Combining Cetacean Soundscape Ecology and Niche Modeling to Contribute in the Mapping of the Brazilian Continental Shelf

6

Marcos R. Rossi-Santos and Guilherme de Oliveira

Abstract

This chapter will introduce readers to the marine soundscape ecology through a cetacean study perspective. Unravelling the behavioral ecology of whales and dolphins in the southwestern Atlantic Ocean provides information about the marine habitat in which they live, in this case, the continental shelf. The study also describes methods for underwater mapping such as bioacoustics, photo-video recordings, GIS and behavioral observations.

6.1 Introduction

Mapping the marine environment became one of the last frontiers in Science, greatly enhanced in the last two decades, due to the great technological advance, that may combine extreme methods such as sound and image acquisition and geographic information system, as important data for marine research.

In order to achieve a broad understanding of the ecological dynamics of a certain marine ecosystem, such as the continental shelf, is important to evaluate flagship species, such as the cetaceans (Fig. 6.1), which represents the entire habitat where they live, commonly attributed to be oceanic sentinels (Wells et al. 2004; Bossart 2006) mainly because their complex integration in the marine food web.

Integrative methods are especially good to be employed in ecologic monitoring, increasing the result efficacy and developing a complex view of different techniques and applications for research questions. Commonly these methods may aggregate how animals behave throughout an area and the specific geographic information related to it.

M.R. Rossi-Santos (✉) • G. de Oliveira
Animal Behavior, Biogeography and Conservation Laboratory (ABBCLab) – Centro de Ciências Agrárias, Ambientais e Biológicas, Universidade Federal do Recôncavo da Bahia (UFRB) – Campus Universitário, Rua Rui Barbosa, 710, Centro, 44380-000 Cruz das Almas, Bahia, Brazil
e-mail: marcos.rossi@ufrb.edu.br

Once mapping could be interpreted as a technique to understand a certain landscape, it is easily linked to another growing branch of marine science, the landscape ecology. As dealing with large scales, much of the Pan-American continental shelf in the Western Atlantic Ocean remains scarcely studied and one could consider the constraints of gathering international scientific information, taking in consideration the small size of the most countries along the Western Atlantic Ocean.

Certainly Brazil, in the South, and United States, in the North, are the two countries with largest coastline in the Western Atlantic Ocean. The Brazilian coast extends along 8000 km. The present work will access the knowledgement of cetacean species along the Brazilian continental shelf to contribute with the understanding of the marine ecology in this habitat trough a soundscape ecology point of view.

6.1.1 Landscape Ecology

The term 'landscape' can be defined as a functional ecological space where the observed patterns reflect the interactions between natural and anthropogenic processes (Wiens et al. 1993; Mazaris et al. 2009). Landscape ecology presents an interdisciplinary nature (Wu and Hobbs 2007; Wu 2012), using and combining methods and information from one discipline in order to answer research questions of the other (Wiens 1999).

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Fig. 6.1 Whales and dolphins are commonly attributed as important ecologic indicators of the marine balance, once they are found in different levels of the oceanic food web, controlling the population of their preys and reverting large biomass amounts back to the marine ecosystem (Photo: Marcos Rossi-Santos)

Farina and Belgrano (2006) demonstrated the need to evaluate and integrate additional elements, such as acoustics, in the study of landscapes, thus to proceed to an organism-centered view leading to the construction of cognitive landscapes.

The acoustic environment is a landscape attribute composed by the heterogeneous distribution of objects and resources and their potential rearrangement through time, describing the spatial structure and configuration and to detect changes resulting from these interactions (Mazaris et al. 2009).

6.1.2 Soundscape Ecology

The term "soundscape" was firstly employed by Schafer (1969, 1977) as the acoustic environment composed by a variety of sounds originating from different sources, such as natural and anthropogenic, emphasizing the way this environment is perceived and understood by any human or non-human individual, or by the society (Truax 1999).

More recently, Pijanowski et al. (2011) described the concept of soundscape ecology as a gathering of all different sounds, such as biological sounds, geological sounds and anthropogenic sounds from a certain landscape, resulting in unique acoustic environments in different spatio-temporal scales. According to Farina (2014), biological sounds are crucial for the soundscape and their diversity totally contributes to the ecological diversity.

