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**Characterization of acoustic activity for recurrent dolphins´
species from the Mexican Central Pacific**



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Characterization of the acoustic activity of recurrent dolphins' species from the Mexican Central Pacific

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Characterization of the acoustic activity of recurrent dolphins' species from the Mexican Central Pacific

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

(María José Ferrer Aguilar)

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Resumo

Os mamíferos marinhos são uma família caracterizada por respirar ar pelos pulmões, ter sangue quente, pelo, ter glândulas mamárias e dar à luz seus filhotes vivos, apresentando adaptações para sobreviver em ecossistemas marinhos. Entre eles estão os cetáceos que incluem dois grupos: os mysticetos que são conhecidos como baleias ou cetáceos com barbas, e os odontocetos ou cetáceos com dentes, aos quais pertencem uma grande variedade de espécies, entre elas golfinhos, botos e cachalotes.

Os golfinhos são uma família representada por pelo menos 37 espécies de tamanho entre pequeno e médio, com uma grande variedade de morfologias. São considerados animais vocais, pois possuem um sistema auditivo muito sensível, capaz de detectar uma faixa de frequência de 100 Hz até 150 kHz. Além disso, eles são capazes de emitir três tipos de sons: a) cliques de ecolocalização, que são sons de banda larga de alta intensidade e curta duração, b) sons de pulsação em rajadas, que são pacotes de pulsos de banda larga e c) sons de assobio ou apitos, de banda estreita geralmente emitida entre 4 e 20 kHz. Neste estudo, foram considerados estes últimos, os apitos, pois sua emissão pode estar relacionada à socialização e alimentação. Esses animais marinhos vivem em grupos e, portanto, são animais muito sociais que precisam de comunicação para se localizar, detectar predadores e evitá-los, se reproduzir e cuidar dos seus filhotes. Nos últimos anos, o tráfego marítimo tem acrescentado muito, assim como outras atividades antrópicas que produzem poluição sonora. Isso pode ter efeitos prejudiciais sobre os golfinhos e muitos outros organismos, uma vez que o oceano é um mundo de sons. Através das características dos assobios (frequência, duração, número de pontos de inflexão e forma), um caminho pode ser traçado para pelo menos para identificar diferentes espécies. Além disso, a bioacústica está começando a ser usada como uma alternativa aos estudos tradicionais de barco, de forma que com hidrofones colocados em áreas diferentes, a preferência de habitat das espécies marinhas pode ser rastreada. Desta forma, podemos também melhorar o conhecimento sobre o comportamento noturno desses animais, já que a falta de luz torna muito difícil observar. Devido à migração do zooplâncton durante o pôr do sol e conseqüentemente peixes que se alimentam dele e são presas para os golfinhos, seria lógico pensar que é uma boa hora para os golfinhos se alimentarem, mas existem muitos estudos que registam esse comportamento durante o dia para algumas espécies e à noite para outras.

Muitas espécies estão distribuídas em todo o mundo, como o roaz-corvineiro (*Tursiops truncatus*), o grampo (*Grampus griseus*) ou as orcas (*Orcinus orca*). Porém, alguns mostram uma distribuição mais limitada com preferências mais costeiras ou mais oceânicas. No Pacífico Central Mexicano (PCM) podem ser encontradas 14 espécies diferentes de mamíferos marinhos. Este estudo foca-se em 5 espécies: roaz- corvineiro, golfinho-rotador (*Stenella longirostris*) e grampo em águas oceânicas e o golfinho-pintado-pantropical (*Stenella attenuata*) e golfinho-de-dentes-rugosos (*Steno bredanensis*) que têm hábitos costeiros. Este estudo foi dividido em duas partes: 1) caracterizar e diferenciar os assobios das 5 espécies de golfinhos e 2) determinar a ocorrência de golfinhos ao longo do dia e nas diferentes localidades da costa de Manzanillo (Colima, México).

No primeiro caso, os registos foram obtidos a partir de um barco e com confirmação visual da espécie, além de registar o número do grupo dos indivíduos e se algum tipo de comportamento se destacou. As gravações foram, então, visualizadas em um software denominado “Spectogram”, de onde foram extraídas as características dos apitos: frequência (inicial, final, mínimo e máximo), duração, número de pontos de inflexão e forma. Com esses parâmetros, uma análise estatística descritiva pode ser realizada para cada espécie. Finalmente, cada uma dessas características foi comparada entre os diferentes tipos de golfinhos para determinar se havia diferenças entre eles. No caso das espécies costeiras, golfinhos-pintados e golfinhos-de-dentes rugosos, eles apresentam diferenças em todos os parâmetros. Em relação aos golfinhos oceânicos, o mais destacado foi o grampo. Tanto os grampos quanto os golfinhos-de-dentes rugosos apresentaram baixas frequências, duração e número de pontos de inflexão em comparação com as outras três espécies. Não obstante, diferenciar o grampo dos golfinhos-de-dentes-rugosos pode ser difícil sem confirmação visual. Igualmente no golfinho-pintado-pantropical, no roaz-corvineiro e no golfinho-rotador, as suas frequências altas são muito semelhantes. As pistas a seguir podem ser tanto o habitat (costeiro ou oceânico) quanto o número de pontos de inflexão no caso do roaz-corvineiro. Porém, as espécies oceânicas foram fruto de um único encontro, portanto seus apitos poderiam ser influenciados pela presença do navio, número de indivíduos, presença de filhotes e outros fatores.

No segundo caso, os dados foram obtidos com uma bóia à qual estava ancorado um contentor hermético que continha o hidrofone e baterias que permitiam uma gravação entre um e dois dias. As bóias foram colocadas na entrada das baías, na baía de Manzanillo e na baía de Santiago. As gravações foram analisadas por meio da contagem do número de assobios dos golfinhos e da detecção da presença acústica dos mesmos.

O registro das horas de chegada e recolha do hidrofone permitiu calcular as horas em que os golfinhos emitiram sons: de noite ou de dia. A análise dos resultados revelou que a atividade acústica é a mesma à noite e de dia, de igual jeito que a mesma na presença: há golfinhos à noite e de dia. Quanto às áreas, constatou-se que eles tinham preferência pela Baía de Manzanillo, talvez por ser uma área que lhes oferece abrigo e alimentação. Dado que as espécies residentes na área são o golfinho-pintado e o roaz- corvineiro, pode-se inferir que são os responsáveis pela emissão desses sons. Também foi constatado que não há diferenças na atividade acústica na estação ou no ano de estudo. Algumas das gravações da entrada poderiam até ser consideradas como sendo de golfinho-de-dentes-rugosos por dois motivos: as frequências dos apitos são baixas, de curta duração, a segmentação dos apitos, quase não têm ponto de inflexão, e porque a equipe do GUIMM vê esta espécie em torno da área com frequência. Portanto, o golfinho-de-dentes-rugosos e o golfinho-pintado podem ser facilmente diferenciados um do outro, assim como o grampo, roaz-corvineiro e o golfinho-rotador. No entanto, se as preferências de habitat forem eliminadas, diferenciar acusticamente as espécies de golfinhos seria mais complicado. Por enquanto, a hipótese de que sejam mais ativos acusticamente à noite é descartada, mas eles têm preferências de habitat, sendo a baía de Manzanillo a mais solicitada.

Palavras-chave: golfinhos, acústica, Pacífico Central Mexicano, assobios, parametros

Abstract

The characteristics of the sound communication are key elements of the behavior of dolphins. Since 2014 the team GUIMM (Grupo Universitario de Investigación de Mamíferos Marinos) of the University of Colima was recording and monitoring with acoustic buoys some populations of dolphins; mainly five species: the bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*), Spinner dolphin (*Stenella longirostris orientalis*), Rough-toothed dolphin (*Steno brenadensis*) and the Pantropical spotted dolphin (*Stenella attenuata*) distributed in Mexican Central Pacific (MCP), specifically in the Colima and Jalisco coasts. This study aimed on whistles analysis to find differences between species or even within the same species. Method was based on whistles parameters, such as: frequency (maximum and minimum), duration, and number of inflection points. Then, a spatial comparison to determine the use of bays by dolphins, and a seasonal comparison to identify differences in the day/night cycle, as well as seasons and years, were made. The whistles' parameters allowed to discriminate two group of dolphin species, 1) those with whistles conformed by higher frequencies (pantropical spotted dolphin, spinner dolphin, and bottlenose dolphin) and 2) those with whistles with lower frequencies (rough-toothed and Risso's dolphins). The spinner and pantropical spotted dolphins showed similar high frequencies in whistles, therefore they only can be differentiated by its presence in oceanic and coastal habitat, respectively. While low frequencies revealed some specific features that allow us to identify acoustically the different species. Moreover, the acoustic activity of the dolphins seemed to predominate in 2016 in the winter months, and during nocturnal periods of time. This allowed us to infer that rough-toothed and spotted dolphin are responsible for most of the whistles recorded in the region. Bioacoustic has turned out to be a great tool in the research of cetaceans, mainly to collect enough information to contribute to the conservation status against anthropic activities.

Key words: dolphins, acoustic, Mexican Central Pacific, whistles, parameters

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CHAPTER 3: Occurrence determination in daytime and among coastal areas of Manzanillo coast

Table 3.1. Whistles registered from dolphins inside the bays of Colima, Mexico during the period of September 2015 to January 2019. N = number of records extracted; Mean = the average of whistles; Range = lowest and highest number of whistles; and WRR = Whistles Recording Rate.

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List of Abbreviations

MCP – Mexican Central Pacific

ETP – Eastern Tropical Pacific

GUIMM – Grupo Universitario de Investigación de Mamíferos Marinos

Hz – Hertz

kHz – Kilohertz

Sb – *Steno bredanensis*

Sa – *Stenella attenuata*

S1 – *Stenella longirostris orientalis*

Gg – *Grampus griseus*

Tt – *Tursiops truncatus*

Start.F – Start frequency

Final.F – Final frequency

Max.F – Maximum frequency

Min. F – Minimum frequency

N.I.P – Number of inflexion points

WRR – Whistles Recording Rate

1- Chapter 1: General introduction

1.1- Marine mammals

1.1.1 General aspects of Marine mammals

Mammals are vertebrate animals characterized by breathing air through lungs, warm-blooded, hair, the presence of mammary glands and give birth to alive offspring (Rowe, 1988). In the marine ecosystem, the mammals could play a keystone role (Kiszka, Heithaus & Wirsing, 2015), specially, those that have special adaptations (*e.g.*, sounds production to conduct ecological activities) to the aquatic life (Mirceta *et al.*, 2013). These marine mammals have been divided in three orders: part of Carnivora, which include pinnipeds, polar bears, and sea otters; Sirenia, for manatees and dugongs; and Artiodactila, being included whales, porpoises, and dolphins (Perrin *et al.*, 1983; Gatesy *et al.*, 1999; Perrin, Wüsig & Thewissen, 2009).

1.1.2 Taxonomy, biology and ecology of dolphins

Inside the order Artiodactila is the infraorder Cetacea, which include baleen and toothed whales (Graur & Higgins, 1994; Gatesy *et al.*, 1999). Mysticeti are those cetaceans whose characteristics are a large size (all whales included in this category), a doubled blowhole to breathe air, a symmetrical skull, a sternum composed by a single bone, and presence of baleens instead of teeth hanging from upper mandible. On the other hand, Odontoceti have a small to medium size (with the sperm whale, being the exception, reaching 16-18 m of total length), these organisms have teeth, a single blowhole, an asymmetrical skull, a sternum composed by three or more bones, a complex system of nasal sacs, and the presence of the melon, an organ to echolocate (Jefferson *et al.*, 1993). They are represented by 75 species, being the Delphinidae family the most abundant with 37 species (Committee of Taxonomy, 2018). Dolphins are small to medium size, being the Hector's dolphin (*Cephalorhynchus hectori*) the smallest with 1.2-1.5 m, and the killer whale (*Orcinus orca*) the biggest with 8 m of total length.

Prey preferences of dolphins are mainly fish and cephalopods, but some of them can predate other marine mammals. One example of this feeding behavior is the killer whale that can hunt pinnipeds, and from small cetaceans such as porpoises, up to big whales (Silber & Newcomer, 2015).

The dolphins' gestation period is variable among species, for example common dolphins, *Delphinus delphis*, is around 10 months (Harrison, 1969), and for pilot whales, *Globicephala melas*, is approximately of 16 months (Frazer & Hugger, 1973). The sexual maturity ranged from 3 years in common dolphins to 16 years in killer whales (Kleinenberg, 1956; Christensen, 1982). The exclusive lactation period could range from three (pan-tropical spotted dolphin, *Stenella attenuata* and striped dolphin *Stenella coeruleoalba*) to 11 months (bottlenose dolphin, *Tursiops truncatus*) and the number of calves is maximum of one each reproductive season (Kasuya, Miyazaki & Dawbin, 1974; Miyazaki, 1977; Leatherwood, Deerman & Potter, 1978).

1.1.3 Target cetacean species

Some dolphin species show a worldwide distribution, *i.e.*, the bottlenose dolphin, Risso's dolphin (*Grampus griseus*) and killer whale (Carwardine, 1995). However, most of the species show a limited distribution with coastal or oceanic preferences. In the Mexican Central Pacific (MCP), species usually found in oceanic waters are bottlenose dolphin, spinner dolphin (*Stenella longirostris orientalis*), and Risso's dolphin. While species found in the coastal waters are pantropical spotted dolphin, and rough-toothed dolphin (*Steno bredanensis*) (Ortega-Ortiz *et al.*, 2013).

1- Spinner dolphin (*Stenella longirostris orientalis*; Gray, 1828)

The spinner dolphin (Fig.1.1A) is a relatively small species, with a slim head, and with an extremely long, thin beak. Its dorsal fin can be ranges from a bit falcate to erect and triangular. This dolphin shows a monotone gray colour pattern of the body, with only patches in the genital area and axillae. Adult females measure 1.71 m and adult males 1.76 of total length, with a weigh of at least 82 kg (FAO, 1993; Jefferson *et al.*, 1993).

2- Bottlenose dolphin (*Tursiops truncatus*; Montagu, 1821)

This dolphin species (Fig.1.1B) is one of the largest animals from the family, it is a relatively robust dolphin. Its beak is considered from short to moderate size, which is separated from the melon by a crease. The dorsal fin is set near the middle of the back and is tall and falcate. The fluke is broad and has a mediannotch.

Colour pattern of the body varies from light to dark gray or black on the dorsal region and sides, being fading to white on the belly (FAO, 1993; Jefferson *et al.*, 1993). Adults range from 1.9-3.8 m of total length, with males being larger than females and weighing at least 650 kg. Usually, adults have a lot of scars and are darker than the calves or juveniles (Harzen & Brunnick, 1997).

3- Risso's dolphin (*Grampus griseus*; Cuvier, 1812)

Risso's dolphins (Fig.1.C) have a robust body and are blunt-headed animals with a squarish profile and without distinct beak. The mouth lines have a slope upward and they have a vertical crease on the front of the melon, important feature to recognize them. Before the flippers these dolphins present a whitish anchor-shaped patch. Adult's total length is around 3.8 m and its weigh range from 400 to 500 kg (FAO, 1993; Jefferson *et al.*, 1993). The colour pattern of the body varies with age, being silvery gray when they are calves to pale gray as juveniles, and finally almost white for mature individuals (Hartman, Fernandez & Azevedo, 2014).

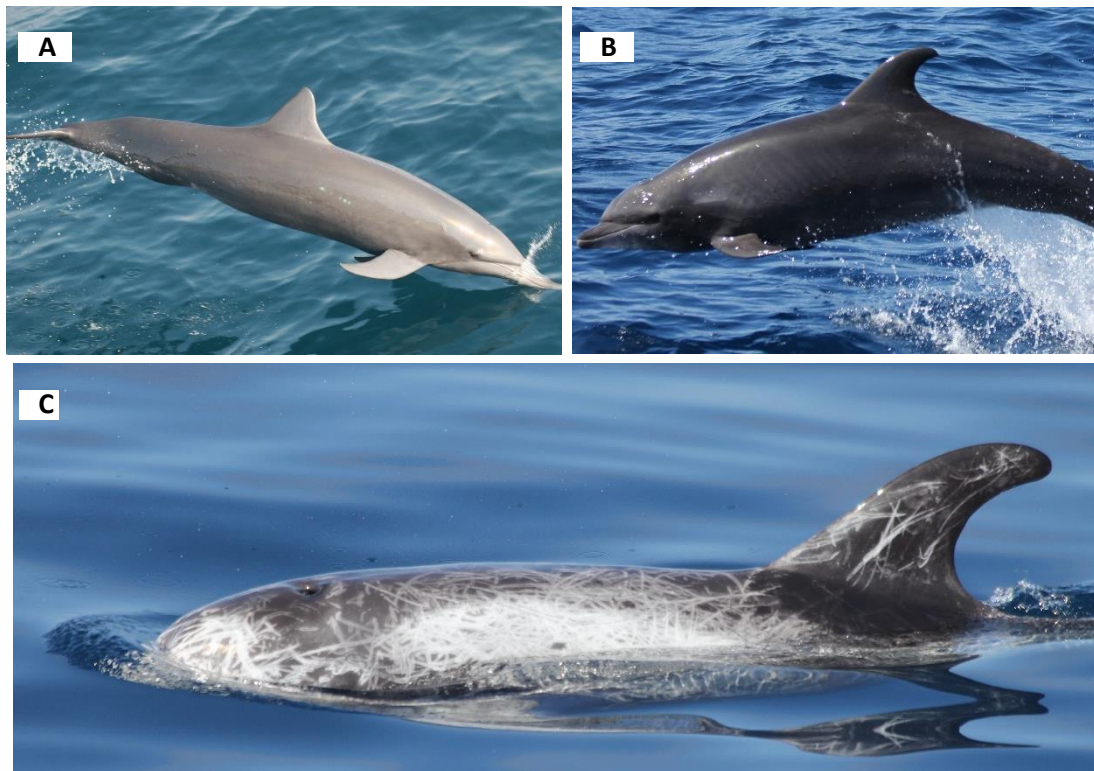


Fig. 1.1 A) The spinner dolphin (*Stenella longirostris orientalis*), B) the bottlenose dolphin (*Tursiops truncatus*), C) the Risso's dolphin (*Grampus griseus*), which have been registered on the oceanic region of the Mexican Central Pacific. Photo credits: GUIMM.

4- Pantropical Spotted dolphin (*Stenella attenuata*; Gray, 1846)

Generally, the spotted dolphin (Fig.1.2) is a slender animal with a long thin beak that is separated from the melon by a distinct crease. The dorsal fin is narrow, falcate, and rounded at the tip. The flippers are very slim, and curves and the fluke are unremarkable. The colour pattern of the body is dark grey on the dorsal cape with degrees of white mottling, which is narrow in the head and growth in front of the dorsal fin. Adults reach between 1.6-2.4 m (female) or 1.6-2.6 (male) of total length, and the maximum weight is around 119 kg (Leatherwood, 1993; Jefferson *et al.*, 1993). Although it is known that this species is dominant in the MCP region (Kono-Martínez *et al.*, 2017), there is not a lot of information about its ecology.



Fig1.2. Rough-toothed dolphin (*Steno bredanensis*) (left) and pantropical spotted dolphin (*Stenella attenuata*) (right) registered on the coastal region of the Mexican Central Pacific. Photo credits: GUIMM.

5- Rough-toothed dolphin (*Steno bredanensis*; Lesson, 1828)

Rough-toothed dolphin (Fig1.2) is characterized by a robust body with a long conical head without demarcation between the melon and the long beak. Large flippers in comparison with the body size of the animal, and they are set farther back on the body than other species of dolphins. The dorsal fin is prominent and a little bit falcate (FAO, 1993; Jefferson *et al.*, 1993). Colour pattern of the body is generally dark or dark brown; while lower jaw and belly are usually blotched with white patches, and with a pinkish tinge. Adults reach about 2.65 m of total length (males are a little longer than females) and weight up to 155 kg (FAO, 1993; Jefferson, Leatherwood & Webber, 1993). This species is found usually in oceanic waters (Miyazaki, 1994) or in insular environments (Baird *et al.*, 2008). Nevertheless, in some regions from the world they occurred on coastal waters, *e.g.*, in Colima and south of Jalisco, Mexico (Ortega-Ortiz *et al.*, 2014a; Figueroa-Soltero, 2017).

1.2 Ecological importance of sounds in dolphins

Dolphins have been considered as acoustic animals, they have an auditory system really sensitive, which is able to detect a range of high frequencies from 100 Hz until 150 kHz (Johnson, 1967; Szymanski *et al.*, 1999). Besides, all dolphin species can create three different kind of sounds: a) *echolocation clicks*, which are broadband sounds of high intensity with short duration, and sometimes, dolphins produced them in rapid succession and they are known like “click train” (Au, 1993; Gridley *et al.*, 2015); b) *burst pulses*, which are broadband packets of pulses that due their high repetition is like fast click series showed in the spectrogram as harmonic bands, listened as continuous sounds by humans (Herzing 2000; Gridley *et al.*, 2015); and finally c) *whistles*, are narrow-band sounds with frequency modulated (Díaz-López & Shirai, 2009), and usually they are emitted in a range between 5 and 20 kHz (Caldwell, Caldwell & Tyak, 1990; Murray, Mercado, & Roitblat, 1998). These sounds increase also during social and feeding behavior (Acevedo-Gutiérrez & Stienessen, 2004).

The discovery of the echolocation in the sixties’ decade induced the research to wonder: How the sound is produced and why dolphins emitted sound? The dolphin sonar is an emission of clicks that allow them to draw “map” of the marine environment and to detect prey (Ketten, 1992). Classically, burst pulses could be related with aggressive social behavior and to help the male in the courtship in order to have the female closer (Overstrom, 1983; Smolker & Connor, 1996), and also it could be used during feeding activities (Arranz *et al.*, 2016). On the other hand, whistles are used for foraging and in 2005, Douglas Nowacek showed that the emission of whistles was highest in alone dolphins that in grouped individuals. In addition, these kinds of sounds are emitted more frequently while they are feeding, and when there are sharks in the area (Acevedo-Gutiérrez & Stienessen, 2004).

