ms for the female. The interclick interval for the male was 26 ± 0.4 ms, and 25 ± 2.1 ms for the female. The mean peak frequencies of clicks were 12.52 ± 1.79 kHz and 10.35 ± 2.18 kHz for the male and female respectively (Fig. 2, Tables 1 and 2). Both high and low frequency clicks were produced when we moved the hydrophone or stirred the water slowly.

Click bursts had a mean duration of 2.22 ± 1 s for the male and 2.12 ± 0.5 s for the female. The clicks had a mean duration of 13 ± 0.3 ms for the male and 15 ± 0.8 ms for the female; a mean interclick interval of 10 ± 1.3 ms for the male and 13 ± 5.3 ms for the female, and a mean peak frequency of 47.44 ± 1.21 kHz for the male and 30.52 ± 1.54 kHz for the female. An example of bursts emitted by these dolphins is shown in Figure 3. In all cases, bursts were accompanied by a movement of the head sideways when dolphins swam freely in the pool.

Recorded sounds contained both burst-pulse and echolocation sequences, similar to clicks emitted by adults in captivity (Von Fersen *et al.* 1997) and in the wild (Busnel *et al.* 1974, Melcon *et al.* 2012). Von Fersen *et al.* (2009) found that captive adults produce a pulse train with a mean click frequency at 130 kHz, a band width of about 20 kHz, and a mean duration of 90 s. These values are similar to the data described by Busnel *et al.* (1974) and the neonate data presented here. Melcón *et al.* (2012) recorded a higher dominant frequency of up to 149 kHz in the Rio Negro Estuary, but found that these click trains were ≤5 s in duration. The differences in sound characteristics between captive and wild individuals such as click duration and frequency could be due to the stress of captivity, and, in the case of a newborn, to the absence of its mother. Caldwell and Caldwell (1979) suggested that in times of stress, muscular control may be momentarily lost, resulting in a decline in production quality such that sounds are more similar to those produced by the underdeveloped sound production system of an infant. Hence, increased click train duration could indicate a developmental stage that infants pass through as they develop neuromuscular control necessary for adult click production. Toothed whales produce sounds internally by controlling air pressure and air flow rate within their respiratory systems (Au 1993, Cranford 2000). As animals develop greater muscular control, they produce sounds more precisely, as in adult dolphins under normal circumstances (Reiss and McCowan 1993). Stressed or excited dolphins may not have sufficient control (Caldwell and Caldwell 1979) to produce sounds similar to those recorded in the wild, as appears to be the case for 1-wk-old infants developing their acoustic skills.

The burst click was the sound most frequently emitted by these neonates. The burst click also seems to be the first or most frequently emitted sound by other species such as *Tursiops truncatus* (Caldwell and Caldwell 1979, Killebrew *et al.* 2001). Although *Tursiops* can also emit whistles, it appears that in newborns burst clicks predominate. Burst pulse sounds are another major category of sound emissions produced by all odontocetes (Au and Hasting 2008). Burst pulse sounds in *T. truncatus* have been associated with alarm and fright, as well as in agonistic and head-to-head open-mouth encounters between individuals often accompanied by head nodding, shaking, and arching (Herzing 1988, Au and Hastings 2008). For cetaceans that do not produce whistles, the burst clicks are very important (Herman and Tavolga 1980, Au and Hastings 2008), as is the case for the harbor porpoise, *Phocoena phocoena*, a species that does not produce whistles and uses burst clicks for communication (Amundin 1991, Au and Hastings 2008, Tubbert-Clausen *et al.* 2010). Thus, burst sounds could be of considerable importance for the franciscana.

These preliminary data on week-old dolphins show that this species is active acoustically at a very young age. Their acoustic records show some similarities with published data in adults, but also some differences, such as in the pulse times emitted. These differences may be due to the young animals lacking full development of their acoustic or neuromuscular skills. Further recordings in the wild, particularly from infants are needed for comparison to these results.

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Literature Cited

Amundin, M. 1991. Sound production in odontocetes with emphasis on the harbor porpoise *Phocoena phocoena*, Ph.D. dissertation, University Stockholm, Stockholm, Sweden. 128 pp.

Au, W. W. L. 1993. The sonar of dolphins. Springer-Verlag, Inc., New York, NY.

Au, W. W. L., and M. C. Hastings. 2008. Principles of marine bioacoustics. Springer, New York, NY.

Brownell, R. L., Jr. 1975. Progress report on the biology of the franciscana dolphin, *Pontoporia blainvillei*, in Uruguayan waters. Journal of the Fisheries Research Board of Canada 32:1073–1078.

Busnel, R., G. A. Dziedzic and G. Alcuri. 1974. Études préliminaries de signaux acoustiques de *Pontoporia blainvillei* Gervaiset D'Orbigny (Cetacea, Platanistidae). Mammalia 38:449–459.

Caldwell, M. C., and D. K. Caldwell. 1979. The whistle of the Atlantic bottlenose dolphin (*Tursiops truncatus*)—Ontogeny. Pages 369–401 *in* H. E. Winn and B. L. Olla, eds. Behavior of marine animals. Volume 3. Cetaceans. Plenum Press, New York, NY.

Cranford, T. W. 2000. In search of impulse sound sources in odontocetes. Pages 109–156 *in* W. W. L Au, A. N. Popper and R. R. Fay, eds. Hearing by whales and dolphins. Springer-Verlag, Inc., New York, NY.

Crespo, E. A. 2002. Franciscana, *Pontoporia blainvillei*. Pages 482–484 *in* W. P. Perrin, B. Würsig and J. G. M. Thewissen, eds. Encyclopedia of marine mammals. Academic Press, San Diego, CA.

Crespo, E. A., G. Harris and R. Gonzalez. 1998. Group size and distribution range of the franciscana, *Pontoporia blainvillei*. Marine Mammal Science 14:845–849.

Danilewicz, D., F. Rosas, R. Bastida, *et al.* 2002. Report of the working group on biology and ecology. The Latin American Journal of Aquatic Mammals (Special Issue) 1:25–42.

Evans, W. E. 1967. Vocalization among marine mammals. Pages 159–186 *in* W. N. Tavolga, ed. Marine bioacoustics. Volume 2. Pergamon, New York, NY.

Franco-Trecu, V., P. Costa, C. Abud, *et al.* 2009. By-catch of franciscana *Pontoporia blainvillei* in Uruguayan artisanal gillnet fisheries: An evaluation after a twelve-year gap in data collection. The Latin American Journal of Aquatic Mammals 7:11–22.

Herman, L. M., and W. N. Tavolga. 1980. The communication systems of cetaceans. Pages 149–209 *in* L. M. Herman, ed. Cetacean behavior: Mechanisms and functions. Wiley Interscience, New York, NY.

Herzing, D. L. 1988. A quantitative description and behavioral associations of a burst-pulsed sound, the squawk, in captive bottlenose dolphins, *Tursiops truncatus*. M.S. thesis, San Francisco State University, San Francisco, CA. 87 pp.

Killebrew, D. A., E. Mercado III, L. M. Herman and A. A. Pack. 2001. Sound production of a neonate bottlenose dolphin. Aquatic Mammals 27:34–44.

Li, S., D. Wang, K. Wang, *et al.* 2007. The ontogeny of echolocation in the Yangtze finless porpoise (*Neophocaena phocaenoides asiaeorientalis*). Journal of the Acoustical Society of America 122:715–718.

Li, S., K. Wang, D. Wang, *et al.* 2008. Simultaneous production of low- and high-frequency sounds by neonatal finless porpoises. Journal of the Acoustical Society of America 124:716–718.

Mazzoni, D. 2006. Audacity 1.2.6. Available at http://audacity.sourceforge.net.

Melcón, M. L., M. Failla and M. A. Iñíguez. 2012. Echolocation behavior of franciscana dolphins (*Pontoporia blainvillei*) in the wild. Journal of Acoustical Society of America 131:448–453.

Ott, P. H., E. Secchi, I. B. Moreno, *et al.* 2002. Report of the Working Group on Fishery Interactions. The Latin American Journal of Aquatic Mammals (Special Issue) 1:55–64.

Popper, A. N. 1980. Sound emission and detection by delphinids. Pages 1–52 *in* L. M. Herman, ed. Cetacean behavior: Mechanisms and functions. John Wiley & Sons, New York, NY.

Praderi, R., M. C. Pinedo and E. A. Crespo. 1989. Conservation and management of *Pontoporia blainvillei* in Uruguay, Brazil and Argentina. Pages 52–56 *in* W. F. Perrin, R. L. Brownell, Jr., Z. Kaiya and L. Jiankang, eds. Biology and conservation of the river dolphins. Occasional Papers of the IUCN Species Survival Commission, Gland, Switzerland.

Reeves, R. R., M. L. Dalebout, T. A. Jefferson *et al.* 2008. *Pontoporia blainvillei*. IUCN Red List of Threatened Species. Version 2010.4. IUCN, Gland, Switzerland.

Reiss, D. 1988. Observations on the development of echolocation in young bottlenose dolphins. Pages 121–128 *in* P. E. Nachtigall and P. W. B. Moore, eds. Animal sonar, process and performance. Plenum Press, New York, NY.

Reiss, D., and B. McCowan. 1993. Spontaneous vocal mimicry and production by bottlenose dolphins (*Tursiops truncatus*): Evidence for vocal learning. The Journal of Comparative Physiology 107:301–312.

Secchi, E. R., P. G. Kinas and M. Muelbert. 2004. Incidental catches of franciscana in coastal gillnet fisheries in the Franciscana Management Area III: Period 1999–2000. The Latin American Journal of Aquatic Mammals (Special Issue) 1:61–68.

Tubbert-Clausen, K., M. Wahlberg, K. Beedholm, *et al.* 2010. Click communication in harbour porpoises *Phocoena phocoena*. Bioacoustics 20:1–28.

Tyack, P. L., and C. W. Clark. 2000. Communication and acoustic behavior of dolphins and whales. Pages 156–224 *in* W. W. L. Au, A. N. Popper and R. R. Fay, eds. Hearing by whales and dolphins. Springer-Verlag, Inc., New York, NY.

UNEP/CMS. 2000. Report of the third workshop for coordinated research and conservation of the franciscana dolphin (*Pontoporia blainvillei*) in the southwestern Atlantic, 26–28 November 1997, Buenos Aires, Argentina. 112 pp. Available at http://www.cms.int/publications/pdf/franciscana_dolphin_buenos_aires_1997.pdf.

Von Fersen, L., C. Kamminga and A. Seidl. 1997. Estudios preliminares sobre el comportamiento de un ejemplar de franciscana (*Pontoporia blainvillei*) en Mundo Marino, Argentina (DT10). Pages 30–33 *in* Report of the third workshop for coordinated research and conservation of the franciscana dolphin (*Pontoporia blainvillei*) in the southwestern Atlantic, 26–28 November 1997, Buenos Aires, Argentina. Available at http://www.cms.int/publications/pdf/franciscana_dolphin_buenos_aires_1997.pdf.

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Capitulo 3.-Utilizacion de boyas PAM en la costa de Rocha: detección de acústica del delfín nariz de botella *T. truncatus* por primera vez en Uruguay.

Manuscrito publicado en Aquatic Mammals Journal: Passive Acoustic Monitoring of Bottlenose Dolphins (*Tursiops truncatus*) on the Uruguayan Coast: Vocal Characteristics and Seasonal Cycles

Resumen.

El objetivo de este estudio fue registrar sonidos de los delfines franciscana y nariz de botella "in situ". Para este propósito se construyeron boyas (PAM) de grabación pasivas en el laboratorio. Dichas boyas pueden grabar hasta 48 horas de sonidos sin interrupción con una frecuencia de 20 hz a 100 Khz. Las boyas se colocaron en los principales puntos de varamientos y enmalle de de la franciscana y de avistamiento del nariz de botella. Los puntos elegidos en la costa fueron: Cerro Verde, Punta del Diablo, Valizas, Cabo Polonio, y La Paloma. No se obtuvieron sonidos de franciscana (*P. blainvillei*) pero si se obtuvieron del delfín nariz de botella (*Tursiops truncatus*), otra especie de delfín recurrente en la costa atlántica de Uruguay. En las costas de Uruguay no existían antecedentes de estudios de comportamiento acústico de esta especie de delfín y en consecuencia no se tenía información acerca de la caracterización de los silbidos y "clicks" en nuestras costas. La pequeña población costera del delfín nariz de botella ha sido estimada en aproximadamente en 40 individuos, con una substancial disminución de ocurrencia en las ultimas décadas en el estuario del Rio de la Plata, siendo frecuente en la actualidad, en las costas atlánticas de Maldonado y Rocha. Un total de 4152 silbidos y 409 "clicks" fueron grabados del grupo de delfines salvajes en las cinco localidades en la costa atlántica uruguaya. El

delfín nariz de botella emite un variado repertorio de silbidos, como ha sido reportado en otras partes del mundo donde habita. Estos silbidos fueron categorizados como ascendentes o comunes, correspondiendo al 44% del total de los silbidos; silbidos “multi looped” (con mas de un punto de inflexión) que representaron el 23 %; silbidos ascendentes-descendentes que representaron el 12% y silbidos descendentes que representaron el 8.1 %. Los silbidos descendente - ascendente (7.5%) y los silbidos constantes fueron los menos frecuentes (5.5%). Los silbidos registraron un rango de frecuencias entre 1.6 y 22.4 kHz y la duración fue de 628 ± 293 ms. La duración del tren de “clicks” tuvo una media de 1,105 ± 59.6 ms y el numero de “clicks” por tren fue de 11.4 ± 1.64. La media de la duración del “click” fue de 63.2 ± 4.06 μs, y el intervalo entre “click” fue de 129.4 ± 3.94 ms. Los trenes de “clicks” tuvieron una frecuencia media de 52.02 ± 12.09 kHz. En general, los delfines parecieron ser más vocales durante los meses de verano y se observó una disminución de las vocalizaciones durante los meses de invierno. Los silbidos mostraron una fuerte variabilidad asociada a la fluctuación de la temperatura superficial del mar (SST). Durante el invierno y principios de la primavera con temperaturas menores a 15° C, el número de silbidos fue bajo. En coincidencia con el aumento de la temperatura del agua, de 16º a 20º (mitad de la primavera a comienzos del verano), el número de silbidos aumentó hasta alcanzar valores máximos en verano. Se observó una tendencia decreciente en el número de silbidos al final del verano y principios de otoño. En otoño, la temperatura del agua disminuyó, y el número de silbidos se redujo drásticamente. Este estudio proporcionó la primera descripción de las características acústicas de los delfines nariz de botella en la costa del Uruguay y aporta información que contribuye a la conservación de esta especie que está desapareciendo de la costa uruguaya.

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Passive Acoustic Monitoring of Bottlenose Dolphins (*Tursiops truncatus*) on the Uruguayan Coast: Vocal Characteristics and Seasonal Cycles

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Abstract

Little is known of the sounds produced by bottlenose dolphins (*Tursiops truncatus*) along the coast of Uruguay, South America. The small population that inhabits the Atlantic Uruguayan coast has been estimated at approximately 40 individuals, with a substantial decrease in occurrence in the estuarine coast of Uruguay over the last two decades. A total of 4,152 whistles and 409 clicks were recorded from free-ranging bottlenose dolphins in five locations along the Atlantic coast of Uruguay with five Passive Acoustic Monitoring (PAM) buoys. Bottlenose dolphins emitted a varied repertoire of whistles. They were categorised as ascending in their contour pattern as the most common, corresponding to 44% of all whistles, whereas multi-looped (more than one inflection point) represented 23%. Ascending-descending (12%) and descending (8.1%) whistles were also frequently documented, while descending-ascending (7.5%) and constant (5.5%) whistles were less frequent. Whistles recorded had a wide frequency range, between 1.6 and 22.4 kHz, and whistle duration was 628 ± 293 ms. Click train duration had a mean of 1,105 ± 59.6 ms, and the mean click number per train was 11.4 ± 1.64. Mean click duration was 63.2 ± 4.06 μs, and the interclick interval was 129.4 ± 3.94 ms. Click trains had a mean peak frequency of 52.02 ± 12.09 kHz. Overall, bottlenose dolphins seemed to be more vocal during the summer months, and declined in vocalizations during the winter months. Whistles showed strong seasonal variability associated with fluctuation in sea surface temperatures (SST). During the winter and early spring (SST < 15° C), the average number of whistles was low. Coincident with water temperatures warming from 16° to 20° C in mid-spring and early summer, the average number of whistles increased to reach maximum values in summer. Meanwhile, a decreasing trend in whistle numbers was found in late summer (N = 1,279) and early autumn (N = 660). In autumn, the water temperature decreased, and the average number of whistles dropped sharply. This study provides the first description of the acoustic characteristics of bottlenose dolphins on the coast of Uruguay, which also assists conservation management efforts for this species that is disappearing from the Uruguayan coast.

Key Words: *tonina*, whistles, clicks, bottlenose dolphin, *Tursiops truncatus*, southwestern Atlantic Ocean

Introduction

Throughout their global range, bottlenose dolphins (*Tursiops truncatus*) are commonly found in shallow, coastal habitats and offshore (Leatherwood & Reeves, 1983; Bearzi et al., 2009). In the southwestern Atlantic Ocean, bottlenose dolphins have a discontinuous distribution from the Amazon River estuary of Brazil to Tierra del Fuego of Argentina and the Falkland (Malvinas) Islands (Bastida et al., 2007). The population that inhabits the Atlantic Uruguayan coast was initially estimated at approximately 40 individuals (Laporta et al., 2008a). There has been a substantial decrease in occurrence of the bottlenose dolphin along the estuarine coast of Uruguay (Lázaro & Praderi, 2000). The cause for this decrease in sightings remains unknown but could be explained by overfishing. On the Atlantic Uruguayan coast, the bottlenose dolphin occurs off the coast of open beaches with a few preferred areas (Laporta, 2004). Previous studies in Uruguay indicate that there is frequent occurrence of this species in two coastal zones: (1) La Coronilla-Cerro Verde (33° 38' S, 53° 24' W) and (2) Cabo Polonio (34° 23' S, 53° 46' W) (Figure 1) (Laporta, 2004; Laporta et al., 2008a). Bottlenose dolphins occur year-round in these areas, using the coastal zone mainly for feeding, socializing, and reproduction. Groups are variable in number of individuals and age composition, ranging from one to 30 individuals, with larger groups also including calves (Laporta, 2004; Laporta et al., 2008a, 2008b).

The bottlenose dolphin produces a wide variety of vocal signals to respond to and interact with group members and their environment. These vocalizations can be grouped into three different categories: (1) broad-band echolocation clicks, (2) broad-band burst pulsed sounds, and (3) frequency-modulated narrow-band whistles (Caldwell et al., 1990; Tyack, 1997; Nowacek, 1999, 2005; Tyack & Clark, 2000; Acevedo-Gutiérrez & Stienessen, 2004; Quick & Janik, 2008; Janik, 2009; Simard et al., 2011).

Many studies of cetaceans rely purely on behavioural observations during surfacing, but details on behaviour can be difficult to accurately identify from visual observations above the water's surface (Evans & Hammond, 2004; Nuuttila et al., 2013). As cetaceans are only visible at the surface for 1 to 10% of their time (Tyack & Miller, 2002), classification of animal activity based on their vocalizations is often a more appropriate method to address their varied activities (Martin & Reeves, 2002; Nuuttila et al., 2013). Due to the difficulties in conducting visual surveys during winter months, when days are shorter and the weather and sea conditions tend to be less favourable, the use of the Uruguayan coast by bottlenose dolphins during this season is poorly known.

Whereas traditional survey techniques describe the distribution and occurrence of animals during daylight hours, with reasonable weather and over short time periods, acoustic data loggers can continue monitoring for up to several weeks at a time in all weather and light conditions. Use of acoustic data collection can therefore provide a more continuous record of the occurrence of animals over longer periods of time. Passive Acoustic Monitoring (PAM) is used on a broad scale to document presence of vocal marine mammals (Carstensen et al., 2006; Mellinger et al., 2007; Koschinski et al., 2008; Simon et al., 2010; Nuuttila et al., 2013). To date, there are no studies about the sounds of bottlenose dolphins off the coast of Uruguay.

Bottlenose dolphins are not the only cetaceans seen regularly in this area of the Uruguayan coast. The Franciscana (*Pontoporia blainvillei*) also lives in this coastal region (Praderi et al., 1989), and southern right whales (*Eubalaena australis*) use the Uruguayan Atlantic coast as an important winter aggregation area (Costa et al., 2007; Tellechea & Norbis, 2012a). The vocal signals of bottlenose dolphins (Caldwell & Caldwell, 1965, 1968; Au et al., 1986; Caldwell et al., 1990; Au, 1993), Franciscana (Busnel et al., 1974; Melcón et al., 2012; Tellechea & Norbis, 2014), and southern right whales (Clark, 1982; Tellechea & Norbis, 2012a) have distinctive acoustic characteristics that are easily distinguished from each other.

To more fully understand the acoustic ecology of bottlenose dolphins, we also considered other sources of sound in their environment. One very important biological source is soniferous fishes in this area (Tellechea et al., 2010, 2011a, 2011b; Tellechea & Norbis, 2012b), many of which are bottlenose dolphin prey (Mermoz, 1977; Barros & Wells, 1998; Gannon et al., 2005). The objectives of this study were to (1) characterize the physical parameters of whistle and pulsed calls emitted by bottlenose dolphins on the Atlantic Uruguayan coast, and (2) describe the daily and seasonal cycles of sound emissions using five PAM buoys deployed along the study site.