Bioacoustics is an interdisciplinary area that contributes with soundscape ecology techniques, because it is linked to ethology, physiology, biophysics and ecology, dedicated to understand the animal sound production and reception mechanisms, and how animals communicate through sounds.

6.1.3 Animal Communication and Soundscape Ecology

Organisms perceive and respond to several signals, including visual, acoustic and olfactory (Alcock 1993; Bradbury and Vehrencamp 1998). To better comprehend the cognitive landscape of the organisms, there is a need to incorporate other environmental signs, most notably the acoustic signs that animals are known to produce and perceive.

Thus, the analysis of acoustic data on the landscape level could be an experimental way to organize our perception and knowledge of the acoustic environment (Zhang and Kan 2007; Pheasant et al. 2008).

Organisms may orientate even in the absence of visual landmarks, just based on the background soundscape, e.g. the sound of sea waves indicates the location of the coast even if the coast is hidden from view. Simpson et al. (2008) demonstrated how adult and juvenile fishes respond to the coral reef soundscape.

Furthermore, the temporal changes in the background soundscape might also act as an environmental cue for the organisms to define their behavior. These signals are usually understood by animals to convey urgent information, such as about an approaching threat. These sounds are classified as foreground sounds and their spatial pattern forms the foreground soundscape (Farina 2014). The variability of the foreground and background soundscapes provides additional information enriching our understanding of the natural environment and the processes taking place on it.

In the last three decades the increased use of the oceans for human exploitation also led to an increased anthropogenic use of marine acoustic niches, even turning the oceans a noisier place (Andrew et al. 2002; Hildebrand 2009). Anthropogenic noise is an important component of virtually every human enterprise in the oceans (Fig. 6.2), whether it is shipping, transport, exploration, research, military activities, construction, or recreation.

Then sound is inherent in daily operations, therefore hearing for any animal is an important sense. Many sensory cues are limited in their distribution and utility, but not sound. There is no habitat, except space, that is soundless, and sound is such a significant cue, carrying information that hearing is very well developed in virtually every vertebrate group (Pough et al. 2008).

The acoustic cues are constant and diverse, providing information on the direction and nature of the sources and how they change through time. Sound is a key factor for survival and hearing is a key component of communication, feeding, mate selection and predator avoidance (Bradbury and Vehrencamp 1998; Tyack 2000a, b).

Fig. 6.2 Oil and gas exploitation as part of the soundscape in the breeding ground of the humpback whale, *Megaptera novaeangliae*, in the Brazilian continental shelf (Photo: Marcos Rossi-Santos)

6.1.4 Cetaceans and Sounds in the Marine Environment

Animal auditory systems are species-specific, as the ear and what it can hear is different for each species and they are also habitat dependent. If every environmental cue available received equal attention, the brain would be barraged by sensory inputs. Instead, sensory organs are essentially multilevel filters, selecting and attending to signals that, evolutionarily, proved to be important (Ketten 1992).

The acoustic communication and social behavior are among the most complex features exhibit by cetaceans, showing diversity and variations from individuals to population (Tyack and Clark 2000). Each species presents a unique communication system, evolved to better respond to the environment requirements to maximize the information transfer among individuals and with the habitat in which they live (Ketten 1992; Tyack 1997). So on, the variation in the acoustic repertoire of a species reflects its behavior and the environmental heterogeneity along its distribution (Norris et al. 1994).

For dolphins, acoustic signals are commonly divided in three categories (Richardson et al. 1995): Pure tonal sounds or whistles and two pulsed sounds, being one the echolocation clicks and the other a variety of less distinct burst pulsed sounds usually grouped into calls, but also being described as squeals or barks (Norris et al. 1994; Rossi-Santos et al. 2008a).

Whistles are basically composed by high frequency sounds, they are mainly attributed to short distance communications among individuals (Bazúa-Durán and Au 2002), while pulse sounds are broadband signals in which pulse interval may vary accord to the environment, creating different intervals between the pulses (Lammers et al. 2003). Some authors argue about the capacity to turn one pattern into the other, through fusion process named as graded vocalization (Rendell et al. 1999).

Since the late 1950s we have been aware that dolphins, at least, use very high ultrasonic signals as a form of biosonar. Using sound they can detect and distinguish amongst fish species and different habitat features, being very effective in mapping their environment (Au 1993; Au et al. 2009; Yovel and Au 2010).