On the other hand, the nocturnal behavior in wild dolphins continue being mysterious. It is known that the nocturnal migration of zooplankton (Marlowe & Miller, 1975) causes a vertical displacement for intermediate trophic level species, mainly composed by fish and cephalopod (Gibbs & Roper, 1971; Roe & Badcock, 1984); consequently the foraging activity by some dolphins species increases (Norris *et al.*, 1994; Sazima, Sazima & Silva-Jr, 2006), which is related with the interaction with other individuals and the acoustic activity.

Remains of cephalopods beaks and nocturnal or crepuscular species of fishes were found in stomach contents of common dolphin, spinner dolphin, and spotted dolphin; results that have suggested that dolphins mainly hunt during night periods (Norris & Dohl, 1980; Wang *et al.*, 2003; Pusineri *et al.*, 2007 ; Benoit-Bird & Au 2009;Marçalo *et al.*, 2018).

1.3 Scientific studies of dolphins in Mexico, particularly in the Mexican Central Pacific

Mexico is located between the two bigger oceans of the world, the Atlantic and the Pacific; therefore, it supports a large diversity of marine fauna. The taxonomic group with a major diversity for marine masto-fauna are the cetaceans, which are represented by 40 species, most of them being dolphins (Torres *et al.*, 1995; Ceballos, 2016). First studies in the Eastern Tropical Pacific (ETP), region extended along the Pacific Coast of the Americas, were focused on the relation between dolphins and fisheries of tuna (Hyde, 1979; Wade & Gerrodette, 1993), besides of changes in its distribution (Reilly, 1990). Although, most of studies about basic ecology, *i.e.*, distribution, abundance, photo-identification, movements, feeding activity, among others, have been conducted in the Gulf of California and the Gulf of Mexico (Acevedo, 1991; Ballance, 1992; Griffin & Griffin 2003; Rosel *et al.*, 2011). For the MCP region studies about dolphins are scarce; only one study about morphometry and sexual dimorphism of spotted dolphin from Banderas Bay had been conducted (Sanvicente-Añorve *et al.*, 2004).

However, recently research effort has been increased, because several ecological aspects of the spotted dolphins are being studied, *i.e.*, distribution, abundance, and trophic niche (Díaz-Torres *et al.*, 2022), and skin diseases (Rojas-Cortes, 2019). While for rough toothed dolphin only, some highlights about its feeding activities (Ortega-Ortiz *et al.*, 2014a) and its spatial ecology have been investigated. Also, the recent pressure in the Mexican coast due to an increment in the touristic and commercial ship traffic, the interest in this kind of studies also is increasing (Ortiz-Lozano *et al.*, 2005; Sanchez-Cabeza & Druffel, 2009; de la Esperanza *et al.*, 2017;). Furthermore, in terms of acoustic, anthropogenic noise can be detrimental in these animals in terms of stress, change in its migrations, masking of their communication, disorientation, hearing loss temporary or permanent, and massive stranding (Hildebrand, 2004; Lusseau, 2005; Weilgart, 2007a: Weilgart, 2007a), which deserves further attention.

Furthermore, most of studies in the Pacific Ocean about dolphin bioacoustics have been conducted in offshore waters, predominating in the south of USA (Oswald, Rankin, & Barlow, 2008; Rankin *et al.*, 2008; Barkley *et al.*, 2011;). The absence of studies about the acoustic in the coast of the MPC region reveal that more investigations are needed.

1.4 Acoustic parameters

1.4.1 Bioacoustics definition

Bioacoustics is the science that studies the sound in relation with the behavior of animals (Salamon *et al.*, 2017). The transmission of the sound in water is much efficient due to its properties than in air, reaching a velocity of 1,500 m/s (Nummela & Thewissen, 2008; Vigness-Raposa & Scowcroft, 2012). This physical feature has been a culminant factor for the adaptation of several marine animals. Dolphins are animals completely adapted to the marine environment; they use sound through specific signals to survive (Vauclair, 1996). Dolphins use sound to navigate, to locate prey, to hunt, to mate, and to communicate (Dudzinski, 1996).

1.4.2 First studies of bioacoustics in dolphins

First bioacoustical studies were conducted in animals in captivity, usually with the bottlenose dolphin because this species shows a cosmopolitan distribution, mainly on coastal waters, therefore maneuvers to capture them have been easier (Perrin, Würsig & Thewissen, 2009). Dolphin sonar was recognized by McBride in 1947 and it was demonstrated using captive experiments in 1956 by Schevill and Lawrence (Ridgway, 1983). Studies with wild dolphins began since the seventy decades, particularly with the bottlenose dolphin echolocation to determine the range and the propagation of one particular sound: the clicks (Au *et al.*, 1976; Murchison, 1976). However, controlled conditions of acoustic experiments in swimming pools have given researchers facilities to understand communication between dolphins.

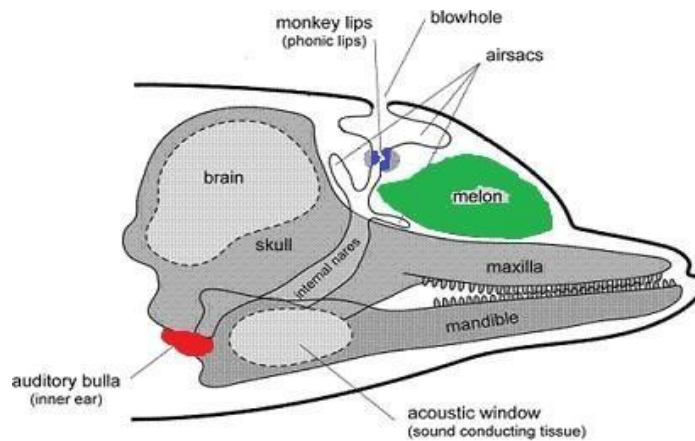
The most common studies have been about the acoustic signature that reveal each individual (Caldwell & Caldwell, 1965) and in relation to age-class or between mother and calf, using methods of positive reinforcement (Wahlberg *et al.*, 2011).

In 1985 at the Sealand, an aquarium, Peter Tyack tried to find whistle signature with two captive bottlenose dolphin individuals. Using a machine called “vocaligh” that was attached in the head of the dolphin with a suction cup. The vocaligh have LEDs with different colors, green and red, for the two different dolphins with the objective of discriminate which sound come from each animal (Tyack, 1986). Years later, investigations were amplifying to other species of wild dolphins. In 2005, Chritiane Ansmann showed that whistles of common dolphin from Celtic Sea varied according encounters, behavior, and group sizes; and proved that frequencies were different from English Channel (Ansmann, 2005). In the case of killer whales were demonstrated that the parameters of whistles are more complex than other species and showed harmonical sounds (Thomsen, Franck & Ford, 2001). On the other hand, whistles emitted by spotted dolphin in South Atlantic Ocean were described for the first time in 2010, and modifications of whistle structure depending of behavior showed (Azevedo *et al.*, 2010).

1.4.3 Production and emission of sounds

Dolphins’ sounds (clicks, burst pulses, and whistles) (Díaz López & Shirai, 2009; Vigness-Raposa & Scowcroft, 2012) are produced in their specific nasal structures located in the head, which are conformed by several anatomical structures: 1) the melon, a compound bulbous fatty organ that contributes to focus sounds (Varanasi, Feldman & Malins, 1975; Liste *et al.*, 2006); 2) air sacs, are oval structures located between the trachea and the blowhole and could be used to produced sound or breathe (Fraser & Purves, 1960);

3) phonic lips, are membranes located in 3-2.5 cm below of the blowhole in the both sides of the nasal complex (Cranford, Amundin, & Norris, 1996; Cranford *et al.*, 2011); 4) auditory bulla, is a bone that contain the middle and inner ear (McCormick *et al.*, 1970); 5) lower jaw divides in two bones, which is composed by adipose tissue (Maxia *et al.*, 2007), and 6) cranial asymmetry, which gives the directional audition very accurate and facilitates echolocation (Fahlke *et al.*, 2011) (Fig.1.3).



Sound generator: The Monkey Lips/Dorsal Bursae Complex (MLDB)

Fig.1.3. Cranial anatomy of *Tursiops truncatus*. In red, the auditory buoy; in green, the melon; in blue phonic lips. In addition, the air sacs and the low jaw (“panbone”) are showed. Image modified from Cranford et al. (1996).

The production sound mechanism was classified into three categories: friction, pneumatic, and cavitation (Cranford, 2000). Nowadays the hypothesis more accepted is the pneumatic mechanism, although, some advances in the compression of the production of sound were performed. It is suggested that the clicks are produced with the right phonic lips; while the whistles are produced with the left pair of phonic lips (Au *et al.*, 2012).

1.4.4 Whistles characterization

Whistles are considered the way of communication in dolphin species, therefore there are a lot of studies about them (Janik & Slater, 1998; Seabra de Lima *et al.*, 2012; Elwen & Gridley, 2017; Erbe *et al.*, 2020; La Manna *et al.*, 2020). Each whistle sound has its own characteristics:

1. Frequency: number of completes oscillations in unit of time (Gayo, 2006), with the Hertz (Hz) as unit of measurement. Human range frequency is between 20 Hz and 20 kHz (Munar *et al.*, 2002); while in whistles dolphins’ range of frequency emission are found between 4 and 40 kHz (Caldwell, Caldwell& Tyak, 1990; Erbe *et al.*, 2017).
2. Duration: time interval between the initial time (moment when a whistle starts) and the final time (moment when the same whistle ends).

3. Inflexion points: it shows the change in the concavity of one whistle.
4. Shapes: whistles have different forms and can be classified following Diaz-López (2011) in: “Rise” (whistle without inflexion point and ascending frequencies), “Fall” (whistle without inflexion point and descending frequency), “Wave” (whistle with one inflexion point and with frequencies ascending-descending), “U-Shape” (whistle with one inflexion point and frequencies descending-ascending), “Flat” (whistle without inflexion point and almost constant frequency), “Sine” (whistle with one or two inflexion point), and “Multi-loop” (whistle with more than two inflexion point) (Fig.1.4).

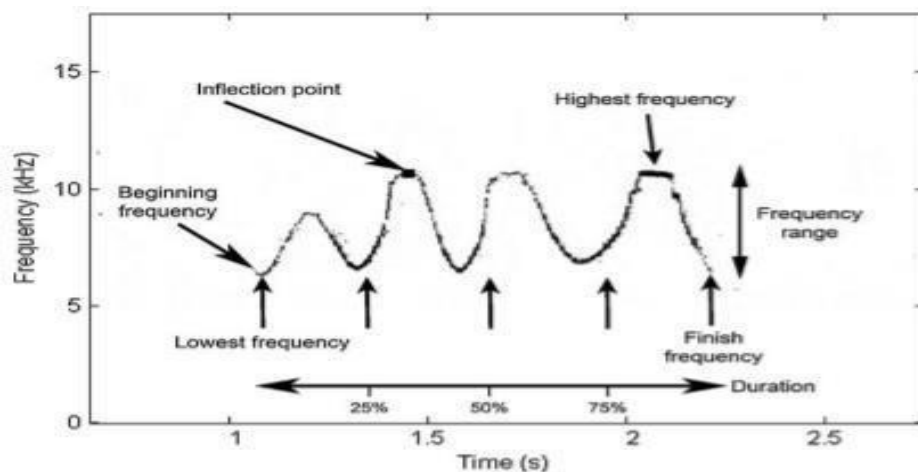


Fig.1.4. Whistle of bottlenose dolphin from a Sardinia record (Italy), which shows a multiloop shape (diagram from Diaz-Lopez, 2011).

The bottlenose dolphin has been considered as a “model” to study acoustics, however, it is necessary to increase research that contribute with acoustic repertoire for other dolphin species, and its ecological implications.

2- Justification

Cetaceans play an important ecological role into the marine food chains as top predators. The dolphin adaptations to the marine ecosystem have enhanced several biological-ecological activities as communication, breeding, feeding, and navigation. Bioacoustics is a research line that increase the knowledge about ecology of these species.

In Mexico, acoustic studies directed to cetaceans are scarce; particularly for the MCP (Mexican Central Pacific), ecology studies about dolphins are almost null. Recent research has been focusing on several ecological parameters for spotted dolphin, but other dolphin species that share the same region have not been studied.

It is necessary a research focus on the description of acoustic parameters for sound types generated by dolphin species distributed in coastal waters of the MCP region, such as the spotted dolphin, the rough-toothed dolphin, the bottlenose dolphin, the spinner dolphin and other occasional species like the Risso's dolphin, in order to understand the importance of the region for ecological activities of these protected species by national and international laws. Besides, in this region the coastal development is increasing; thereby, anthropogenic activities could cause a noisy environment, which could be a potential disturbance for marine fauna.

3- Hypothesis

Could acoustic activity (whistles) be different among dolphin species in the MCP region, with a differential occurrence along the Colima coast? Will this activity increase during nocturnal periods?

4- Objectives

General Objective

To investigate acoustic activity of dolphin species from Mexican Central Pacific (MCP)

Particular Objectives

1. To characterize acoustic parameters of whistles produced by dolphin species from MCP region
2. To discriminate whistles differences between dolphins from MCP region
3. To determine the occurrence of the acoustic activity of dolphins among sites of Colima coast
4. To describe the occurrence of the acoustic activity of dolphins during day/night cycles in the Colima coast.

Chapter 2: Whistle's characterization of dominant dolphin species distributed in the waters of the Mexican Central Pacific

2.1 Introduction

Communication is the exchange of information between individuals and plays an important role in the ecology of many marine species (Díaz López & Shirai, 2009; Fouda *et al.*, 2018). Dolphins are one of the most vocal and social group of marine mammals (Lammers, Au & Herzing 2003; Committee on Taxonomy, 2018). It was thought that dolphin species showed a frequency range of whistles emission between 4 and 20 kHz but recent studies revealed that could be emitted until 40 kHz (Caldwell, Caldwell & Tyack, 1990; Erbe *et al.*, 2017), while they are able to detect sounds in frequencies from 100 Hz until 150 kHz (Johnson, 1967; Szymanski *et al.*, 1999).

The acoustic repertoire of the bottlenose dolphin (*Tursiops truncatus*) has been the most studied because this species shows a worldwide coastal distribution, and it also show a high adaptation to captivity (Overstrom, 1983; Tyack, 1986; Harzen & Brunnick, 1997; Nowacek, Wells & Solow, 2001; Cotter, Maldini & Jefferson, 2012). Considered as a model, research of the bottlenose dolphin acoustics had revealed different types of sounds characterized by the frequency and the shape: *clicks*, *burst pulses* and *whistles* (Van Parijs, Parra & Corkeron, 2000; Thomas, Fristrup & Tyack, 2002). *Clicks* are broadband sounds of high intensity with short duration (Au, 1993; Gridley *et al.*, 2015); broadband packets of pulses are known as *burst pulses* (Herzing, 2000; Gridley *et al.*, 2015); and *whistles* are tonal signals with frequency modulated, usually not exceed 20 kHz (dos Santos *et al.*, 2005; Díaz-López & Shirai, 2009; Azevedo *et al.*, 2010). The use of these types of sounds by wild dolphin species is unknown, due to the difficulties to obtain data at sea, followed by their analyses and interpretation. But it has been suggested that some acoustic repertoire is related with social and feeding behavior (Acevedo-Gutiérrez & Stienessen, 2004). On the other hand, the increase of the noise pollution in recent years in all oceans around the world, is a current concern because the noise produced by ships could produce that dolphins' species changes their repertoire of sounds (Tyack, 2008; Peng, Zhao & Liu, 2015; Rodrigo-Saura *et al.*, 2019). For example, some studies have evidenced modifications in whistles characteristics, particularly an adjusting of the frequencies, due to the "masking" related with the ship noise (Jensen *et al.*, 2009; Heiler *et al.*, 2016; Fouda *et al.*, 2018).

However, to obtain a complete evaluation about this disturbance agent, more scientific evidence on this topic is needed, mainly improved knowledge regarding the baseline information about acoustic of dolphins.

Particularly for whistle sounds, several characteristics have been described, *i.e.*, frequency, duration, number of inflexion points, and shape. According to Díaz-López (2011), the shapes of whistles are divided in seven categories: “rise”, “fall”, “wave”, “u-shape”, “flat”, “sine” and “multi-loop”. Characterization of whistles have allowed to show differences or similarities in the same species due to the social separation, habitat division and the connectivity of populations (May-Collado & Wartzok, 2008; Lima *et al.*, 2020). Besides, the whistles shape could be a clue to identify different groups of dolphins (Datta & Sturtivant, 2002), and it could variate depending on the individual behavior (Díaz López, 2011). For example, in captivity, it was demonstrated that pregnant females produced a high emission of whistles, potentially to prepare the calf to recognize the mother’s signature whistle in the postpartum, something crucial to survive (Mello & Amundin, 2005). Also, groups research showed that in conditions of travel speed, common dolphin (*Delphinus delphis*) increases the number and complexity of sounds (Henderson *et al.*, 2012).

Acoustical identity is given by the whistle signature based on the frequency modulation pattern used to playing a role of individual recognition (Sayigh *et al.*, 1999; Janik & Sayigh, 2013). Thereby, current research has been directed to try to discriminate signature of whistles among individuals, groups, and dolphin species (Oswald *et al.*, 2007; Esch, Sayigh & Wells 2009; Azevedo *et al.*, 2010; La Manna *et al.*, 2019). In this way, it is also known that dolphins can recognize and response to whistle signature from other individuals from the same pod (Sayigh *et al.*, 1999). Moreover, some research suggests that whistles differentiation among dolphin wild pods is feasible, with the condition that the pods must be small (Janik, Sayigh, & Wells, 2006; Quick & Janik, 2012). However, other research suggests that whistles of dolphins are not similar even though they are from the same family or pod, because immature individuals select sounds from sporadic individuals to make the whistle signature (Fripp *et al.*, 2005; Janik *et al.*, 2006). Additional research was performed with 17 residents Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Australia, to match the whistles’ signature with photo-identified individuals resulting in a two hierarchical cluster trees, but without achieving an unique match (Erbe *et al.*, 2020). Likewise, differences in whistles for Atlantic spotted dolphins

(*Stenella frontalis*) from coastal and offshore pods have been reported (Baron *et al.*, 2008). All these particular examples show that, whistle differences between individuals are one of the most difficult tasks to conduct with wild dolphins.

Given the previous background, it is evident that more research on dolphin acoustics is needed. The study of acoustic differences among species should be actually prioritized ahead of other particular studies (*i.e.*, among pods or individuals). In this context, whistle signatures for short-beaked common dolphin (*Delphinus delphis*), Pacific spotted dolphin (*Stenella attenuata*), and Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) have been described (Caldwell & Caldwell, 1968; Caldwell & Caldwell, 1971; Caldwell, Caldwell & Miller, 1973), but these have not been compared. Instead, Simões Amorim *et al.* (2019) found differences in a descriptive approach of the repertoire of whistles for eight species: spinner dolphin (*Stenella longirostris*), Atlantic spotted, rough-toothed dolphin (*Steno bredanensis*), Risso's dolphin (*Grampus griseus*), bottlenose dolphin, short-beaked common dolphins, killer whale (*Orcinus orca*) and long-finned pilot whales (*Globicephala melas*). More recently, Gannier *et al.* (2020) conducted an acoustic study to differentiate between common dolphins and Atlantic spotted dolphins in Azores.

With the hypothesis that parameters of whistles will be easily differentiable among dolphins' species from the Mexican Central Pacific (MCP), a region that shows a relevant coastal development and is also an habitat of several species of marine mammals (Wade & Gerrodette, 1993; Ortega-Ortiz *et al.*, 2013); this research is the first acoustic regional approach to characterize and differentiate whistles emitted by five species: Pacific spotted dolphin, rough-toothed dolphin, both with a coastal distribution (Ortega-Ortiz *et al.*, 2014a; Kono-Martínez *et al.*, 2017), and bottlenose dolphin, spinner dolphin and Risso's dolphin, which have not been studied in the region, but considered mainly from oceanic habitats. Our potential results will contribute to describe the habitat use of these protected species in the MCP region, in order to obtain the basic knowledge for future conservation strategies.

2.2 Methods

2.2.1 Study area

Surveys were conducted along the Colima, Jalisco, and Michoacán coasts considering as a limit Cabo Corrientes towards north (Jalisco), and Maruata towards south (Michoacán) (Fig.2.1).

This area is known as part of the Mexican Central Pacific (MCP) which is influenced by two ocean currents: the California and the Mexican Coastal (De la Lanza, 1991; Gómez-Valdivia *et al.*, 2015).