Methods

Study Area

Data collection was conducted on 13 nonconsecutive days between August 2011 and August 2012, recording sounds 1 d/mo at each buoy along the Atlantic coast of Uruguay. Recordings were conducted using five PAM buoys placed at five locations along the coast where sightings of bottlenose dolphins are relatively frequent (Laporta, 2004; Laporta et al., 2008a): Cerro Verde, Punta del Diablo, Valizas, Cabo Polonio, and La Paloma (Figure 1). All five buoys were deployed at the same time.

Acoustic Monitoring

Acoustic monitoring was conducted with a PAM buoy, an acoustic self-contained data logger, comprising a hydrophone, digital memory, and power source (Figure 2). These PAM buoys are commonly used in acoustic monitoring of several fish species in Uruguay (Tellechea et al., 2010, 2011a, 2011b; Tellechea & Norbis, 2012b) and were set to continuously monitor the acoustic environment for 24 h at frequencies ranging between 20 Hz and 96 kHz (sample rate = 192 kHz) with a calibrated omnidirectional hydrophone (built by *Tellechea-Bouvier*, -40 dB Newton m^{-2} re 1 μPa, and linear from 20 Hz to 100 kHz). The calibration was carried out in tanks and open water, where simultaneous recordings of synthetic sounds (created with a Digital Function Generator, Digital Recordings, www.digitalrecordings.com and www-dfg/www-dfg-products.html), including pure tones, frequency sweeps, and pulses of varying duration, were made to test for accuracy in recording frequency, amplitude, and temporal characteristics of underwater sounds registered by our hydrophones.

Recordings were analysed using *Audacity* free software, Version 1.2.3 (Mazzoni, 2006) and *Raven Lite*, Version 1.0 (free license). Power

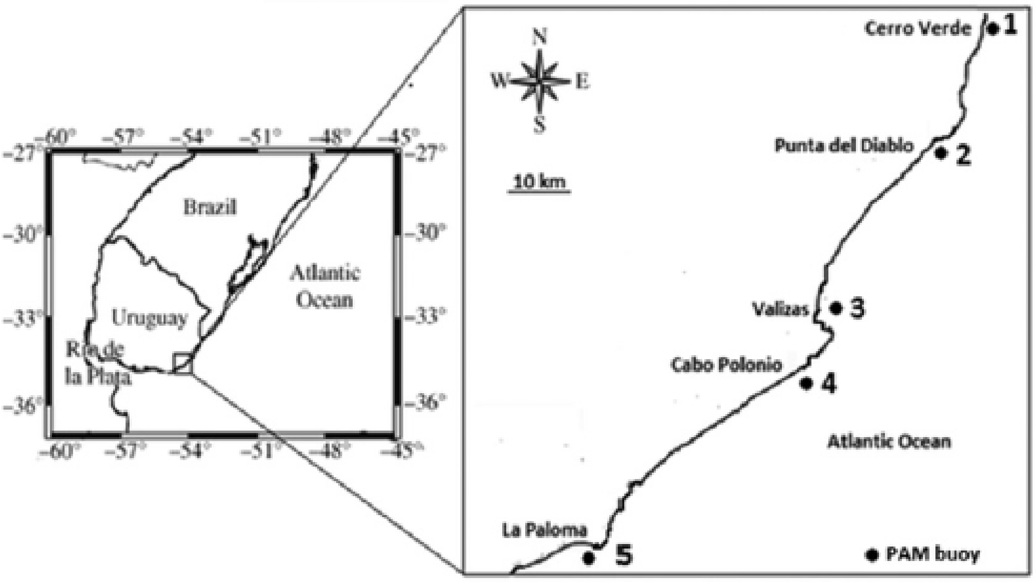

Figure 1. Map of Uruguay and the Atlantic coast of Uruguay showing the position of the PAM buoys from which acoustic recordings of bottlenose dolphins (*Tursiops truncatus*) were obtained

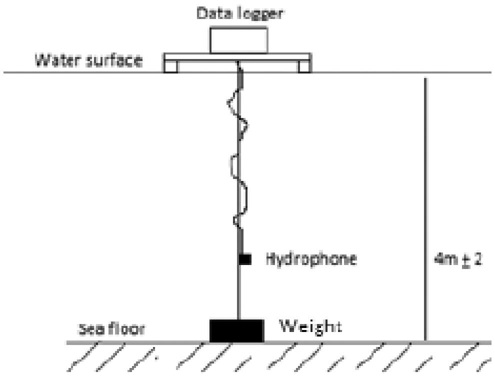

Figure 2. Schematic illustration of the deployment used in this study

spectra were calculated using a 1,024-point Fast Fourier Transform (FFT) with a Hanning window. At each of the five locations (Figure 1), the PAM buoys were placed 300 m from shore to a depth of 4 ± 2 m and exposed to similar weather conditions with Beaufort sea states of ≤ 2 in each location.

Sound Detection and Measurements

Whistles—Seven acoustic parameters from the fundamental component of each whistle were measured: (1) starting frequency (SF), (2) ending frequency (EF), (3) minimum frequency (MinF), (4) maximum frequency (MaxF), (5) the average frequency, (6) duration (DUR), and (7) number of inflection points (defined as points when whistle contours changed slope). Frequency variables were measured in kHz and duration in ms. We calculated the average frequency (MeF) as the averages of SF, EF, MinF, and MaxF (Azevedo et al., 2007). These whistle parameters were chosen based upon previous studies of bottlenose dolphins (Ding et al., 1995; Morisaka et al., 2005; Azevedo et al., 2007) and other dolphin species (Bazúa-Duran & Au, 2004; Azevedo & Van Sluys, 2005). For this analysis, we included only whistles for which all parameters of a spectral contour were measurable.

Pulses—Click trains produced by bottlenose dolphins were analysed manually using the previously mentioned acoustic software. We obtained peak frequencies with a FFT size of 1,024 points, an overlap of 50%, and a Hanning window. High-quality click trains were chosen for the analysis by considering the waveform and by avoiding an oversampling of clicks. Four standard click variables were measured from the waveform: (1) click train duration, (2) click number, (3) click duration, and (4) click interval (Au, 1993), despite the fact that we were unable to distinguish which clicks were on-axis (Au & Hastings, 2008).

Statistical Analysis

We used descriptive statistics to examine all whistle variables, including minimum values, maximum values, average, and standard deviations. For the entire set of whistles, distributions were calculated for start frequency, end frequency, frequency range, and duration (Zar, 1999). A paired-sample *t* test (Zar, 1999) was used to verify whether the mean start frequency was different from the end frequency for all whistles analysed. For all echolocation variables, we calculated the mean, standard deviation, maximum, and minimum values for each click train dataset. The selection of parametric or nonparametric tests was determined via Shapiro-Wilk tests (SW) for normality of data and by Levene's tests (LV) for homogeneity of the variance.

A two-way Analysis of Variance without replication was used for comparing the whistles and the click trains recorded by buoys among months (Quinn & Keough, 2002). In both cases, data were transformed using $ln(x + 1)$. Multiple comparison *post-hoc* pairwise Tukey tests were performed to test significant differences among the five buoys and across all months.

Mean sea surface temperatures (SST) for each month were obtained from publically available datasets at a resolution of 1° of latitude-longitude for the quadrant 34.5° S, 53.5° W (Reynolds & Smith, 1994; Reynolds et al., 2002). The nonparametric Spearman's Rank Correlation Coefficient was used to analyse the relationship between whistle parameters and SST (Conover, 1999). In all cases, the significance level considered was $p = 0.05$. The statistical software *PAST* was used for all statistical analyses.

Results

Whistles

Based on their contour pattern, whistles categorised as ascending were the most common, representing to 44% of all whistles, whereas multi-looped (with more than one inflection point) comprised 23%. Ascending-descending (12%) and descending (8.1%) whistles were also recorded, while descending-ascending (7.5%) and constant (5.5%) contour whistles were less frequent.

We estimated that groups of approximately six to 30 bottlenose dolphins were acoustically recorded, based on opportunistic sightings of individuals and groups around the buoys. As a result, multiple recordings of the same individual likely occurred. A total of 4,890 whistles were recorded during the entire acoustic deployment period of 805 min. In total, 4,152 whistles (84.9%) had adequate signal-to-noise ratio for acoustic analysis of which 1,245 (30%) were tones with harmonics. Whistles presented up to 11 inflection points, while 90% displayed zero to three inflection points (Figure 3).

Average whistle duration was 628 ± 293 ms, with 58.3% of the whistles lasting < 700 ms. The average minimum frequency was 6.12 ± 2.29 kHz, and 74.2% of whistles had a minimum frequency between 1.8 and 10 kHz. Average maximum frequency was 9.72 ± 4.22 kHz, with 77.7% of the whistles ranging between 8.4 and 14.0 kHz. The average frequency was 7.89 ± 3.17 kHz, and 84.1% of the whistles had MeFs ranging from 7.33 to 10.6 kHz. Descriptive statistics of all whistle parameters are shown in Table 1. There was no significant difference ($t = 0.604$, df = 256, $p = 0.699$) between the start frequency (5.89 ± 1.78 kHz) and the end frequency (6.24 ± 3.44 kHz).

Pulses

Click train characteristics were described based on N = 409 clicks recorded during the deployment period. The data logged on each click were insufficient to calculate a reliable estimate of intensity. Click train duration had an average of 1,105 ±

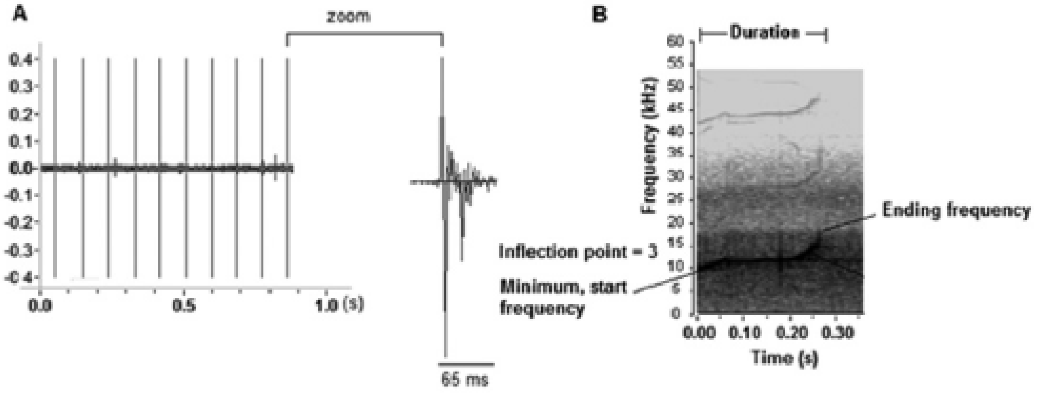

Figure 3. (A) An example of a bottlenose dolphin click train; and (B) an example of bottlenose dolphin whistles showing the fundamental frequency (whistle contour) and two harmonics.

Table 1. Descriptive statistics of bottlenose dolphin (*Tursiops truncatus*) whistle parameters detected by PAM buoys along the Atlantic coast of Uruguay during the entire acoustic deployment period (range, average, and SD are shown; N = 4,152)

Whistle parameters	Range	Average	± SD
Starting frequency kHz	3.2-22.4	5.89	1.78
Ending frequency kHz	2.9-18.1	6.24	3.44
Minimum frequency kHz	1.6-20.3	6.12	2.29
Maximum frequency kHz	2.9-20	9.72	4.22
Average frequency kHz	3.1-19.6	7.89	3.17
Durations (ms)	41-2,879	628	293
Inflections (ms)	0-12	0.76	1.10

59.6 ms, and the average click number per train was 11.4 ± 1.64 clicks. Average click duration was 63.2 ± 4.06 µs, with an interclick interval of 129.4 ± 3.94 ms. Click trains had an average peak frequency of 52.02 ± 12.09 kHz (Table 2). A typical train of high-frequency clicks is shown in Figure 3.

Clicks and Whistles Tallied During the Sampling Period

Whistle and click sounds were recorded and counted from bottlenose dolphins for each PAM buoy (N = 5 buoys; Figure 4) during the entire acoustic deployment period. These data show how the sounds are distributed across all months of the study (Figure 4), using all recorded sounds (N = 4,152 whistles; N = 409 clicks).

Whistles showed a strong seasonal variation associated with changes in SST (Figure 4). There were a lower number of whistles in winter months (June, July, and August) and early spring (September), when water temperature reached the colder phase (less than 15° C), compared to summer months. With warming waters (from 16° to 20° C) in the spring (October and November) and early summer (December), the number of whistles recorded increased and eventually peaked in December and January, followed by a decline in February and early autumn (March). Also during this period, a decrease in the whistle coefficients of variation was found (Figure 4). In autumn (April and May), water temperature decreased in coincidence with a sharp drop in the average number of whistles and an increase in the coefficients of variation of them (Figure 4).

The error distribution of whistle data was non-normal (SW = 0.86; p = 0.023), but variance was homogeneous (LV= 0.8407; p = 0.161) and varied significantly throughout the months analysed (F = 2.83, $F_{12,48;\,0.05}$ = 1.96, p = 0.0053), but not among buoys (F = 1.147, $F_{4,48;\,0.05}$ = 2.565, p = 0.346). *Post-hoc* pairwise comparisons between all months of the study showed that December 2011 and January 2012 were significantly different ($p < 0.05$) from the following months: August, September, and October 2011 as well as April, May, and June 2012. February 2012 was significantly different ($p < 0.05$) from September 2011 and April, May, and June 2012. Finally, March 2012 was significantly different from April, May, and June 2012 for all buoys.

The clicks were also non-normal (SW = 0.641; p = 0.0024), but variances were homogeneous (LV = 1.223; p = 0.311). Nonsignificant differences among buoys (F = 1.163, $F_{4,48;\,0.05}$ = 2.565, p = 0.339) and between months (F = 0.7533, $F_{12,48;\,0.05}$= 1.961, p = 0.693) were found.

A positive relationship (r_s = 0.53; p = 0.031) was found between whistles and SST, and a nonsignificant relationship (r_s = -0.191; p = 0.534) was documented between clicks and SST.

Discussion

This study provides the first known recordings of bottlenose dolphin sounds from the Atlantic coast of Uruguay. Our recordings describe the clicks and varied repertoire of whistles emitted by these bottlenose dolphins. The call characteristics

Table 2. Descriptive statistics of bottlenose dolphin echolocation click parameters detected by PAM buoys along the Atlantic coast of Uruguay during the entire acoustic deployment period (range, average, and SD are shown; N = 409)

Click parameters	Range	Average	± SD
Click train duration (ms)	989-3,220	1.105	59.6
Click number in train	6-32	11.4	1.64
Click duration (µs)	56-70	63.2	4.06
Interclick intervals (ms)	65-115	129.4	3.94
Peak frequency (kHz)	27-73	52.02	12.09

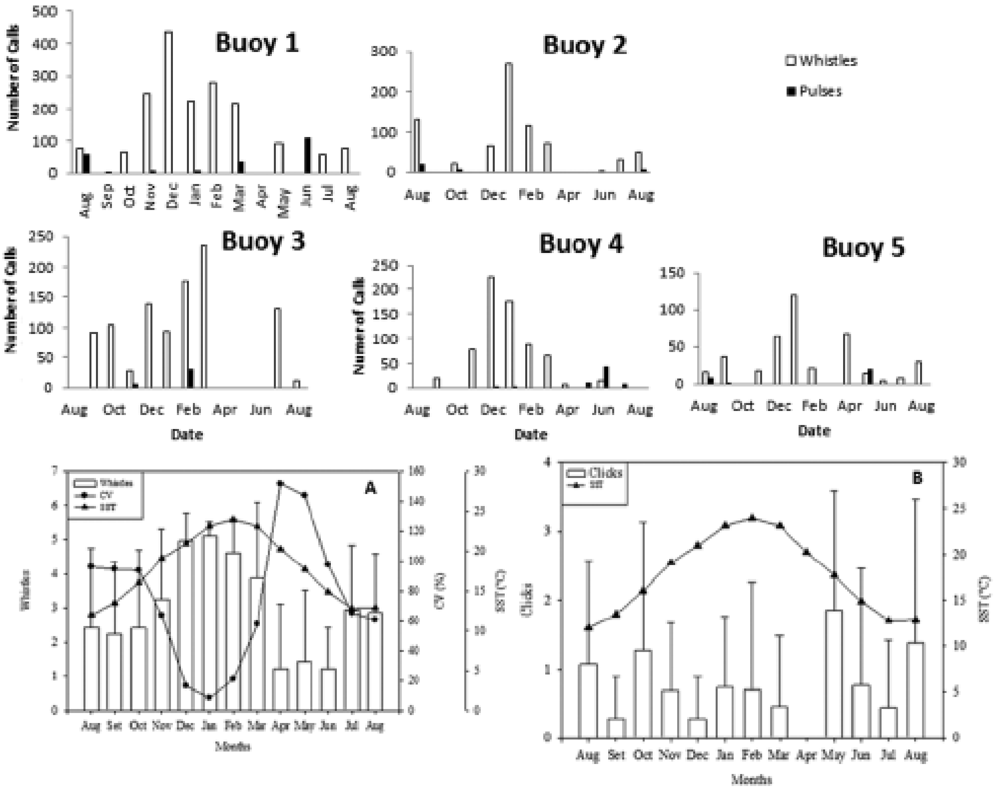

Figure 4. Total number of whistles and clicks tallied during each sampling period (buoys are labelled as one to five. (A) Mean number of whistles (ln [X+1]) with standard deviations and coefficients of variation (CV) as percentages and SST across all months between August 2011 to August 2012. (B) Mean number of clicks (ln [X+1]) with standard deviations and SST plotted across all months for the deployment period of August 2011 to August 2012.

described herein are very similar to those presented by previous studies of the vocalizations of free-ranging bottlenose dolphins (Caldwell et al., 1990; Tyack, 1997; Nowacek, 1999, 2005; Tyack & Clark, 2000; Acevedo-Gutiérrez & Stienessen, 2004; Quick & Janik, 2008; Janik, 2009; Simard et al., 2011).

The most frequently documented whistles had more than one inflection point (90% displayed between 1 to 3 points) as has also been found in previous studies of free-ranging bottlenose dolphins (Steiner, 1981; Morisaka et al., 2005; Azevedo et al., 2007). Whistle frequency was also similar to published frequency ranges for this species, reaching a minimum of 0.8 kHz (Schultz & Corkeron, 1994) and a maximum of 22.3 kHz (Azevedo et al., 2007) (Table 3). The range for whistle duration documented in this study (0.62 ± 0.29 ms) is also consistent with previous studies that showed a minimum duration of 0.37 s (Morisaka et al., 2005) to a maximum of 1.30 s (Ding et al., 1995). For comparative purposes, we included data from Azevedo et al. (2007) in Table 3.

Whistle data collected in this study show both similarities and differences from values previously reported for *Tursiops* spp. Whistle data closely resemble those reported by Azevedo et al. (2007) from Laguna de los Patos in Brazil (Table 3). This regional similarity in all whistle parameters analysed could be a result of recording the same individuals from the Patos Lagoon estuary in the area studied herein as regional movements of identified individuals between Uruguay and southern Brazil have been observed (Laporta et al., 2008b).

With regard to click sounds, the click duration described in the literature ranges from 8 to 72 µs with peak frequencies of 30 to 150 kHz (Au, 1993; Au & Hastings, 2008; Wahlberg et al., 2011). The click sounds recorded during this study were well within these previously published ranges, averaging 63.2 ± 4.06 µs and displaying a mean peak

Table 3. Means and standard deviations of whistle parameters for bottlenose dolphins from this study and previous studies (data obtained from Azevedo et al., 2007); an asterisk indicates data not reported by authors.