For large whales, sound is mostly composed by low frequency signals that can travel along entire ocean basins (Richardson et al. 1995) and can be used for long distance communication (Mellinger and Clark 2003; Sirovic et al. 2007). One exception for the low frequency sounds is shown in the humpback whales, whose complex singing behavior produce as much high frequencies as those of the dolphin whistles (Payne and Mac Vay 1971). Humpbacks use sound in their complex mating system, where male singers are supposed to court females transmitting important information to their reproductive success (Payne and Mac Vay 1971).

Previous revision works (e.g., Tyack and Janik 2013) demonstrated that increased underwater noise causes marine mammals to alter the source level, frequency, duration, and redundancy of their signals. The evidence that marine mammals modify their calling behavior in response to anthropogenic noise also suggests that it does interfere with their ability to communicate (Branstetter and Finneran 2008).

Not outstanding, cetacean studies dealing with behavioral ecology, including bioacoustics, occurrence, distribution and habitat characterization area an appropriated tool to estimate habitat availability and may largely contribute with a better understanding of the continued mapping process of the continental shelves worldwide.

6.2 Study Area

6.2.1 The American Continental Shelf and the Brazilian Coastal Zone

In the American continent, each margin is originated from diverse dynamic forces during the continental drift, resulting in two types: Atlantic (or passive, with great sediment accumulation) and Pacific (or active, with volcanos and earthquake occurrences). The morphology of the continental margins presents physiographical provinces, including the continental shelf (Baptista-Neto and Silva 2003).

The continental shelf is a smooth depth gradient strip (less than 1:1000) that surrounds the continental landmasses. It extends from the coastline to the continental break, where an abrupt depth gradient begins. Depending on the locality, depth and wideness present variations, but the overall mean depth is 130 m and the mean width is 75 km (Muehe 1988; Baptista-Neto and Silva 2003).

The shelf environment is mainly sedimentary, occurring different sediments such as terrigenous, biogenic, volcanogenic and authigenic. This sea floor is under influences from the continental and marine dynamic forces, including the stratigraphic evolution, amount of sediment and its transportation from the continent and the biological activity (Muehe 1988; Baptista-Neto and Silva 2003). Another important characteristic to this environment is the high dynamic of oceanic forces, such as tidal cycle, storms, wind currents, influencing the continental shelf in different scales (Silveira et al. 1994; Stramma 1989, 1991), which shapes the sea floor and it is ultimately related to local biodiversity, who will be morphologic and physiologic adapted (Paiva and Garcez 1998; Muehe and Garcez 2005).

The Brazilian Continental shelf (Fig. 6.3) is classified as Atlantic type or passive, presenting many variations in shape, width and sediment. The Amazonian Gulf (04°10′ S and 47°40′ W) and the Abrolhos Bank (16°40′–19°30′ S and 38°00′–39°30′ W) are the larger places, respectively 350 km and 246 of extension from the coastline. Concerning the sea bottom, terrigenous sedimentation is distinguishable, as well biogenic and biodetritic sediments. There are three main currents influencing the shelf that are the North Brazil, South Equatorial and Brazil currents (Muehe 1988; Baptista-Neto and Silva 2003).

6.2.2 Importance and Impacts on the Continental Shelf

Despite they represent only 7.5 % of the oceans, the shelves have a great scientific, economic and environmental importance, acting in the wave propagation, or constituting sediments to characterize the beaches and hold a rich biodiversity. This dynamic zone has facing great resource exploitation (e.g., Matsuura 1996; Paiva 1997) which may imply in problems disturbing the ecological balance (Muehe and Neves 1995; Marrul-Filho 2003).

So on, the studies on continental shelves must be intensified to understand and preserve this important environment for the future generations. The scientific knowledge about the Brazilian continental shelf has increased with the technological advance, mainly provided for economic purposes such as oil and gas exploitation.

6.3 Methods

6.3.1 Long-Term Monitoring Program

In order to better evaluate the behavioral ecology, the complex social relationships and population trends on long life animals, as the cetaceans, there is a need to develop a long-term monitoring program (Mann et al. 2000; Wells et al. 2004; Connor 2007; Wells 2009; Mizroch et al. 2011; Gendron 2015).