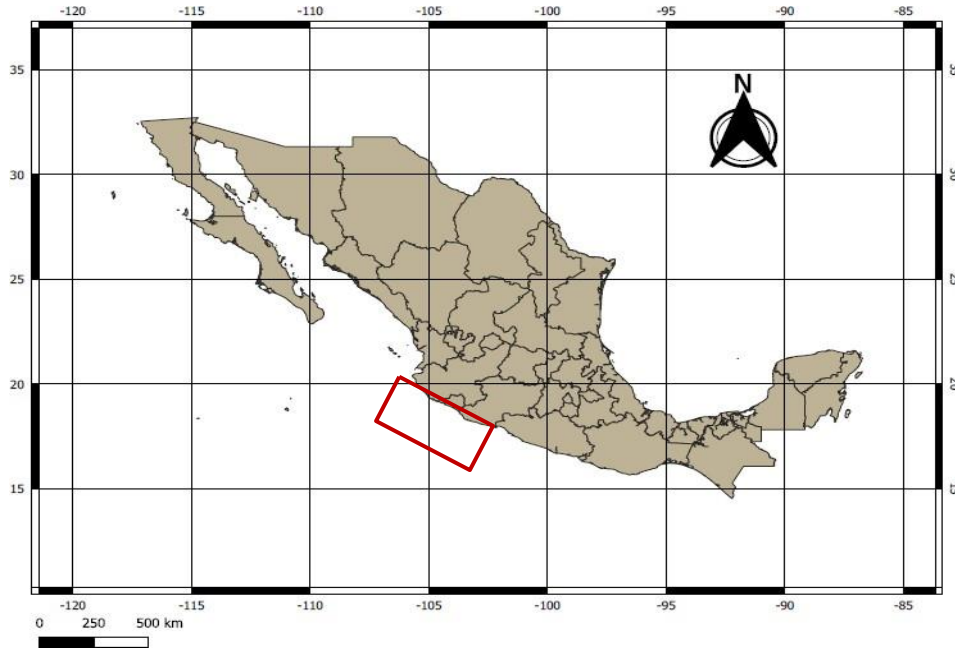


Figure 2.1. Study region in the Mexican Central Pacific (MCP) that includes the coast of three states: Jalisco, Colima and Michoacán.

2.2.2 Data collection

During 2013-2019 the research team (Grupo Universitario de Investigación de Mamíferos Marinos, GUIMM) of the Faculty of Marine Sciences (FACIMAR) of the University of Colima, conducted surveys on board of *Facimar II*, the University vessel, with 7.9 m in length and equipped with a 75hp four strokes engine.

Boat surveys were non-systematic during sun light, taking a mean of $8:39 \pm 1:43$ hours of travel, in the coasts of the MCP region to look for dolphins. Data collection was carried out by the crew, composed of five people, through direct observations when the visibility was not reduced by rain or fog. For each dolphin encounter the following data were collected: time, date, geographic location (registered by a Garmin map 76CS global positioning system), species identification, group size estimation, and behavior activities. Additionally, photographs and acoustic recordings were taken. Photographs were taken using a digital camera Canon EOS 60D, to distinguish morphological features to support species identification.

After taking photographs or simultaneously, acoustic data was recorded manually with a unidirectional hydrophone (0.020-45 kHz; re1V/ μ Pa=-169) with a maximum depth of 6-7 meters and connected to the digital recorder (Zoom H1, sampling rate: 48kHz). Depending on the acoustic activity or the behavior of dolphins, the duration of recordings could change. The vessel's engine was stopped for acoustic data acquisition.

2.2.3 Data analysis

The recordings obtained were downloaded in a computer for analysis with a specific software called Spectrogram version 6.2.3.

It faces the duration of the recording (abscissa axis) with the sound frequency (ordinate axis). Parameters were selected for the frequency at which these dolphin species emit, in this case, the maximum (30.470 Hz) allowed by the software.

The most important part of the analysis was to discriminate whistles, from those sounds emitted from other sources. For this, firstly the whistles with the best quality were selected, through the extraction of its main characteristics. The shape, frequencies, and even the sound itself were the key to discriminate dolphins' whistles from the environmental noise. Therefore, recordings were only selected when they showed medium or low background noise (*i.e.*, less than 7 kHz).

Recordings were heard and displayed minute by minute in 10-second windows. In order to identify the whistles, the shapes classification given by Diaz-López (2011) was considered: "Rise" (without inflexion point and ascending frequencies), "Fall" (without inflexion point and descending frequency), "Wave" (with one inflexion point and with frequencies ascending-descending), "U-Shape" (with one inflexion point and frequencies descending-ascending), "Flat" (without inflexion point and almost constant frequency), "Sine" (with one or two inflexion point), and "Multi-loop" (with more than two inflexion point). Besides, the identification and exclusion of a harmonic (*i.e.*, the repetition of the same whistle at different frequencies) was considered to avoid bias (Díaz-Lopez, 2011). Whistles overlapping could be registered in some cases, when they interfere with the extraction of the desired characteristics. In addition, "fractured" sounds were found, which may or may not belong to the same whistle. To discriminate it, temporal separation between sounds was not more than 3 ms to consider the same whistle. In cases where limit time was exceeded, it was considered as two independent whistles.

All whistles were identified in Spectrogram visually and acoustically, which is known as double confirmation; then, whistles with good quality were those with the entire contour visible (May-Collado & Wartzok, 2008). Consecutive repetition of the same whistle structure which are known as “bout” was also tabulated. In these cases, the data was extracted with the best whistle and the other repetitions were assumed to have the same characteristics. When the time between whistles was greater than 10 s, it was considered a new whistle or a new “bout”.

2.2.4 Determination of the characteristics of whistles

In whistles with good quality, the extraction of their characteristics was performed, these being: start time, end time, and number of inflection points, and duration (from initial time to final time).

These variables were chosen because they can be easily measured from a spectrogram and to allow comparisons with results of previous studies of any dolphin species. Frequency (Hz) of whistles in this study was described with these values: maximum and minimum (Díaz-López, 2011). All these characteristics could allow to determine differences between whistles from dolphins’ species (Steiner, 1981).

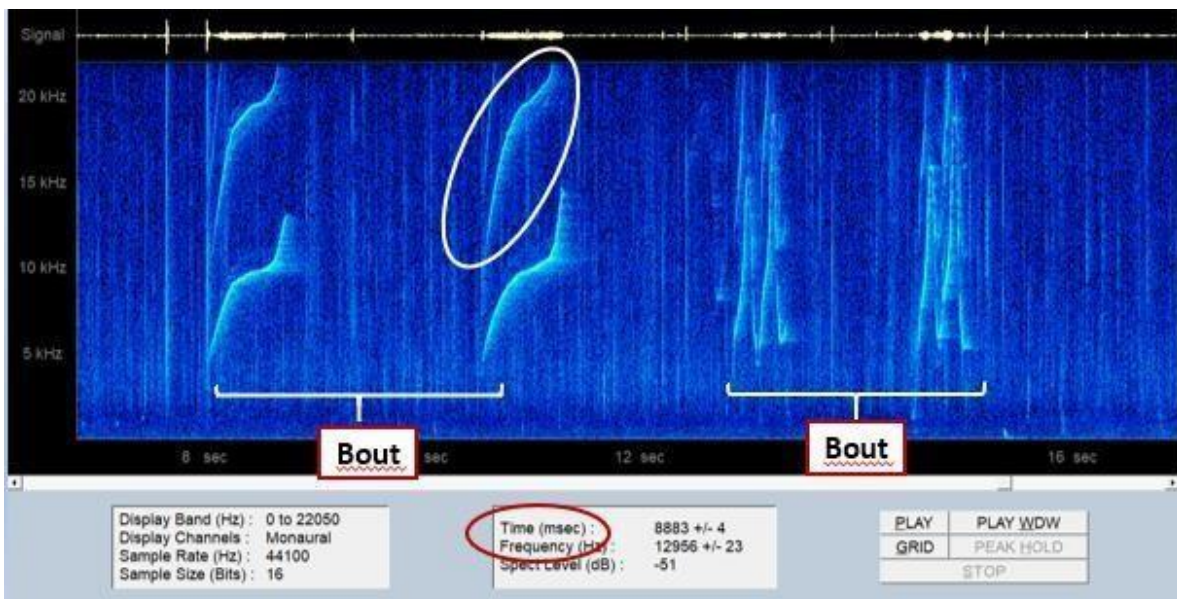


Figure 2.2. Spectrogram screen that show four whistles in which the time and the frequency are surrounded in red. Harmonic is surrounded in white and two different bouts are shown.

The extraction of these characteristics was carried out manually by placing the pointer in the screen where the whistle begins until it ends; except to estimate the maximum frequency and minimum that was placed in the precise part of the curve.

In the lower part of the screen the program data was extracted giving us the time and frequency, to create the database in Excel.

2.2.5 Statistical analyses

Summarized data (mean, SD, and sample number) and statistics analysis were performed with the software SPSS. Normality of the data in all the variables for each species was tested with the Kolmogorov-Smirnov, except for the bottlenose dolphin due to the low number of samples (n=30); in this case the test used was the Shapiro-Wilk.

Levene test gave the evaluation of the homogeneity of variance. To determine if there were significant differences in the whistle's parameters among species, it was used the Kruskal-Wallis (H) test. A post-hoc Tukey test was performed to evaluate differences in characteristics and species. A χ^2 test was performed to detect differences in whistles shape. Spearman test was performed to check the relation between the acoustic activity and the number of individuals.

2.3 Results

During 145 survey days a total of 439 dolphin encounters were recorded, in which 166 times the hydrophone was launched. Thus, a total of 26 acoustic records with dolphins' sounds were collected, mainly for coastal species: spotted dolphin with 17 records and rough-toothed dolphin with four records; although for oceanic species (spinner, bottlenose, and Risso's dolphin) one or two records were obtained as a reference of each species for the comparative section. This acoustic effort summed up 1 hr and 40 min of dolphin sounds, and 1,297 whistles were obtained and analyzed. A preliminary analysis showed that there is a poor correlation between the number of the individuals in a dolphin group and the whistling activity ($r = 0.5168$; $P > 0.05$; $n = 25$).

2.3.1 Whistle parameters

Summarized descriptive statistics (mean, the standard deviation and the number of whistles) is presented in Table 2.1. Spotted dolphins showed the largest number of whistles registered (n=753), while bottlenose dolphins showed the lowest number (n=30). Higher start frequency was emitted by spinner dolphins (11,408 Hz), while rough-toothed dolphin showed the lowest value (8,071 Hz, Table 2.1), with this difference being significant ($q = 6.287$; $P < 0.05$, Table 2.2).

Higher final frequency also was emitted by spinner dolphin (13,400 Hz), and again rough-toothed dolphins produced the lowest final frequency (8,569 Hz), being this difference also significant ($q= 6.287$; $P<0.05$). About the maximum and minimum frequency emitted during the whistles production, bottlenose dolphins showed the highest maximum frequency (15,422 Hz), which was significantly different to values emitted by rough-toothed and Risso's dolphins (9,676-9,869 Hz) ($q= 6.287$; $P<0.05$); and also, bottlenose dolphins showed the lowest value of minimum frequency (7,071 Hz), which was significantly different to values emitted by spotted and spinner dolphins (9,165-9,989 Hz) ($q= 6.287$; $P<0.05$). Likewise, bottlenose dolphin presented the longest whistling duration (903 ms), and the highest number of inflexion points (2); both results were significantly different to values from other dolphin species ($q= 6.287$; $P<0.05$, Table 2.2).

Table 2.1. Whistles characteristics registered for different dolphins' species from Mexican Central Pacific. Mean and the standard deviation of the start frequency (Start.F), final frequency (Final.F), maximum frequency (Max.F), minimum frequency (Min.F) (all of them in Hz units); duration (ms) and number of inflexion points (N.I.P.).

Species	Start.F(Hz)	Final.F(Hz)	Max.F(Hz)	Min.F(Hz)	Duration(ms)	N.I.P.
<i>S. attenuata</i> (n=753) Mean SD	10,973 ±4,032	13,068 ±4,337	14,768 ±4,134	9,165 ±2,949	615 ±518	0.71 ±0.87
<i>S. bredanensis</i> (n=254) Mean SD	8,071 ±3,547	8,569 ±3,499	9,676 ±3,917	7,174 ±2,828	371 ±345	0.44 ±0.76
<i>G. griseus</i> (n=62) Mean SD	8,728 ±2,265	9,096 ±2,097	9,869 ±2,114	7,725 ±1,917	487 ±1,156	0.56 ±0.67
<i>T. truncatus</i> (n=30) Mean SD	10,029 ±3,634	8,846 ±3,275	15,422 ±3,120	7,071 ±1,776	903 ±619	2 ±2.5
<i>S. longirostris orientalis</i> (n=198) Mean SD	11,408 ±3,620	13,400 ±3,994	14,765 ±3,688	9,989 ±2,803	609 ±361	0.76 ±1.26

Table 2.2 Tukey p-value results for whistles characteristics: start frequency (Start.F), final frequency (Final.F), maximum frequency (Max. F), minimum frequency (Min. F), duration and number of inflexion points (N.I.P.) of (*Steno bredanensis* (Sb), *Stenela attenuata* (Sa), *Stenella longirostris orientalis* (Sl), *Grampus griseus* (Gg), *Tursiops truncatus* (Tt)). * Indicates significant differences.

Species	Start.F	Final.F	Max. F	Min. F	Duration	N.I.P.
Sb/Sa	0.000*	0.000*	0.000*	0.000*	0.000*	0.002*
Sb/Sl	0.000*	0.000*	0.000*	0.000*	0.000*	0.005*
Sb/Gg	0.000*	0.888	0.997	0.648	0.511	0.902
Sb/Tt	0.059	0.997	0.000*	1.000	0.000*	0.000*
Sa/Sl	0.607	0.840	1.000	0.003*	1.000	0.953
Sa/Gg	0.000*	0.000*	0.000*	0.001*	0.341	0.812
Sa/Tt	0.670	0.000*	0.900	0.001*	0.025*	0.000*
Sl/Gg	0.000*	0.000*	0.000*	0.000*	0.488	0.639
Sl/Tt	0.345	0.000*	0.914	0.000*	0.033*	0.000*
Gg/Tt	0.538	0.999	0.000*	0.839	0.003*	0.000*

In addition, spotted dolphins showed similarities with most whistle's characteristics of spinner dolphins ($q= 6.287$; $P>0.05$, Table 2.2); thereby, whistle repertoire of spotted dolphins was significantly different ($q= 6.287$; $P<0.05$) to the other dolphins with coastal distribution (rough-toothed dolphin). Finally, these species showed similarities in most of the whistle's characteristics with Risso's dolphins, a species with commonly oceanic habits ($q= 6.287$; $P>0.05$, Table 2.2).

2.3.2 Whistles shapes

In general terms, the predominating whistle shape (Figure 2.3) was that denominated "Rise" with percentages of use of 32.10%, followed by "U-shape" with 24.24% (Figure 2.4). The shape "Rise" was used mainly by spinner dolphin (36.86%) and spotted dolphins (34.79% of the total whistles; Figure 2.5). While "U-shape" was mainly emitted by Risso's dolphins, who used it up to 40.30% in their whistle records. While the "Flat" and "Multiloop" shapes were less frequent (Figure 2.4).

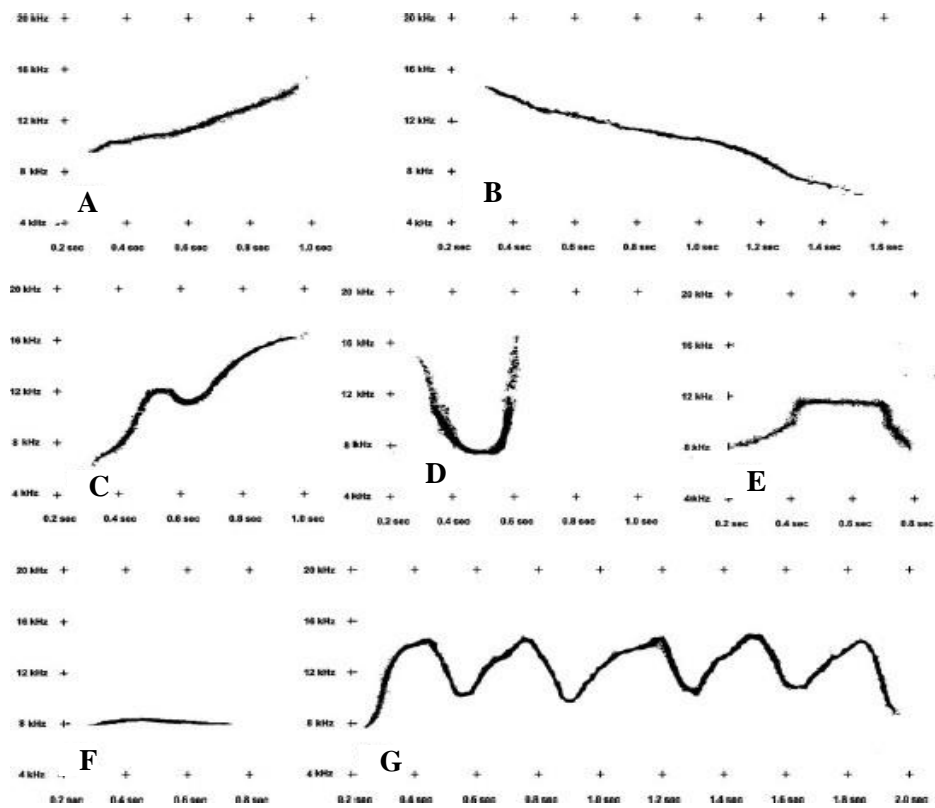


Figure 2.3. Example of the different shapes of whistles in a spectrogram: (A) Rise, (B) Fall, (C) Sine, (D) U-shape, (E) Wave, (F) Flat, and (G) Multiloop. Figure from Díaz-López (2010).

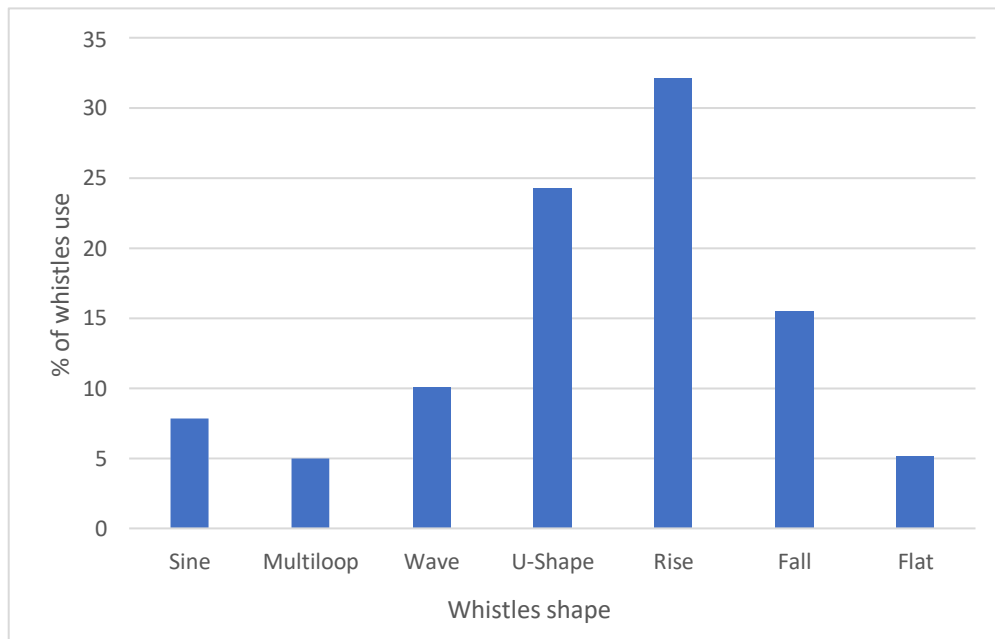


Figure 2.4. General representation of whistle's shapes recorded for different dolphins' species from Mexican Central Pacific.

Nonetheless, “Flat” shape was representative in rough-toothed dolphins with a 20% of its repertoire, and “Multiloop” shape was commonly used (33.33%) by the bottlenose dolphin, but it did not show “Flat” whistle shape in their acoustic repertoire (Figure 2.5). Comparing whistle’s shapes among species, rough-toothed dolphins showed a homogeneous use of these shapes between 3 and 24% for “Multiloop”, “Rise” and “U-shape”.

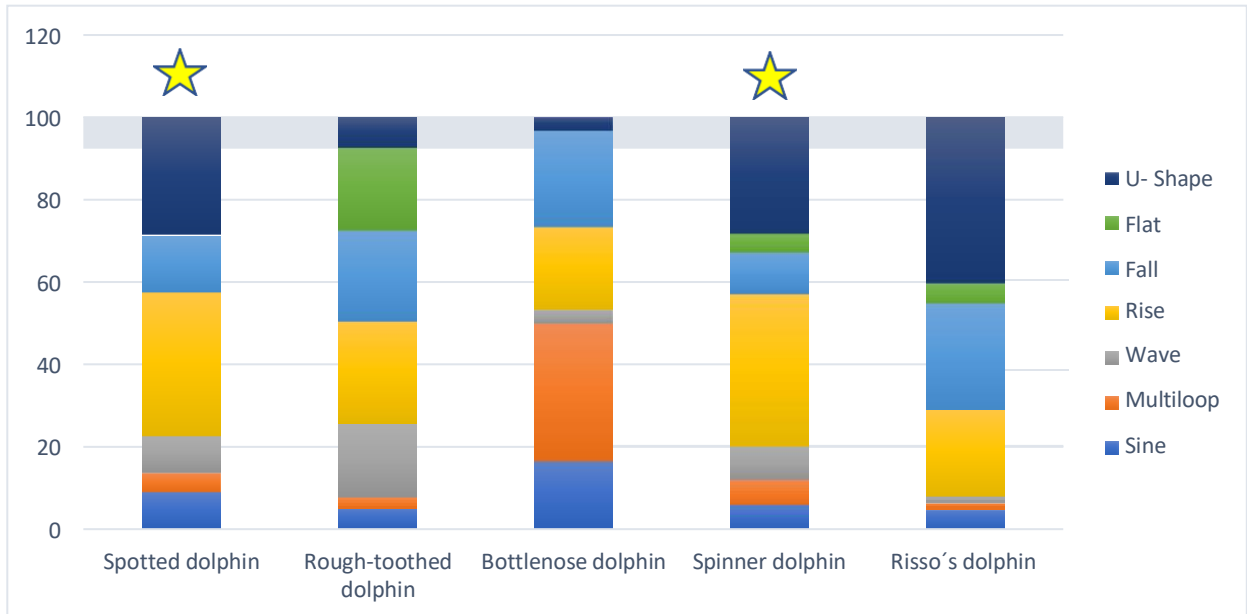


Figure 2.5. Whistle’s shapes repertoire for each dolphins’ species from Mexican Central Pacific. Yellow star indicates not significant differences ($P > 0.05$).