Location	SF	EF	MinF	MaxF	DUR	I	N	Study
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)		
Atlantic coast of Uruguay	5.89 (1.78)	6.24 (3.44)	6.12 (2.29)	9.72 (4.22)	0.62 (0.29)	0.76 (1.10)	4,152	This study
Patos Lagoon estuary, Brazil[a]	8.28 (3.11)	8.37 (3.70)	5.96 (2.15)	12.21 (3.20)	0.55 (0.39)	1.42 (1.85)	788	Azevedo et al., 2007
Argentina[a]	9.24 (2.74)	6.63 (2.29)	5.91 (1.50)	13.65 (1.54)	1.14 (0.49)	1.58 (1.24)	110	Ding et al., 1995
Texas, USA[a]	8.01 (2.81)	8.16 (3.78)	5.77 (1.84)	11.32 (3.31)	0.68 (0.40)	2.09 (2.54)	2,022	Ding et al., 1995
North Atlantic Ocean[a]	11.26 (3.99)	10.20 (3.65)	7.33 (1.66)	16.24 (2.69)	1.30 (0.63)	2.86 (2.45)	858	Steiner, 1981
Sado estuary, Portugal[a]	5.8 (1.8)	12.1 (4.4)	15.0 (2.7)	5.4 (1.2)	0.86 (0.40)	--	735	dos Santos et al., 2005
Gulf of California[a]	12.10 (2.89)	9.19 (3.44)	6.91 (2.11)	13.68 (1.72)	0.66 (0.35)	1.15 (1.32)	110	Ding et al., 1995
Eastern Tropical Pacific Ocean[a]	11.2 (4.6)	9.0 (3.7)	7.4 (2.2)	17.2 (3.1)	1.4 (0.7)	3.7 (3.0)	157	Oswald et al., 2003
Moreton Bay, Australia[b]	--	--	--	--	0.38 (0.21)	--	404	Schultz & Corkeron, 1994
Shark Bay, Australia[b]	3.84 (1.42)	7.56 (3.80)	3.57 (0.97)	10.57 (3.02)	0.68 (0.35)	1.63 (1.53)	658	Ding et al., 1995
Japan[b]	10.33 (2.41)	8.87 (2.21)	7.37 (1.54)	11.62 (2.00)	0.62 (0.34)	0.88 (0.79)	215	Ding et al., 1995
Mikura Island, Japan[b]	7.17 (2.85)	9.82 (4.18)	5.98 (2.44)	12.21 (3.20)	0.39 (0.33)	1.22 (1.39)	851	Morisaka et al., 2005
Ogasawara Island, Japan[b]	6.91 (3.12)	10.35 (4.86)	5.61 (2.06)	12.34 (4.93)	0.44 (0.44)	1.19 (1.50)	247	Morisaka et al., 2005
Amakura-Shimoshima Island, Japan[b]	6.74 (2.82)	8.06 (3.80)	5.63 (2.21)	9.39 (3.90)	0.37 (0.25)	0.78 (0.88)	515	Morisaka et al., 2005

[a] *Tursiops truncatus*

[b] *Tursiops aduncus*

frequency of 52.02 ± 12.09 kHz, respectively, although our equipment would not record greater than 96 kHz. The interclick intervals produced by bottlenose dolphins vary with behavior, such as during navigation and prey localization, as these intervals are known to steadily decrease with decreasing distance to a target (Jensen et al., 2009). The interclick intervals recorded here (129.4 ± 3.94 ms) were within the range previously published for this species in other coastal regions (Au, 1993; Au & Hastings, 2008; Jensen et al., 2009; Wahlberg et al., 2011). The relatively fewer recordings of clicks as compared to whistles documented in this study may be explained by differences in foraging/feeding behaviour in this area; or it could also be that the animals were not facing the PAM units, which therefore did not capture all the clicks emitted by the animals. Click train characteristics have been associated with foraging/feeding by bottlenose dolphins in other locations (Au et al., 1974; Au, 1993; Tyack, 1997; Mann et al., 2000; Jensen et al., 2009), but this species is also known to use passive listening for foraging/feeding (Gannon et al., 2005; Berens et al., 2010). Gannon et al. (2005) found that bottlenose dolphins use passive listening extensively during the search phase of foraging in Sarasota Bay, Florida. By listening, bottlenose dolphins may obtain useful information on the identity, number, size, and location of soniferous prey. Once bottlenose dolphins discover the prey by passive means, they then appear to use echolocation to track the prey during pursuit and capture phases. Such judicious use of echolocation suggests that this sensory modality incurs significant energetic or ecological costs.

This study was developed within a limited geographic region, and the knowledge of cetacean habits along the Uruguayan coast related to its behavior and availability of near-shore waters is scarce (Laporta, 2004; Laporta et al., 2008a, 2008b; Tellechea & Norbis, 2012a). Species-specific habitats along its distribution area remain largely undefined, and the variability on one of the more important oceanographic features (SST) can be compiled to understand the ecology and behavior of the species. In the region, the SST, which controls seasonal stratification over the continental shelf, describes a pronounced seasonal cycle typical of temperate areas, reaching a maximum in summer and a minimum in winter (Podesta et al., 1991; Provost et al., 1992; Guerrero et al., 1997). The more abundant and dominant species of sciaenid fishes in the region—the whitemouth croaker (*Micropogonias furnieri*) and striped weakfish (*Cynoscion guatucupa*) (Norbis et al., 2006)—spawn in the Rió de la Plata estuary and Uruguayan Atlantic coast in spring-summer (Vizziano, 2002; Vizziano et al., 2002a, 2002b; Macchi et al., 2003; Militelli & Macchi, 2006; Jaureguizar et al., 2006, 2008; Jaureguizar & Guerrero, 2009). Seasonal and annual variability in the water temperature affect various fish biological behaviors, particularly the timing of reproduction in sciaenids (Vizziano et al., 2002a, 2002b; Macchi et al., 2003; Norbis & Verocai, 2005; Militelli & Macchi, 2006). Advertisement call choruses found by these principal and more abundant sciaenids species, take place during spring and summer spawning season (Tellechea et al., 2010, 2011a, 2011b; Tellechea & Norbis, 2012b). Knowledge about spawning of soniferous fish species may provide a means of directly measuring the availability of some potential prey species, and the bottlenose dolphins have a significant positive selection of soniferous fishes, particularly sciaenids (Berens et al., 2010).

These species are food items for the bottlenose dolphin in this area (Mermoz, 1977; Pinedo, 1982; Mehsen et al., 2005). Additionally, the majority of click activity by bottlenose dolphins occurred outside the austral summer, during which sciaenid species generally do not emit sounds associated with reproduction (Tellechea et al., 2010, 2011a, 2011b; Tellechea & Norbis, 2012b). As such, the low number of clicks in summer months could be explained by the use of passive listening rather than echolocation as a primary means of prey detection by bottlenose dolphins as has been proposed by Berens et al. (2010). In contrast, in the winter, when other soniferous fishes are largely absent, bottlenose dolphins may increase use of clicks to locate prey. Alternatively, whistles were largely recorded during the summer, suggesting that whistles could be used for individual recognition or group cohesion (Caldwell et al., 1990; Sayigh et al., 1990, 2007; Janik & Slater, 1998; Watwood et al., 2004). Nonetheless, our method of data collection did not permit identification of the whistler, and, as such, we could not evaluate individual whistle recognition or a group cohesion hypothesis. The observed increase in whistles could also be associated with foraging/feeding behaviour as described by Acevedo-Gutiérrez & Stienessen (2004).

Based on our findings, we suggest that the low number of click trains and increased whistle activity during the summer months may be due to the use of passive listening during foraging activity. In contrast, bottlenose dolphins may move or migrate to Brazil (Laporta et al., 2008b) in search of warmer waters in winter. Further studies with playback experiments, surveys of the actual animals, and behavioural studies would be necessary to test this hypothesis. In conclusion, this study provides the first description of acoustic data obtained and the acoustic seasonal cycles from a small population of bottlenose dolphins observed along the Atlantic coast of Uruguay.

This new data will contribute to the preservation of this species that actually could be at risk from high maritime traffic, overfishing in fishery resources that are a food item of this species of dolphin, and future port construction on the Atlantic coast.

Acknowledgments

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Literature Cited

Acevedo-Gutiérrez, A., & Stienessen, S. C. (2004). Bottlenose dolphins (*Tursiops truncatus*) increase number of whistles when feeding. *Aquatic Mammals*, *30*(3), 357-362. http://dx.doi.org/10.1578/AM.30.3.2004.357

Au, W. W. L. (1993). *The sonar of dolphins*. New York: Springer-Verlag. http://dx.doi.org/10.1007/978-1-4612-4356-4

Au, W. W. L., & Hastings, M. C. (2008). *Principles of marine bioacoustics*. New York: Springer. http://dx.doi.org/10.1007/978-0-387-78365-9

Au, W. W. L., Moore, P. W. B., & Pawlowski, D. (1986). Echolocation transmitting beam of the Atlantic bottlenose dolphin. *The Journal of the Acoustical Society of America*, *80*, 688-691. http://dx.doi.org/10.1121/1.394012

Au, W. W. L., Floyd, R. W., Penner, R. H., & Murchison, A. E. (1974). Measurement of echolocation signals of the Atlantic bottlenose dolphin, *Tursiops truncatus* Montagu in open waters. *The Journal of the Acoustical Society of America*, *56*(4), 1280-1290. http://dx.doi.org/10.1121/1.1903419

Azevedo, A. F., & Van Sluys, M. (2005). Whistles of tucuxi dolphins (*Sotalia fluviatilis*) in Brazil: Comparisons among populations. *The Journal of the Acoustical Society of America*, *117*, 1456-1464. http://dx.doi.org/10.1121/1.1859232

Azevedo, F. A., Oliveira, A. M., Dalla Rosa, L., & Lailson-Brito, J. (2007). Characteristics of whistles from resident bottlenose dolphins (*Tursiops truncatus*) in southern Brazil. *The Journal of the Acoustical Society of America*, *121*(5), 2978-2983. http://dx.doi.org/10.1121/1.2713726

Barros, N. B., & Wells, R. S. (1998). Prey and feeding patterns of resident bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Journal of Mammalogy*, *79*, 1045-1059. http://dx.doi.org/10.2307/1383114

Bastida, R., Rodríguez, D., Secchi, E., & Da Silva, V. M. F. (2007). *Mamíferos acuáticos de Sudamérica y Antártida* [Aquatic Mammals of South America and Antarctica]. Buenos Aires, Argentina: Vazquez Mazzini.

Bazúa-Duran, M. C., & Au, W. W. L. (2004). Geographic variations in the whistles of spinner dolphins (*Stenella longirostris*) of the main Hawaiian islands. *The Journal of the Acoustical Society of America*, *116*, 3757-3769. http://dx.doi.org/10.1121/1.1785672

Bearzi, M., Saylan, C. A., & Hwang, A. (2009). Ecology and comparison of coastal and offshore bottlenose dolphins (*Tursiops truncatus*) in California. *Marine & Freshwater Research*, *60*(6), 584-593. http://dx.doi.org/10.1071/MF08279

Berens, E., Gannon, D., Barros, N., & Wells, R. S. (2010). Prey selection by resident common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Marine Biology*, *157*, 931-942. http://dx.doi.org/10.1007/s00227-009-1371-2

Busnel, R., Dziedzic, G. A., & Alcuri, G. (1974). Estudes preliminaries de signaux acoustiques de *Pontoporia blainvillei* Gervaiset D'Orbigny (Cetacea, Platanistidae) [Preliminary studies of acoustic signals of *Pontoporia blainvillei* Gervaiset D'Orbigny (Cetacea, Platanistidae)]. *Mammalia*, *38*, 449-459.

Caldwell, M. C., & Caldwell, D. K. (1965). Individualized whistle contours in bottlenose dolphins (*Tursiops truncatus*). *Nature*, *207*, 434-435. http://dx.doi.org/10.1038/207434a0

Caldwell, M. C., & Caldwell, D. K. (1968). Vocalization of naive captive dolphins in small groups. *Science*, *159*, 1121-1123. http://dx.doi.org/10.1126/science.159.3819.1121

Caldwell, M. C., Caldwell, D. K., & Tyack, P. L. (1990). Review of the signature-whistle hypothesis for the Atlantic bottlenose dolphin. In S. Leatherwood & R. R. Reeves (Eds.), *The bottlenose dolphin* (pp. 199-233). New York: Academic Press.

Carstensen, J., Henriksen, O. D., & Teilmann, J. (2006). Impacts of offshore wind farm construction on harbour porpoises: Acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series*, *321*, 295-308. http://dx.doi.org/10.3354/meps321295

Clark, C. W. (1982). The acoustic repertoire of the Southern right whale: A quantitative analysis. *Animal Behaviour*, *30*, 1060-1071. http://dx.doi.org/10.1016/S0003-3472(82)80196-6

Conover, W. J. (1999). *Practical nonparametric statistics* (3rd ed.). New York: John Wiley & Sons. 584 pp.

Costa, P., Piedra, M., Franco, P., & Paez, E. (2007). Distribution and habitat use patterns of southern right whales, *Eubalaena australis*, off Uruguay. *Journal of Cetacean Research and Management*, *9*(1), 45-51.

Ding, W., Würsig, B., & Evans, W. E. (1995). Whistles of bottlenose dolphins: Comparisons among populations. *Aquatic Mammals*, *21*(1), 65-77.

Evans, P. G. H., & Hammond, P. S. (2004). Monitoring cetaceans in European waters. *Mammal Review*, *34*(1-2), 131-156. http://dx.doi.org/10.1046/j.0305-1838.2003.00027.x

Gannon, D. P., Barros, N. B., Nowacek, D. P., Read, A. J., Waples, D. M., & Wells, R. S. (2005). Prey detection by bottlenose dolphins (*Tursiops truncatus*): An experimental test of the passive listening hypothesis. *Animal Behaviour*, *69*, 709-720. http://dx.doi.org/10.1016/j.anbehav.2004.06.020

Guerrero, R. A., Acha, E. M., Framiñán, M. B., & Lasta, C. A. (1997). Physical oceanography of the Río de la Plata estuary, Argentina. *Continental Shelf Research*, *17*, 727-742. http://dx.doi.org/10.1016/S0278-4343(96)00061-1

Janik, V. M. (2009). Acoustic communication in delphinids. In M. Naguib & V. M. Janik (Eds.), *Advances in the study of behavior* (Vol. 40, pp. 123-157). Burlington, VT: Academic Press. http://dx.doi.org/10.1016/S0065-3454(09)40004-4

Janik, V. M., & Slater, P. J. B. (1998). Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. *Animal Behaviour*, *56*, 829-838. http://dx.doi.org/10.1006/anbe.1998.0881

Jaureguizar, A., & Guerrero, R. (2009). Striped weakfish (*Cynoscion guatucupa*) population structure in waters adjacent to Río de la Plata: Environmental influence on its inter-annual variability. *Estuarine, Coastal and Shelf Science*, *85*, 89-96. http://dx.doi.org/10.1016/j.ecss.2009.04.013

Jaureguizar, A., Militelli, M. I., & Guerrero, R. A. (2008). Environmental influence on maturity stage spatial distribution of whitemouth croaker (*Micropogonias furnieri*) along an estuarine gradient. *Journal of Marine Biology*, *88*, 175-181.

Jaureguizar, A., Ruarte, C., & Guerrero, R. (2006). Distribution of age-classes of striped weakfish (*Cynoscion guatucupa*) along an estuarine-marine gradient: Correlations with the environmental parameters. *Estuarine, Coastal and Shelf Science*, *67*, 82-92. http://dx.doi.org/10.1016/j.ecss.2005.10.014

Jensen, F. H., Bejder, L., Wahlberg, M., & Madsen, P. T. (2009). Biosonar adjustments to target range of echolocating bottlenose dolphins (*Tursiops* sp.) in the wild. *The Journal of Experimental Biology*, *212*(8), 1078-1086. http://dx.doi.org/10.1242/jeb.025619

Koschinski, S., Diederichs, A., & Amundin, M. (2008). Click train pattern of free-ranging harbour porpoise acquired using T-PODs may be useful as indicators of their behaviour. *Journal of Cetacean Research and Management*, *10*(2), 147-155.

Laporta, P. (2004). *¿Cómo estudiar el comportamiento en pequeños cetáceos?: La tonina* Tursiops truncatus *en La Coronilla-Cerro Verde (Rocha, Uruguay)* [How to study the behavior of small cetacean? The dolphin *Tursiops truncatus* in La Coronilla-Cerro Verde (Rocha, Uruguay)] (Tesis de Licenciatura). Facultad de Ciencias, Universidad de la Republica, Montevideo, Uruguay.

Laporta, P., Fruet, J., & Secchi, E. (2008a). *Estimación de abundancia de toninas* Tursiops truncatus *en la costa oceánica Uruguaya* [Abundance estimation of the dolphin *Tursiops truncatus* in the Uruguayan oceanic coast]. 13° Reunión de Trabajo de Especialistas en Mamíferos Acuáticos de América del Sur/7° Congreso Solamac, Montevideo, Uruguay.

Laporta, P., Fruet, J., Di Tullio, J., & Secchi, E. (2008b). *Movimientos de toninas* Tursiops truncatus *entre la costa oceánica Uruguaya y sur de Brasil* [Movement of dolphins *Tursiops truncatus* between Uruguayan oceanic coast and South of Brasil]. 13° Reunión de Trabajo de Especialistas en Mamíferos Acuáticos de America del Sur/7° Congreso Solamac, Montevideo, Uruguay.

Lázaro, M., & Praderi, R. (2000). Problems and status of species in Uruguay. In R. Hucke-Gaete (Ed.), *Review of the conservation status of small cetaceans in southern South America* (pp. 8-9). Bonn, Germany: UNEP/CMS Secretariat. 24 pp.

Leatherwood, S., & Reeves, R. R. (1983). *The Sierra Club handbook of whales and dolphins*. San Francisco: Sierra Club Books.

Macchi, G., Acha, E., & Militelli, M. I. (2003). Seasonal egg production of whitemouth croaker (*Micropogonias furnieri*) in the Río de la Plata estuary Argentina-Uruguay. *Fishery Bulletin*, *10*, 332-342.

Mann, J., Connor, R. C., Tyack, P. L., & Whitehead, H. (Eds.). (2000). *Cetacean societies: Field studies of dolphins and whales*. Chicago and London: University of Chicago Press.

Martin, A. R., & Reeves, R. R. (2002). Diversity and zoogeography. In A. R. Hoelzel (Ed.), *Marine mammal biology: An evolutionary approach* (pp. 1-37). Oxford, UK: Blackwell Publishing.

Mazzoni, D. (2006). *Audacity 1.2.6*. Available from http://audacity.sourceforge.net.

Mehsen, M., Secchi, E. R., Fruet, P., & Di Tullio, J. (2005). *Feeding habits of bottlenose dolphins,* Tursiops truncatus, *in southern Brazil* (Artigo SC/58/SM8). Apresentado durante a reunião da CBI, Ulsan, South Korea.

Melcón, M. L., Failla, M., & Iñíguez, M. A. (2012). Echolocation behavior of Franciscana dolphins (*Pontoporia blainvillei*) in the wild. *The Journal of the Acoustical Society of America*, *131*(6), 448-453. http://dx.doi.org/10.1121/1.4710837

Mellinger, D. K., Stafford, K. M., Moore, S. E., Dziak, R. P., & Matsumoto, H. (2007). An overview of acoustic observation methods for cetaceans. *Oceanography*, *20*, 36-45. http://dx.doi.org/10.5670/oceanog.2007.03

Mermoz, J. F. (1977). On the stranding of a bottle-nosed dolphin *Tursiops truncatus* in the mouth of La Plata River, Buenos Aires, Argentina. *Physis* (Section C), *37*(93), 227-235.

Militelli, M. I., & Macchi, G. (2006). Spawning and fecundity of striped weakfish, *Cynoscion guatucupa*, in the Río de la Plata estuary and adjacent marine waters, Argentina-Uruguay. *Fisheries Research*, *77*, 110-114. http://dx.doi.org/10.1016/j.fishres.2005.08.004

Morisaka, T., Shinohara, M., Nakahara, F., & Akamatsu, T. (2005). Geographic variations in the whistles among three Indo-Pacific bottlenose dolphin *Tursiops aduncus* populations in Japan. *Fisheries Science*, *71*, 568-576. http://dx.doi.org/10.1111/j.1444-2906.2005.01001.x

Norbis, W., & Verocai, J. (2005). Presence of two whitemouth croaker (*Micropogonias furnieri*, Pisces: Sciaenidae) groups in the Rió de la Plata spawning coastal area as consequence of reproductive migration. *Fisheries Research*, *74*, 134-141. http://dx.doi.org/10.1016/j.fishres.2005.03.005

Norbis, W., Paesch, L., & Galli, O. (2006). The fishery resources of the Uruguay coast, environment, biology and management. In R. Menafra, L. Rodríguez-Gallego, F. Scarabino, & D. Conde (Eds.), *Basis for the conservation and management of the Uruguayan coast* (pp. 197-209). Montevideo, Uruguay: Vida Silvestre. [In Spanish]

Nowacek, D. P. (1999). *Sound use, sequential behavior and ecology of foraging bottlenose dolphins,* Tursiops truncatus (Doctoral dissertation). Massachusetts Institute of Technology and Woods Hole Oceanographic Institution. Retrieved 10 April 2014 from www.dtic.mil/dtic/tr/fulltext/u2/a376514.pdf.

Nowacek, D. P. (2005). Acoustic ecology of foraging bottlenose dolphins (*Tursiops truncatus*): Habitat-specific use of three sound types. *Marine Mammal Science*, *21*(4), 587-602. http://dx.doi.org/10.1111/j.1748-7692.2005.tb01253.x

Nuuttila, H. K., Meier, R., Evans, P. G. H., Turner, J. R., Bennell, J. D., & Hiddink, J. G. (2013). Identifying foraging behaviour of wild bottlenose dolphins (*Tursiops truncatus*) and harbour porpoises (*Phocoena phocoena*) with static acoustic dataloggers. *Aquatic Mammals*, *39*(2), 147-161. http://dx.doi.org/10.1578/AM.39.2.2013.147

Pinedo, M. C. (1982). *Análisis comparativo de los contenidos estomacales de* Pontoporia blainvillei *y* Tursiops gephyreus *(Cetacea, Platanistidae, Delphinidea) en la zona estuarial y costera de Rio Grande, R.S. Brasil* [Comparative analysis of stomach contents of *Pontoporia blainvillei* and *Tursiops gephyreus* (Cetacea, Platanistidae, Delphinidea) in estuarine and coastal zone of Rio Grande, RS Brazil]. Resúmenes III Reunión Iberoamericana de Conservación y Zoología de Vertebrados, Buenos Aires, Argentina.

Podesta, G., Brown, O., & Evans, R. (1991). The annual cycle of satellite-derived sea surface temperature in the southwestern Atlantic Ocean. *Journal of Climate*, *4*, 457-467. http://dx.doi.org/10.1175/1520-0442(1991)004<0457:TACOSD>2.0.CO;2

Praderi, R., Pinedo, M. C., & Crespo, E. A. (1989). Conservation and management of *Pontoporia blainvillei* in Uruguay, Brazil and Argentina. In W. F. Perrin, R. L. Brownell, Jr., Z. Kaiya, & L. Jiankang (Eds.), *Biology and conservation of the river dolphins* (Occasional Papers, IUCN SSC 3, pp. 52-56). Gland, Switzerland: International Union for Conservation of Nature.

Provost, C., Garcia, O., & Garçon, V. (1992). Analysis of satellite sea surface temperature time series in the Brazil-Malvinas current confluence region: Dominance of the annual and semiannual periods. *Journal of Geophysical Research*, *97*(C11), 17841-17858. http://dx.doi.org/10.1029/92JC01693

Quick, N. J., & Janik, V. M. (2008). Whistle rates of wild bottlenose dolphins (*Tursiops truncatus*): Influences of group size and behaviour. *Journal of Comparative Psychology*, *122*(3), 305-311. http://dx.doi.org/10.1037/0735-7036.122.3.305

Quinn, G. P., & Keough, M. J. (2002). *Experimental design and data analysis for biologists*. Cambridge, UK: Cambridge University Press. 556 pp. http://dx.doi.org/10.1017/CBO9780511806384

Reynolds, R. W., & Smith, T. M. (1994). Improved global sea surface temperature analyses. *Journal of Climate*, *7*, 929-948. http://dx.doi.org/10.1175/1520-0442(1994)007<0929:IGSSTA>2.0.CO;2

Reynolds, R. W., Rayner, N. A., Smith, T. M., Stokes, D. C., & Wang, W. (2002). An improved in situ and satellite SST analysis for climate. *Journal of Climate*, *15*, 1609-1625. Retrieved 14 April 2014 from http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_SmithOIv2/.monthly/.sst. http://dx.doi.org/10.1175/1520-0442(2002)015<1609:AIISAS>2.0.CO;2

Sayigh, L. S., Esch, H. C., Wells, R. S., & Janik, V. M. (2007). Facts about signature whistles of bottlenose dolphins, *Tursiops truncatus*. *Animal Behaviour*, *74*, 1631-1642. http://dx.doi.org/10.1016/j.anbehav.2007.02.018

Sayigh, L. S., Tyack, P. L., Wells, R. S., & Scott, M. D. (1990). Signature whistles of free-ranging bottlenose dolphins *Tursiops truncatus*: Stability and mother-offspring comparisons. *Behavioral Ecology and Sociobiology*, *26*, 247-260. http://dx.doi.org/10.1007/BF00178318

Schultz, K. W., & Corkeron, P. J. (1994). Interspecific differences in whistles produced by inshore dolphins in Moreton Bay, Queensland, Australia. *Canadian Journal of Zoology*, *72*, 1061-1068. http://dx.doi.org/10.1139/z94-143

Simard, P., Lace, N., Gowans, S., Quintana-Rizzo, E., Kuczaj II, S. A., Wells, R. S., & Mann, D. A. (2011). Low frequency narrow-band calls in bottlenose dolphins (*Tursiops truncatus*): Signal properties, function, and conservation implications. *The Journal of the Acoustical Society of America*, *130*(5), 3068-3076. http://dx.doi.org/10.1121/1.3641442

Simon, M., Nuuttila, H., Reyes-Zamudio, M. M., Ugarte, F., Verfuß, U., & Evans, P. G. H. (2010). Passive acoustic monitoring of bottlenose dolphin and harbour porpoise, in Cardigan Bay, Wales, with implications for habitat use and partitioning. *Journal of the Marine Biological Association of the UK*, *90*(8), 1539-1545. http://dx.doi.org/10.1017/S0025315409991226

Steiner, W. W. (1981). Species-specific differences in pure tonal whistle vocalizations of five western North Atlantic dolphin species. *Behavioral Ecology and Sociobiology*, *9*, 241-246. http://dx.doi.org/10.1007/BF00299878

Tellechea, S. J., & Norbis, W. (2012a). Southern right whale (*Eubalaena australis*): Preliminary recordings of the acoustics emission in coast of Uruguay. *Journal of Cetacean Research and Management*, *12*(3), 361-364.

Tellechea, S. J., & Norbis, W. (2012b). Sexual dimorphism in sound production and relationship between fish size and call characteristics in the striped weakfish *Cynoscion guatucupa*. *Zoological Studies*, *51*(7), 946-955.

Tellechea, S. J., & Norbis, W. (2014, in press). Sound characteristics of two neonatal Franciscana dolphins (*Pontoporia blainvillei*). *Marine Mammal Science*. http://dx.doi.org/10.1111/mms.12122

Tellechea, S. J., Bouvier, D., & Norbis, W. (2011a). Spawning sounds in whitemouth croaker (Sciaenidae), seasonal and daily cycles. *Bioacoustics*, *20*(2), 159-168. http://dx.doi.org/10.1080/09524622.2011.9753641

Tellechea, S. J., Olsson, D., Norbis, W., & Fine, M. L. (2011b). Calls of the black drum (*Pogonias cromis*–Sciaenidae): Geographical differences in sound production between Northern and Southern hemisphere populations. *Journal of Experimental Zoology*, *315A*(1), 48-55.

Tellechea, S. J., Martinez, C., Fine, L., & Norbis, W. (2010). Sound production in whitemouth croaker (*Micropogonias furnieri*–Sciaenidae) and relationship between fish size and disturbance call parameters. *Environmental Biology of Fishes*, *89*(2), 163. http://dx.doi.org/10.1007/s10641-010-9709-7

Tyack, P. L. (1997). Development and social functions of signature whistles in bottlenose dolphins *Tursiops truncatus*. *Bioacoustics*, *8*, 21-46. http://dx.doi.org/10.1080/09524622.1997.9753352

Tyack, P. L., & Clark, C. W. (2000). Communication and acoustic behavior of dolphins and whales. In W. W. L. Au, A. N. Popper, & R. R. Fay (Eds.), *Hearing by whales and dolphins* (pp. 156-224). New York: Springer-Verlag. http://dx.doi.org/10.1007/978-1-4612-1150-1_4

Tyack, P. L., & Miller, E. H. (2002). Vocal anatomy, acoustic communication and echolocation. In A. R. Hoelzel (Ed.), *Marine mammal biology: An evolutionary approach* (pp. 142-184). Oxford, UK: Blackwell Publishing.

Vizziano, D. (2002). Reproductive cycle of the white croaker *Micropogonias furnieri* in the frontal zone of the Río de la Plata. In D. Vizziano, P. Puig, C. Mesones, & G. Nagy (Eds.), *The Río de la Plata: Research to manage the environment, fish resource and the fishery in the saline front* (pp. 103-111). Montevideo, Uruguay: Ecoplata Program.

Vizziano, D., Forni, F., Saona, G., & Norbis, W. (2002a). Reproduction of the white croaker *Micropogonias furnieri* (Pisces: Sciaenidae) in a shallow temperate coastal lagoon of the southern Atlantic Ocean (Uruguay). *Journal of Fish Biology*, *61*, 196-206. http://dx.doi.org/10.1111/j.1095-8649.2002.tb01771.x

Vizziano, D., Saona, G., Franco, J., & Nagy, G. (2002b). Environmental characterization of the spawning area of the white croaker *Micropogonias furnieri*. In D. Vizziano, P. Puig, C. Mesones, & G. Nagy (Eds.), *The Rió de la Plata: Research to manage the environment, fish resource and the fishery in the saline front* (pp. 113-124). Montevideo, Uruguay: Ecoplata Program.

Wahlberg, M., Jensen, F. H., Aguilar-Soto, N., Beedholm, K., Bejder, L., Oliveira, C., . . . Madsen, P. T. (2011). Source parameters of echolocation clicks from wild bottlenose dolphins (*Tursiops aduncus* and *Tursiops truncatus*). *The Journal of the Acoustical Society of America*, *130*, 2263. http://dx.doi.org/10.1121/1.3624822

Watwood, S. L., Tyack, P. L., & Wells, R. S. (2004). Whistle sharing in paired male bottlenose dolphins, *Tursiops truncatus*. *Behavioral Ecology and Sociobiology*, *55*, 531-543. http://dx.doi.org/10.1007/s00265-003-0724-y

Zar, J. H. (1999). *Biostatistical analysis*. Englewood Cliffs, NJ: Prentice Hall.

Capitulo 4.- Obtención de sonidos de *Pontoporia blainvillei* salvajes en Santa Lucía del Este, Canelones, caracterización de los clicks.

Manuscrito in press en Marine Mammals Science Journal: Echolocation and burst clicks from Franciscana dolphins (*Pontoporia blainvillei*) on the coast of Uruguay

Resumen.

Los estudios de cetáceos mediante la utilización de métodos de escucha pasiva, permiten llevar a cabo el registro de las emisiones en su ambiente natural, aunque muchas veces éstos solo pueden llevarse a cabo con buen tiempo y durante las horas diurnas. Sin embargo, el uso de boyas autónomas permite recoger datos las 24 horas y sin importar el estado del tiempo y del mar. Poco se conoce sobre las señales de ecolocalización que emite la franciscana. Utilizando dos boyas de escucha pasiva construidas en el laboratorio durante cinco días no consecutivos (1° de Marzo al 16 de Abril de 2016), se pudieron registrar 24 minutos de “clicks” de ecolocalización en la costa de Uruguay, mas específicamente en el Río de la Plata. Los sonidos fueron clasificados en “clicks” de baja frecuencia, “clicks” de alta frecuencia, y “burst clicks”, con medias de 14 ± 2.73 kHz, 86 ± 1.87 kHz y 41 ± 4.69 kHz, respectivamente. Este es el primer registro de “burst clicks” en el ambiente natural para la especie y podría contribuir a localizar y delinear áreas de conservación para este delfín en peligro de extinción.

Note

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Echolocation and burst clicks from franciscana dolphins (*Pontoporia blainvillei*) on the coast of Uruguay

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Passive acoustic monitoring (PAM) is being used increasingly to study, survey and census cetaceans, many of which are easier to hear than to see (Zimmer 2011). Due to its small size, color, and rare aerial displays it is difficult to study the franciscana dolphin (*Pontoporia blainvillei*, Gervais and d'Orbigny 1844) in the wild. In fact, most of our information on this species has been collected from individuals caught in fishing nets (*e.g.*, Ott *et al.* 2002, Cappozzo *et al.* 2007). Therefore, PAM should be ideal for surveying and studying this elusive species.

The franciscana is endemic to the southwestern Atlantic Ocean (Itaúnas, Brazil, 18°25′S, 30°42′W; Península Valdés, Argentina, 42°35′S, 64°48′W) (Crespo *et al.* 1998, Siciliano *et al.* 2002) and is classified as Vulnerable (A3d) by the International Union for Conservation of Nature (IUCN, Reeves *et al.* 2008). Little is known about franciscana echolocation sounds. Busnel *et al.* (1974) obtained the first clicks in the wild with limited equipment, and Von Fersen *et al.* (1997) recorded clicks from a captive individual. Recently, Melcon *et al.* (2012, 2016) recorded clicks in the wild, and Tellechea and Norbis (2014) recorded clicks from a pair of 2-wk-old dolphins in captivity.

We were informed by an artisanal and recreational fisherman that in Santa Lucia del Este (Rio de la Plata estuary, 34°47′S 55°31′W), franciscana dolphins are commonly caught and die in artisanal fishing nets (JST, unpublished data) (Fig. 1). The aim of this study was to record sounds in the wild using passive acoustic monitoring technology and characterizes franciscana dolphin clicks trains.

Data were collected over five nonconsecutive days in March and April 2016 (16–17, 20–21, 23–24, 25–26 March and 30 April–1 May). Recordings were obtained using two PAM buoys placed 1,200 m apart at the site (Fig. 1). The buoys were placed 200 m from shore at a depth of 2 m and were set to record between 1000 and 1200 the next day. We picked days with Beaufort sea state 2 because the sea state can

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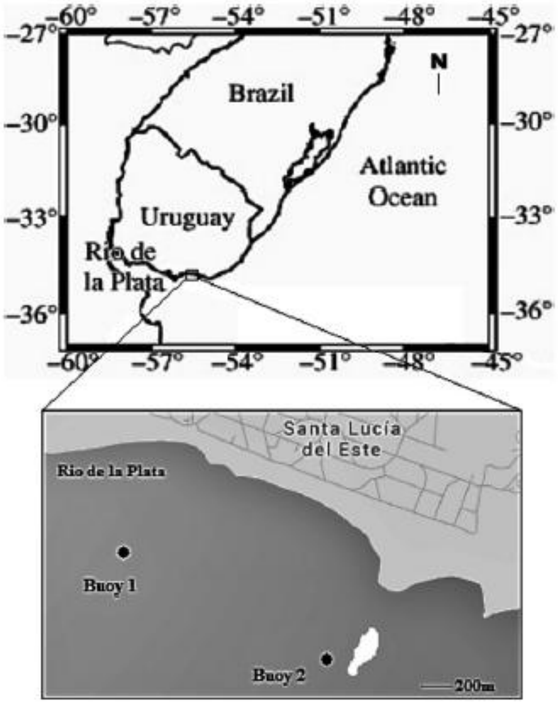


Figure 1. Map of Uruguay and the Rio de la Plata estuary showing the position of the PAM buoys from which acoustic recordings of franciscana dolphins (*P. blainvillei*) were obtained.

change rapidly in this area and it would be difficult to recover the buoys if bad weather occurred. The presence of the franciscanas near the buoys area was confirmed throughout observation with binoculars.

The PAM buoy contained a calibrated omnidirectional hydrophone (built in the laboratory, –40 dB: re 1 µPa, and linear from 20 Hz to 100 kHz), connected to amplifier with antialiasing filter and a TASCAM HD-P2 digital recorder (20 Hz and 96 kHz, sample rate = 192 kHz). A voltage regulator was built to keep the system working for 26 h. The response of the system is limited at high frequencies, and it may not have recorded the highest frequencies in the clicks.

Recordings were analyzed using *Audacity* free software, Version 1.2.3 (Mazzoni 2006) (free license) and *Ishmael* open-access bioacoustics analysis software (Mellinger 2001). All sound files were manually verified for echolocation sounds, and only clear clicks were selected for further analysis. Power spectra used a 1,024-point Fast Fourier Transform (FFT) with a Hann window. Peak frequency, interclick interval, rms click duration and 3 dB bandwidth (defined as the bandwidth at 3 dB points below the maximum intensity) were measured manually following Au (1993). Data are presented as the mean, standard deviation, maximum, and minimum values for each click train.

The sounds recorded during 20–21 March (buoy one = 6 min; buoy two = eight minutes) and 23–24 March (buoy one = 3 min; buoy two = 7 min) were emitted in the afternoon, night, and early morning. On day one, sounds were registered from 1923 to 1939 on buoy one and from 2046 to 2120 on buoy two. On day two (23–24) sounds were registered from 0053 to 0104 on buoy 1 and 0437 to 0458 on buoy 2 (local time).

Forty-two of 50 click trains were clear and analyzed. Twenty-six had high frequencies (trains <2 s), 11 low frequencies (trains <3 s), and there were five burst-click trains (trains <2 s). Clicks were separated into high and low frequency types based on accepted classification criteria (Evans 1967, Au and Hastings 2008). Table 1 summarizes parameters of the burst and clicks trains emitted (n = 283 burst clicks, 860 high-frequency clicks and 363 low-frequency clicks).

High-frequency click trains had a mean duration of 1.0 ± 0.6 s (mean ± SD). Click duration was 0.21 ± 0.23 ms and interclick interval was 35 ± 2.24 ms. Click trains had a peak frequency of 86 ± 1.87 kHz (Table 1).

Low-frequency click trains had a mean duration of 0.5 ± 0.35 s. Click duration was 0.20 ± 0.12 ms, interclick interval was 20.0 ± 2.0 ms. Click trains had a peak frequency of 14 ± 2.73 kHz (Fig. 2, Table 1). Therefore, clicks of similar durations can vary in frequency.

Burst click trains had a mean duration of 90 ± 0.40 s. The clicks had duration of 15 ± 1.71 ms, interclick interval was 10 ± 1.02 ms, and peak frequency was 41 ± 4.69 kHz (Fig. 3). The mean 3 dB bandwidth for high-frequency clicks was 3 kHz, for low-frequency clicks was 5 kHz and for burst clicks was 9 kHz. Due to overlap, click train likely came from more than one animal.

Although it is unlikely all clicks were on-axis (Au 1993), frequencies in this study were similar to those from two neonates in captivity (Tellechea and Norbis 2014). Busnel *et al.* (1974), recording in the wild, found clicks with a range of 14–23 kHz and interclick intervals between 19 and 228 ms. However, our data differ in

Table 1. Characteristics (mean, standard deviation and range) of click sounds emitted by the wild franciscana dolphins in the Rio de la Plata estuary, Uruguay.

Click parameters	n	Mean	SD	Maximum	Minimum
High frequency clicks					
Number of trains	26				
Number of clicks per train		38	3.55	49	22
Interclick interval (ms)		35	2.24	40	17
Click duration (ms)		0.21	0.23	0.23	0.20
Frequency (kHz)		86	1.86	93	82
Low frequency clicks					
Number of trains	11				
Number of clicks per train		33	6.21	41	18
Interclick interval (ms)		34	1.97	35	22
Click duration (ms)		0.20	0.12	0.21	0.19
Frequency (kHz)		14	2.73	19	8
Burst parameters					
Click train	5				
Number of clicks per train		52	5.66	58	39
Interclick interval (ms)		10	1.02	12	9
Click duration (ms)		15	1.71	17	10
Frequency (kHz)		41	4.69	63	32

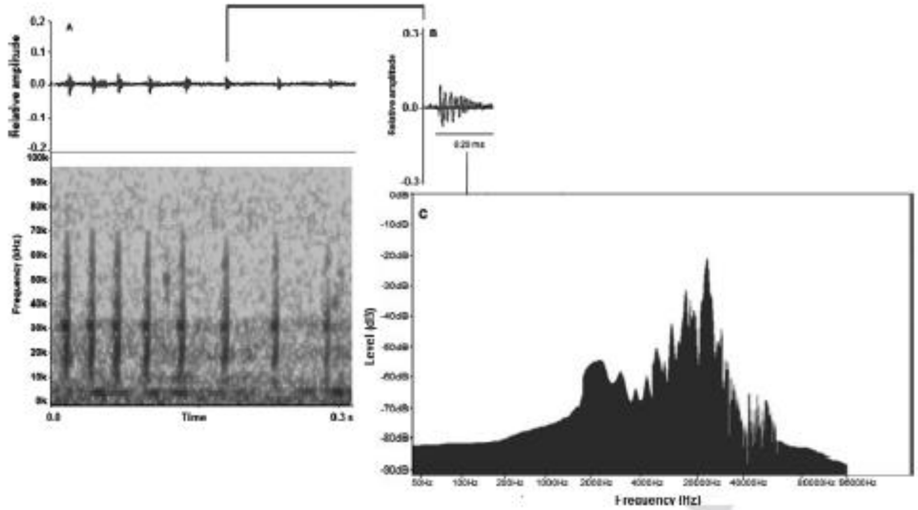


Figure 2. An example of franciscana dolphin low-frequency click train recorded by the PAM buoy off the coast of Uruguay; (A) oscillogram and spectrogram (Hanning window FFT: 1,024), (B) single expanded pulses, (C) spectrum of the expanded pulse showing the peak frequency.

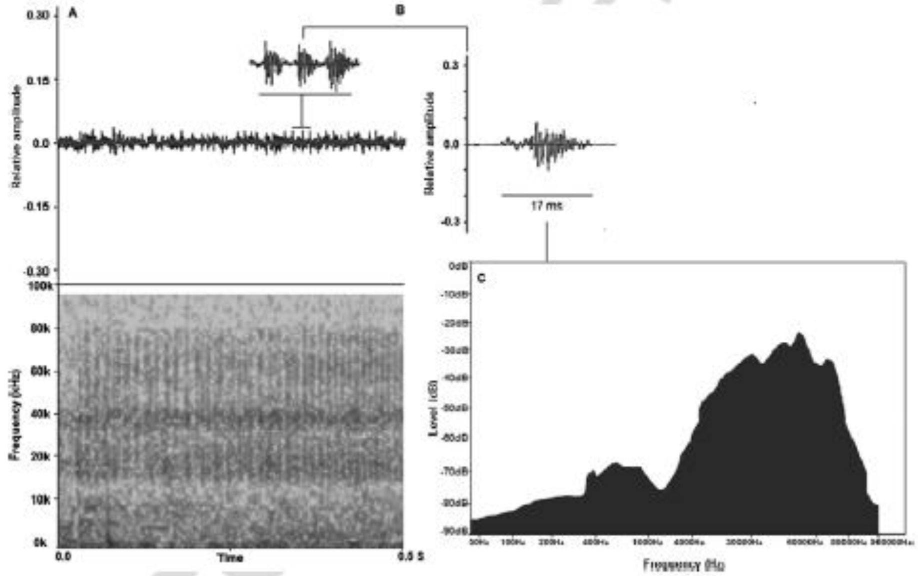


Figure 3. An example of franciscana dolphin burst click train recorded by the PAM buoy off the coast of Uruguay. Representative burst click train (A) oscillogram and spectrogram (Hanning window FFT: 1,024), (B) single expanded pulses, (C) spectrum of the expanded pulse showing the peak frequency.

frequency compared with those presented by Von Fersen *et al.* (1997) and Melcon *et al.* (2012, 2016). Captive adult click trains had a mean frequency of 130 kHz and a bandwidth of 20 kHz (Von Fersen *et al.* 1997) and wild ones had a mean peak frequency of 139 kHz and an interclick interval of 33 ± 4 ms (ranging between 14 and 43 ms). Melcon *et al.* (2016) found wild neonate clicks had a frequency ranging between 37 kHz and 160 kHz with bandwidth of 120 kHz. Low-frequency clicks in this study were similar to those described by Tellechea and Norbis (2014) and the low-frequency component registered by Melcon *et al.* (2016). Our recording sampling rate was limited and may have been cut off spectral content at frequencies beyond 96 kHz. Also click-train overlap from more than one animal may have compromised some measurements of interclick interval.