Whistle repertoire for spotted and spinner dolphins was similar in structure, being predominated by “Rise” and “U-shape” (1% and 4%, respectively), and with a low use of the “Flat” shape.

While Risso’s and bottlenose dolphins showed inverse structures of the whistle’s shapes, the “U-shape” was the most used by Risso’s dolphins (40.3%); but for bottlenoses it was the lowest used (3%), and vice versa with the “Multiloop” and “Sine” shapes, these were most common in the bottlenose dolphin whistle repertoire (33 and 17%, respectively). Spinner and spotted dolphins did not show significant differences in their shape whistle use ($\chi^2_{6,5} = 6,919, P > 0.05$) (Fig. 2.5).

2.3.3 Dolphin's whistles interspecific comparison

By analysing whistles parameters and shapes, two groups were identified for the MCP region, dolphins that showed predominantly whistles with higher frequency and those that showed whistles with lower frequency.

Spotted, spinner, and bottlenose dolphin belong to the group with whistles of higher frequencies in this study. The analysis of frequencies revealed that spinner and spotted dolphins were similar in start, maximum and final frequency; being different only in the emission of the minimum frequency. Because even, these two species, did not show statistical differences in the analysis of duration and N.I.P.; which suggest acoustic similarities in these species. On the other hand, bottlenose dolphin differed exactly in the same whistle's parameters with spotted and spinner dolphin, turning this species the most easily recognizable of this group in terms of whistles features. Shapes could offer a clue to recognize them, however, spinner and spotted dolphin did not presented differences in the use of the shapes. Bottlenose dolphin presented differences with spinner and spotted dolphin in all the shapes, added to the fact that bottlenoses also have the highest percentage of multiloop whistle, which is a good track to identify it.

The low frequency group was made up with rough-toothed and Risso's dolphin. The analysis of the whistles features only revealed differences in the start frequency, with values of the duration and the N.I.P being similar for both species. But whistle shapes could apport information to discriminate these species, because Risso's dolphin used mostly "u-shape" while rough-tooted dolphin emitted "flat" and "wave" shapes that were almost missing in Risso's dolphin acoustic repertoire. Although, the parameters and shapes of whistles would be similar, in this case, there was a particular feature in the rough-toothed dolphin whistles that it is the key to identify it, which is the segmentation of the whistles. In addition, the short duration, and the segmentation of the whistles in the rough-toothed dolphin allow to be differentiated easily from the spotted dolphin.

Spinner dolphin duration and N.I.P. were similar to Risso's dolphin, but they frequencies were completely different, only with frequencies this two species could be identified. In relation with the frequencies the bottlenose dolphin was the most similar to Risso's dolphin, but N.I.P and duration were different.

Even, the whistles shapes use was different, being the "u-shape" and the "multiloop" the commonest forms emitted by Risso's and bottlenose dolphin, respectively.

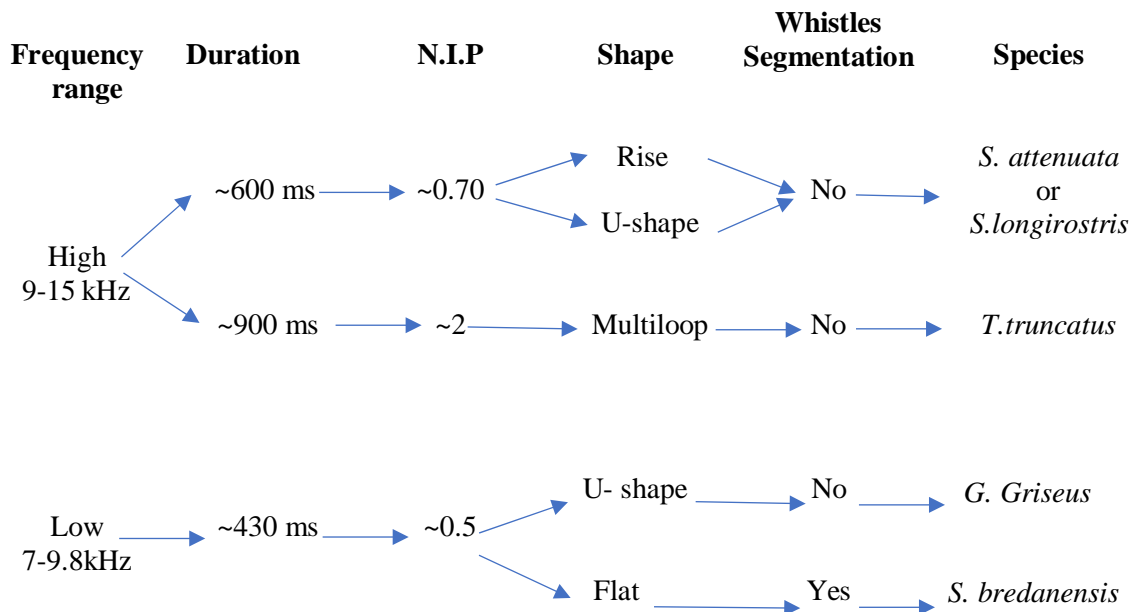


Figure 2.6. Dichotomous key to identify acoustically dolphin species from MCP. Being duration, the mean of maximum and minimum values showed; a mean duration; mean of number of inflexion points; shapes more used by dolphins; presence of the whistle's segmentation.

2.4 Discussion

This descriptive research represents an effort to increase knowledge about the ecology of dolphin species, being the only acoustic approach to describe whistles repertoire emitted by five regional dolphin species with coastal and oceanic habits in the MCP. Occasionally, in surveys conducted on oceanic waters bottlenose, spinner, and Risso's dolphins were found given the possibility to record their sounds. The most difficult species to distinguish acoustically in the oceanic group were spinner and bottlenose dolphin (Figure 2.6), because their frequencies of whistles were very similar, so, the possibility to differentiate them without the visual confirmation of the spectrogram was difficult; but N.I.P and shapes could offer the key to distinguish them without a visual confirmation.

2.4.2 Dolphin's whistles intraspecific comparison

The mean of the low frequency whistles, *i.e.*, 10kHz, quoted by Quintana-Rizzo *et al.* (2016) was considered as the boundary frequency to discriminate these groups. Spinner dolphin showed the higher frequencies (initial, final, minimal, and maximal) of the whistle characteristics, and the shape “Rise” was the most used by this species. These results were similar to those recorded in spinner dolphins from southern coasts of Brazil (Simões Amorim *et al.*, 2019), USA/Mexico, and Peru (Oswald *et al.*, 2007). However, the final frequency differed slightly from the Hawaiian spinner dolphin, which emitted frequencies around 13,000-15,000 Hz (Bazúa-Durán & Au, 2002). While, the average of N.I.P in spinner dolphins from Hawaii was 0.46 ± 0.8 (Bazúa-Durán & Au, 2002), similar to the results of this study (0.76 ± 1.26). Comparatively, for spinner dolphins from Eastern Tropical Pacific (ETP), a lower value of the maximal frequency (13,700 Hz) and a higher N.I.P. (1.9) have been reported (Oswald, Barlow, & Norris, 2003).

Spotted dolphin also showed whistle characteristics with high frequency values, while the shapes more used were “Rise” and “U-shape”. However, these results in maximum frequency and N.I.P. were different to other studied areas. For spotted dolphins from USA/Mexico and Peru, a higher maximal frequency (17 kHz) and higher N.I.P. (2.85) were recorded (Oswald *et al.*, 2007). On the other hand, Atlantic spotted dolphin in Canary Islands have a similar acoustic pattern excepting maximal frequency with higher values (16.87 kHz) and N.I.P. with lower values (0.48) in travelling behavior (Papale *et al.*, 2017).

Bottlenose dolphins showed whistles with the highest value for maximal frequency and lowest value for minimal frequency, which makes up to the wider frequency repertoire of all dolphin species studies. These results were similar with those recorded for bottlenose dolphins from Isla del Coco, Costa Rica, during non-feeding behavior (Acevedo-Gutiérrez & Stienessen, 2004), and also was similar to whistle characteristics of dolphins from Patos Lagoon estuary in Brazil (Azevedo *et al.*, 2007). Nevertheless, whistles differed in all parameters in comparison with those recorded for the Indo-Pacific bottlenose dolphins from Ogasawara Islands, which showed lower frequencies around 6-11 kHz, a minor duration around 320-380 ms, and N.I.P. < 1 (Morisaka *et al.*, 2005).

Finally, the predominant shape used by this bottlenose dolphin species from MCP region was the “Multiloop”, the most complex of all shapes, which is used usually by adults (Sayigh *et al.*, 1990). In this case, it coincides with the longest duration and the highest amount of N.I.P. Moreover, multiloop whistles have been reported to be emitted in predation activities for this species (Díaz-López, 2011).

On the other hand, other two species showed low frequency values for whistles parameters. Risso’s and rough-toothed dolphins presented lowest frequency values, shortest duration, and lowest N.I.P. Particularly, Risso’s whistles features were similar to those recorded for Risso’s from Brazil and Scotland coasts (Neves, 2013; Simões Amorim *et al.*, 2019), excepting the maximal frequency which was higher in Brazil (~14,900 Hz, Simões Amorim *et al.*, 2019) and also the N.I.P. showed in whistles of dolphins from Scotland (1.38; Neves, 2013). Furthermore, Risso’s dolphins recorded in Canary and the Islands of Azores exposed higher values for almost all whistle parameters (Neves, 2013).

Rough-toothed dolphin displayed the lowest values in all whistle’s characteristics. Whistles shapes for this species showed even a particular “separation” among them, a feature that has been reported in rough-toothed dolphins from Rio de Janeiro and beluga whales (*Delphinapterus leucas*) in Beluzhii Cape of Solovetskii Island in the White Sea (Belikov & Bel’kovich, 2007; Seabra *et al.*, 2012). Frequency values were similar to those whistles values of rough-toothed pods from Brazil (Simões Amorim *et al.*, 2019; Seabra *et al.*, 2012), USA/Mexico, and Perú (Oswald *et al.*, 2007), and the ETP (Oswald, Barlow, & Norris, 2003). However, the duration and N.I.P. in whistles of rough-toothed dolphin seemed be different in those from ETP, USA/Mexico, and Perú, showing a higher value with ~620 ms and ~2 N.I.P.

Both Risso’s dolphins and the rough-toothed dolphins showed a low use of the “Multiloop” shape, but Risso’s used mainly the “U-shape” and rough-toothed the “Rise”. Also, these species showed a scarce N.I.P., which indicates that their whistles are represented by a less complex shape (Belikov & Bel’Kovich, 2007; Seabra *et al.*, 2012). Using frequencies, duration, N.I.P and shapes of whistles, would make it difficult to differentiate dolphin species without visual confirmation, however, the segmentation in the whistles of rough-toothed dolphin (Belikov & Bel’kovich, 2007; Seabra *et al.*, 2012) allow to distinguish between them perfectly.

Rough-toothed and pantropical spotted dolphin are considered the most common species in the Colima coast (Ortega-Ortiz *et al.*, 2014a; Kono-Martínez *et al.*, 2017).

From this study, these species were differentiated significantly, where it was shown that the spotted dolphin whistles are predominantly characterized with high frequencies and rough-toothed whistles characterized with low frequencies. In addition, the short duration, and the segmentation (Seabra *et al.*, 2012) of the whistles in the rough-toothed dolphin allow to be differentiated easily from the spotted dolphin.

In summary, spinner and spotted dolphins showed several acoustic similitudes that make their differentiation impossible; while bottlenose, rough-toothed, and Risso's revealed some specific features that allow to identify acoustically.

2.4.3 Potential whistles relationships

Whistles description from this study revealed that there are differences among the five species distributed in the MCP waters. Diverse causes could be responsible such as sea temperature, biogeographic region, habitat (Galatius *et al.*, 2011), prey preferences (McCurry *et al.*, 2017), cranial morphology (Galatius *et al.*, 2020), noise pollution (May-Collado & Wartzok, 2008; Morisaka *et al.*, 2005) or group features and behavioural state of individuals (Bazúa-Durán & Au, 2004).

Due to the fact that bottlenose and Risso's dolphin show a worldwide distribution, while rough-toothed, spinner and pantropical spotted dolphin are limited to tropical waters, it is possible that climate could modify morphologies (Galatius *et al.*, 2020) *e.g.*, Hourglass dolphin (*Lagenorhynchus cruciger*) has a robust skull and its habitat is in colder waters while the other members of the Lissodelphininae subfamily inhabiting warmer waters (Galatius & Goodall, 2016).

Geographical variation in whistles of several dolphins species as the pantropical spotted and bottlenose dolphin were showed (Jones & Sayigh, 2002; Yao *et al.*, 2008). Whistle's variability could be related with differences in regional acoustic conditions (Morisaka *et al.*, 2005; May-Collado & Wartzok, 2008), *e.g.* striped dolphin from the Mediterranean showed regional differences in their whistles; also, in bottlenose dolphins from Brazil whistles differentiations were found (Azzolin *et al.*, 2013; Lima *et al.*, 2020).

The modification of the whistles' frequencies in presence of acoustic pollution could also explain these regional differences (Morisaka *et al.*, 2005; May-Collado & Wartzok, 2008), as also group size and the general behavioural state (Bazúa-Durán & Au, 2004). These are all aspects that need further investigation to determine differences among species and in different areas.

Prey items among these five species could variate between fish and cephalopods being the Risso's dolphin mainly teutophagous (Blanco, Raduán & Raga, 2006). Perhaps, whistles characteristics could variate depending on the prey item to facilitate its capture. Nevertheless, bottlenose, spinner, and spotted dolphins which are in the high frequencies group and are considered mainly ichthyophagous (fish feeders) (Norris, & Dohl, 1980; Irvine *et al.*, 1981; Barros & Wells, 1998; Scott & Chivers, 2009), but they could also include cephalopods in their diet when these preys are available (Dolar *et al.*, 2003; Gimenez *et al.*, 2017). However, considering the prey size, it could determine the four feeding strategies recognized for odontocetes: raptorial feeding, grip and tear feeding, suction feeding, and filter feeding (Werth, 2000a; Kienle & Berta, 2016; McCurry *et al.*, 2017b). Likewise, these feeding strategies could suggest some shapes and anatomy variations of the skulls, which has been related in toothed whales to feeding and prey preferences (Werth, 2006a; McCurry *et al.*, 2017a) (Fig 2.6).

A factor contributing to acoustic differences in dolphins is differences in their cranial morphologies. For example, Risso's dolphins are considered suction feeders because they create a negative intraoral pressure to capture the prey item as well as to aid in swallowing (Johnston & Berta, 2011). This feeding technique implied modifications to the hyolingual apparatus and often to the skull and jaws (Werth, 2007) and it could be the answer to low frequencies in the whistles' parameters. While rough-toothed, spinner, and bottlenose dolphins are considered raptorial (Galatius *et al.*, 2020) due to the use of teeth and jaws alone to capture prey (Hocking *et al.*, 2017) (Fig 2.7). The rostrum morphology could determinate the sound emission (Frainer *et al.*, 2021); however, the group of raptorial feeders is composed by three species with high frequencies and one with low. Then, rough-toothed dolphin as raptorial feeder should have high frequencies maybe the habitat or the evolutionary studies could offer some answer.

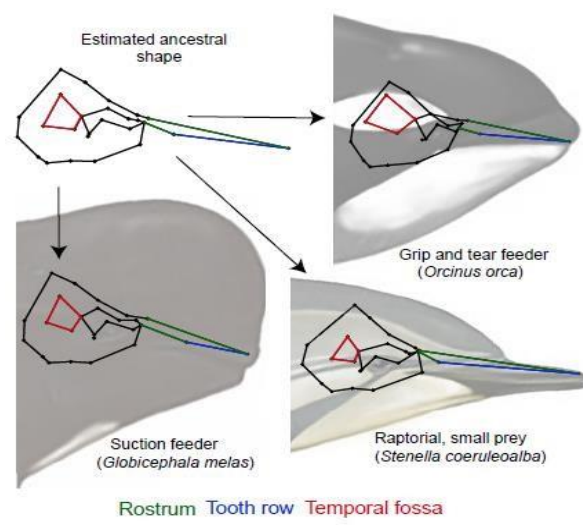


Fig 2.7. Comparison between the different shapes in relation with the feeding strategy. Image taken from Galatius et al. (2020).

Prey and feeding strategies are dependent of the habitat (Monteiro-Filho *et al.*, 2002; Galatius *et al.*, 2011), being the depth an important factor into lifestyle of dolphins. The fact that these five species are found in deep waters (Gannier & West, 2005; Moreno *et al.*, 2005; Baird *et al.*, 2008) does not mean that they dive at deep zones, although the Risso's dolphin is known as good diver (Jensenet *et al.*, 2020). On the other hand, rough-toothed dolphin is a species with scarce data about diving (Baird *et al.*, 2008), but known it to prefer deep waters (Baird *et al.*, 2013) of around 400 m (Shaff & Baird, 2021), in which they feed on fish and squids (Kerem *et al.*, 2016). The association of both species to deep waters habitats could explain differences in the whistle's characteristics. Likewise, baleen whales use low frequencies to communicate in long distances because sound is more effective in deep waters and the low frequencies travel more distance (Darling, 2015). However, it was shown that bottlenose dolphin could dive up to 500 m in Bahamas (Klatsky, Wells & Sweeney, 2007) and squids become available to dolphins at night due to the diel migrations (Benoit-Bird & Au 2003).

Evolutionary studies showed that rough-toothed and Risso's dolphins are closer to each other in the phylogenetic trees (Geisler *et al.*, 2011; Amaral *et al.*, 2012; Gatesy *et al.*, 2013; McGowen *et al.*, 2020), what could explain similarities in the whistles features for these species, and differences comparing with the high frequencies group.

Moreover, rough-toothed and Risso's dolphin whistles characteristics also similar to those from false killer whale (*Pseudorca crassidens*) (Oswald, Barlow & Norris, 2003), a species also evolutionary closer to these two species.

2.4.4 Study limitations and future perspectives

Several limitations to collect data arose during the field work, *i.e.*, unfavourable sea state conditions and visibility to detect dolphins emerging on the water surface, and then, other difficulties with electronic failures of the equipment when it was introduced to the sea to record sounds. Further, sometimes, dolphins do not feel comfortable with the ship presence, and they drift away, hindering the data extraction. However, a representative sample of the dolphin acoustic repertoire, including a large number of whistles was obtained; even with a few whistles from oceanic species that were recorded from sporadic encounters in order to take it as reference.

On other hand, studies show that in presence of sharks and ships (while there are socializing) rise the number of whistles (Scarpaci *et al.*, 2000; Acevedo-Gutiérrez & Stienessen, 2004) that their characteristics could be modify depending on the behavior of the dolphin group. Dolphins from the Mediterranean increases the emission of the "Rise" shape while they are socializing (Díaz López, 2011), this means that the initial frequency is going to be always equal to the minimum frequency, the final frequency will be equal to the maximum frequency, and it will not be inflexion points. Also, they rise the "Multiloop" shape while they are hunting (Díaz López, 2011), increasing the number of inflexion points. Each shape has determinate characteristics that in their increase could change the median of the frequencies and number of inflexion points so that could give an error in the identification of the dolphin's species. In future studies the behavior of dolphins should be studied at the same time that the sounds are recorded to avoid mistakes

Therefore, future acoustic studies should be planned and foreseen with coastal and oceanic cetacean species in the MCP region, in order improve knowledge on the biology and ecology of these species and contribute to conservation and management works in the area.

This study showed that the description of whistles characteristics of the five species of the MCP region contributed to bioacoustic research improvements in the area. Moreover, outcomes of this work revealed the exhibition of geographical differences.

Coastal species were easier to differentiate due to the high frequencies in the spotted dolphin while rough-toothed dolphins have in their repertoire the lowest frequencies, duration, N.I.P. and presents the segmentation of whistles. For the same reasons, oceanic species revealed that Risso's dolphin is easier to recognise in comparing with bottlenose and spinner dolphin. Among all species, 1) rough-toothed and Risso's dolphin presented similarities in almost all the parameters; 2) Bottlenose, spinner and spotted dolphin showed common characteristics. In the high category frequencies, spinner and spotted dolphin were so similar that in conditions without visibility it would be impossible to distinguish acoustically between them. Additionally, for these two species, concerning acoustic patterns, even the proportions of the use in the shapes were the same, being the "u-shape" and the "rise", the most common forms emitted. Whereas the bottlenose dolphin is the species with lower values in frequencies, but the N.I.P and the duration results were superior to spinner and spotted dolphin, what provides a clue to identify acoustically.

Chapter 3: Spatial-temporal recording of dolphin whistles in the bays of the Mexican Central Pacific

3.1- Introduction

Cetaceans have adaptative skills to live and survive in the aquatic environment, which creates obstacles to study them and understanding more about their ecology (Kremers *et al.*, 2014). Through diurnal surveys several studies have been performed on species identification, distribution and density of populations, and behavior of individuals (Küsel *et al.*, 2011; Marques *et al.*, 2012; Stevenson *et al.*, 2015). However, the collection of this information at sea depends on visual detections during surveys, which involve a great human effort due to a high level of physical demand, are expensive, occasionally there are risks due to oceanographic and climatic conditions, and also the results provided may be limited. On the other hand, acoustic methodologies allow to obtain data about the dolphin presence through the registration of their sounds, and for longer periods (Mellinger *et al.*, 2007). Passive acoustics is based on receiving sound by a hydrophone directly put into the water or installed in a buoy (Mellinger *et al.*, 2007). This type of monitoring is not only a non-invasive technique, since it is independent of daylight to study marine mammals (Baumgartner *et al.*, 2020), and the data obtained could be used to study several features of their sounds, the population density, and habitat preference (Díaz-López, 2011; Marques *et al.*, 2012; Stevenson *et al.*, 2015; Baumgartner *et al.*, 2020). Besides, most ecological and behavioural data on dolphins is taken during daytime observations, while knowledge about their ecology during their nocturnal life cycle is limited.