All studies show the franciscana emits a fairly wide range of click frequencies for echolocation and burst clicks. For cetaceans that do not produce whistles, the burst clicks are very important for communication (Herman and Tavolga 1980, Au and Hastings 2008), as demonstrated for the harbor porpoise, *Phocoena phocoena* (Amundin 1991, Au and Hastings 2008, Tubbert-Clausen *et al.* 2010) are another major category of sound emissions produced by all odontocetes (Au and Hasting 2008). In *T. truncatus* burst clicks have been associated with alarm and fright and in agonistic and head-to-head open-mouth encounters between individuals often accompanied by head nodding, shaking and arching (Herzing 1988, Au and Hastings 2008). Tellechea and Norbis (2014) reported them in two captive neonates franciscana dolphins. Here we report burst clicks of franciscana dolphins for the first time in the wild.

Frainer *et al.* (2015) have suggested that the development of the main biosonar structures may be one cause among others for increased bycatch mortality and the diet shift of young *Pontoporia*. Due to improved motor skills and probably more experience with echolocation, adult *Pontoporia* are less likely to be caught in nets and more successful in catching different types of prey. However, the bycatch mortality of this species includes mostly adults with developed sonar, (Fitch and Brownell 1971, Bordino *et al.* 2002, Rodriguez *et al.* 2002, Bassoi 2005, Paso-Viola *et al.* 2014).

Infrequent use of echolocation may be an adaptation to avoid detection by large predators such as killer whales (*Orcinus orca*) (Madsen *et al.* 2005, Melcon *et al.* 2012) or because of energy costs (Gannon *et al.* 2005). We suggest that the franciscana uses its sonar sparingly because it employs passive listening to find food. The prey most consumed by the franciscana along the coast of Uruguay are *Cynoscion guatucupa, Micropogonias furnieri, Porichthys porosissimus, Macrodon atricauda*, and *Umbrina canosai* (Fitch and Brownell 1971, Praderi 1984, Brownell 1989). These fish are active sound producers, generating advertisement and disturbance calls (Tellechea *et al.* 2010, 2011*a*; Tellechea and Norbis 2012*b*). They are likely to produce disturbance calls when tangled in a net (Tellechea *et al.* 2010, 2011*a*; Tellechea and Norbis 2012*b*). As long as water is not too shallow, these sounds can propagate over long distances in black drum (*Pogonias cromis*) (Locascio and Mann 2011) and Atlantic croaker (*Micropogonias undulatus*) (Gannon and Taylor 2007). Gannon (2003) estimated that croaker sounds may be audible for up to 630 m, which is further than the maximum echolocation detection range known for any dolphin (Au 1993). Given that fish sounds propagate omnidirectionally (Barimo and Fine 1998), passive listening would allow a dolphin to keep a large area under surveillance, without expending energy or advertising its presence (Gannon *et al.* 2005). Therefore, franciscana may be attracted to artisanal fishing nets because of the sounds produced by fish caught in nets and becoming entangled.

Click train characteristics have been associated with foraging/feeding in bottlenose dolphin (Au 1993, Nowacek 2006, Jensen *et al.* 2009, Ridgway *et al.* 2015). Compared to Melcon *et al.* (2012) who found abundant click production during feeding behavior, few click sounds were registered in this study. Fewer sounds may be explained by foraging/feeding behavior in an area with known fishing nets. Alternatively, the animals may not have faced the PAM units. However, the same species may have different foraging behavior in different places. Gannon *et al*. (2005) found that bottlenose dolphins use passive listening extensively during the search phase of foraging in Sarasota Bay, Florida. By listening, bottlenose dolphins may obtain useful information on the identity, number, size, and location of soniferous prey. Once they discover the prey by passive means, they then use echolocation to track the prey during pursuit and capture phases (Au 1993, Gannon *et al*. 2005). Such judicious use of echolocation suggests that this ability incurs significant energetic or ecological costs. Gannon's strategy of listening and then echolocating could be used by franciscana dolphins who prey abundantly on sciaenids.

These records show that this species can swim close to shore in depths of 2 m and emit clicks and burst clicks in its natural environment. The hypotheses discussed in this paper will hopefully form the basis for experimental playback experiments using prey sounds to determine whether the franciscana is attracted to fish nets. More studies with PAM buoys will help locate franciscana hot spots to delineate specific protected areas for this endangered dolphin, where fish nets should be prohibited.

Acknowledgments

We thank the artisanal and recreational fisherman in the study area who alerted us about the franciscanas that were entangled in his nets. We thank ANII (Agencia Nacional de Investigación e Innovación) through the National Research System (ANII–SIN–Uruguay) and Programa de Desarrollo de las Ciencias Básicas (PEDECIBA) for support. Also, thanks to Ambar Suarez, Geremias Evia de Castro, Paula Triller, and Roy McKenzie for their invaluable support in the field, and to Dr. Michael L. Fine for his suggestions and improvement to the English text.

Literature Cited

Amundin, M. 1991. Sound production in odontocetes with emphasis on the harbor porpoise *Phocoena phocoena*, Ph.D. dissertation, University Stockholm, Stockholm, Sweden. 128 pp.

Au, W. W. L. 1993. The sonar of dolphins. Springer-Verlag, New York, NY.

Au, W. W. L., and M. C. Hastings. 2008. Principles of marine bioacoustics. Springer, New York, NY.

Barimo, J. F., and M. L. Fine. 1998. Relationship of swim-bladder shape to the directionality pattern of underwater sound in the oyster toadfish. Canadian Journal of Zoology 76:134–143.

Bassoi, M. 2005. Feeding ecology of franciscana dolphin, *Pontoporia blainvillei* (Cetacea: Pontoporiidae), and oceanographic processes on the southern Brazilian coast. Ph.D. thesis, University of Southampton, Southampton, U.K. 190 pp.

Bordino, P., S. Kraus, D. Albareda, A. Fazio, A. Palmerio, M. Mendez and S. Botta. 2002. Reducing incidental mortality of franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. Marine Mammal Science 18:833–842.

Brownell, R. L., Jr. 1989. Franciscana, *Pontoporia blainvillei* (Gervais and D'Orbigny, 1844). Pages 45–68 *in* S. H. Ridgway and R. J. Harrison, eds. Handbook of marine mammals. Volume 4. River dolphins and the larger toothed whales. Academic Press, San Diego, CA.

Busnel, R., G. A. Dziedzic and G. Alcuri. 1974. Études préliminaries de signaux acoustiques de *Pontoporia blainvillei* Gervaiset et D'Orbigny (Cetacea, Platanistidae) [Preliminary studies of acoustic signals of *Pontoporia blainvillei* Gervaiset and D'Orbigny (Cetacea, Platanistidae)]. Mammalia 38:449–459.

Cappozzo, H. L., M. F. Negri, F. H. Pérez, D. Albareda, F. Monzón and J. F. Corcuera. 2007. Incidental mortality of franciscana dolphin (*Pontoporia blainvillei*) in Argentina. Latin American Journal of Aquatic Mammals 6:127–137.

Crespo, E. A., G. Harris and R. González. 1998. Group size and distributional range of the franciscana, *Pontoporia blainvillei*. Marine Mammal Science 14:845–849.

Evans, W. E. 1967. Vocalization among marine mammals. Pages 159–186 *in* W. N. Tavolga, ed. Marine bioacoustics. Volume 2. Pergamon, New York, NY.

Fitch, J. E., and R. L. Brownell, Jr. 1971. Food habits of the franciscana, *Pontoporia blainvillei* (Cetacea, Platanistidae) from South America. Bulletin of Marine Science 21:626–636.

Frainer, G., S. Huggenberger and I. Benites-Moreno. 2015. Postnatal development of franciscana's (*Pontoporia blainvillei*) biosonar relevant structures with potential implications for function, life history, and bycatch. Marine Mammal Science 31:1193–1212.

Gannon, D. P. 2003. Behavioral ecology of an acoustically mediated predator–prey system: Bottlenose dolphins and sciaenid fishes. Ph.D. thesis, Duke University, Durham, NC. 244 pp.

Gannon, D. P., and C. M. Taylor. 2007. Acoustic behavior of Atlantic croaker, *Micropogonias undulatus* (Sciaenidae). Copeia 2007:193–204.

Gannon, D. P., N. B. Barros, D. P. Nowacek, A. J. Read, D. M. Waples and R. S. Wells. 2005. Prey detection by bottlenose dolphins (*Tursiops truncatus*): An experimental test of the passive listening hypothesis. Animal Behaviour 69:709–720.

Herman, L. M., and W. N. Tavolga. 1980. The communication systems of cetaceans. Pages 149–209 *in* L. M. Herman, ed. Cetacean behavior: Mechanisms and functions. Wiley Interscience, New York, NY.

Herzing, D. L. 1988. A quantitative description and behavioral associations of a burst-pulsed sound, the squawk, in captive bottlenose dolphins, *Tursiops truncatus*. M.S. thesis, San Francisco State University, San Francisco, CA. 87 pp.

Jensen, F. H., L. Bejder, M. Wahlberg and P. T. Madsen. 2009. Biosonar adjustments to target range of echolocating bottlenose dolphins (*Tursiops* sp.) in the wild. The Journal of Experimental Biology 212:1078–1086.

Locascio, J., and D. Mann. 2011. Localization and source level estimates of black drum (*Pogonias cromis*) calls. Journal of the Acoustical Society of America 130:1868–1879.

Mazzoni, D. 2006. Audacity 1.2.6. Available at http://audacity.sourceforge.net.

Madsen, P., D. A. Carder, K. Bedholm and S. H. Ridgway. 2005. Porpoise clicks from a sperm whale nose – convergent evolution of 130 KHz pulses in toothed whale sonars? Bioacoustics 15:195–206.

Melcon, M. L., M. Failla and M. A. Íñiguez. 2012. Echolocation behavior of franciscana dolphins (*Pontoporia blainvillei*) in the wild. Journal of Acoustical Society of America 131:448–453.

Melcon, M. L., M. Failla and M. A. Íñiguez. 2016. Towards understanding the ontogeny of echolocation in franciscana dolphins (*Pontoporia blainvillei*). Marine Mammal Science 32:1516–1521.

Mellinger, D. K. 2001. Ishmael 1.0 user's guide. NOAA Technical Memorandum OAR PMEL-120. Available from NOAA/PMEL/OERD, 2115 SE OSU Drive, Newport, OR 97365-5258. 30 pp.

Nowacek, D. P. 2006. Acoustic ecology of foraging bottlenose dolphins (*Tursiops truncatus*), habitat-specific use of three sound types. Marine Mammal Science 21:587–602.

Ott, P. H., E. R. Secchi, I. B. Moreno, *et al.* 2002. Report of the working group on fishery interactions. Latin American Journal of Aquatic Mammals 1:55–64.

Paso-Viola, M. N., P. Denuncio, M. V. Panebianco, M. F. Negri, D. Rodriguez, R. Bastida and H. L. Cappozzo. 2014. Diet composition of franciscana dolphin *Pontoporia blainvillei* from southern Buenos Aires, Argentina and its interaction with fisheries. Revista de Biología Marina y Oceanografía 49:393–400.

Praderi, R. 1984. Mortalidad de franciscana, *Pontoporia blainvillei*, en pesquerías artesanales de tiburón de la costa atlántica uruguaya [Mortality of franciscana, *Pontoporia blainvillei*, in artisanal shark fisheries on the Uruguayan Atlantic coast]. Revista del Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" (Zoología) 13:259–272.

Reeves, R. R., M. L. Dalebout and T. A. Jefferson, *et al*. 2008. *Pontoporia blainvillei*. IUCN Red List of Threatened Species. Version 2010.4. Available at http://www.iucnredlist.org.

Ridgway, S., D. Samuelson, K. Van Alstyne and D. Price. 2015. On doing two things at once: Dolphin brain and nose coordinate sonar clicks, buzzes, and emotional squeals with social sounds during fish capture. Journal of Experimental Biology 218:3987–3995.

Rodríguez, D., L. Rivero and R. Bastida. 2002. Feeding ecology of franciscana in marine and estuarine waters of Argentina. Latin American Journal of Aquatic Mammals (Special Issue 1):77–94.

Siciliano, S., A. P. M. Di Beneditto and R. M. A. Ramos. 2002. A toninha, *Pontoporia blainvillei* (Gervais & d'Orbigny, 1844) (Mammalia, Cetacea, Pontoporiidae), nos estados do Rio de Janeiro e Espírito Santo, costa sudeste do Brasil: Caracterização dos hábitats e fatores de isolamento das populações [The dolphin, *Pontoporia blainvillei* (Gervais & d'Orbigny, 1844) (Mammalia, Cetacea, Pontoporiidae), in the states of Rio de Janeiro and Espírito Santo, southeast coast of Brazil: Characterization of habitats and isolation factors of populations]. Boletim do Museu Nacional 476:1–15.

Tellechea, S. J., and W. Norbis. 2012*a*. Southern right whale (*Eubalaena australis*): Preliminary recordings of the acoustics emission in coast of Uruguay. Journal of Cetacean Research and Management 12:361–364.

Tellechea, S. J., and W. Norbis. 2012*b*. Sexual dimorphism in sound production and relationship between fish size and call characteristics in the striped weakfish *Cynoscion guatucupa*. Zoological Studies 51:946–955.

Tellechea, J. S., and W. Norbis. 2014. Sound characteristics of two neonatal franciscana dolphins (*Pontoporia blainvillei*). Marine Mammal Science 30:1573–1580.

Tellechea, S. J., C. Martinez, M. L. Fine and W. Norbis. 2010. Sound production in whitemouth croaker (*Micropogonias furnieri*–Sciaenidae) and relationship between fish size and disturbance call parameters. Environmental Biology of Fishes 89:163–172.

Tellechea, S. J., D. Bouvier and W. Norbis. 2011*a*. Spawning sounds in whitemouth croaker (Sciaenidae), seasonal and daily cycles. Bioacoustics 20:159–168.

Tellechea, S. J., D. Olsson, W. Norbis and M. L. Fine. 2011*b*. Calls of the black drum (*Pogonias cromis*–Sciaenidae): Geographical differences in sound production between Northern and Southern hemisphere populations. Journal of Experimental Zoology 315A:48–55.

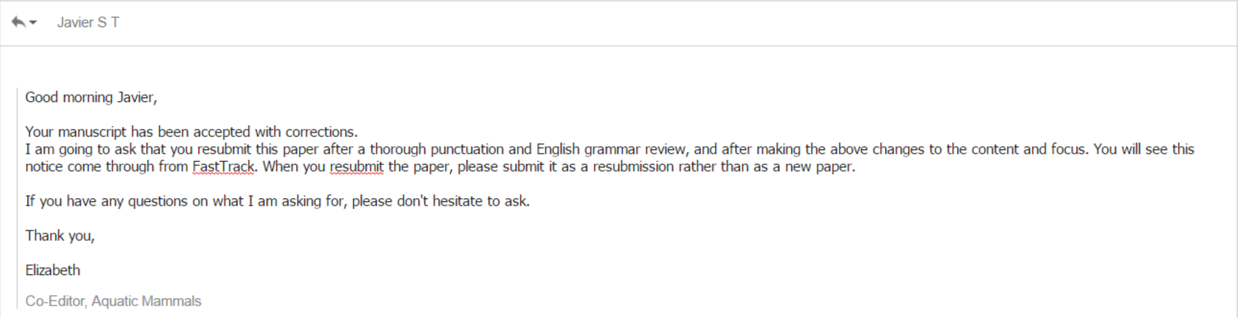
Tubbert-Clausen, K., M. Wahlberg, K. Beedholm, *et al*. 2010. Click communication in harbour porpoises *Phocoena phocoena*. Bioacoustics 20:1–28.

Von Fersen, L., C. Kamminga and A. Seidl. 1997. Estudios preliminares sobre el comportamiento de un ejemplar de franciscana (*Pontoporia blainvillei*) en Mundo Marino, Argentina (DT10) [Preliminary studies on the behavior of a specimen of franciscana (*Pontoporia blainvillei*) in Mundo Marino, Argentina]. Pages 30–33 in Report of the third workshop for coordinated research and conservation of the franciscana dolphin (Pontoporia blainvillei) in the southwestern Atlantic, 26–28 November 1997, Buenos Aires, Argentina. Available at http://www.cms.int/publications/pdf/franciscana_dolphin_buenos_aires_1997.pdf.

Zimmer, W. 2011. Passive acoustic monitoring of cetaceans. Cambridge University Press, Cambridge, U.K..

Capitulo 5.- Contenido estomacal de *Pontoporia blainvillei*, estudio de presas para dilucidar si la franciscana tiene preferencia alimenticia por los peces productores de sonido.

Articulo aceptado con correcciones para su publicación en Aquatic Mammals Journal: Feeding Habits of Franciscana Dolphin (*Pontoporia blainvillei*): Echolocation or Passive Listening?



Javier S T

Good morning Javier,

Your manuscript has been accepted with corrections.
I am going to ask that you resubmit this paper after a thorough punctuation and English grammar review, and after making the above changes to the content and focus. You will see this notice come through from FastTrack. When you resubmit the paper, please submit it as a resubmission rather than as a new paper.

If you have any questions on what I am asking for, please don't hesitate to ask.

Thank you,

Elizabeth

Co-Editor, Aquatic Mammals

Resumen.

Los hábitos de alimentación del delfín la franciscana fueron investigados en la costa uruguaya utilizando el contenido del estomacal de ejemplares que fueron capturadas accidentalmente en las redes de la pesca artesanal y de animales varados en la playa. Fue analizado el contenido estomacal de 41 delfines con el objetivo de conocer los hábitos de alimentación de esta especie. Un total de nueve especies fueron identificadas, ocho de ellas fueron peces teleósteos y una especie de calamar (*Loligo sanpaulensis*). Los teleósteos ocuparon el 99.8% de las presas de los 41 estómagos analizados y corresponden a un total de 342 individuos. La pescadilla *Cynoscion guatucupa*, fue la presa mas importante (n = 127; %IRI = 49.43) seguida de *Porichthys porosissimus* (n = 90; %IRI = 26.61) y *Micropogonias furnieri* (n = 66; %IRI = 17.33), mientras que las restantes especies de peces representaron el 6,5% del índice de importancia relativa (IRI). De las ocho especies de peces encontradas en los estómagos, cinco son productores activos de

sonido: *Cynoscion guatucupa, Porichthys porosissimus, Micropogonias furnieri, Macrodon atricauda* y *Umbrina canossai.* Los peces, particularmente los que emiten sonidos, fueron los ítems alimenticios mas importantes y representan el 97.4 % IRI. El índice de Levin estandarizado de amplitud de nicho muestra una estrategia de alimentación especialista y los datos presentados en este manuscrito indican que la Franciscana en la costa uruguaya escoge como presas peces productores de sonidos. De esta manera la Franciscana podría utilizar la escucha pasiva para obtener presas en las oscuras aguas del Rio de la Plata y turbias aguas de la costa Atlántica. Estos resultados contribuyen de manera directa a la hipótesis de que los delfines franciscana utilizan escucha pasiva para localizar peces que emiten sonidos. Se discute que en ciertas condiciones, la escucha pasiva parece ser mas ventajosa sobre la ecolocalización, con respecto a los costos energéticos y / o ecológicos.

Feeding Habits of Franciscana Dolphin (*Pontoporia blainvillei*): Echolocation or Passive Listening?

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Abstract

Research on the feeding habits of Franciscana dolphins in the Uruguayan coast was carried out using stomach contents from dolphins which were incidentally entangled in artisanal fishing nets and stranded on the beach. Stomach contents of 41 dolphins were analyzed in order to improve knowledge about the feeding habits of this species. A total of nine food items were identified, eight teleost and one squid species. Teleosts were recorded in 99.8% of the 41 stomachs analyzed and corresponded to a total of 342 individuals. The striped weakfish *Cynoscion guatucupa,* was the most important teleost (n = 127; %IRI = 49.43) followed by *Porichthys porosissimus* (n = 90; %IRI = 26.61), and *Micropogonias furnieri* (n = 66; %IRI = 17.33), whereas the remaining fish species represented less than 6.5 % of index of relative importance. From eight species of fish found in the stomach, five of them actively produce sound: *Cynoscion* *guatucupa*, *Porichthys porosissimus*, *Micropogonias furnieri*, *Umbrina canossai* and *Macrodon atricauda.* Fishes, particularly those emitting sound, were the most important Franciscana food item representing 97.4 % Index of Relative Importance. The Levin's index standardized of niche breadth show a specialist feeding strategy, and data present in this paper indicates that the Franciscana dolphin in the Uruguayan coast chooses soniferous prey. Therefore, a way the Franciscana finds the preys within dark waters like the Rio de la Plata estuary and the murky waters of the Uruguayan oceanic coast could be through the passive listening.

Key words: *Pontoporia blainvillei*, diet, Uruguay coast, passive listening, soniferous fishes

Introduction

Understanding predator-prey relationships is one of the main goals of animal ecology. Information on prey selection is often used to provide the foundation for dietary niche characterization (Bearhop et al., 2004) and along with diet composition is one of the most important input parameters in food web models (Christensen & Pauly 1992; Berens-McCabe et al., 2010).

Cetacean diets are commonly quantified through stomach content analyses of stranded, by-caught, or harvested animals (e.g., Fitch & Brownell 1971; Gannon et al., 1997; Barros & Wells 1998). The Franciscana dolphin (*Pontoporia blainvillei*, Gervais & d'Orbigny 1844) is an endemic dolphin from the Southwestern Atlantic Ocean that is caught incidentally in coastal fishing nets all along its geographical distribution (from Itaúnas (18°25'S, 30°42'W, Brazil) to

Península Valdés (42° 35´S, 64°48’W, Argentina) (Praderi et al., 1989; Secchi et al., 1997; Crespo et al., 1998; Rodriguez et al., 2002; Bordino et al., 2002; Franco-Trecu et al., 2009). Due to their continued incidental mortality throughout most of its distribution it is considered the most endangered small cetacean of the Southwestern Atlantic Ocean (Secchi & Wang 2003). Consequently, the Franciscana dolphin is classified as Vulnerable (A3d) by the International Union for Conservation of Nature (IUCN, Reeves et al., 2008). Little is known of the ecology and behavior of individuals in the wild (Bordino et al., 2002; Crespo et al., 2010; Tellechea & Norbis 2014).

Many studies on trophic ecology of the Franciscana dolphin have been performed in the southwestern Atlantic Ocean region (Fitch & Brownell 1971; Pinedo 1982; Brownell 1989; Ott 1994; Rodríguez et al., 2002; Bassoi 2005; Paso-Viola et al., 2014). Studies of feeding habits have found that this dolphin exhibits opportunistic feeding behavior and is a prey generalist, consuming fish, cephalopods and crustaceans as the most common prey (Rodríguez et al., 2002; Bassoi 2005; Paso-Viola et al., 2014). Like the bottlenose dolphin (*Tursiops truncatus*), the Franciscana dolphin feeds on soniferous (i.e. noise-producing) fishes, particularly sciaenids (Fitch & Brownell 1971; Brownell 1989; Rodríguez et al., 2002; Bassoi 2005; Cremer et al., 2012; Paso-Viola et al.; 2014). This data would suggests that Franciscana select soniferous prey, using passive listening to locate noise-producing prey but this has not been studied yet.

Some researchers have hypothesized that coastal bottlenose dolphins uses passive listening to locate noise-producing prey (Barros & Odell 1990; Barros 1993; Barros & Wells 1998). In a novel experiment in Sarasota Bay, Gannon et al. (2005) found that bottlenose dolphins indeed responded to the playback of fish sounds. The dolphins changed their direction of travel, turning towards the sound source when fish noises were played. In addition, dolphins significantly increased their rate of echolocation immediately following playback of fish sounds. The authors concluded that bottlenose dolphins use passive listening extensively during the search phase of foraging. By listening passively, dolphins may obtain useful information regarding the identity, number, size and location of soniferous prey. Berens-Mccabe et al., (2010), indicated that at the population level, resident bottlenose dolphins of Sarasota Bay also preferred soniferous fish prey.

Determining prey selection in wild dolphins is a relevant and important step in understanding their role as predators in the ecosystem. The aim of this work was to analyze the feeding habits and quantify the relative importance of prey species eaten by wild resident Franciscana dolphins off the Uruguayan coast by evaluating stomach contents of dolphins entangled in artisanal fishing nets or stranded on the beach.

Methods

Stomach contents analysis

A total of 41 Franciscana dolphins (24 females and 17 males) stomachs were analyzed. All died as a result of becoming incidentally entangled in artisanal fishing nets or stranded on the beach off the Uruguayan coast during 2013 and 2016 (Figure 1, Table 1). They were kept in freezers at -20°C until necropsy was performed. Each dolphin specimen's total length (FTL) (cm) was recorded according to Norris (1961) and intact stomachs were carefully removed and examined.

Food items were identified to the lowest possible taxon using laboratory catalogs. The total numbers of empty stomachs were also recorded. Total length for all prey (PTL) species were measured and total mass (g) of each species identified was estimate using length – weight relationships previously described (Ehrhardt et al., 1977; Haimovici 1982; Bugoni & Vooren 2004; Rodriguez & Gasalla 2008; Segura et al., 2012). (Place Figure 1 here)

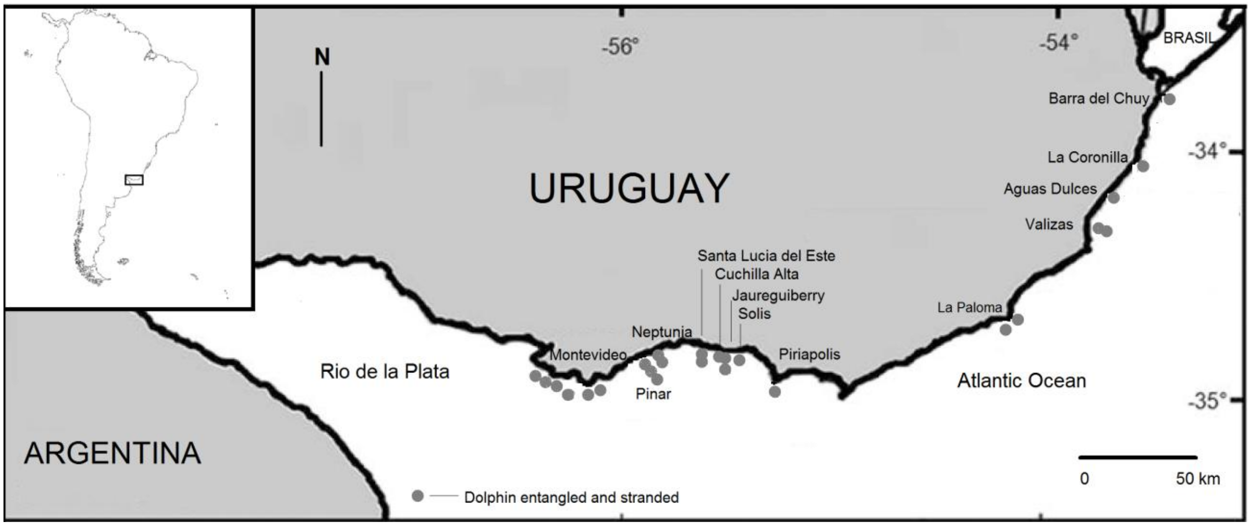

Figure 1. Map of the study area off the Uruguayan coast. Positions of entangled and stranded dolphins included in this study are shown as grey dots. .

(Place Table 1 here)

Table 1. Summary of the Franciscana dolphins collected from the coast of Uruguay from 2013 to 2016 (TL= total length, cm)

Locality	Date	Sex	Range TL (cm)	Cause of death
Naptunia	Feb-13	female	99	entangled
Pinar	Dec-13	male	127	entangled
Neptunia	Apr-14	male	119	stranding
Sanra Lucia del Este	Jun-14	feamle	114	stranding
Jaureguiberry	Jul-14	male	146	stranding
Piriapolis	Oct-14	female	92	stranding
Valisas	Nov-14	female	87	stranding
Solis	Dec-14	female	110	entangled
Aguas Dulces	Dec-14	male	134	stranding
Valisas	Jan-15	female	103	stranding
Cuchilla Alta	Feb-15	female	88	stranding

Pinar	Mar-15	female	84	entangled
Pinar	May-15	male	152	stranding
Montevideo	Aug-15	female	105	entangled
Montevideo	Oct-15	female	95	entangled
Barra del Chuy	Oct-15	female	129	stranding
Cuchilla Alta	Nov-15	male	120	stranding
La Coronilla	Nov-15	male	133	stranding
Montevideo	Jun-16	male	136	stranding
Montevideo	Jul-16	male	105	entangled
Montevideo	Jul-16	female	95	entangled
Montevideo	Jul-16	female	154	entangled
Santa Lucia del Este	Jul-16	female	110	stranding
Montevideo	Jul-16	female	149	stranding
Montevideo	Aug-16	female	105	stranding
Pinar	Aug-16	male	95	stranding
Montevideo	Aug-16	female	154	stranding
Montevideo	Aug-16	female	164	stranding
Montevideo	Sep-16	female	152	stranding
San Luis	Sep-16	male	147	stranding
San Luis	Sep-16	female	165	stranding
Pinar	Sep-16	male	129	stranding
Piriapolis	Sep-16	male	111	stranding
Piriapolis	Sep-16	female	147	stranding
La Paloma	Sep-16	female	136	stranding
La Paloma	Sep-16	male	106	stranding
Jose Ignacio	Sep-16	male	113	entangled
Piriapolis	Oct-16	male	93	entangled
Pinar	Oct-16	male	105	entangled
Pinar	Oct-16	female	115	entangled
Pinar	Oct-16	female	121	entangled

The relationship between the Franciscana dolphin total length (FTL) and prey total length (PTL) was analyzed using linear regressions (Sokal and Rohlf 1995). The frequency of occurrence (%FO) was calculated as the number of stomachs in which prey occurred, the numerical abundance (%N) as the number of individuals of each prey type / total number of individuals of all prey types, and the reconstructed biomass (%W) as the biomass of each prey type / total biomass represented by all prey; all these indexes were expressed as percentages (Hyslop 1981, Castley *et al*. 1991, Cortés 1997). The relative importance of prey species was evaluated using the index of relative importance (IRI) calculated as IRI = [%N+%W] * %FO and then transformed as percentage (%IRI) (Pinkas et al., 1971; Hyslop 1981).

Diet diversity was analyzed using Shannon diversity index H (H = -Σ (ni n-1) ln (ni n-1), where ni = number of individuals of the species in a sample and n = total number of individuals registered in the sample), Shannon equitability (H/ln(S), S = total richness of the sample) and Berger Parker species richness (*d= Nmax/N* where Nmax is the number of individuals in the most abundant species, and N is the total number of individuals in the sample) (Magurran 2004). Lower and upper percentiles 25% and 75% of the indices were calculated using bootstrap for the stomach sampled. Specialization diet was analyzed using Levin's index (niche breadth) standardized by the Hulbert (1978) method. This index varies between 0 and 1 and the predator is considered specialist when the value is close to zero and generalist when it is close to 1 (Ludwig & Reynolds 1988).In all cases, the significance level considered was p = 0.05. The statistical software *PAST (*Hammer et al 2001) was used for all statistical analyses and diversity index.

Results

Prey consumption: stomach contents analysis

The measured total length of the Franciscana dolphins included in this study ranged between 84 and 165 cm (Table 1). From the 41 stomachs sampled only 4 were empty.

A total of nine food items in fresh condition or in the beginning of digestion were identified: the striped weakfish *Cynoscion guatucupa* (Cuvier 1830), the whitemouth croaker *Micropogonias furnieri* (Desmarest 1823), the argentine croaker *Umbrina canossai* (Berg 1895) the banded croaker *Paralonchorus brasiliensis* (Steindachner 1875), *Southern King Weakfish Macrodon articauda* (Günther, 1880), all species belonging to the family Sciaenidae; the toadfish *Porichthys porosissimus* (Valenciennes 1837) (Family Batrachoididae), the Atlantic anchovy *Engraulis anchoita* (Hubbs & Marini 1935) (Family Engraulidae), Brazilian codling *Urophycis brasiliensis* (Kaup, 1858). The squid *Loligo sanpaulensis* (Brakoniecki 1984) (Family Loligindae) (Table 2) was only detected in one stomach. In eight stomachs unidentified rest (UI) was found (Table 2). The UI was not taken into account in the quantitative analysis due to it only being found in small quantities and hence its contribution was considered to be insignificant overall. Teleosts were recorded in 99.8% of the 41 stomachs analyzed and corresponded to a total of 342 individuals. The striped weakfish *C. guatucupa*, was the most important teleost (n = 127; %IRI = 49.43) followed by *P. porosissimus* (n = 90; %IRI = 26.61), and *M. furnieri* (n = 66; %IRI = 17.33), whereas the remaining fish species represented less than 6.5 %IRI (Table 2).

Length composition of species eaten ranged from 7 to 24 cm PTL with modal length at 13 cm, mean 13.18 ± 0.14 cm, and a median of 13 cm PTL (Table 3). The cumulative frequency at 50% of prey was 13 cm PTL. Fish mean PTL by species eaten were between 11.11 ± 0.22 cm (SD) and 14.65 ± 0.24 cm (SD) (Table 3). Significant inverse relationships was found between Fransiscana dolphin total length (FTL) and prey total length (PTL) (cm) (PTL = 14.87 – 0.013 FTL, r = - 0.122; Student t - test = 2.28; p = 0.022 < 0.05), but only 1.5 % of PTL was explained by FTL (determination coefficient = r^2 = 0,015).

The Shannon diversity index was 1.633 (lower (25%) = 1.532, upper (75%) = 1.705), the evenness index was 0.568 (lower (25%) = 0.514, upper (75%) = 0.611) and the Berger – Parker index was 0.363 (lower (25%) = 0.315, upper (75%) = 0.415). Levin´s index standardized of niche breadth was 0.078 which indicate a specialist feeding strategy of the Franciscana dolphin in the Uruguayan coast.

Table 2. Summary of diet composition of the Franciscana dolphins collected off the Uruguayan coast.

Prey item	Sound	FO	%FO	N	%N	%W	IRI	%IRI
Teleosts		93		349				
Cynoscion guatucupa	Yes	22	23.15	127	36.38	50.78	2018.83	49.43
Porichthys porosissimus	Yes	24	25.26	90	25.78	17.23	1087.01	26.61
Micropogonias furnieri	Yes	20	21.05	66	18.91	14.71	707.92	17.33
Umbrina canosai	Yes	9	9.47	26	7.44	9.51	160.72	3.93
Engraulis anchoita	Not	8	8.42	19	5.44	3.94	79.06	1.93
Paralonchurus brasiliensis	Not	4	4.21	7	2.00	1.10	13.11	0.32
Macrodon articauda	Yes	2	2.10	3	0.85	1.00	3.93	0.096
Urophisis brasiliensis	Not	4	4.21	4	1.14	0.49	6.89	0.16
Cephalopods		2		7				
Loligo sanpaulensis	Not	4	2.10	7	2.00	1.18	6.72	0.16
Unidentified species (UI)		8		12				

Table 3. Prey size characteristics: size of sample (n), max, min, mean standard error (SE), variance (s^2), standard deviation (SD), median $(\bar{x})$, percentiles (PCTL) and coefficient of variation (CV).

	n	Min	Max	Mean	SE	s^2	SD	□	25 PCTL	75 PCTL	CV
All preys	349	7	24	13.18	0.14	7.05	2.65	13	12	14	20.14
Cynoscion guatucupa	127	11	24	14.65	0.24	7.36	2.71	14.00	*13.00*	16	18.52
Porichthys porosissimus	90	*7*	16	11.11	0.22	4.46	2.11	12.00	10.00	12	19.01
Micropogonias furnieri	66	*10*	21	13.11	0.25	4.07	2.02	13.00	12.00	14	15.38
Umbrina canosai	26	*10*	16	13.54	0.31	2.58	1.61	13.50	12.00	15	11.86
Engraulis anchoita	19	*10*	17	12.95	0.40	3.05	1.75	13.00	12.00	14	13.49
Paralonchurus brasiliensis	7	*11*	13	12.14	0.34	0.81	0.90	12.00	11.00	13	7.41
Macrodon articauda	7	*9*	16	12.86	0.86	5.14	2.27	13.00	12.00	15	17.64
Urophisis brasiliensis	3	*15*	18	16.33	0.88	2.33	1.53	16.00	15.00	18	9.35
Loligo sanpaulensis	4	*12*	15	13.50	0.65	1.67	1.29	13.50	12.25	14.75	9.56

Discussion

The animals analyzed in this study do not exhibit signs of disease or trauma but most specimens showed signs of net marks in the skin, including some that were found stranded in the beaches also had these marks, so probably these dolphins died as a consequence of entanglement in fishing nets, which is big problem previously described.

The analysis of stomach contents confirms the importance of fish in the diet of the Franciscana dolphin. The feeding habits along its distribution area is composed by, at least, 76 food items and the majority of prey belonged to three main zoological groups: fish (82.8%), crustaceans (9.2%), and molluscs (7.9%) (Fitch & Brownell 1971; Brownell 1975; Pinedo 1982; Brownell 1989;

Bassoi & Secchi 1999; Rodriguez et al., 2002; Bassoi 2005; Paso-Viola et al., 2014). The number of prey species in this study (nine prey species) is considerably lower compared with other studies previously performed along its distribution range. In Brazil, a total of 25 prey were found in dolphins collected north of Rio de Janeiro (Di Beneditto & Ramos 2001), 36 prey species were identified in a study performed in Rio Grande do Sul (Bassoi 2005), a total of 24 different prey from the northern coast of Buenos Aires (Rodríguez et al., 2002), and finally 11 prey from the southern Buenos Aires coast (Pazo-Viola et al., 2014). Diversity and species richness indices (Shannon & Berger – Parker, respectively) were low for the Uruguayan coast and the number of prey species noteworthy low. However, the species reported in this study are consistent with those found by Fitch & Brownell (1976) and Brownell (1989) from the Uruguayan coast.

Eight fishes species were found in the stomach in this study, and the preys most important were *C. guatucupa*, *P. porosissimus* and *M. furnieri*. From this eight fishes species, five are actively sound producers: *M. furnieri* (Tellechea et al., 2010, 2011a), *C. guatucupa* (Tellechea & Norbis 2012), *U. canossai* (Tellechea et al., 2016), *M. articauda* and *P. porosissimus* (Tellechea unpublished data). The fishes, particularly those emitting sound, were the most important Franciscana dolphin food item representing 97.4 % IRI of total prey (Table 2). As reported for southern Brazil and Argentina, Franciscanas in this study prey on juvenile fish (mean 13.18 ± 0.14) cm and small squids, being the target species *C. guatucupa* and *P. porosisimus*.

In terms of IRI *C. guatucupa* was the most important prey identified off the Brazilian and Argentinean coasts together with other sciaenids with smaller IRI as *M. furnieri* and *M.*

atricauda (Bassoi & Secchi 1999; Di Beneditto & Ramos 2001; Rodriguez et al., 2002; Bassoi 2005; Paso-Viola et al., 2014). Throughout its distribution area, Franciscana dolphins are classified as opportunistic in their feeding habits (Rodriguez et al., 2002, Bassoi 2005; Paso-Viola et al., 2014), however the Levin's index standardized of niche breadth indicates a specialist feeding strategy of the Franciscana dolphin population investigated in this study.

It is noteworthy that the toadfish *P. porosisimus* is second most recurrent prey, and is the prey with more frequency of occurrence (%25), as previous studies off the Uruguayan coast has also identified this species as the most consumed prey (Brownell et al., 1989). The *P. porosisimus* is still the main difference in the diet of Franciscanas from Uruguay and Argentina, this species is one of the most important prey item in Uruguay as show this study and past studies (Praderi 1984; Brownell et al., 1989), but in Argentina is very little recurring (Rodriguez et al., 2002; Paso-Viola et al., 2014). This fish is hard to find, it inhabits caves in the rocks or stays buried. This suggests that the Franciscana dolphin may locate this fish in the dark waters of the Rio de la Plata estuary and the murky waters of the Uruguayan oceanic coast could be through passive listening.

The hypothesis of using passive listening to find prey is not new, this strategy have been already described in cetaceans (Barret-Leonard et al., 1996; Barros & Odell 1990; Barros 1993; Barros & Wells 1998; Gannon et al., 2005; Berens et al., 2010). Passive listening would increase the capture efficiencies of energetically rich prey (Barros & Wells 1998; Gannon 2005) as many soniferous fish species raise their frequency and intensity of calls during spawning periods (Tellechea et al., 2010, 2011a, 2011b; Tellechea & Norbis, 2012). The sounds emitted by fishes is audible up to 630 m (Gannon 2003) which is much further than the maximum echolocation detection range known for any other dolphin, regardless of target strength (Au 1993). Given that fish sounds propagate more or less omnidirectionally (Barimo & Fine 1998), passive listening would allow dolphins to keep a large area under surveillance without expending energy or advertising its presence. Therefore, the Franciscana dolphin may obtain useful information from it, like prey identification and location, body size and number of fish. Using this information to assess the quality of prey from a distance would surely be advantageous for these predators (Gannon et al., 2005), once the prey has been detected the Franciscana dolphin could be using the echolocation to track the prey and capture phases (Au 1993; Gannon et al., 2005; Rigdway et al., 2015).

Passive listening could contribute to the frequency of Franciscana dolphins ending up as bycatch as the sound-producing species are the target of some fisheries, possibly causing the dolphin to approach the artisanal fishing net to feed. These *M. furnieri, C. guatucupa, and U. canosai* fish emit disturbance calls when they are tangled in the fisheries nets (Tellechea et al., 2010, 2011a, Tellechea & Norbis 2012). Bordino et al. (2002) show that even with sonorous alarms in fishermen nets focused on fishing *C. guatucupa, M. furnieri, P. brasiliensis, U. canosai*, all sound producing species, it still caused the Franciscana dolphin to continue to get entangled in the nets. We therefore suggest that even with the use of acoustic alarms this dolphin still prefers to go for the easy food in the nets. Franciscana dolphin has been classified as ‘vulnerable’in its whole distribution, principally as a consequence of the incidental mortality in artisanal fisheries. In consequence, further studies are needed to clarify if this dolphin is attracted to the fisherman nets by soniferous fish, and to identify ways to successfully prevent them doing so.

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Literature cited

Au, W. W. L. 1993. The sonar of dolphins. New York: Springer-Verlag. http://dx.doi.org/10.1007/978-1-4612-4356-4.

Barimo, J. F. & Fine, M. L. (1998). Relationship of swim-bladder shape to the directionality pattern of underwater sound in the oyster toadfish. *Canadian Journal of Zoology*, 76, 134-143.

Bassoi, M. & Secchi, E. R. (1999). Temporal variation in the diet of Franciscana, Pontoporiablainvillei (Cetacea, Pontoporiidae), as a consequence of fish stocks depletion off southern Brazil. In Ecosystem Effects of Fishing, p. 51. ICES/SCOR Symposium.

Bassoi, M. (2005). Feeding ecology of Franciscana dolphin, Pontoporia blainvillei (Cetacea: Pontoporiidae), and oceanographic processes on the Southern Brazilian coast. (Doctoral dissertation), School of Ocean & Earth Sciences, University of Southampton, Southampton, 190 pp. http://eprints.soton.ac.uk/25133/

Barrett-Lennard, L. G., Ford, J. K. B. & Heise, K. A. (1996). The mixed blessing of echolocation: Differences in sonar use by fish-eating and mammal-eating killer whales. *Animal Behaviour*, 51:553–565.