The interest of the research in the acoustics began with the First World War due to the dolphin's capacity to identify obstacles in the marine environment being a feature that people wanted to copy (Pailhas, Capus, & Brown, 2012). The earliest bioacoustical studies were conducted with captive animals usually with the bottlenose dolphin (*Tursiops truncatus*) due to the worldwide coastal distribution and the high adaptation to captive life (Overstrom, 1983; Tyack, 1986; Nowacek, Wells & Solow, 2001; Cotter, Maldini & Jefferson, 2012).

Studies revealed that dolphins are able to emit three types of sounds: *clicks*, *burst pulses* and *whistles* (Van Parijs, Parra & Corkeron, 2000; Thomas, Fristrup & Tyack 2002).

Whistles are tonal signals with frequency modulated, usually not exceed 20 kHz (dos Santos *et al.*, 2005; Díaz-López & Shirai, 2009; Azevedo *et al.*, 2010) and were the main indicator to identify individuals in captivity. Caldwell & Caldwell (1965) suggested that bottlenose dolphins produce individually characteristic and recognizable whistles known as “signatures”. Later, an experiment in an aquarium was conducted to find whistle signature with two captives bottlenose dolphins; using a machine called “vocaligh” that was attached in two different dolphins with the objective to discriminate which sound came from each animal (Tyack, 1986).

In the seventies, studies with wild dolphins begun with the objective to investigate the range in echolocation (Au *et al.*, 1976; Murchison, 1976). Vocal emissions play an important ecological role because they are essential to locate and capture prey, to detect potential predators and to avoid them, to breed, and to parenting (Dudzinski, 1996). Also, studies show that sounds are important to maintain the group cohesion (Janik & Slater, 1998) and to communicate over distance (Janik, 1998). Dolphins, as social animals live in fission–fusion societies, with flexible aggrupation patterns while some individuals showing a long-term association with specific individuals (Würsig & Würsig 1977; Wells *et al.* 1987; Elliser, 2010; Eater *et al.*, 2013; Elliser & Herzing, 2014). Social behavior could be expressed through the number of whistles, *i.e.*, the rates of whistles increased when new individuals joined the group (Quick & Janik, 2012). Besides, the characteristics of whistles, as frequency, could infer behavior of dolphins because when they are in action (*i.e.*, jumping, socializing, or chasing prey) their whistles are longer and with higher frequency than whistles emitted when they are traveling (Azevedo *et al.*, 2010). Whistles’ shape could also suggest information about the behavior, as was recorded in dolphins from the Ria of Arousa, where the “sine” whistle shape was detected in 53% of the feeding behaviour events (Férriz Rosell, 2017). Killer whales (*Orcinus orca*) have been observed to feed during daytime periods, but an increase in calls has also been recorded at night, which could indicate an increase in foraging behavior (Newman & Springer, 2008; Richard *et al.*, 2017). Similarly spinner dolphins (*Stenella longirostris*) in Hawaii, feed at night in open waters, and rest in bays during the day (Norris *et al.*, 1994a); but a new study revealed that this behavior could change with seasonal fluctuations (Silva & Da Silva, 2009). Common dolphin (*Delphinus delphis*) and Indo-Pacific humpback dolphins (*Sousa chinensis*) showed a relationship between the lunar cycle and the echolocation (Wang *et al.*, 2015; Cascão, *et al.*, 2020).

Both species answered differences in environmental lighting, acoustic activity increased during the darkness period (new moon) (Goold, 2000; Wang *et al.*, 2015; Cascão, *et al.*, 2020). For Risso's dolphin (*Grampus griseus*) a similar pattern had been reported, an increase in acoustic activity at night, because they are searching for food (Soldevilla, Wiggins & Hildebrand, 2010). However, there is little research on the acoustic behavior of dolphins during night-time periods, especially in whistles emissions.

In this way, this scarce scientific background of whistles suggests as potential hypothesis, an active acoustic behavior related to feeding activities during the night periods, and a passive acoustic record during the diurnal periods for dolphins distributed in any coastal region.

In the Mexican Central Pacific (MCP) coastal region, 14 species of marine mammals have been registered (Ortega-Ortiz *et al.*, 2013; Wade & Gerrodette, 1993). The spotted dolphin (*Stenella attenuata*) is the dominant species, maintaining a relatively constant density of individuals throughout the year (González-Salguero, 2017; Kono-Martínez *et al.*, 2017), and rough-toothed dolphin (*Steno bredanensis*) have been registered in the area, performing foraging activities (Ortega-Ortiz *et al.*, 2014a); but research on its ecological aspects is still limited. The largest Mexican commercial port is located on the coast of Manzanillo, Colima; in addition, the increase in tourism in recent years could increase interactions between cetaceans and humans (Rosales-Chapula *et al.*, In press). Therefore, any ecological study could be useful to contribute to the conservation of dolphin species (La Manna, Manghi, & Sara, 2014). In this regard, the aims of this study were 1): to determine the occurrence of the acoustic activity of dolphins among sites of Colima coast; and 2) to describe the occurrence of the acoustic activity of dolphins during several temporal scale: years, seasons, and day/night cycles in the Colima coast.

3.2- Methods

3.2.1 Study area

Study area was in the Pacific coast of Mexico, in the state of Colima is located the Manzanillo Bay, where the most important commercial port is housed; and Santiago Bay, where tourist activities predominate (Silva Iñiguez *et al.*, 2013) (Fig.3.1).

3.2.2 Data collection

During the period of September 2015 to January 2019, a monthly sampling (which was represented by two or three day of work at sea) was conducted, which consisted of placing two acoustic recording devices within both bays, and one more at the entrance of these, separated by 4 km to get more detection range.

However, because of technical issues with the hydrophone of the Entrance only 2015 and 2016 could be recorded while the Santiago and Manzanillo Bay could be recorded the entire sampling period (see table 3.2).

Based in other designs of passive acoustic monitoring, each device was put in a plastic container with hermetic conditions (Rosales-Chapula *et al.*, In press).

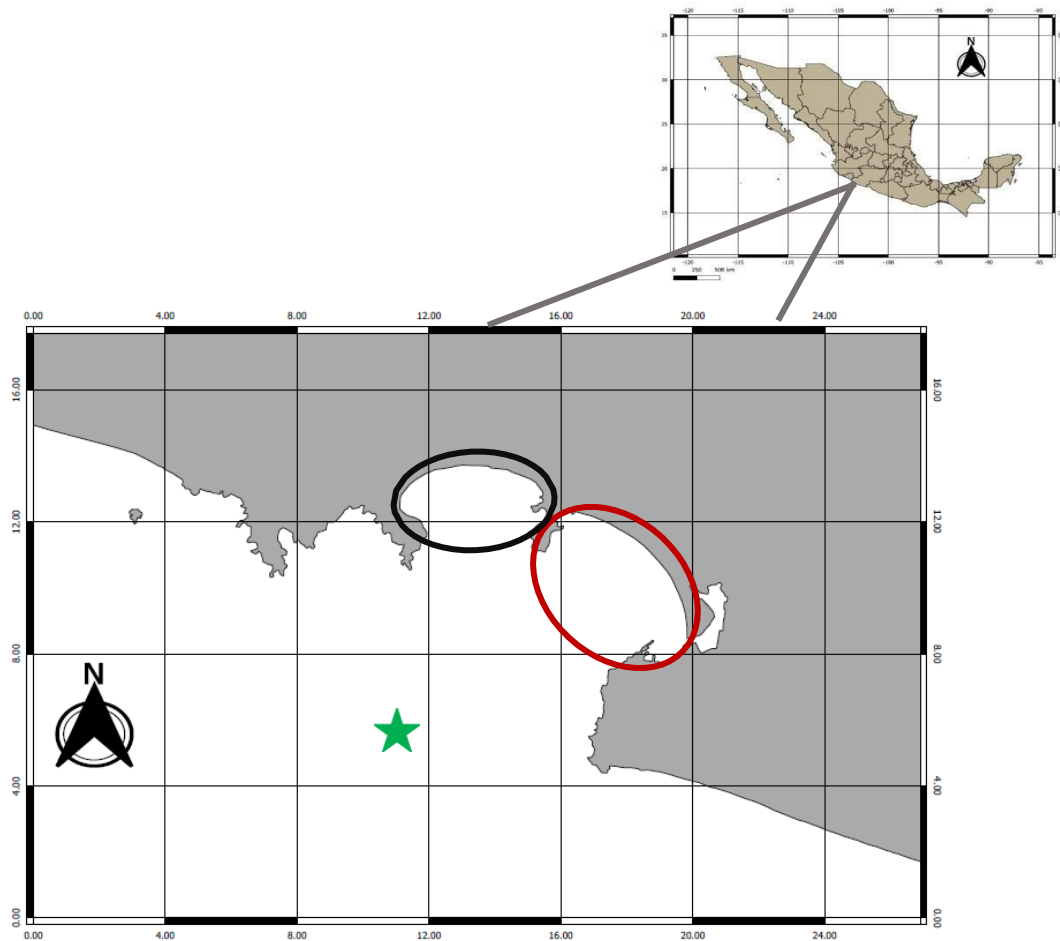


Figure 3.1 Study area in Manzanillo (Colima, Mexico). Red circle is Manzanillo Bay; black circle is Santiago Bay, and the green star is the location of the bouy in the entrance of the bays.

The sensor hydrophone (1, model TC4013 trademark Reson or 2, model SQ26-08 of the company Cetacean Research Technology), a battery package (lasting up to ~48 h), and a digital recorder (Zoom H1), were the equipment submerged 5-7 meters of depth, which were anchored in the sea bottom in each of the three sampling site, using a dead weight, an anchor and a red buoy on the surface of the water for easy detection and retrieval (Fig. 3.2).

Through this methodological effort, it was possible to record the acoustic activity in continuous for day and night periods, mainly whistles of the dolphins.

3.2.3 Data analysis

The audio files were stored for further analysis using Adobe Audition software due to the huge size of records. Each audio file was inspected to identify visually (seeing on the screen) and acoustically (listening the sound with earphones) the whistles of dolphins. Shape and frequency were considered as characteristics to discriminate whistles from other dolphin sounds and from noise in the marine environment. Whistles were identified and accounted, for describing the occurrence of the acoustic activity of dolphins among sites of Colima coast, and during diurnal/nocturnal cycles.



Figure 3.2. Map of the Manzanillo and Santiago Bays that shows the point of the location of the buoys. In the right, the structure with the hydrophone, the buoy, the plastic container with acoustic equipment, and the anchor used in each sampling site.

Each audio file obtained could have a duration of 20 to 48 h; therefore, these audio files were subdivided into small recording samples lasting 3 h and 36 min.

Whistles were identified based on the frequency range between 4-20 kHz, besides it is a continuous sound that spans a period, usually showing a particular shape of upward or downward slope.

These features differentiated the whistles from other marine sounds produced by whales, birds, crabs, or fishes (Montgomery & Radford, 2017). Clicks were excluded as it was differentiated as an isolated sound that can be identified as a short duration vertical shape, with a frequency range of a few hundred Hz to about 160 kHz (Aubauer, Lammers & Au, 2000; Rankin *et al.*, 2017).

Burst pulses were also excluded as it were distinguished as serially produced broadband clicks with very short intervals between clicks (Rankin *et al.*, 2017). In figure 3.3 it is possible to observe an example of these three types of sounds produced by dolphins, so it becomes evident that the visual analysis is an important key to correctly identify the type of sound, in addition to the auditory evaluation.

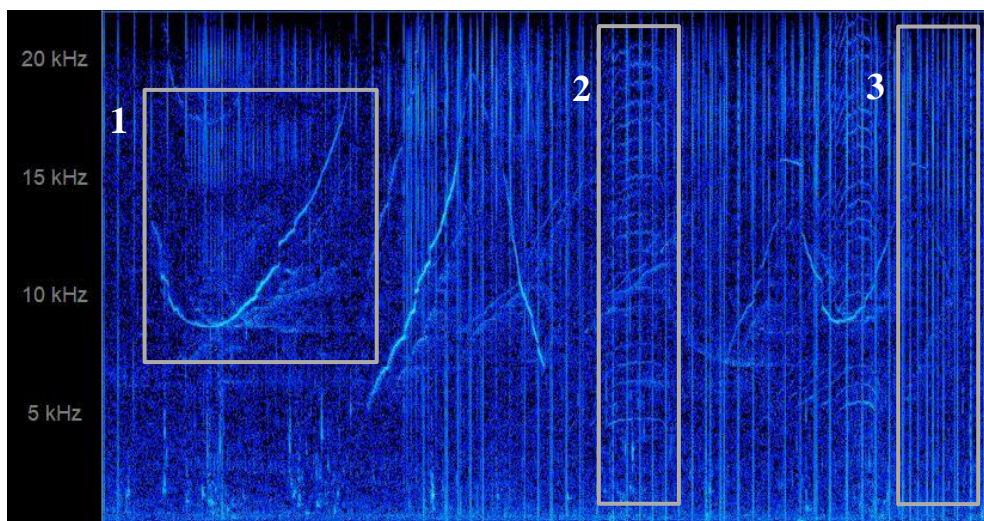


Figure 3.3. An example of a spectrogram of dolphin sounds; from left to right marked in the boxes: 1) a whistle with “u-shape” form, 2) a burst pulse, and 3) clicks.

To determine the occurrence of the acoustic activity of dolphins, only the number of whistles was extracted from each sampling sites; and a whistle recording rate (WRR), was obtained by dividing the number of whistles per hour of recording monthly (location, years, season, and time frame). The WRR was a way to equalize the effort in the Entrance with the Manzanillo and Santiago Bay due to the lack of sampling in the first area.

Besides, whistles were catalogued in night/day cycles, specific time frames of four hours were considered for a better management of data, *i.e.*, 2–6 h (A), 6–10 h (B), 10–14 h (C), 14–18 h (D), 18–22 h (E) and 22–2 h (F). In this way, the time frame was summarized in E-F-A as night cycle and B-C-D as diurnal cycle.

3.2.4 Statistical analyses

To determinate differences of acoustic activity among location and daytime, normality of data was evaluated with Kolmogorov-Smirnov test; while chi squared test (X^2), and non-parametric Kruskal-Wallis test were used to determine if number of whistles were significant different among location and daytime. Data that followed a normal distribution were analysed with ANOVA. A post-hoc Tukey test was performance to identify the groups with differences. These analyses were performed using software SPSS, with a 0.05 significance value.

3.3- Results

A total of 501 acoustic record samples were collected during the period of study (September 2015 to January 2019), of which 71 records were not functional. From 430 good records: 224 recording samples were taken from Manzanillo Bay, 150 samples were taken from Santiago Bay, and 56 records were obtained from the entrance of the bays.

These recorded samples represented a total of 1,289 h and 23 min of sounds, being 679 h and 29 min from Manzanillo Bay, 464 h and 25 min from Santiago Bay, and 145 h and 28 min from the entrance of the bays.

A total of 11,884 whistles signals were identified, of which 7,886 belonged to Manzanillo Bay, 3,306 to Santiago Bay, and 692 to the entrance of the bays. The mean whistles number (438.1) and range (0-1,446) was higher in Manzanillo sampling site (Table 3.1). Whistles Recording Rate (WRR) revealed significant differences among locations ($F_{42,2}=4.973$, $p=0.012$) and a higher value of 11.23 whistles/h in Manzanillo location, which showed significant differences compared with Santiago Bay ($q=9.798$, $p=0.023$).

Table 3.1. Whistles registers from dolphins obtained in different sampling location in bays of Colima, Mexico during the period of September 2015 to January 2019. N = number of records extracted; Mean = the average of whistles; Range = lowest and highest number of whistles; and WRR = Whistles Recording Rate.

Location	N	Mean	Range	WRR (whistles/h)
Entrance	692	98.8	0-343	4.74 (0-12.85)
Santiago	3,306	194.4	2-825	5.65 (0.59-14.14)
Manzanillo	7,886	438.1	0-1,446	11.23 (0-27.3)

Annual analysis of these 11,884 whistle records, showed that the highest number of whistles collected was during 2016 (4,283 records), and lowest during 2018 (681 records); similarly, the highest value of WRR was in 2016 (194.84) and the lowest during 2018 (30.11). In the entrance of the bays for the two years sampled, in 2015, the highest number of whistles and WRR (372 and 20.32, respectively) was obtained, while during 2016 the smallest values were obtained (320 and 10.79, respectively). Santiago Bay showed a high acoustic activity in 2016 (1,752 whistles and a WRR of 76.63), while Manzanillo Bay was in 2019 (3,008 whistles and a WRR of 84.91); while lowest acoustic activity of dolphins in Santiago was during 2019 (62 whistles and a WRR of 1.75), and in Manzanillo was during 2015 (408 whistles and WRR of 18.78). The values of mean revealed that in 2017 was the highest (mean = 11.20) and the lowest in 2015(mean = 6.10).

Table 3.2. Number of whistles (top) and Whistles Recording Rate (*WRR*, bottom), mean, maximum and minimum WRR of dolphins obtained annually from different sampling location in bays of Colima, Mexico during the period of September 2015 to January 2019.

Year	Entrance	Santiago	Manzanillo	Total	Mean (sd) Min-max
2015	372 20.32	486 21.91	408 18.78	1,266 61.01	6.10 (±1.50) 0.28-12.85
2016	320 10.79	1,752 76.63	2,211 107.42	4,283 194.84	7.49 (±1.07) 0-19.81
2017	-	930 34.78	1,654 54.89	2,584 89.67	11.20 (±3.52) 0.59-27.31
2018	-	76 2.81	605 27.30	681 30.11	10.03 (±5.50) 2.81-20.85
2019	-	62 1.75	3,008 84.91	3070 86.66	9.63 (±2.49) 1.75-7.47
Total	692	3,306	7,886	11,884 462.29	

Also, the maximum value was 27.31 in 2017 while the minimum was 0 in 2016. However, mean differences between years were not significant ($H_{56,4} = 1.764$; $p = 0.779$) (Table 3.2).

Seasonal analysis showed that highest acoustic activity occurred during winter periods (7,456 whistles and a WRR of 264.16), and lowest number during autumn periods (785 whistles and a WRR of 35.96). The highest number of whistles and WRR in the entrance of the bays occurred in autumn (346 and 13.13, respectively), while in Santiago (1,441 and 57.27, respectively), and Manzanillo (6,015 and 206.89, respectively) bay occurred in winter. The lowest number of whistles and WRR in the entrance was in spring (77 and 3.34, respectively), whereas in Santiago and Manzanillo Bay lowest data concurred during autumn with (202-8.98 and 237-13.85, respectively) (Table 3.3). The highest mean of the WRR in seasons was in the winter with 10.15 and the lowest was in autumn with 5.14. The maximum value registered in the mean of WRR was in winter (max= 27.31) and the minimum was in summer (min= 0). Seasonal mean results that did not show significant differences ($H_{56,3} = 3.932$; $p = 0.269$).

Table 3.3. Number of whistles (top) and Whistles Recording Rate (WRR, bottom), mean, maximum and minimum WRR of dolphins obtained seasonally from different sampling location in bays of Colima, Mexico during the period of September 2015 to January 2019.

Season	Entrance	Santiago	Manzanillo	Total	Mean (sd)
					Min- max
Summer	269	1,190	629	2,088	7.37 (± 1.45)
	14.64	49.46	31.74	95.84	0-14.66
Autumn	346	202	237	785	5.14 (± 1.49)
	13.13	8.98	13.85	35.96	0.28-12.85
Winter	-	1,441	6015	7,456	10.15 (± 1.52)
	-	57.27	206.89	264.16	0-27.31
Spring	77	473	1,005	1,555	6.63 (± 1.81)
	3.34	22.17	40.87	66.38	0.9-19.81
Total	692	3306	7886	11,884 462.34	

The frame time of the quadrant F showed the highest number of whistles (2,864) while the quadrant E presented the highest WRR (439.4), and mainly in the location of Manzanillo (WWR=292.29). Also, the quadrant F revealed the highest values of whistles (1,223) and WRR (169.37) in the Santiago Bay.

The frame time of the quadrant A showed the lowest number of whistles (1,075) and WRR (189.5), mainly in the entrance of the bays (43 and 6.83, respectively) (Table 3.4).

The presence or absence of dolphins was independent of the day/night time ($\chi^2_{1,2}=2,739$, $p= 0.098$). The time frame with the highest value in the mean of WRR was F (mean = 11.54) while C had the lowest value (mean = 5.00).

Table 3.4. Number of whistles (top) and Whistles Recording Rate (WRR, bottom), mean, maximum and minimum WRR of dolphins obtained during time frames of different sampling location in bays of Colima, Mexico during the period of September 2015 to January 2019. Time frame: 2–6 h (A), 6–10 h (B), 10–14 h (C), 14–18 h (D), 18–22 h (E) and 22–2 h (F).