Barros, N. B. (1993). Feeding ecology and foraging strategies of bottlenose dolphins on the central east coast of Florida. (Doctoral dissertation). University of Miami.

Barros, N. B. & Odell, D. K (1990). Food habits of bottlenose dolphins in the southeastern United States. In: The Bottlenose Dolphin (Ed. by S. Leatherwood & R. R. Reeves), pp. 309–328. San Diego: Academic Press.

Barros, N. B. & Wells, R. S. (1998). Prey and feeding patterns of resident bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Journal of Mammalogy*, 79, 1045–1059.

Berens-McCabe, E. J, Gannon, D. P., Barros, N. B. & Wells, R. S. (2010). Prey selection by resident common bottlenose dolphins (T*ursiops truncatus*) in Sarasota Bay, Florida. *Marine Biology*, 157: 931–942.

Bordino, P., Thompson, G., & Iniguez, M. (1999). Ecology and behaviour of the Franciscanas dolphin *Pontoporia blainwillei* in Bahk Anegada, Argentina. *Journal of Cetacean Research and Management*, 1:213-222.

Bordino, P., Kraus, S. , Albareda, D. , Fazio, A., Palmerio, A., Mendez, M. & Botta, S. (2002). Reducing incidental mortality of Franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. *Marine Mammal Science*, 18: 833–842. doi: 10.1111/j.1748-7692.2002.tb01076.x

Brownell, R. L. J. (1989). Handbook of Marine Mammals: River Dolphins and the Larger Toothed Whales, chapter Franciscana, Pontoporia blainvillei (Gervais and D'Orbigny, 1844). Academic Press.

Bugoni, L. & Vooren, C. M. (2004). Feeding ecology of the Common Tern *Sterna hirundo* in a wintering area in southern Brazil. *Ibis*, 146: 438-453.

Christensen, V. & Pauly, D. (1992). ECOPATH II–a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling*, 61:169–185.

Cremer, M. J, Pinheiro, P. C. & Simões-Lopes, P. C. (2012). Prey consumed by Guiana dolphin *Sotalia guianensis* (Cetacea, Delphinidae) and Franciscana dolphin *Pontoporia blainvillei* (Cetacea, Pontoporiidae) in an estuarine environment in southern Brazil. Iheringia, Série Zoologia 102(2): 131-137.

Crespo, E., Harris, G. & Gonzales, R. (1998). Group size and distributional range of the Franciscana, Pontoporia blainvillei. *Marine Mammal Science*, 14:845–849.

Crespo, E. A., Pedraza, S. N., Grandi, M. F., Dans, S. L. & Garaffo, G. V. (2010). Abundance and distribution of endangered Franciscana dolphins in Argentine waters and conservation implications. *Marine Mammal Science*, 26: 17–35. doi:10.1111/j.1748-7692.2009.00313.x

Di Beneditto, A. P. M. & Ramos, R. M. A. 2001. Biology and conservation of the Franciscana (*Pontoporia blainvillei*) in the north of Rio de Janeiro State, Brazil. *Journal of Cetacean Research Management* 3(2): 185-192.

Ehrhardt, N., Nion, H., Castaldo, H. & Barea, L. (1977). Evaluación preliminar de los recursos pelágicos del área común de pesca Argentino-Uruguaya [Preliminary assessment of pelagic resources of the common fishing area of Argentine-Uruguayan] . INAPE, Montevideo, Documento Técnico Nº14, 79 pp.

Fitch, J. E. & Brownell, R. L. J. (1971). Food habitats of the Franciscana, Pontoporia blainvillei (Cetacea, Platanistidae) from South America. *Bulletin of Marine Science*, 21:626–636.

Franco-Trecu, V., Costa, P., Abud, C. Dimitriadis, C., Laporta P., Passadore C., & Szephegyim M. (2009). By-catch of Franciscana Pontoporia blainvillei in Uruguayan artisanal gillnet fisheries: An evaluation after a twelve-year gap in data collection. *The Latin American Journal of Aquatic Mammals*, 7:11–22.

Gannon D. P., Read, A. J., Craddock, J. E., Fristrup, K. & Nicolas, J. (1997). Feeding ecology of long Winned pilot whales (*Globicephala melas*) in the western North Atlantic. *Marine Ecology Progress Series*, 148:1–10.

Gannon, D. P. (2003). Behavioral ecology of an acoustically mediated predator–prey system: bottlenose dolphins and sciaenid fishes. (Doctoral dissertation). Duke University.

Gannon, D.P, Barros, N. B., Nowacek, D. P., Read, A. J., Waples, D. M. & Wells, R. S. (2005). Prey detection by bottlenose dolphins (*Tursiops truncatus*): an experimental test of the passive listening hypothesis. *Animal Behavior*, 69:709–720. doi:10.1016/j.anbehav.2004.06.020

Hammer, Ǿ., Harper, D. A.T. & Ryan, P. D. (2001). PAST: paleontological statistic software package for education and data analysis. *Palaeontol Electronica*, 4(1):1–9

Hulbert, S. H. (1978). The measurement of niche overlap and some relatives. *Ecology*, 59: 67-77.

Hyslop, E. J. (1980). Stomach content analysis: A review of methods and their application. Jounalof Fish Biology, 17: 411–429. http://dx.doi.org/10.1111/j.1095-8649.1980.tb02775.x

Magurran, A. E. (2004). Measuring biological diversity. Oxford: Blackwell Publishing. ISBN 0-632- 05633-9.

Ludwig, J. A. & Reynolds, J. F. (1988). Statistical Ecology: A Primer on Methods and Computing. John Wiley and Sons, New York. 337 p.

Paso Viola, M. N., Denuncio, P., Panebianco, M. V., Negri, M. F., Rodriguez, D., Bastida, R., Cappozzo, H. L. (2014). Diet composition of Franciscana dolphin Pontoporia blainvillei from southern Buenos Aires, Argentina and its interaction with fisheries. *Revista de Biología Marina y Oceanografía*, 49: 393 – 400.

Pinedo, M. C. (1982). Analise dos conteúdos estomacais de Pontoporia blainvillei (Gervaise D'Orbigny, 1844) e Tursiops gephyreus (Lahille, 1908) (Cetacea, Platanistidae e Delphinidae) na zona estuarial e costeira de Rio Grande, R.S., Brasil [Analysis of the stomach contents of Pontoporia blainvillei (Gervaise D'Orbigny, 1844) and Tursiops gephyreus (Lahille, 1908) (Cetacea, Platanistidae and Delphinidae) in estuarial and coastal zone of Rio Grande]. (Master's thesis). University of Rio Grande, Brazil.

Praderi, R. (1984). Mortalidad de franciscana, Pontoporia blainvillei, en pesquerías artesanales de tiburón en la costa atlántica uruguaya. Revista del Museo Argentino de Ciencias Naturales .Bernardino Rivadavia., Zoología XIII: 259-272

Praderi, R, Pinedo, M. C. & Crespo, E. A. (1989). Conservation and management of *Pontoporia blainvillei* in Uruguay, Brazil and Argentina. In: Perrin WF, RL Brownell Jr, Z Kaiya & L Jiankang (eds). Biology and conservation of the River Dolphins. Occasional Papers of the IUCN Species Survival Commission 3: 52-56.

Ridgway, S., Samuelson, D., Van Alstyne, K. & Price, D. (2015). On doing two things at once: dolphin brain and nose coordinate sonar clicks, buzzes, and emotional squeals with social sounds during fish capture. *Journal of Experimental Biology*, 218, 3987-3995. doi: 10.1242/jeb.130559

Rodriguez, A. R. & Gasalla, M. A. (2008). Spatial and temporal patterns in size and maturation of *Loligo plei* and *Loligo sanpaulensis* (Cephalopoda: Loliginidae) in southeastern Brazilian waters, between 23°S and 27°S. *Scientia Marina*, 72(4): 631-643, doi:10.3989/scimar.2008.72n4631

Rodríguez, D, Rivero, L. & Bastida, R. (2002). Feeding ecology of Franciscana in marine and estuarine waters of Argentina. *Latin American Journal of Aquatic Mammals*, 1 (Special Issue 1): 77-94.

Reeves, R. R., Dalebout, M. L., Jefferson, T. A., Karczmarski, L., Laidre, K., O'Corry-Crowe, G., Rojas-Bracho, L., Secchi, E. R., Slooten, E., Smith, B. D., Wang, J. Y., Zerbini, A. N.

& Zhou, K. (2008). *Pontoporia blainvillei*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1. www.iucnredlist.org.

Secchi, E.R., Zerbini, A. N., Bassoi, M., Dalla Rosa, L., Möller, L. M. & Rocha-Campos, C. C. (1997). Mortality of Franciscanas, Pontoporia blainvillei, in coastal gillnetting in southern Brazil. *Report of the International Whaling Commission*, 47: 653-658.

Secchi, E. & Wang, J. 2003. Pontoporia blainvillei (Rio Grande do Sul/Uruguay subpopulation).Technical report, 2003 IUCN Red List of Threatened Species.

Segura A. M., Trinchin, R., Rabellino, J., Scarabino, F., Teixeira-de Mello, F. & Carranza, A. (2012). Length–weight relationships of 14 coastal fish species from Punta del Diablo (Rocha, Uruguay). *Journal* of A*pplied Ichthyology*, 1–2. doi: 10.1111/j.1439-0426.2012.02011.x

Sokal, R.R. & Rohlf, F. J. (1995). Biometry: the principles and practice of statistics in biological research. W.H. Freeman and Company, New York, 850 p.

Tellechea, S. J., Martinez, C., Fine, L. & Norbis, W. (2010). Sound production in whitemouth croaker (*Micropogonias furnieri*–Sciaenidae) and relationship between fish size and disturbance call parameters. *Environmental Biology of Fishes*, 89(2), 163. http://dx.doi.org/10.1007/s10641-010-9709-7

Tellechea, S. J., Bouvier, D., & Norbis, W. (2011a). Spawning sounds in whitemouth croaker (Sciaenidae), seasonal and daily cycles. *Bioacoustics*, 20(2), 159-168. http://dx.doi.org/10.1080/09524622.2011.9753641

Tellechea, S. J., Olsson, D., Norbis, W., & Fine, M. L.(2011b). Calls of the black drum (*Pogonias cromis*–Sciaenidae): Geographical differences in sound production between Northern and Southern hemisphere populations. *Journal of Experimental Zoology*, 315A(1), 48-55.

Tellechea, S. J. & M. L. Norbis, M. L. (2012). Sexual dimorphism in sound production and relationship between fish size and call characteristics in the striped weakfish *Cynoscion guatucupa*. *Zoological Studies*, 51(7), 946-955.

Tellechea, J. S. & Norbis, W. (2014). Sound characteristics of two neonatal Franciscana dolphins (Pontoporia blainvillei). *Marine Mammal Science*, 30:1573–1580.

Tellechea S. J., M. L. Fine, & C., Norbis, W. (2017). Passive acoustic monitoring, development of disturbance calls and differentiation of disturbance and advertisement calls in the Argentine croaker *Umbrina canosai* (Sciaenidae). Journal of Fish Biology. In press.

Discusión General y Conclusiones

En este estudio se caracterizaron los sonidos que emite el delfín la franciscana (*P. blainvilei*) y el delfin nariz de botella (*T. truncatus*) en su ambiente natural en la costa uruguaya. Tambien se caracterizaron por primera vez los sonidos emitidos por dos neonatos, un macho y una hembra, en cautiverio.

Los sonidos registrados de laa franciscana fueron de dos tipos: “clicks” de ecolocalización y “burt clicks”. En comparación con los datos publicados hasta el momento sobre los sonidos de la franciscana, los datos presentados en esta tesis muestran que la frecuencia de los “clicks” de los dos neonatos estudiados en cautiverio y de los individuos salvajes registrados son similares a los descriptos por Busnel et al (1974) en animales salvajes (Rango de frecuencia 4-23 kHz, intervalo “inter-click” entre 19 y 228 ms) en Punta del Diablo, Uruguay. Sin embargo las frecuencia obtenidas en estos estudios son menores a las presentadas por Von Fersen et al. (1997), quienes registraron en un individuo en cautiverio, frecuencias altas de 130 kHz. También en individuos adultos salvajes fueron registradas frecuencias mas altas (promedio de 139 kHz y un promedio de intervalo “inter-click” de 33 ± 4 ms) (Melcon et al. 2012) y para los sonidos de un neonato en cautiverio (frecuencia con rango entre 37 kHz y 160 kHz) (Melcon et al. 2016). Con relación a este último estudio, la frecuencia descripta tiene un componente que abarca las frecuencias descriptas por los dos estudios de sonidos realizados en esta tesis (Tellechea and Norbis 2014; Tellechea et al. 2016).

Una novedad descripta en esta tesis fue el registro por primera vez para la especie de sonidos “burst clicks”, tanto en cautiverio (Tellechea and Norbis 2014), como en individuos salvajes

(Tellechea et al. 2016). Para cetáceos como la franciscana en donde no se han registrado silbidos, los "burst clicks" son muy importantes (Herman and Tavolga 1980; Au and Hastings 2008), como lo son para la marsopa *Phocoena phocoena* para comunicación (Amundin 1991; Au and Hastings 2008; Tubbert-Clausen et al. 2010). Los "burts clicks" son una categoría de sonido muy emitida por todos los odontocetos (Au and Hasting 2008). En el delfín nariz de botella (*T. truncatus*) los "burts clicks" están asociados con un comportamiento de alarma, miedo y combate y son emitidos en encuentros cabeza a cabeza y boca abierta entre los individuos, a menudo acompañados de movimiento rápidos de la cabeza, sacudiendo y arqueando el cuerpo (Herzing 1988; Au and Hastings 2008).

Como resultado de posicionar boyas acústicas en la costa atlántica de Rocha para obtener los sonidos de los delfines franciscana y nariz de botella en su ambiente natural, solo se pudieron obtener los sonidos emitidos por el delfín nariz de botella o tonina (*T. truncatus*). En el capítulo 3 se describieron toda la gama de sonidos registrados de esta especie como son los silbidos y "clicks" de ecolocalización. Las boyas, fueron colocadas desde 200 m a 1000 m de la línea de costa que no serian lugares frecuentados por las franciscanas. En el sector de la costa donde se colocaron las boyas, la franciscana podría frecuentar distancias mayores a 1000 m de la costa, donde generalmente la especie es capturada de manera incidental por las redes de enmalle utilizadas por los pescadores artesanales (Fitch and Brownell 1971; Brownell and Praderi 1974; Brownell 1975; Praderi et al. 1989; Franco-Trecu et al., 2009). No se conocen registros de co – ocurrencia para estas dos especies de delfines (*T. truncatus y P. blanvillei*), fenómeno que puede ser debido a que los cetáceos mas pequeños que *T. truncatus*, como la franciscana, evitan encuentros para no ser agredidos (Ross and Wilson 1996; Jepson et al. 1998; Patterson et al 1998; Dunn et al. 2002; Wedekin et al. 2004; Cotter, 20012).

De los registros acústicos de los individuos salvajes de franciscana en Santa Lucía del Este (Canelones) (capitulo 4), se puede inferir que el uso del sonar no es tan activo como en el delfín nariz de botella (*T. truncatus*). Si bien la franciscana muestra un desarrollo del sonar a temprana edad (Tellechea and Norbis 2014, Melcon et al. 2016), los pocos minutos registrados descriptos en su ambiente natural (capitulo 4), podrían indicar que la franciscana no estaría usando su sonar muy a menudo y si bien el análisis del intervalo entre registros demuestra que los delfines estuvieron mas tiempo alrededor de las boyas, las emisiones de sonido no fueron muy frecuentes. Este poco uso del sonar podría estar relacionado a su costo metabólico (Gannon 2003; Gannon et al. 2005), o a otra estrategia para encontrar el alimento como es la escucha pasiva (Gannon et al. 2005; Berens- McCabe et al. 2010), muy utilizada por diferentes especies de cetáceos (Bigg et al. 1987; Barrett-Lennard et al. 1996). La franciscana tiene como ítems alimenticios a varias especies de peces que producen sonido (capítulo 5). En dicho capítulo se mostró que la franciscana tiene preferencia por presas productoras de sonido y se discutió que podría utilizar la escucha pasiva para localizar y encontrar sus presas mientras que utilizaria el sonar para capturarlas (Tellechea et al. 2016 submitted). Esta misma estrategia fue descripta para el delfín nariz de botella (Gannon et al. 2005; Berens- McCabe et al. 2010). La utilización de la escucha pasiva por parte de la franciscana podría estar también involucrada en la retención incidental de la especie por las redes de pesca, ya que la franciscana podría ser atraída a las redes de los pescadores por los sonidos que producen los peces cuando quedan enmallados en las redes (Tellechea et al. 2010, 2011; Tellechea and Norbis 2012b; Fine and Waybright 2015; Tellechea et al. 2016). El uso de dispositivos de advertencia acústica colocados en las redes de los pescadores artesanales para comprobar si la franciscana era ahuyentada por las emisiones de un sonido de alarma (banda ancha en frecuencia media de 10 kHz y 132 dB), demostró que la especie igual se enmallaba en las redes de pesca que tenían como objetivo la captura de corvina blanca (*M. furnieri*) y pescadilla (*C. guatucupa*) (Bordino et al. 2002), ambas especies productoras de sonido, inclusive cuando quedan enmalladas en la red (Tellechea et al. 2010; 2011; Tellechea and Norbis 2012b). El experimento realizado por Bordino et al (2002), demostró que aun con alarmas acústicas la franciscana seguía enredándose en estas redes donde también se atrapaban peces productores de sonido, lo que contribuiría a la hipótesis de que la franciscana, estimulada por el sonido de los peces enmallados, podría quedar atrapada al intentar alimentarse.

Algunos autores postulan que la franciscana no puede detectar las redes porque no tiene desarrollado el sonar como es el caso de los neonatos y jóvenes (Frainer et al. 2015). Sin embargo este estudio demostró que los dos neonatos estudiados emitieron "clicks" de ecolocalización (Tellechea and Norbis 2014). Además la hipótesis de Frainer et al. (2015) no explica porqué los adultos de franciscana quedan atrapados en las redes, ya que tienen un sonar desarrollado (Tellechea and Norbis 2014; Melcon et al 2012; Melcon et al 2016; Tellechea et al 2016) y de esta manera este delfín podría detectar las redes. Las redes contienen objetos como flotadores, cuerdas de anclaje de espesor de más de 2 cm y nudos. Estos objetos, al estar en contacto con la corriente del mar y el movimiento de la superficie del agua, generan importantes sonidos que pueden ser detectados fácilmente por la cualquier delfín y esto estaría reforzando la hipótesis de que la franciscana podría detectar y ser atraída hacia las redes fácilmente, aunque mas experimentos son necesarios para comprobar este comportamiento.

Implicancias de estos resultados en la conservación de la franciscana

La franciscana está amenazada en toda su área de distribución por la captura incidental en las redes de enmalle utilizadas por la pesca artesanal (Praderi et al. 1989; Crespo 2002; Danilewicz et al. 2002; Ott et al. 2002; Secchi et al. 2004; Franco-Trecu et al. 2009, Tellechea et al 2016). Si bien se han realizado esfuerzos para conocer las tallas, edades y grupos de franciscanas que mueren por el efecto de las redes, no se ha determinado como podría ser mitigado este efecto. El uso juicioso de la ecolocalización sugiere que esta modalidad sensorial incurre en costes energéticos o ecológicos significativos y que quizás este delfín está utilizando la escucha pasiva para alimentarse y tal vez la modalidad de escucha pasiva podría ser responsable de que este delfín muera enredado en las redes de pesca utilizadas por la pesca artesanal al ser atraída por los peces sonoros enredados en las redes que son presa de este delfin.

Perspectivas

Se considera que futuros trabajos podrían analizar las hipótesis planteadas en esta tesis y servir de base para diseños experimentales como aquellos que consideren el uso de “playbacks” con sonidos de peces enmallados en las redes y así poder dilucidar si la franciscana se siente atraída para alimentarse de tales peces. También será necesario realizar más estudios con boyas de escucha pasiva para localizar áreas de preferencias de la franciscana, sobre todo relacionadas al comportamiento reproductivo (Diciembre – Febrero) (Harrison et al. 1981), áreas donde podría ser necesario prohibir el uso de redes para la pesca, y delinear la creación de áreas protegidas específicas para este delfín en peligro de extinción.

Capitulo 7.- Resultados acústicos obtenidos en mamíferos marinos utilizando la bioacustica

Los siguientes artículos publicados tienen que ver con el uso de la bioacustica como herramienta en la investigación en mamíferos marinos como el primer estudio acústico realizado en las costas de Uruguay para la ballena franca austral (*Eubalaena australis*) y un estudio realizado en la Bahía Jobos, Puerto Rico-USA, de como el sonido antropogénico cambia los patrones de comportamiento en el manati (*Trichechus manatus manatus*).

Tellechea S. J., Roman G.P., and Martinez N. (2012). Distribution of manatees and noise near a coastal power plant. *Journal Caribean Science* v.: 47, p.: 363 - 366.

Tellechea S. J., & Norbis, W. (2012). A note on recordings of Southern right whales (*Eubalaena australis*) off the coast of Uruguay. *Journal of Cetacean Research and Management*. 12(3): 361–364.

Bibliografia

Au, W.W., Floyd, R.D.W., Penner, R.H., and Murchison, E.A. (1974). Measurement of echolocation signals of the Atlantic Bottlenose dolphin, Tursiops truncatus Montagu, in open waters. J. Acoust. Soc. Am. 56:1280-1290.