Time frame	Entrance	Santiago	Manzanillo	Total	Mean (sd) Min- max
A	43	474	558	1,075	6.11 (± 1.08)
	6.83	92.66	90.5	189.5	0-20.26
B	45	234	1,155	1,434	9.29 (± 2.47)
	19.25	66.68	192.33	278.26	0-47.69
C	300	269	1,593	2,159	5.00 (± 1.42)
	48.13	38.97	129.79	216.89	0-32.28
D	21	407	1,587	2,018	6.69 (± 1.96)
	1.21	64.73	172	237.94	0-64.91
E	99	699	1,536	2,334	11.20 (± 3.59)
	11.72	135.39	292.29	439.4	0-135.15
F	184	1,223	1,457	2,864	11.54 (± 2.88)
	43.65	169.37	221.57	434.59	0-68.41
Total	692	3306	7886	11,884 1,796.58	

The maximum WRR was registered in the E time frame (135.15) and the minimum was presented in all the time framed (0). Also, the results revealed that the mean WRR did not show differences among quadrants ($H_{206,5} = 6.744$, $p = 0.240$).

3.4- Discussion

Through this research was possible to identify the occurrence of the acoustic activity of dolphins among sites, and during several temporal scales such as years, seasons, and day/night cycles, which was an important contribution on the ecology of dolphin species that inhabit in waters of the Mexican Central Pacific, particularly Colima coasts.

Despite of the inequality in the sampling, this study is an approach to the ecological and habitats of the dolphins from this region.

3.4.1- Whistles spatial locations

Whistle spatial location suggests that dolphins prefer the Manzanillo Bay as a habitat, in comparison to the other bay and outside of them. This preference may be related to area size as Manzanillo Bay is bigger, probably offers more protection from predators, and it is a good refuge to rest and/or to socialize because it is made up by shallow waters. Even, migratory humpback whales use bays from Colima to nurse their calves, and probably also to avoid predators (Ortega-Ortiz *et al.*, In press). Killer whales are recognized as potential predators of humpback whales and dolphins on the coasts of Colima, since a probable new ecotype with a generalist feeding behavior has been proposed (Vargas-Bravo *et al.*, 2020).

Additionally, a greater number of whistles that suggest a preference in Manzanillo Bay as a habitat, could be related with dolphins finding optimal conditions to complete an ecological activity, which could be feeding. In general, dolphins have been described as an opportunistic predator with ichthyophagous and teutophagous habits (Dolar *et al.*, 2003; Scott & Chivers, 2009; Gimenez *et al.*, 2017). In particular, on the coast of Colima, several species of dolphins have been recorded in feeding activities, *i.e.*, killer whales, false killer whales, rough-toothed dolphins, and spotted dolphins (Vargas-Bravo *et al.*, 2020; Ortega-Ortiz *et al.*, 2014a, 2014b, Díaz-Torres *et al.*, 2022). The last two dolphin species are recognized as predominant in Colima coasts (Ortega-Ortiz *et al.*, 2014a; Kono-Martínez *et al.*, 2017), which can be discriminated based on whistles parameters (see chapter 2). Therefore, the idea that these two species are the predominant ones in Manzanillo Bay, in order to search for food, is not ruled out.

There are sightings in the area of killer whales and on some occasion dolphins stranded in the beaches with corporal marks of interactions with these predators. In both environments, oceanic and shallow waters, they could be attacked, but shallow waters can offer additional protection (Maldini, 2003).

3.4.2- Temporal whistles variation

The acoustic activity of dolphins, described through number or frequency rate of whistles, showed some differences among years. During 2016 the highest acoustic activities were registered, while during 2018 the lowest values were obtained.

This result is coincident with Díaz-Torres *et al.* that showed that during 2016 spotted dolphins were also more abundant and showed a wider dispersion, during warm conditions, in waters of the Mexican Central Pacific (MCP).

Furthermore, acoustic activity showed some slight variations among seasons, being the whistles' frequency higher during winter seasons than in fall seasons. Other works refers that usually, the movements of dolphins may correspond to prey availability or prey movements (Reilly 1990; Young & Cockcroft, 1994; Silva, 1999; Wang *et al.*, 2003). For example, some bottlenose dolphins from warmer waters showed a localized seasonal movement while dolphins from highest latitudes showed a tendency to seasonal migrations (Shane, Wells, & Würsig, 1986). The spotted dolphins showed higher density/abundance estimates during the Mixed periods (winter-spring), when they showed a greater breadth of trophic niche in the coastal waters of the MCP (Díaz-Torres *et al.*, 2022; Díaz-Torres *et al.*, In prep.); during the same autumn and winter seasons, other species of dolphins, such as the rough-toothed dolphin and the false killer whales use the waters of the MCP to carry out feeding activities (Ortega-Ortiz *et al.*, 2014a, 2014b); while the killer whales also use the habitat of the MCP to search for food resources, but throughout the year. In summary, this seasonal variation in acoustic activity of dolphins, given by whistles records, suggest a close relationship with feeding behavior.

3.4.3- Diurnal/nocturnal patterns

The acoustic activity of dolphins did not show differences during the diurnal time, which coincides with continues sightings of a spotted dolphin species, probably more than two groupings, and with reports of sightings of rough-toothed dolphins that use the coastal area for foraging activities (Ortega-Ortiz *et al.*, 2014a; González-Salguero, 2017). This fact could be explained by the favorable oceanographic conditions (Kono-Martínez *et al.*, 2017) that allowed these dolphins to feed in each moment of the day.

However, during the time frame of the E-F night cycle the WWR was higher than the other frames, despite of significant differences, this result suggests that after sunset the zooplankton begins a vertical migration attracting all kind of fishes and squids (McLaren, 1963), which, in turn, are prey to dolphins enhancing their foraging activity and consequently leading to the increase of their acoustic activity. Comparatively, in shallow waters of the Mediterranean, dolphins emitted more whistles during dark periods due to possibly foraging (Castellote *et al.*, 2015; Gregoriotti *et al.*, 2021).

In contrast, in North Carolina the whistling increased during the day at higher depths, most probably because the number of dolphins groups increased (Hodge *et al.*, 2013), which indicated that whistles function as a social call. Species such as the white-beaked dolphins (*Lagenorhynchus albirostris*) are vocal actives when they are socializing but never during the feeding, traveling, or resting (Rasmussen & Miller, 2002); although, spinner dolphins more abundant in our area of study are vocal when they are traveling or feeding (Norris *et al.*, 1994a).

The behaviour of whistling during night periods has been little studied, as well as the nocturnal behaviour in freedom of dolphins, since most research analyses the sounds of clicks (Soldevilla, 2008; Leeney, Carslake & Elwen, 2011). Although, most of the whistles studied during night periods are in captivity (Kremers *et al.*, 2014; Rachinas-Lopes *et al.*, 2017), those results suggested that whistles could be used in feeding activities and to maintain the group coordination (Simon, McGregor & Ugarte, 2007; Benoit-Bird & Au, 2009). Just as it has been suggested that the Icelandic killer whale uses a specific call to manipulate the herring's behaviour (Simon, McGregor & Ugarte, 2007).

3.4.4- Final considerations

Although, there is a lack of visual confirmation of the dolphin species with this methodology, it could be inferred that the sounds probably were produced most likely by spotted dolphins and rough-toothed dolphins as they are dominant species distributed in coastal region (Ortega-Ortiz *et al.*, 2013; Ortega-Ortiz *et al.*, 2014a; González-Salguero, 2017; Kono-Martínez *et al.*, 2017). The rough-toothed dolphin is frequently found in deep waters in the eastern Pacific, Hawaii and in the Mediterranean Sea (Miyazaki, 1994; Baird *et al.*, 2008; Kerem *et al.*, 2016), in the present area it was found being their sightings commonly in the Entrance of the bays (Ortega-Ortiz *et al.*,

2014a). Data analysis from the Entrance of the bays showed mainly whistles with specific characteristic as segmentation (307 whistles), low frequencies, and low duration; which are typical features of the whistles from the rough-toothed dolphin (see chapter 2).

Some audio files were lost due to electronic failures, damage to the equipment due to the introduction of water into the plastic case, or even the loss of equipment due to adverse oceanographic conditions caused by regional storms; as well as because it was stolen by regional fishermen.

The entrance only was recorded 2 years because of technical issues with a hydrophone, despite of this, the study was focused like a general approach to the dolphins' habits. Nevertheless, a total of 430 successful acoustic records were collected, from which more than 1,289 h of aquatic sounds allowed the identification of 11,884 whistle signals from dolphins distributed in the region.

Although the spotted dolphin is known to be a dominant specie in the area, it is more difficult to determine which whistles belong to it. Whistles of spotted dolphin are similar to oceanic species such as bottlenose or spinner dolphins. Different behaviors of oceanic species could explain their presence at night, for example, in the southwestern Indian Ocean spinner dolphins feed offshore and rest close to shore (Gross *et al.*, 2009). The same study showed that spotted dolphins in the region are oceanic and have preferences by deep waters. Nevertheless, other study in the Gulf of Mexico showed that spotted dolphin prefers shallow waters (Mills & Rademacher, 1996). However, the nonexistence of night sightings suggested that some records could belong to oceanic species.

The present study showed that the acoustic habits of the dolphins that are distributed in the coast of Colima have an important implication towards their trophic ecology and the use they make of the region. Manzanillo Bay is the area with highest habitat use compared to Santiago Bay, and the Entrance to both bays.

Slight annual differences suggest that the acoustic activity of the dolphins predominated in 2016, in the winter months, and during nocturnal periods of time. This allow us to infer that rough-toothed and spotted dolphin are responsible for most of the whistles recorded in the region. Future studies should be performed to clarify the results of the present study.

Chapter 4: Final conclusions

This study represents the first insight about the dolphin's acoustic behaviour and habitat preference in the Mexican Central Pacific (MCP) region. Recurrent dolphin species in this region were recorded acoustically and with visual confirmation. The dolphin species were: rough-toothed dolphin (*Steno bredanensis*), spotted dolphin (*Stenella attenuata*), spinner dolphin (*Stenella longirostris*), bottlenose dolphin (*Tursiops truncatus*) and Risso's dolphin (*Grampus griseus*). These species could be distinguished by their distribution habitat, being the rough-toothed and spotted dolphin usually observed on coastal waters, and the spinner, bottlenose and Risso's dolphin observed on oceanic waters. To investigate acoustic activity of dolphin species from Mexican Central Pacific (MCP), two methodologies were performed in this study: 1) Recording dolphin sounds with a hydrophone and visual confirmation of the species during surveys (chapter 2), and 2) Recording dolphin sounds through a hydrophone anchored in the sea bottom (passive acoustic monitoring) in three different locations (Entrance, Santiago and Manzanillo Bays, chapter 3).

Dolphins emit three kinds of sounds: echolocation clicks, burst pulse and whistles. This study was focused on the analysis of the whistles, which are characterized by: frequency, shape, duration, and N.I.P. Through the analysis of the whistle records and visual confirmation of dolphin species distributed along of the MCP, it was discovered that:

- There are geographical differences in the whistle's repertoire of dolphins.
- In the group of oceanic species, the Risso's dolphin was distinguished acoustically, by its low frequencies and short duration. While the bottlenose and spinner dolphin showed acoustic similarities.
- Coastal species showed acoustic distinction, as spotted dolphins emit whistles at a higher frequency compared to the whistles of rough toothed dolphins.
- Two acoustic groups, with mixed distribution habitats, could be identified, 1) those that usually whistle with a frequency >10 kHz (spotted, spinner and bottlenose dolphin) and 2) those that usually whistle with a frequency <10 kHz (rough-toothed and Risso's dolphin).

- Similar whistles parameters were observed in the group of dolphins that emit these sounds at high frequencies, with the exception of bottlenose dolphin, which presented a high number of N.I.P, a longer duration in the whistles and with a predominant “multiloop” shape.
- Whistles characteristics in the group of dolphins that emit these sounds at low frequencies were differentiated by a “segmentation” and a predominance of the shape “flat” in sounds from rough-toothed dolphin, while Risso’s dolphin emitted non-segmented whistles and with “u-shape”.

In addition, hydrophones anchored in the sea bottom were placed in the Entrance, Santiago and Manzanillo Bays, where shipping and touristic traffic is frequent. Dolphins’ acoustic records were obtained during 2015-2019, in order to obtain the number and features of emitted whistles. These dolphin sounds were standardized in relation to the effort with a whistle recording rate (WRR), in order to apply statistical analyses, to be compared by year, season, location, and daytime. The results of this chapter revealed that:

- Manzanillo Bay seems to be the area with higher use by dolphins.
- Annual acoustic activity of dolphins was similar, although during 2016 a major acoustic activity was detected.
- Seasonal acoustic activity of dolphins was similar, however during winter periods a higher number of whistles were recorded.
- Daytime acoustic activities did not present significant differences, but during the night-time more acoustic detections were registered.
- Spotted and rough-toothed dolphin should be the responsible of the most of the whistles sounds due to their predominance in the area.

Acoustics research definitively is a very useful tool to investigate several ecological aspects of dolphins, as the use of the habitat, considering annual, month and day-night time scales.

On the other hand, the characterization of dolphin whistles makes it possible to establish a pattern for each species. In the future, this pattern can be used for the discrimination of the species, to evaluate potential changes in presence trends of dolphin species and maybe to infer if the noise caused by ship traffic has any effect on the communication of these animals. The results of this study allowed us to obtain valuable information about the ecology of dolphins that can be used for future conservation measures.

4- Literature cited

- Acevedo, A. (1991). Behaviour and movements of bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. *Aquatic Mammals*, 17(3), 137-147.
- Acevedo-Gutiérrez, A., & Stienessen, S. C. (2004). Bottlenose dolphins (*Tursiops truncatus*) increase number of whistles when feeding. *Aquatic Mammals*, 30(3), 357-362. <https://doi.org/10.1578/am.30.3.2004.357>
- Ansmann, I. C. (2005). The whistle repertoire and acoustic behaviour of short-beaked common dolphins, *Delphinus delphis*, around the British Isles, with applications for acoustic surveying (Doctoral dissertation, University of Wales Bangor). *School of Biological Sciences* (December): 100.
- Amaral, A. R., Jackson, J. A., Möller, L. M., Beheregaray, L. B., & Coelho, M. M. (2012). Species tree of a recent radiation: the subfamily Delphininae (Cetacea, Mammalia). *Molecular Phylogenetics and Evolution*, 64(1), 243-253.
- Arranz, P., DeRuiter, S. L., Stimpert, A. K., Neves, S., Friedlaender, A. S., Goldbogen, J. A., Visser F., Calambokidis, J., Southall, B.L. & Tyack, P. L. (2016). Discrimination of fast click series produced by tagged Risso's dolphins (*Grampus griseus*) for echolocation or communication. *Journal of Experimental Biology*, 219, 2898–2907. <https://doi.org/10.1242/jeb.144295>.
- Au, W. W., Floyd, R. W., & Haun, J. E. (1976). Propagation of dolphin echolocation signals. *The Journal of the Acoustical Society of America*, 60(S1), S6-S6.
- Au, W. W. (1993). Characteristics of dolphin sonar signals. In: *The sonar of dolphins* (pp. 115-139). Springer, New York, NY.
- Au, W. W. (1993). *The sonar of dolphins*. Springer Science & Business Media. 32(2), 1–277
- Au, W. W. L., Branstetter, B., Moore, P. W., & Finneran, J. J. (2012). Dolphin biosonar signals measured at extreme off-axis angles: Insights to sound propagation in the head. *The Journal of the Acoustical Society of America*, 132(2), 1199–1206. <https://doi.org/10.1121/1.4730901>
- Aubauer, R., Lammers, M. O., & Au, W. W. (2000). One-hydrophone method of estimating distance and depth of phonating dolphins in shallow water. *The Journal of the Acoustical Society of America*, 107(5), 2744-2749.
- Azevedo, Alexandre F. et al. 2010. “Ansmann, I. C. (2005). The Whistle Repertoire and Acoustic Behaviour of Short-Beaked Common Dolphins, *Delphinus Delphis*, around the British Isles, with Applications for Acoustic Surveying (Doctoral Dissertation, University of Wales Bangor).Zil.” *The Journal of the Acoustical Society of America* 127(4): 2646–51.
- Azevedo, A. F., Oliveira, A. M., Rosa, L. D., & 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.

- Azevedo, A. F., Flach, L., Bisi, T. L., Andrade, L. G., Dorneles, P. R., & Lailson-Brito, J. (2010). Whistles emitted by Atlantic spotted dolphins (*Stenella frontalis*) in southeastern Brazil. *The Journal of the Acoustical Society of America*, 127(4), 2646-2651.
- Baird, R. W., Webster, D. L., Mahaffy, S. D., McSweeney, D. J., Schorr, G. S., & Ligon, A. D. (2008). Site fidelity and association patterns in a deep-water dolphin: Rough-toothed dolphins (*Steno bredanensis*) in the Hawaiian Archipelago. *Marine Mammal Science*, 24(3), 535-553. <https://doi.org/10.1111/j.1748-7692.2008.00201.x>
- Baird, R. W., Webster, D. L., Aschettino, J. M., Schorr, G. S., & McSweeney, D. J. (2013). Odontocete cetaceans around the main Hawaiian Islands: Habitat use and relative abundance from small-boat sighting surveys. *Aquatic Mammals*, 39(3).
- Ballance, L. T. (1992). Habitat use patterns and ranges of the bottlenose dolphin in the Gulf of California, Mexico. *Marine Mammal Science*, 8(3), 262-274.
- Barkley, Y., Oswald, J. N., Carretta, J. V., Rankin, S., Rudd, A., & Lammers, M. O. (2011). Comparison of Real-Time and Post-Cruise Acoustic Species Identification of Dolphin Whistles Using ROCCA (Real-Time Odontocete Call Classification Algorithm). *NOAA Technical Memorandum*, (NMFS-SWFSC-473), 29.
- Baron, S. C., Martinez, A., Garrison, L. P., & Keith, E. O. (2008). Differences in acoustic signals from Delphinids in the western North Atlantic and northern Gulf of Mexico. *Marine Mammal Science*, 24(1), 42-56.
- Baumgartner, M. F., Bonnell, J., Corkeron, P. J., Van Parijs, S. M., Hotchkiss, C., Hodges, B. A., Bort Thornton, J., Mensi, B. L., Bruner, S. M. (2020). Slocum gliders provide accurate near real-time estimates of baleen whale presence from human-reviewed passive acoustic detection information. *Frontiers in Marine Science*, 7, 100.
- Bazúa-Durán, C., & Au, W. W. (2002). The whistles of Hawaiian spinner dolphins. *The Journal of the Acoustical Society of America*, 112(6), 3064-3072.
- Bazúa-Durán, C., & Au, W. W. (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(6), 3757-3769.
- Belikov, R. A., & Bel'kovich, V. M. (2007). Whistles of beluga whales in the reproductive gathering off Solovetskii Island in the White Sea. *Acoustical Physics*, 53(4), 528-534.
- Benoit-Bird, K. J., & Au, W. W. (2003). Prey dynamics affect foraging by a pelagic predator (*Stenella longirostris*) over a range of spatial and temporal scales. *Behavioral Ecology and Sociobiology*, 53(6), 364-373.
- Benoit-Bird, K. J., & Au, W. W. (2009). Cooperative prey herding by the pelagic dolphin, *Stenella longirostris*. *The Journal of the Acoustical Society of America*, 125(1), 125-137.

- Benoit-Bird, K. J., & Au, W. W. (2009). Phonation behavior of cooperatively foraging spinner dolphins. *The Journal of the Acoustical Society of America*, 125(1), 539-546.
- Blanco, C., Raduán, M. Á., & Raga, J. A. (2006). Diet of Risso's dolphin (*Grampus griseus*) in the western Mediterranean Sea. *Scientia Marina*, 70(3), 407-411.
- Caldwell MC, Caldwell DK (1965) Individualized whistle contours in bottlenose dolphins (*Tursiops truncatus*). *Nature*, 207, 434-435
- Caldwell, M. C. & Caldwell, D. K. (1968). Vocalization of naive captive dolphins in small groups. *Science*, 159, 1121e1123.
- Caldwell, M. C. & Caldwell, D. K. (1971). Statistical evidence for individual signature whistles in Pacific white sided dolphins, *Lagenorhynchus obliquidens*. *Cetology*, 3, 1e9.
- Caldwell, M. C., Caldwell, D. K. & Miller, J. F. (1973). Statistical evidence for individual signature whistles in the spotted dolphin, *Stenella plagiodon*. *Cetology*, 16, 1e21.
- Caldwell MC, Caldwell DK, Tyack PL (1990) A review of the signature-whistle-hypothesis for the Atlantic bottlenose dolphin. In: Leatherwood S, Reeves RR (eds) The bottlenose dolphin. Academic Press, San Diego, pp 199-234.
- Cascão, I., Lammers, M. O., Prieto, R., Santos, R. S., & Silva, M. A. (2020). Temporal patterns in acoustic presence and foraging activity of oceanic dolphins at seamounts in the Azores. *Scientific reports*, 10(1), 1-11.
- Castellote, M., Brotons, J. M., Chicote, C., Gazo, M., & Cerdà, M. (2015). Long-term acoustic monitoring of bottlenose dolphins, *Tursiops truncatus*, in marine protected areas in the Spanish Mediterranean Sea. *Ocean & Coastal Management*, 113, 54-66.
- Carwardine, M. (1995). *Whales, dolphins and porpoises* (No. 599.5 CARw).
- CEBALLOS, H. (1997). Los mamíferos de México: distribución y estado de conservación the mammals of Mexico: distribution and conservation status. *Revista Mexicana de Mastozoología*, 2, 33-71.
- Christensen, I. 1982. Killer whales in Norwegian coastal waters. *Reports International Whaling Commission*, 32, 633-12.
- Committee on Taxonomy. 2018. List of marine mammal species and subspecies. Society for Marine Mammalogy, www.marinemammalscience.org
- Constantine, Rochelle. (2002). The Behavioural Ecology of the Bottlenose Dolphins (*Tursiops Truncatus*) of Northeastern New Zealand: A Population Exposed to Tourism. *Philosophy Doctor of* (January 2002): 232.
- Cotter, Mark P., Daniela Maldini, & Thomas A. Jefferson. (2012). Porpicide' in California: Killing of Harbor Porpoises (*Phocoena Phocoena*) by Coastal Bottlenose Dolphins (*Tursiops Truncatus*). *Marine Mammal Science*, 28(1), 1-15.

- Cranford, T. W., Amundin, M., & Norris, K. S. (1996). Functional morphology and homology in the odontocete nasal complex: Implications for sound generation. *Journal of Morphology*, 228(3), 223–285.
- Cranford, T. W. (1999). The sperm whale's nose: Sexual selection on a grand scale? *Marine Mammal Science*, 15(4), 1133–1157. <https://doi.org/10.1111/j.1748-7692.1999.tb00882.x>
- Darling, J. D. (2015). Low frequency, ca. 40 Hz, pulse trains recorded in the humpback whale assembly in Hawaii. *The Journal of the Acoustical Society of America*, 138(5), EL452-EL458.
- Datta, S., & Sturtivant, C. (2002). Dolphin whistle classification for determining group identities. *Signal processing*, 82(2), 251-258.
- Díaz-López B & Shirai JAB (2009). Mediterranean common bottlenose dolphin's repertoire and communication use. *Dolphins: Anatomy, behavior and threats*, 1-20.
- Díaz-López, Bruno. (2011). “Whistle Characteristics in Free-Ranging Bottlenose Dolphins (*Tursiops truncatus*) in the Mediterranean Sea: Influence of Behaviour.” *Mammalian Biology*, 76(2), 180–89.
- Díaz-Torres, E. R., Christian D. Ortega-Ortiz, Antonio Corgos López-Prado, Luis M. Enríquez-Paredes, Arturo Tripp-Valdez, & Fernando R. Elorriaga-Verplancken: **In prep.** Insights into the trophic ecology of the Spotted Dolphin (*Stenella attenuata*) from the Mexican Central Pacific, through stable isotopes analysis. To submit *Marine Mammal Science*. November 2021. 27 pp.
- Díaz-Torres, E. R., Emigdio Marín-Enríquez, Antonio Corgos, Aramis Olivos-Ortiz & Christian D Ortega-Ortiz. In press. Influence of environmental variability on the distribution and abundance of the pantropical spotted dolphin (*Stenella attenuata*) in the Mexican Central Pacific. *Ciencias Marinas*.
- Dolar, M. L. L., Walker, W. A., Kooyman, G. L., & Perrin, W. F. (2003). Comparative feeding ecology of spinner dolphins (*Stenella longirostris*) and Fraser's dolphins (*Lagenodelphis hosei*) in the Sulu Sea. *Marine Mammal Science*, 19(1), 1-19.
- Dudzinski, K. M. (1996). Communication and Behavior in the Atlantic Spotted Dolphins (*Stenella frontalis*): Relationships Between Vocal and Behavioral Activities. *Society*, (August), 218. <https://doi.org/10.1007/s13398-014-0173-7.2>
- Eater, D. B., Miller, L. E., Caffery, K. A., & Kuczaj II, S. A. (2013). Effects of an Increase in Group Size on the Social Behavior of a Group of Rough-Toothed Dolphins (*Steno bredanensis*). *Aquatic Mammals*, 39(4), 344-355.
- Elliser, C. R. 2010: Intra and interspecies association patterns of Atlantic spotted dolphins, *Stenella frontalis*, and Atlantic bottlenose dolphins, *Tursiops truncatus*, and the effects of demographic changes following two major hurricanes. Ph.D. Thesis, Florida Atlantic Univ., Boca Raton, FL.
- Elliser, C. R., & Herzing, D. L. (2014). Social structure of Atlantic spotted dolphins, *Stenella frontalis*, following environmental disturbance and demographic changes. *Marine Mammal Science*, 30(1), 329-347.

- Erbe, C., Dunlop, R., Jenner, K.C.S., Jenner, M.-N.M., McCauley, R.D., Parnum, I., Parsons, M., Rogers, T., & Salgado-Kent, C. (2017). Review of underwater and in-air sounds emitted by Australian and Antarctic marine mammals. *Acoustics Australia*, 45, 179–241.
- Erbe, C., Salgado-Kent, C., De Winter, S., Marley, S., & Ward, R. (2020). Matching signature whistles with photo-identification of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the Fremantle Inner Harbour, Western Australia. *Acoustics Australia*, 48(1), 23-38.
<https://doi.org/10.1007/s40857-020-00178-2>.
- Esch, H. Carter, Laela S. Sayigh, & Randall S. Wells. (2009). Quantifying Parameters of Bottlenose Dolphin Signature Whistles. *Marine Mammal Science*, 25(4), 976–86.
- de la Esperanza, A. O., Martínez, A. A., Tuz, M. T., & Pérez-Collazos, E. (2017). Are anthropogenic factors affecting nesting habitat of sea turtles? The case of Kanzul beach, Riviera Maya-Tulum (Mexico). *Journal of coastal conservation*, 21(1), 85-93.
- Fahlke, J. M., Gingerich, P. D., Welsh, R. C., & Wood, A. R. (2011). Cranial asymmetry in eocene archaeocete whales and the evolution of directional hearing in water. *Proceedings of the National Academy of Sciences of the United States of America*, 108(35), 14545– 14548.
<https://doi.org/10.1073/pnas.1108927108>
- Férriz Rosell, B. (2017). Effect of behaviour on free wild Bottlenose dolphins' whistles in the Arousa Ria, Galicia. Degree in Biology.
- Figueroa-Soltero, N. A. (2017). Aspectos de la ecología especial del delfín de dientes rugosos (*Steno bredanensis*) en la costa de Colima y sur de Jalisco. Tesis de Licenciatura, Universidad de Colima.
- Fraser F.C. & Purves P.E. (1960). Hearing in cetaceans: evolution of the accessory air sacs and the structure and function of the outer and middle ear in recent cetaceans. *Bulletin of the British Museum*, 7, 1-140.
- Fouda, L., Wingfield, J. E., Fandel, A. D., Garrod, A., Hodge, K. B., Rice, A. N., & Bailey, H. (2018). Dolphins simplify their vocal calls in response to increased ambient noise. *Biology letters*, 14(10), 20180484.
- Fripp, D., Owen, C., Quintana-Rizzo, E., Shapiro, A., Buckstaff, K., Jankowski, K., Wells R., & Tyack, P. (2005). Bottlenose dolphin (*Tursiops truncatus*) calves appear to model their signature whistles on the signature whistles of community members. *Animal cognition*, 8(1), 17-26.
- Frazer, J. F. D., & Huggett, A. S. G. (1973). Specific foetal growth rates of cetaceans. *Journal of Zoology*, 169(1), 111-126.
- Frainer, G., Huggenberger, S., Moreno, I. B., Plön, S., & Galatius, A. (2021). Head adaptation for sound production and feeding strategy in dolphins (Odontoceti: Delphinida). *Journal of Anatomy*, 238(5), 1070-1081.

- Galatius, A., Berta, A., Frandsen, M. S., & Goodall, R. N. P. (2011). Interspecific variation of ontogeny and skull shape among porpoises (Phocoenidae). *Journal of Morphology*, 272(2), 136-148.
- Galatius, A., & Goodall, R. N. P. (2016). Skull shapes of the Lissodelphininae: radiation, adaptation and asymmetry. *Journal of morphology*, 277(6), 776-785.
- Galatius, A., Racicot, R., McGowen, M., & Olsen, M. T. (2020). Evolution and diversification of delphinid skull shapes. *IScience*, 23(10), 101543.
- Gannier, A., & West, K. L. (2005). Distribution of the rough-toothed dolphin (*Steno bredanensis*) around the Windward Islands (French Polynesia) 1. *Pacific Science*, 59(1), 17-24.
- Gannier, A., Fuchs, S., Gannier, A., Fernandez, M., & Azevedo, J. M. (2020). Dolphin whistle repertoires around São Miguel (Azores): Are you common or spotted?. *Applied Acoustics*, 161, 107169.
- Gatesy, J., Milinkovitch, M., Waddell, V., & Stanhope, M. (1999). Stability of cladistic relationships between Cetacea and higher-level artiodactyl taxa. *Systematic Biology*, 48(1), 6-20.
- Gatesy, J., Geisler, J. H., Chang, J., Buell, C., Berta, A., Meredith, R. W., ... & McGowen, M. R. (2013). A phylogenetic blueprint for a modern whale. *Molecular phylogenetics and evolution*, 66(2), 479-506.
- Gayo, J. L. P. (2006). *Acústica ambiental*. Universidad de Oviedo
- Geisler, J. H., McGowen, M. R., Yang, G., & Gatesy, J. (2011). A supermatrix analysis of genomic, morphological, and paleontological data from crown Cetacea. *BMC evolutionary biology*, 11(1), 1-33.
- Gibbs Jr, R. H., & Roper, C. F. (1971). Ocean Acre: Preliminary report on vertical distribution of fishes and cephalopods. In *Proceedings of an international symposium on biological sound scattering in the ocean* (Vol. 1970, pp. 119-133). US Govt. Print. Off., Washington.
- Gimenez J., Marçalo A., Ramirez F., Verborgh P., Gauffier P., Esteban R., Nicolau L., Gonzalez- Ortegón E., Baldó F., Vilas C., Vingada J., Forero M.G., & Stephanis R. (2017). Diet of bottlenose dolphins (*Tursiops truncatus*) from the Gulf of Cadiz: Insights from stomach content and stable isotope analyses.
- Gómez-Valdivia, F. Parés-Sierra, A., & A. L. Flores-Morales. 2015. The mexican coastal current: A subsurface seasonal bridge that connects the tropical and subtropical Northeastern Pacific. *Continental Shelf Research*, 110(1), 100-107.
- González-Salguero J.E. (2017). Hábitat preferencial del delfín moteado (*Stenella attenuata*) en la costa de Colima y sur de Jalisco. Tesis licenciatura. Universidad de Colima. Facultad de Ciencias Marinas, 82pp.
- Goold, J. C. (2000). A diel pattern in vocal activity of short-beaked common dolphins, *Delphinus delphis*. *Marine Mammal Science*, 16(1), 240-244.

- Graur, D., & Higgins, D. G. (1994). Molecular evidence for the inclusion of cetaceans within the order Artiodactyla. *Molecular Biology and Evolution*, *11*(3), 357-364.
- Gregorietti, M., Papale, E., Ceraulo, M., de Vita, C., Pace, D. S., Tranchida, G., Mazzola S., & Buscaino, G. (2021). Acoustic Presence of Dolphins through Whistles Detection in Mediterranean Shallow Waters. *Journal of Marine Science and Engineering*, *9*(1), 78.
- Gridley, T., Nastasi, A., Kriesell, H. J., & Elwen, S. H. (2015). The acoustic repertoire of wild common bottlenose dolphins (*Tursiops truncatus*) in Walvis Bay, Namibia. *Bioacoustics*, *24*(2), 153–174. <https://doi.org/10.1080/09524622.2015.1014851>
- Griffin, R. B., & Griffin, N. J. (2003). Distribution, habitat partitioning, and abundance of Atlantic spotted dolphins, bottlenose dolphins, and loggerhead sea turtles on the eastern Gulf of Mexico continental shelf. *Gulf of Mexico Science*, *21*(1), 3.
- Gross, A., Kiszka, J., Van Canneyt, O., Richard, P., & Ridoux, V. (2009). A preliminary study of habitat and resource partitioning among co-occurring tropical dolphins around Mayotte, southwest Indian Ocean. *Estuarine, Coastal and Shelf Science*, *84*(3), 367-374.
- Hartman, K. L., Fernandez, M., & Azevedo, J. M. N. (2014). Spatial segregation of calving and nursing Risso's dolphins (*Grampus griseus*) in the Azores, and its conservation implications. *Marine Biology*, *161*(6), 1419–1428. <https://doi.org/10.1007/s00227-014-2430-x>
- Harzen, S., & Brunnick, B. J. (1997). Skin disorders in bottlenose dolphins (*Tursiops truncatus*), resident in the Sado estuary, Portugal. *Aquatic Mammals*, *23*(1), 59–68. Retrieved from http://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/1997/AquaticMammals_23-01/23-01_Harzen.pdf
- Heiler, J., S. H. Elwen, H. J. Kriesell, & T. Gridley. (2016). Changes in Bottlenose Dolphin Whistle Parameters Related to Vessel Presence, Surface Behaviour and Group Composition. *Animal Behaviour*, *117*, 167–77.
- Henderson, E. E., Hildebrand, J. A., Smith, M. H., & Falcone, E. A. (2012). The behavioral context of common dolphin (*Delphinus* sp.) vocalizations. *Marine Mammal Science*, *28*(3), 439-460.
- Herzing, D. L. (2000). Acoustics and social behavior of wild dolphins: implications for a sound society. In *Hearing by whales and dolphins* (pp. 225-272).
- Hildebrand, J. (2004). Impacts of anthropogenic sound on cetaceans. *IWC/SC/56 E*, *13*, 32.
- Hocking, D. P., Marx, F. G., Park, T., Fitzgerald, E. M., & Evans, A. R. (2017). A behavioural framework for the evolution of feeding in predatory aquatic mammals. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1850), 20162750.
- Hodge, L. E., Bell, J. T., Kumar, A., & Read, A. J. (2013). The influence of habitat and time of day on the occurrence of odontocete vocalizations in Onslow Bay, North Carolina. *Marine Mammal Science*, *29*(4), E411-E427.

- Hyde, L. L. (1979). Dolphin Conservation in the Tuna Industry: The United States' Role in an International Problem. *San Diego Law Review*, 16(3), 665.
- Irvine, A. B., Scott, M. D., Wells, R. S., & Kaufmann, J. H. (1981). Movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. *Fishery bulletin*, 79(4), 671-688.
- Janik, Vincent M., & Peter J.B. Slater. 1998. "Context-Specific Use Suggests That Bottlenose Dolphin Signature Whistles Are Cohesion Calls." *Animal Behaviour* 56(4): 829–38.
- Janik, V. M., Sayigh, L. S., & Wells, R. S. (2006). Signature whistle shape conveys identity information to bottlenose dolphins. *Proceedings of the National Academy of Sciences*, 103(21), 8293-8297.
- Janik, V. M., & Sayigh, L. S. (2013). Communication in bottlenose dolphins: 50 years of signature whistle research. *Journal of Comparative Physiology A*, 199(6), 479-489.
- Jefferson, T. A., Leatherwood, S., & Webber, M. A. (1993). *Marine mammals of the world*. Food & Agriculture Org.
- Jensen, F. H., Bejder, L., Wahlberg, M., Soto, N. A., Johnson, M., & Madsen, P. T. (2009). Vessel noise effects on delphinid communication. *Marine Ecology Progress Series*, 395, 161-175.
- Johnson, C. S. (1967). Sound detection thresholds in marine mammals. *Marine BioAcoustics*, W. N. Tavoga (Pergamon, New York), pp. 247–260.
- Johnston, C., & Berta, A. (2011). Comparative anatomy and evolutionary history of suction feeding in cetaceans. *Marine Mammal Science*, 27(3), 493-513.
- Jones, G. J., & Sayigh, L. S. (2002). Geographic variation in rates of vocal production of free-ranging bottlenose dolphins. *Marine Mammal Science*, 18(2), 374-393.
- Kerem, D., Goffman, O., Elasar, M., Hadar, N., Scheinin, A., & Lewis, T. (2016). The Rough-Toothed Dolphin, *Steno bredanensis*, in the Eastern Mediterranean Sea: A Relict Population?. In *Advances in Marine Biology* (Vol. 75, pp. 233-258). Academic Press.
- Ketten, D. R. (1992). *The Evolutionary Biology of Hearing*. *The Evolutionary Biology of Hearing*. <https://doi.org/10.1007/978-1-4612-2784-7>
- Kienle, S. S., & Berta, A. (2016). The better to eat you with: the comparative feeding morphology of phocid seals (Pinnipedia, Phocidae). *Journal of Anatomy*, 228(3), 396-413.
- Kiszka, J. J., Heithaus, M. R., & Wirsing, A. J. (2015). Behavioural drivers of the ecological roles and importance of marine mammals. *Marine Ecology Progress Series*, 523, 267-281.
- Kono-Martínez, T., Ortega-Ortiz, C. D., Olivos-Ortiz, A., Torres-Orozco, E., & González-Rodríguez, E. (2017). Oceanographic conditions and marine mammals: identifying a potential relationship in the coastal region of the Mexican Central Pacific. *Revista de Biología Marina y Oceanografía*, 52(3), 479-494.

- Kremers, D., Briseño-Jaramillo, M., Böye, M., Lemasson, A., & Hausberger, M. (2014). Nocturnal vocal activity in captive bottlenose dolphins (*Tursiops truncatus*): could dolphins have presleep choruses?. *Animal Behavior and Cognition*, 1(4), 464-469.
- Küsel, E. T., Mellinger, D. K., Thomas, L., Marques, T. A., Moretti, D., & Ward, J. (2011). Cetacean population density estimation from single fixed sensors using passive acoustics. *The Journal of the Acoustical Society of America*, 129(6), 3610-3622.
- Lammers, Marc O., Whitlow W. L. Au, & Denise L. Herzing. (2003). "The Broadband Social Acoustic Signaling Behavior of Spinner and Spotted Dolphins." *The Journal of the Acoustical Society of America*, 114(3), 1629–39.
- Leatherwood, S. (1993). *Marine mammals of the world* (No. 599 F3). FAO.
- Lima, I. M., Venuto, R., Menchaca, C., Hoffmann, L. S., Dalla Rosa, L., Genoves, R., Fruet, P.F, Milanelli, A., Laporta, P., Tassino, B., Freitas, T.R.O., Bittencourt, L., Laison- Britor, J.Jr., Azevedo, A. F., & Bueno, S. M. (2020). Geographic variation in the whistles of bottlenose dolphins (*Tursiops spp.*) in the southwestern Atlantic Ocean. *Marine Mammal Scienc*, 36(3), 1058-1067e.
- Liste, F., Palacio, J., Ribes, V., Álvarez-Clau, A., Domínguez, L. F., & Corpa, J. M. (2006). Anatomic and computed tomographic atlas of the head of the newborn bottlenose dolphin (*Tursiops truncatus*). *Veterinary Radiology and Ultrasound*, 47(5), 453–460. <https://doi.org/10.1111/j.1740-8261.2006.00167.x>
- Lusseau, D. (2005). Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic. *Marine Ecology Progress Series*, 295, 265-272.
- La Manna, G., Manghi, M., & Sara, G. (2014). Monitoring the habitat use of common Bottlenose Dolphins (*Tursiops truncatus*) using passive acoustics in a Mediterranean marine protected area. *Mediterranean Marine Science*, 15(2), 327-337.
- La Manna, G., Rako-Gospic, N., Manghi, M., & Ceccherelli, G. (2019). Influence of environmental, social and behavioural variables on the whistling of the common bottlenose dolphin (*Tursiops truncatus*). *Behavioral Ecology Society*, 2019(73), 121
- La Manna, G., Rako-Gospic, N., Sarà, G., Gatti, F., Bonizzoni, S., & Ceccherelli, G. (2020). Whistle variation in Mediterranean common bottlenose dolphin: The role of geographical, anthropogenic, social, and behavioral factors. *Ecology and evolution*, 10(4), 1971-1987.
- Maldini, D. (2003). Evidence of predation by a tiger shark (*Galeocerdo cuvier*) on a spotted dolphin (*Stenella attenuata*) off O'ahu, Hawai'i. *Aquatic Mammals*, 29(1), 84-87.
- Marçalo A., Nicolau L., Giménez J., Ferreira M., Santos J., Araújo H., Silva A., Vingada J., Pierce G.J. (2018) Feeding ecology of the common dolphin (*Delphinus delphis*) in Western Iberian waters: has the decline in sardine (*Sardina pilchardus*) affected dolphin diet? *Marine Biology*, 165, 44. <https://doi.org/10.1007/s00227-018-3285-3>

- Marlowe, C. J., & Miller, C. B. (1975). Patterns of vertical distribution and migration of zooplankton at Ocean Station "P" 1. *Limnology and Oceanography*, 20(5), 824-844.
- Marques, T. A., Thomas, L., Martin, S. W., Mellinger, D. K., Jarvis, S., Morrissey, R. P., Ciminello, C., & DiMarzio, N. (2012). Spatially explicit capture–recapture methods to estimate minke whale density from data collected at bottom-mounted hydrophones. *Journal of Ornithology*, 152(2), 445-455.
- Maxia C., Scano P., Maggiani F., Murtas D., Piras F., Crnjar R., Lai A., & Sirigu P. (2007). A morphological and 13C NMR study of the extramandibular fat bodies of the striped dolphin (*Stenella coeruleoalba*). *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology*, 290(7), 913-919.
- May-Collado, L. J., & Wartzok, D. (2008). A comparison of bottlenose dolphin whistles in the Atlantic Ocean: factors promoting whistle variation. *Journal of Mammalogy*, 89(5), 1229-1240.
- McCurry, M. R., Fitzgerald, E. M., Evans, A. R., Adams, J. W., & McHenry, C. R. (2017). Skull shape reflects prey size niche in toothed whales. *Biological Journal of the Linnean Society*, 121(4), 936-946.
- McCormick, J. G., Wever, E. G., Palin, J., & Ridgway, S. H. (1970). Sound Conduction in the Dolphin Ear. *The Journal of the Acoustical Society of America*, 48(6B), 1418–1428. <https://doi.org/10.1121/1.1912302>
- McGowen, M. R., G. Tsagkogeorga, S. Álvarez-Carretero, M. dos Reis, M. Struebig, R. Deaville, P. D. Jepson, S. Jarman, A. Polanowski, P. A. Morin, and S. J. Rossiter. (2020). Phylogenomic resolution of the cetacean tree of life using target sequence capture. *Systematic Biology*, 69(3), 479-501
- McLaren, I. A. (1963). Effects of temperature on growth of zooplankton, and the adaptive value of vertical migration. *Journal of the Fisheries Board of Canada*, 20(3), 685-727.
- Mellinger, D. K., Stafford, K. M., Moore, S. E., Dziak, R. P., & Matsumoto, H. (2007). An overview of fixed passive acoustic observation methods for cetaceans. *Oceanography*, 20(4), 36-45.
- Mello, Inês, and Mats Amundin. (2005). "Whistle Production Pre- and Post-Partum in Bottlenose Dolphins (*Tursiops Truncatus*) in Human Care." *Aquatic Mammals*, 31(2), 169–75.
- Miller, L. J., Solangi, M., & Kuczaj II, S. A. (2008). Immediate response of Atlantic bottlenose dolphins to high-speed personal watercraft in the Mississippi Sound. *Marine Biological Association of the United Kingdom. Journal of the Marine Biological Association of the United Kingdom*, 88(6), 1139.
- Mills, L. R., & Rademacher, K. R. (1996). Atlantic spotted dolphins (*Stenella frontalis*) in the Gulf of Mexico. *Gulf of Mexico Science*, 14(2), 8.
- Mirceta, S., Signore, A. V., Burns, J. M., Cossins, A. R., Campbell, K. L., & Berenbrink, M. (2013). Evolution of mammalian diving capacity traced by myoglobin net surface charge. *Science*, 340(6138). <https://doi.org/10.1126/science.1234192>