Au, W.W. (1980). Echolocation signals of the Atlantic bottlenose dolphin (Tursiops truncatus) in open water. P. 251-282. In: R. –G. Busnel and J. F. Fish (Eds) Animal Sonar Systems. Plenum Press, New York and London 1135 pp.

Au, W.W., D.A. Carder, R.H. Penner, B.L. Scronce (1985). Demonstration of adaptation in beluga whale echolocation signals, J. Acoust. Soc. Am. **77**, 726– 730.

Au, W.W., Poper A.N., Fay, R.R. (2000). Hering by Whales and Dolphins. Springer Hnadbook of Auditory Research (eds).

Au, W.W. and Hastings, M. C. (2008). Principles Of Marine Bioacoustics. Springer-Verlag.

Barrett-Lennard, L. G., Ford, J. K. B., and Heise, K. A. (1996). The mixed blessing of echolocation: differences in sonar use by fish-eating and mammal-eating killer whales. AnimalBehaviour, 51: 553–565.

Barros, N. B. and Odell, D. K. (1990). Food habits of bottlenose dolphins in the southeastern United States. In: The Bottlenose Dolphin (Ed. by S. Leatherwood & R. R. Reeves), pp. 309–328. San Diego: Academic Press.

Barros, N. B. (1993). Feeding ecology and foraging strategies of bottlenose dolphins on the central east coast of Florida. Ph.D. thesis, University of Miami.

Barros NB, Wells RS (1998) Prey and feeding patterns of resident bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida.J Mammal 79:1045–1059

Bazua-Duran, M. C. (1997). Comparasisons of whistles among different groups dolphins (*Tursiops truncatus*) from the gulf of Mexico, MS thesis, Universidad Nacional Autonoma de Mexico.

Bordino, P., G. Thompson and M. I niguez. (1999). Ecology and behaviour of the Franciscana (*Pontoporia blainvillei*) in Bahia Anegada, Argentina. Journal of Cetacean Research and Management 1:213–222.

Bordino, P., S. Kraus, D. Albareda, A. Fazio, A. Palmerio, M. M´endez and S. Botta. (2002). Reducing incidental mortality of Franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. Marine Mammal Science 18:833–842.

Brownell RL.Jr.and R Praderi (1974). Present research and conservation problems with the Franciscana, *Pontoporia blainvillei*, in Uruguayan waters. ACMRR/FAO/Doc.23, La Jolla, Calif., USA, Dec. 16-19, 1974

Brownell, R.L. Jr (1975) Progress report on the biology of the Franciscana Dolphin, *Pontoporia blainville*i, in Uruguayan waters. *Journ. Fish. Res. Bd. Canada*, 32 (7): 1073-1078

Busnel R, . G., A. Dziedzic and G. Alcuri. (1974). Etudes preliminaries de signaux acoustiques de *Pontoporia blainoillet* Gervais et D'Orbigny (Cetacea, Platanistidae). Marnmalia 38:449-459.

Caldwell, M. C., and Cadwell, D. K. (1965). Individualized whistles contours in bottlenose dolphins (Tursiops truncates). Science, 207, 434-435.

Connaughton MA, Taylor MH (1996) Drumming, courtship and spawning behavior in captive weakfish, Cynoscion regalis. Copeia 1996:195–199.

Connaughton MA, Taylor MH, Fine ML (2000). Effects of fish size and temperature on weakfish disturbance calls: implications for the mechanism of sound generation. J Exp Biol 203:1503–1512.

Connaughton MA, Lunn ML, Fine ML, Taylor MH (2003). characterization of sounds and their use in two sciaenid species: weakfish and Atlantic croaker. In: Rountree RA, Goudey C.
Cotter, M.P. 2012. "Porpicide" in California: Killing of harbor porpoises (Phocoena phocoena) by coastal bottlenose dolphins (Tursiops truncatus). Marine Mammal Science. 28, 1: E1-E15.

Corcuera, J. (1994). Incidental mortality of Franciscanas in Argentine waters: The threat of small fishing camps. Report of the International Whaling Commission (Special Issue 15):291–294.

Corcuera J., Monzon F., Crespo E.A., Aguilar A. and Raga J.A. (1994) Interactions between marine mammals and the coastal fisheries of Necochea and Claromeco´ (Buenos Aires, Argentina). Reports of the International Whaling Commission (Special Issue) 15, 283–290.

Corcuera J., F. Monzoni, I . Cornejo, J. Perez, A Beilis, M. Gingareldlia, L. Bareda and A. Arias. (1998). Mortalidad de *Pontoporia blainvillei* en el Norte de la Provincia de Buenos Aires. UNEPKMS. 2000. Report of the Third Workshop for Coordinated Research and Conservation of the Franciscana Dolphin *Pontoporia blainvillei* in the Southwestern Atlantic. Available from UNEPiCMS Secretariat, United Nations Premises in Bonn, Martin Luther King Str. 8, 53 175 Bonn, Germany.

Crespo, E. A. (1992). Report of the workshop. Workshop for the Coordination of Research and Conservation of the franciscana Dolphin (*Pontoporia blainvillei*) in the southwestern Atlantic.

Buenos Aires, Argentina. Internal Report, United Nations Environment Programme, Nairobi, Kenya. 30 pp.

Crespo, E. A., J. Corcuera and A. Lopez Cazorla (1994). Interactions between marine mammals and fisheries in some fishing areas of the coast of Argentina. Report of the International Whaling Commission (Special Issue 15):269–282.

Crespo, E. A. (1998). Informe del Tercer Taller para la Coordinaci´on de la Investigacion y la Conservacion de la franciscana (*Pontoporia blainvillei*) en el Atlantico Sudoccidental. Report to the Convention of Migratory Species (UNEP), Bonn, Germany. 23 pp.

Crespo, E. A. (2002). Franciscana, *Pontoporia blainvillei*. *In*: Perrin, W.F., Wursig, B., Thewissen, J.G.M. (Eds). Encyclopedia of marine mammals. San Diego, CA: Academic Press. p. 482-485.

Cousseau M B Nión H Denegri M & S Olivera (1998). Lista de peces de la Zona Común de Pesca Argentino-Uruguaya. Frente Marítimo 17:123-154. Montevideo.

Desportes G, Mouritsen R (1993). Preliminary results on the diet of long-Wnned pilot whales of the Faroe Islands. Rep Int Whal Comm (special issue 14):304–324

Dunn, D.G., Barco, S.G., Pabst, D.A., McLellan, W.A. 2002. Evidence for infanticide in bottlenose dolphins of the western north Atlantic. Journal of Wildlife Disease. 38, 3: 505-510.

Evans W.E. (1967). Vocalization among marine mammals. In: Tavolga WN (ed) Marine Bioacoustics, Vol. 2. New York: Pergamon, pp. 159-186.

Fine ML, Winn HE, Olla B (1977) Communication in fishes. In: Sebeok T (ed) How animals communicate. Indiana University Press, Bloomington, pp 472–518.

Fine ML, Malloy KL, King CB, Mitchell SL, Cameron TM. (2001). Movement and sound generation by the toadfish swimbladder. J Comp Physiol A 187:371–379.

Fine, ML, Schrinel J, Cameron TM (2004) The effect of loading on disturbance sounds of the Atlantic croaker Micropogonius undulatus: air versus water. J Acoust Soc Am 116:1271– 1275.

Fish MP, Mowbray WH (1970) Sound of the Western North Atlantic fishes. Johns Hopkins Press, Baltimore.

Fitch, J.E., and Brownell R.L. (1971). Food habits of the Franciscana Pontoporia blainvillei (Cetacea:Plantanistidae) from South America. Bull. Marine Sci., vol. 21, pp. 626-636.

Franco-Trecu V., Costa P., Abud C., Dimitriadis C., Laporta P., Passadore C. & Szephegyi M., (2009). Franciscana Pontoporia blainvillei bycatch in uruguayan artisanal gillnet fisheries: an evaluation after a twelve-year gap in data. Latin American Journal of Aquatic Mammals, 7(1-2): 11-22. ISSN 1676-7497.

Gannon DP, Read AJ, Craddock JE, Fristrup K, Nicolas J (1997) Feeding ecology of long-Wnned pilot whales (*Globicephala melas*) in the western North Atlantic. Mar Ecol Prog Ser 148:1–10.

Gannon DP, Barros NB, Nowacek DP, Read AJ, Waples DM, Wells RS (2005) Prey detection by bottlenose dolphins (*Tursiops truncatus*): an experimental test of the passive listening hypothesis. Anim Behav 69:709–720. doi:10.1016/j.anbehav.2004.06.020

Grafen A and R. Hails. 2002. Modern Statistics for the Life Sciences', Oxford University Press. 62.

Harrison, R. J., Bryden, M. M., McBrearty, D. A. and Jr, R. L. B. (1981), The ovaries and reproduction in *Pontoporia blainvillei* (Cetacea: Platanistidae). Journal of Zoology, 193: 563–580. doi:10.1111/j.1469-7998.1981.tb01504.x

Hawkins T (eds) Listening to fish: Proceedings of the International Workshop on the Applications of Passive Acoustics to Fisheries, April 8–10, 2002. MIT Sea Grant Technical Report, Dedham, MA, pp 1–4

Herman, L. M. and Tavolga, W. N. (1980). The communication systems of cetaceans. In L. M. Herman (Ed.), *Cetacean behavior: Mechanisms and functions*, 149-209. New York: Wiley Interscience.

Herzing, D.L. and dos Santos, M. (2004). Functional Aspects of Echolocation in Dolphins. In: Echolocation in Bats and Dolphins (Ed. by J. A. Thomas, C. F. Moss & M. Vater), pp. 386–393. Chicago: University of Chicago Press.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs, 54, 187–211.

Irvine AB, Scott MD, Wells RS, Kaufmann JH (1981) Movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. Fish Bull US 79:671–688

Jefferson, T.A., S. Leatherwood, and M.A. Webber (1993). FAO species identification guide. Marine mammals of the world. Rome, FAO. 320. p. 587 figs.

Johnson, S. C. 1967. Sound detection thresholds in marine mammals. Marine Bioacoustics, edited by W. N. Tavolga (Pergamon, New York), Vol. 2. pp. 247–260

Kroodsma, D. E., Byers, B. E., Goodale, E., Johnson, S. & Liu, W. C. 2001. Pseudoreplication in playback experiments, revisited a decade later. Animal Behaviour, 61, 1029–1033.

MacLeod CD, Santos MB, Lopez A, Pierce GJ (2006). Relative prey size consumption in toothed whales: implications for prey selection and level of specialization. Mar Ecol Prog Ser 326:295–307

Martin, P. and Bateson. P. 2007. *Measuring Behaviour: An Introductory Guide.* 3rd edition. Cambridge: Cambridge University Press.

May-Collado LJ and Wartzok D. (2007). The freshwater dolphin Inia geoffrensis geoffrensis produces high frequency whistles. J Acoust Soc Am. 121(2):1203-12.

Melcon, M. L., M. Failla and M. A. Íñiguez. 2012. Echolocation behavior of franciscana dolphins (Pontoporia blainvillei) in the wild. Journal of Acoustical Society of America 131:448–453

Mok HK, Gilmore RG (1983). Analysis of sound production in estuarine aggregations of Pogonias cromis, Bairdiella chrysoura, and Cynoscion nebulosus (Sciaenidae). Bull Inst Zool Acad Sin 22:157–186.

Monzon F. and Corcuera J.F (1991). Franciscana *Pontoporia blainvillei* (Gervais and d'Orbigny, 1844). In Cappozzo H.L. and Junı´n M. (eds) Estado de conservacion de los mamıferos marinos del Atlantico sudoccidental. Informes y estudios del Programa de Mares Regionales del PNUMA, No 138, pp. 16–22.

Nakasai, K., and Takemura, A. (1975). ‘‘Studies on the underwater sound VI: On the underwater calls of fresh dolphins in South America,’’ Bull. Fac. Fish. Nagasaki. Univ. 40, 7–13.

Norbis W (1995) Influence of wind, behaviour and characteristics of the croaker (Micropogonias furnieri) artisanal fishery in the Río de la Plata (Uruguay). Fish Res 22:43– 58

Norbis W, Paesch L, Galli O. (2006). Los recursos pesqueros de la costa de Uruguay: ambiente, biología y gestión. In: MenafraR,Rodriguez-GallegoL, ScarabinoFy, CondeD, editors. *“Bases para la conservación y manejo de la costa uruguaya”*. Montevideo: VIDA SILVESTRE URUGUAY, i–xiv+668 p. (ISBN: 9974-7589-2-0). Paginas: 197–211.

Norris, K. S., Harvey, G. W., Burzell, L. A., and Kartha, T. D. K. (1972). Sound production in the freshwater porpoises *Sotalia fluviatilis* and *Inia geoffrensis*, in the Rio Negro, Brazil, Investig. Cetacea 4, 251–260.

Ladich F, Fine ML (2006) Sound-generating mechanisms in fishes: a unique diversity in vertebrates. In: Ladich F et al (eds) Communication in fishes. Science, Enfield, pp 3–43

Patterson, A.P., Reid, R.J., Wilson, B., Grellier, K., Ross, H.M., Thompson, P.M. 1998. Evidence for infanticide in bottlenose dolphins: an explanation for violent interactions with harbour porpoises? Proceedings of the Royal Society London B. 265: 1167-1170

Jepson, P.D. & Baker, J.R. 1998. Bottlenosed dolphins (Tursiops truncatus) as a possible cause of acute traumatic injuries in porpoises (Phocoena phocoena). 143: 614-614.

Pinedo, M. C., R. Praderi and R. Brownell Jr. (1989). Review of the biology and status of the franciscana *Pontoporia blainvillei*. Pages 46–51 *in* W. F. Perrin, R. L. Brownell Jr., Z. Kaiya and L. Jiankang, eds. Biology and conservation of the river dolphins. Occasional papers of the IUCN Species Survival Commission (SSC) 3.

Pinedo, M. C. (1994). Report of the workshop. Anais do 2◦ Encontro sobre Coordenacao de Pesquisa e Manejo da franciscana. Florian´opolis, Brasil. 77 pp.

Perez-Macri G. and Crespo E.A. (1989) Survey of the franciscana, *Pontoporia blainvillei*, along the Argentine coast, with a preliminary evaluation of mortality in coastal fisheries. IUCN Occasional papers IUCN SSC 3, 57–63.

Perrin,W. F., R. L. Brownell Jr., Z. Kaiya and L. Jiankang. (1989). Biology and conservation of the river dolphins. Occasional papers of the IUCN Species Survival Commission (SSC) 3. 173 pp.

Perrin W, . F., G. P. Donovan and J. Barlowe, DS. (1994). Gillnets and cetaceans. Reports of the International Whaling Commission. (Special Issue 15).

Praderi, R. (1984). Mortalidad de franciscana, en pesquerias artesanales de tiburon de la costa Atlantica Uruguayana. Revista del Museo Argentino de Ciencias Naturales ‘Bernardino Rivadavia’ e Instituto Nacional de Investigation de las Ciencias Naturales, 13, 259–272.

Praderi, R., Pinedo, M.C. and Crespo, E.A. (1989). Conservation and management of *Pontoporia blainvillei* in Uruguay, Brazil and Argentina. Pages 52-56 *in* Perrin, W.F., Brownell, R.L., Kaiya, Z. and Jiankang, L. (Eds) *Biology and Conservation of the River Dolphins*. Occasional Papers. IUCN SSC 3: Gland, Switzerland.

Praderi, R. (1994). Analisis comparativo de estadısticos de captura y mortalidad incidental de *Pontoporia blainvillei* en Uruguay durante 20 años. Anais do 2◦ Encontro sobre Coordenacao de Pesquisa e Manejo da franciscana, Florianopolis, Brasil. EF/2/DT9. pp 42–53.

Purves, P.E., and Pilleri G. (1983). Echolocation in Whales and Dolphins. London: Academic Press.

Reeves, R.R., Dalebout, M.L., Jefferson, T.A., Karczmarski, L., Laidre, K., O'Corry-Crowe, G., Rojas-Bracho, L., Secchi, E.R., Slooten, E., Smith, B.D., Wang, J.Y., Zerbini, A.N. & Zhou, K. (2008). *Pontoporia blainvillei*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. www.iucnredlist.org.

Rosas, F., Monteiro-Filho, E. L. A. And Oliveira, M. R. de (2002). Incidental catches of franciscana (Pontoporia blainvillei) on the southern coast of São Paulo State and the coast of Paraná State, Brazil. Latin American Journal of Aquatic Mammals 1(1): 161-167. Special Issue 1. 2002

Ross, H.M. & Wilson, B. 1996. Violent interactions between bottlenose dolphins and harbour porpoises. Proceedings of the Royal Society London B. 263: 283-286.

Scott MD, Wells RS, Irvine AB (1990) A long-term study of bottlenose dolphins on the west coast of Florida. In: Leatherwood S, Reeves RR (eds) The bottlenose dolphin. Academic Press Inc, San Diego, pp 235–244.

Secchi, E. R., J. Y. Wang, B. Murray, C. C. Roccha-Campos and B. N. White. (1998). Populational differences between Franciscanas, *Pontoporia blainvillei*, from two geographical locations as indicated by sequences of mtDNA control region. Canadian Journal of Zoology 76:1–6.

Secchi, E. R., P. H. Ott and D. Danilewicz. (2001*a*). Report of the IV workshop for the coordinated research and conservation of the Franciscana dolphin (*Pontoporia blainvillei*) in the western south Atlantic. Porto Alegre, Brazil.

Secchi, E. R., P. H. Ott and D. Danilewicz. (2003). Effects of fishing bycatch and the conservation status of the Franciscana dolphin, *Pontoporia blainvillei*. Pages 174–191 *in* N.

Sokal RR, Rohlf FJ (1995) Biometry: the principles and practice of statistics in biological research. W.H. Freeman and Company, New York, 850 p

Steiner, W.W. (1981). Species-specific differences in pure-tonal whistle vocalizations of five Western North Atlantic dolphin species. Behav. Ecol. Sociobiol. 9, 241-246.

Tellechea S. J., Martinez, Michael L. Fine, & C., Norbis, W. 2010. Sound production in whitemouth croaker (*Micropogonias furnieri* -Sciaenidae) and relationship between fish size and disturbance call parameters. Environmental Biology of Fishes, Volume 89, Issue 2, 163.

Tellechea, S. J., Olsson D., Norbis W, & Fine M. L. (2011a). Calls of the black drum (*Pogonias cromis*-Sciaenidae): Geographical differences in sound production between Northern and Southern hemisphere populations. *Journal Experimental Zoology*, 315 A , issue 1, 48-55.

Tellechea, S. J., Bouvier, D. & Norbis, W. (2011b). Spawning sounds in whitemouth croaker (Sciaenidae), seasonal and daily cycles. *Bioacoustics* in press.

Tellechea S. J., Olsson D.,& Norbis, W. (2012). Sexual dimorphism in sound production and sonic muscle in the striped weakfish *Cynoscion guatucupa* (C.), Submit in *Zoological Studies*.

Tellechea S. J., M. L. Fine, & C., Norbis, W. (2017). Passive acoustic monitoring, development of disturbance calls and differentiation of disturbance and advertisement calls in the Argentine croaker *Umbrina canosai* (Sciaenidae). Journal of Fish Biology. In press.

Von Fersen L., C. Kamminga and A. Seidl. (1998). Estudios preliminaries sobre el comportamiento de un ejemplar de Franciscana *Pontoporia blainvillei* en Mundo Marino, Argentina. UNEPKMS. 2000. Report of the Third Workshop for Coordinated Research and Conservation of the Franciscana Dolphin *Pontoporia blainuillei* in the Southwestern Atlantic. Available from UNEPKMS Secretariat, United Nations Premises in Bonn, Martin Luther King Str. 8, 53 175 Bonn, Germany.

Wedekin, L.L., Daura-Jorge, F.G., Simoes-Lopes, P.C. 2004. An Aggressive Interaction Between Bottlenose Dolphins (Tursiops truncatus) and Estuarine Dolphins (Sotalia guianensis) in Southern Brazil. Aquatic Mammals. 30, 3: 391-397.

Wells RS, Irvine AB, Scott MD (1980). Ecology of inshore odontocetes. In: Herman LM (ed) Cetacean behavior: mechanisms and functions. Wiley, New York, pp 263–315

Wells RS, Scott MD, Irvine AB (1987). The social structure of freeranging bottlenose dolphins. In: Genoways H (ed) Current mammalogy, vol 1. Plenum Press, New York, pp 247–305

Wells RS, Scott MD (1999). Bottlenose dolphin *Tursiops truncates* (Montagu, 1821). In: Ridgway SH, Harrison R (eds) Handbook of marine mammals, the second book of dolphins and porpoises, vol 6. Academic Press, San Diego, pp 137–182

Wells RS, Tornero V, Borrell A, Aguilar A, Rowles TK, Rhinehart HL, Hofmann S, Jarman WM, Hohn AA, Sweeney JC (2005) Integrating potential life history and reproductive success data to examine potential relationships with organochlorine compounds for bottlenose dolphins

(*Tursiops truncatus*) in Sarasota Bay, Florida. Sci Total Environ. doi: 10.1016/j.scitotenv.2005.01.010

Wood III FG (1964). Discussion. In: Tavolga W. (ed) Marine Bio-Acoustics, Vol 2 Oxford: Pergamon Press, pp. 395-396

Ximenez, A., Langguth, A., and Praderi R.(1972). Lista sistemática de los mamíferos del Uruguay. An. Mus. Nac. Hist. Nat. Montevideo, ser. 2, vol. 7, no. 5, pp. 1-49.