- Miyazaki, N. (1977). Growth and reproduction of *Stenella coeruleoalba* off the Pacific coast of Japan. *Scientific Reports of the Whales Research Institute*, 29(2), 1-48.
- Miyazaki, N. (1994). Rough-toothed dolphin *Steno bredanensis* (Lesson, 1828). *Handbook of marine mammals*, 5, 1-21.
- Montgomery, J. C., & Radford, C. A. (2017). Marine bioacoustics. *Current Biology*, 27(11), R502-R507.
- Monteiro-Filho, E. L. D. A., Monteiro, L. R., & dos Reis, S. F. (2002). Skull shape and size divergence in dolphins of the genus *Sotalia*: a tridimensional morphometric analysis. *Journal of Mammalogy*, 83(1), 125-134.
- Moreno, I. B., Zerbini, A. N., Danilewicz, D., de Oliveira Santos, M. C., Simões-Lopes, P. C., Lailson-Brito Jr, J., & Azevedo, A. F. (2005). Distribution and habitat characteristics of dolphins of the genus *Stenella* (Cetacea: Delphinidae) in the southwest Atlantic Ocean. *Marine Ecology Progress Series*, 300, 229-240.
- Morisaka, T., Shinohara, M., Nakahara, F., & Akamatsu, T. (2005). Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations. *Journal of Mammalogy*, 86(3), 541-546.
- Munar E, Rosselló J, Mas C, Morente P & Quetgle M (2002). El desarrollo de la audición humana, *Psicothema*, 14, 247-254.
- Murchison, A. E. (1976). Range resolution by an echolocating bottlenosed dolphin (*Tursiops truncatus*). *The Journal of the Acoustical Society of America*, 60(S1), S5-S5.
- Murray, S. O., Mercado, E., & Roitblat, H. L. (1998). Characterizing the graded structure of false killer whale (*Pseudorca crassidens*) vocalizations. *The Journal of the Acoustical Society of America*, 104(3), 1679–1688. <https://doi.org/10.1121/1.424380>
- Neves, S. (2013). *Acoustic behaviour of Risso's dolphins, Grampus griseus, in the Canary Islands, Spain* (Doctoral dissertation, University of St Andrews).
- Newman, K., & A. M. Springer. (2008). Nocturnal Activity by Mammal-Eating Killer Whales at a Predation Hot Spot in the Bering Sea. *Marine Mammal Science*, 24(4), 990–99.
- Norris, K. S., & Dohl, T. P. (1980). Behavior of the Hawaiian spinner dolphin, *Stenella longirostris*. *Fishery bulletin*, 77(4), 821-849.
- Norris, K. S., Wursig, B., Wells, R. S., & Wursig, M. (1994). *The Hawaiian spinner dolphin*. Univ of California Press.
- Nowacek, Stephanie M., Randall S. Wells, & Andrew R. Solow. (2001). Short-Term Effects of Boat Traffic on Bottlenose Dolphins, *Tursiops Truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science*, 17(4), 673–88.
- 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.

- Nummela, S., & Thewissen, J. G. M. (2008). The physics of sound in air and water. *Sensory evolution on the threshold: adaptations in secondarily aquatic vertebrates*, 358.
- Ortega-Ortiz, C. D., Díaz-Torres, E. R., Juárez-Ruiz, A. E., & Hernández-Dueñas, M. J. (2013). Cetáceos de la costa de Jalisco, Colima y Michoacán. 136.
- Ortega-Ortiz, C. D., Elorriaga-Verplancken, F. R., Arroyo-Salazar, S. A., García-Valencia, R. X., Juárez-Ruiz, A. E., Figueroa-Soltero, N. A., Liñán-Cabello, M. A., & Chávez-Comparán, J. C. (2014a). Foraging Behavior of the Rough-Toothed Dolphin (*Steno bredanensis*) in Coastal Waters of the Mexican Central Pacific. *Aquatic Mammals*, 40(4), 357-363.
<https://doi.org/10.1578/AM.40.4.2014.357>
- Ortega-Ortiz, C. D., Fernando R. Elorriaga-Verplancken, Aramis Olivos Ortiz, Marco A. Liñán-Cabello & Manuel Hueman Vargas Bravo. (2014b). Insights into the Feeding Habits of False Killer Whales (*Pseudorca crassidens*) in the Mexican Central Pacific. *Aquatic Mammals*, 40(4), 386-393.
- Ortega-Ortiz, C. D., Andrea B. Cuevas-Soltero, Reyna Xóchitl García-Valencia, Astrid Frisch-Jordán, Katherina Audley, Aramis Olivos-Ortiz, & Marco A. Liñán-Cabello. In press. Spatial ecology of humpback whales (*Megaptera novaeangliae*, Cetacea-Balaenopteridae) from the Mexican Central Pacific. *Pacific Science*. Mayo 2021. 37 pp.
- Ortiz-Lozano, L., A. Granados-Barba, V. Solís-Weiss, & M. A. García-Salgado. (2005). Environmental Evaluation and Development Problems of the Mexican Coastal Zone. *Ocean and Coastal Management*, 48(2), 161–76.
- Oswald, J. N., Barlow, J., & Norris, T. F. (2003). Acoustic identification of nine delphinid species in the eastern tropical Pacific Ocean. *Marine mammal science*, 19(1), 20-037.
- Oswald, Julie N., Shannon Rankin, Jay Barlow, and Marc O. Lammers. (2007). A Tool for Real-Time Acoustic Species Identification of Delphinid Whistles. *The Journal of the Acoustical Society of America*, 122(1), 587–95.
- Oswald, J. N., Rankin, S., & Barlow, J. (2008). To whistle or not to whistle? Geographic variation in the whistling behavior of small odontocetes. *Aquatic Mammals*, 34(3), 288-302.
- Overstrom, N. A. (1983). Association between burst-pulse sounds and aggressive behavior in captive Atlantic bottlenosed dolphins (*Tursiops truncatus*). *Zoo Biology*, 2(2), 93–103.
<https://doi.org/10.1002/zoo.1430020203>
- Pailhas, Y., Capus, C., & Brown, K. (2012). Dolphin-inspired sonar system and its performance. *IET Radar, Sonar & Navigation*, 6(8), 753-763.
- Papale, E., Perez-Gil, M., Castrillon, J., Perez-Gil, E., Ruiz, L., Servidio, A., Tejedor M., Giacoma C., & Martín, V. (2017). Context specificity of Atlantic spotted dolphin acoustic signals in the Canary Islands. *Ethology Ecology & Evolution*, 29(4), 311-329.
- Peng, C., Zhao, X., & Liu, G. (2015). Noise in the sea and its impacts on marine organisms. *International journal of environmental research and public health*, 12(10), 12304-12323.

- Perrin, W. F., Scott, M. D., Walker, G. J., Ralston, F. M., & Au, D. W. K. (1983). Distribution of four dolphins (*Stenella spp.* and *Delphinus delphis*) in the Eastern Tropical Pacific, with an annotated catalog of data sources. *NOAA Technical Memorandum*, (NOAA-TM- NMFS-S WFC-38), 70.
- Perrin, W. F., Würsig, B., & Thewissen, J. G. M. (Eds.). (2009). *Encyclopedia of marine mammals*. London: Elsevier.
- Pusineri, C., Magnin, V., Meynier, L., Spitz, J., Hassani, S., & Ridoux, V. (2007). Food and feeding ecology of the common dolphin (*Delphinus delphis*) in the oceanic Northeast Atlantic and comparison with its diet in neritic areas. *Marine Mammal Science*, 23(1), 30-47.
- Quick, N. J., & Janik, V. M. (2012). Bottlenose dolphins exchange signature whistles when meeting at sea. *Proceedings of the Royal Society B: Biological Sciences*, 279(1738), 2539-2545.
- Quintana-Rizzo, E., Mann, D.A., & Wells R.S. (2016). Estimated communication range of social sounds used by bottlenose dolphins (*Tursiops truncatus*). *The Journal of the Acoustical Society of America*, 120(3), 1671-83.
- Rachinas-Lopes, P., Luís, A. R., Borges, A. S., Neto, M., & dos Santos, M. E. (2017). Whistle Stability and Variation in Captive Bottlenose Dolphins (*Tursiops truncatus*) Recorded in Isolation and Social Contexts. *Aquatic Mammals*, 43,1-13.
- Rankin, S., Barlow, J., Oswald, J. N., & Ballance, L. (2008). Acoustic Studies of Marine Mammals During Seven Years of Combined Visual and Acoustic Line-Transect Surveys for Cetaceans in the Eastern and Central Pacific Ocean. *NOAA Technical Memorandum*, (NMFS-SWFSC-429), 69.
- Rankin, S., Archer, F., Keating, J. L., Oswald, J. N., Oswald, M., Curtis, A., & Barlow, J. (2017). Acoustic classification of dolphins in the California Current using whistles, echolocation clicks, and burst pulses. *Marine Mammal Science*, 33(2), 520-540.
- Rasmussen, M. H., & Miller, L. A. (2002). Whistles and clicks from white-beaked dolphins, *Lagenorhynchus albirostris*, recorded in Faxaflói Bay, Iceland. *Aquatic Mammals*, 28(1), 78-89.
- Reilly, S. B. (1990). Seasonal changes in distribution and habitat differences among dolphins in the eastern tropical Pacific. *Marine Ecology Progress Series*, 66(1-2), 1-11.
- Richard, G., Filatova, O. A., Samarra, F. I., Fedutin, I. D., Lammers, M., & Miller, P. J. (2017). Icelandic herring-eating killer whales feed at night. *Marine biology*, 164(2), 32.
- Ridgway, S. A. M. H. (1983). Dolphin hearing and sound production in health and illness. In: *Hearing and Other Senses: Presentations in Honor of E. G. Wever. R. R. Fay and G. Gourevitch (Eds.)*. p.247-296. *The Amphora Press, Box N, Groton, CT 06340*. 405pgs. 1983., 45, 50.
- Rodrigo-Saura, F. J., Poveda, P., Carbajo, J., & Ramis, J. (2019). Monitoring Long-Term underwater acoustic pollution in Mediterranean Sea waters. In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings* (Vol. 259, No. 4, pp. 5877-5888). Institute of Noise Control Engineering.

- Roe, H. S. J., & Badcock, J. (1984). The diel migrations and distributions within a mesopelagic community in the North East Atlantic. 5. Vertical migrations and feeding of fish. *Progress in Oceanography*, 13(3-4), 389-424.
- Rosales-Chapula, D.A., Christian D. Ortega-Ortiz, Myriam Llamas-González, Aramis Olivos-Ortiz, Ernesto Torres-Orozco, Braulio Leon-Lopez & Eduardo Romero-Vivas. In press. Underwater ship noise in a commercial and tourist bay complex in the Mexican Central Pacific. *Ciencias Marinas*. Accepted June 2021. 31 pp.
- Rosel, P. E., Hohn, A. A., Mullin, K., Garrison, L. P., Schwacke, L. H., Adams, J., Mazzoil M., Schwarz C., Sinclair C., Speakman T., Urian K., Vollmer N., Wade P., Wells R., Gorgone, A. M., & Zolman E. (2011). Photo-identification capture-mark-recapture techniques for estimating abundance of bay, sound and estuary populations of Bottlenose dolphins along the US East Coast and Gulf of Mexico, a workshop report.
- Rowe, T. (1988). Definition, diagnosis, and origin of mammalia. *Journal of Vertebrate Paleontology*, 8(3), 241–264. <https://doi.org/10.1080/02724634.1988.10011708>.
- Salamon J, Bello JP, Farnsworth A & Kelling S. (2017). Fusing shallow and deep learning for bioacoustic bird species classification, In *Acoustics, Speech and Signal Processing*, número?, 141-145.
- Sanchez-Cabeza, J. A., & Druffel, E. R. (2009). Environmental records of anthropogenic impacts on coastal ecosystems: an introduction. *Marine Pollution Bulletin*, 59(4-7), 87-90.
- dos Santos, Manuel E., Sónia Louro, Miguel Couchinho, & Cristina Brito. (2005). Whistles of Bottlenose Dolphins (*Tursiops Truncatus*) in the Sado Estuary, Portugal: Characteristics, Production Rates, and Long-Term Contour Stability. *Aquatic Mammals*, 31(4), 453–62.
- Sanvicente-Añorve, L., López-Sánchez, J. L., Aguayo-Lobo, A., & Medrano-González, L. (2004). Morphometry and sexual dimorphism of the coastal spotted dolphin, *Stenella attenuata graffmani*, from Bahía de Banderas, Mexico. *Acta Zoologica*, 85(4), 223-232. <https://doi.org/10.1111/j.0001-7272.2004.00175.x>
- 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(4), 247-260.
- Sayigh, L. S., Tyack, P. L., Wells, R. S., Solow, A. R., Scott, M. D., & Irvine, A. B. (1999). Individual recognition in wild bottlenose dolphins: a field test using playback experiments. *Animal behaviour*, 57(1), 41-50.
- Sazima, I., Sazima, C., & Silva-Jr, J. M. D. (2006). Fishes associated with spinner dolphins at Fernando de Noronha Archipelago, tropical Western Atlantic: an update and overview. *Neotropical Ichthyology*, 4(4), 451-455.

- Scarpaci, C., Bigger, S. W., CORKERON, P. J., & Nugegoda, D. (2000). Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence of swim-with-dolphin/tour operations. *Journal of Cetacean Research and Management*, 2(3), 183-185.
- Scott, M. D., & Chivers, S. J. (2009). Movements and diving behavior of pelagic spotted dolphins. *Marine Mammal Science*, 25(1), 137-160.
- Seabra de Lima, I. M., de Andrade, L. G., Ramos de Carvalho, R., Lailson-Brito, J., & de Freitas Azevedo, A. (2012). Characteristics of whistles from rough-toothed dolphins (*Steno bredanensis*) in Rio de Janeiro coast, southeastern Brazil. *The Journal of the Acoustical Society of America*, 131(5), 4173-4181.
- Shaff, J. F., & Baird, R. W. (2021). Diel and lunar variation in diving behavior of rough-toothed dolphins (*Steno bredanensis*) off Kaua'i, Hawai'i. *Marine Mammal Science*, 37(4), 1261-1276.
- Simões Amorim, T. O., Rezende de Castro, F., Rodrigues Moron, J., Ribeiro Duque, B., Couto Di Tullio, J., Resende Secchi, E., & Andriolo, A. (2019). Integrative bioacoustics discrimination of eight delphinid species in the western South Atlantic Ocean. *Plos one*, 14(6), e0217977.
- Simon, M., McGregor, P. K., & Ugarte, F. (2007). The relationship between the acoustic behaviour and surface activity of killer whales (*Orcinus orca*) that feed on herring (*Clupea harengus*). *Acta ethologica*, 10(2), 47-53.
- Silber, G. K., & Newcomer, M. W. (1990). Killer whales (*Orcinus orca*) attack and kill a Bryde's whale (*Balaenoptera edeni*). *Canadian Journal of Zoology*, 68(7), 1603-1606.
- Smolker, R. A., & Connor, R. C. (1996). 'Pop' goes the dolphin: A vocalization male bottlenose dolphins produce during consortships. *Behaviour*, 133(9-10), 643-662.
- Steiner, W. W. (1981). Species-specific differences in pure tonal whistle vocalizations of five western North Atlantic dolphin species. *Behavioral Ecology and Sociobiology*, 9(4), 241-246.
- Stevenson, B. C., Borchers, D. L., Altwegg, R., Swift, R. J., Gillespie, D. M., & Measey, G. J. (2015). "A General Framework for Animal Density Estimation from Acoustic Detections across a Fixed Microphone Array." *Methods in Ecology and Evolution*, 6(1), 38-48.
- Szymanski, M. D., Bain, D. E., Kiehl, K., Pennington, S., Wong, S., & Henry, K. R. (1999). Killer whale (*Orcinus orca*) hearing: Auditory brainstem response and behavioral audiograms. *The Journal of the Acoustical Society of America*, 106(2), 1134-1141. <https://doi.org/10.1121/1.427121>
- Thomas, Rebecca E., Kurt M. Fristrup, & Peter L. Tyack. (2002). Linking the Sounds of Dolphins to Their Locations and Behavior Using Video and Multichannel Acoustic Recordings. *The Journal of the Acoustical Society of America*, 112(4), 1692-1701.

- Thomsen, F., D. Franck, & J. K. B. Ford. (2001). Characteristics of Whistles from the Acoustic Repertoire of Resident Killer Whales (*Orcinus Orca*) off Vancouver Island, British Columbia. *The Journal of the Acoustical Society of America*, 109(3), 1240–46.
- Tyack, Peter. (1986). “Whistle Repertoires of Two Bottlenosed Dolphins, *Tursiops Truncatus*: Mimicry of Signature Whistles?” *Behavioral Ecology and Sociobiology*, 18(4), 251–57.
- Tyack, P. L. (2008). Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy*, 89(3), 549-558.
- Van Parijs, S. M., Parra, G. J., & Corkeron, P. J. (2000). Sounds produced by Australian Irrawaddy dolphins, *Orcaella brevirostris*. *The Journal of the Acoustical Society of America*, 108(4), 1938-1940.
- Varanasi U., Feldman H.R. & Malins D.C. (1975). Molecular basis for formation of lipid sound lens in echolocating cetaceans, *Nature*, 255, 340- 343.
- Vargas-Bravo, M. H., Fernando R. Elorriaga-Verplancken, Aramis Olivos-Ortiz, Blanca Morales-Guerrero, Marco A. Liñán-Cabello & Christian D. Ortega-Ortiz. (2020). Ecological aspects of the killer whales from the Mexican Central Pacific: contribution to the distinction of an ecotype from the Eastern Tropical Pacific. *Marine Mammal Science*, 37(2), 674-689.
- Vauclair J., (1996). *Animal Cognition: recent Developments in Modern Comparative Psychology*. Cambridge, Mass.: Harvard University Press.
- Vigness-Raposa, K. J., & Scowcroft, G. (2012). *Discovery of Sound in the Sea*. Rhode island university Narragansett graduate school of oceanography.
- Wade, P. R., & Gerrodette, T. (1993). Estimates of cetacean abundance and distribution in the eastern tropical Pacific. *Report - International Whaling Commission*, 43, 477–493.
- Wahlberg, M., Jensen, F. H., Aguilar Soto, N., Beedholm, K., Bejder, L., Oliveira, C., Rasmussen M., Simon M., Villadsgaard A., & 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(4), 2263–2274. <https://doi.org/10.1121/1.3624822>
- Wang, M. C., Walker, W. A., Shao, K. T., & Chou, L. S. (2003). Feeding habits of the pantropical spotted dolphin, *Stenella attenuata*, off the eastern coast of Taiwan. *Zoological studies-taipei*, 42(2), 368-378.
- Weilgart, L. S. (2007). “The Impacts of Anthropogenic Ocean Noise on Cetaceans and Implications for Management.” *Canadian Journal of Zoology*, 85(11), 1091–1116.
- Weilgart, L.S. (2007a). A brief review of known effects of noise on marine mammals. *International Journal of Comparative Psychology*, 20, 159-168.
- Wells R.S, Scott M.D, Irvine A.B. (1987). The social structure of freeranging bottlenose dolphins. In: Genoways HH (ed) *Current mammalogy*. Plenum, New York, pp 247–305.

- Werth, A. J. (2000). Feeding in marine mammals. *Feeding: form, function and evolution in tetrapod vertebrates*, 475-514.
- Werth, A. J. (2007). Adaptations of the cetacean hyolingual apparatus for aquatic feeding and thermoregulation. *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology: Advances in Integrative Anatomy and Evolutionary Biology*, 290(6), 546-568.
- Würsig B, Würsig M. (1977) The photographic determination of group size, composition, and stability of coastal porpoises (*Tursiops truncatus*). *Science*, 198, 755–756.
- Yao, C. J., Yamada, T. K., Chen, Y. J., & Chou, L. S. (2008). Cranial variation in the pantropical spotted dolphin, *Stenella attenuata*, in the Pacific Ocean. *Zoological science*, 25(12), 1234-1246.
- Young, D. D., & Cockcroft, V. G. (1994). Diet of common dolphins (*Delphinus delphis*) off the south-east coast of southern Africa: opportunism or specialization?. *Journal of Zoology*, 234(1), 41-53.