Many discoveries of the cetacean behavior and social interactions come from long-term studies. Wells (2009), in Sarasota Bay, Florida, have been studied the bottlenose dolphins for at least two decades, developing a solid understanding of patterns of life history, social structure, health, and reproductive success, by following individuals through time and space in long-term field research. Humpback whales were tagged in 1976 and resighted trough photo-identification in 2010, showing the benefits or research efforts in bringing information about long-lived animals such as the cetaceans (Mizroch et al. 2011).

Fig. 6.3 The study area, the Brazilian continental shelf (*red lines*), in the southwestern Atlantic Ocean, with the influence of the South Equatorial current that reach South America and splits into the Brazil current and the North Brazil current

To elaborate an ideal research program, one should take into consideration a series of methodological procedures that when integrated may contribute to understand how animals react to different habitats and also to evaluate any potential anthropogenic impact. Some of these topics should include habitat and ecologic relations, such as the way cetaceans use their habitats are frequently the first response from any species or population to an impact occurrence (Mann et al. 2000; Franzosini et al. 2013).

A direct approach to understand cetacean ecology includes geographic records of individual or population behavior, which may be related to potential surveys (on-board, on-aircraft, telemetry) (see Mann et al. 2000; Todd et al. 2015). The boat-based surveys are more common in Brazil, utilizing diverse boat types (Fig. 6.4)

Behavioral observations often follow focal individuals or groups, in continuous time, registering all they can record (*Ad libitum* sampling, see Altmann 1974) to later establish behavioral patterns and analyze them during subsequent years. Usually data are registered in paper sheets, but recently in data-loggers. Eventually, voice recorders such as portable devices (even cell phones) plugged to a lapel microphone may free the observer's hand and lead to more attention to what is happening during the sighting.

Photographic and video recordings from research boats (Fig. 6.5) are commonly used for photo-identification and behavior purposes in cetacean ecologic long-term studies (e.g., Mann et al. 2000; De Oliveira and Monteiro-Filho 2008; Wedekin et al. 2010; Cantor et al. 2012) registering sequential observational facts, when cetacean come to the surface, also registering important conservation issues such as anthropogenic impacts and health assessment, through the photographic analyzes of human interactions and skin anomalies in the animal's body (Groch 2014).

Underwater recordings (Fig. 6.6) require more planning and caution, because many factors may result in a possible chance to come into the water with dolphins and whales in the wild: (1) research permits are required to dive with cetaceans in many countries; (2) favorable sea conditions (good wind, currents, visibility, location); (3) calm animal behavior, that will allow researchers to approach animals – always the cetacean will rule if you can approach or not (4) the researcher

Fig. 6.4 Multiples boat types have been used as a research platform for visual and acoustic cetacean surveys in the Brazilian continental shelf along time (Photos: Marcos Rossi-Santos)

must have experience in swimming, snorkeling and scuba-diving (5) Perform a correct approach and cautionary gesture underwater, slowly towards the animals and never trying to touch them or interrupt their natural behavior.

The acoustic Monitoring, using spectrographic analyzes on acquired data from sea-mounted, towed or even launched hydrophones from boats (Fig. 6.4), is an important tool to investigate cetacean distribution, behavior and abundance (e.g., Mann et al. 2000; Mellinger et al. 2007).

In poorly known areas for cetaceans, such as the Brazilian continental shelf (Lodi and Borobia 2013), towed or bottom-mounted hydrophones allied to visual surveys will be useful to acoustically determine cetacean identification and compose a dataset that can be used in future evaluations and long term comparison of the cetacean community distribution and habitat preferences.

6.3.2 Spectrographic Analyzes

Time and frequency domain play an important role in the acoustic analysis (Rossing 2007). Any acoustic signal can be represented either in the time domain, with its amplitude displayed as a function of time, or in the frequency domain, with its amplitude displayed as a function of frequency. The time domain representation of a signal is usually referred to as the waveform, while the frequency representation of a signal is usually referred to as the

Fig. 6.5 Photographic and video recordings are an important research component for long-term studies, demonstrating cetacean habitat use preferences and social ecology, when photographed in a certain location (Photo: Marcos Rossi-Santos)

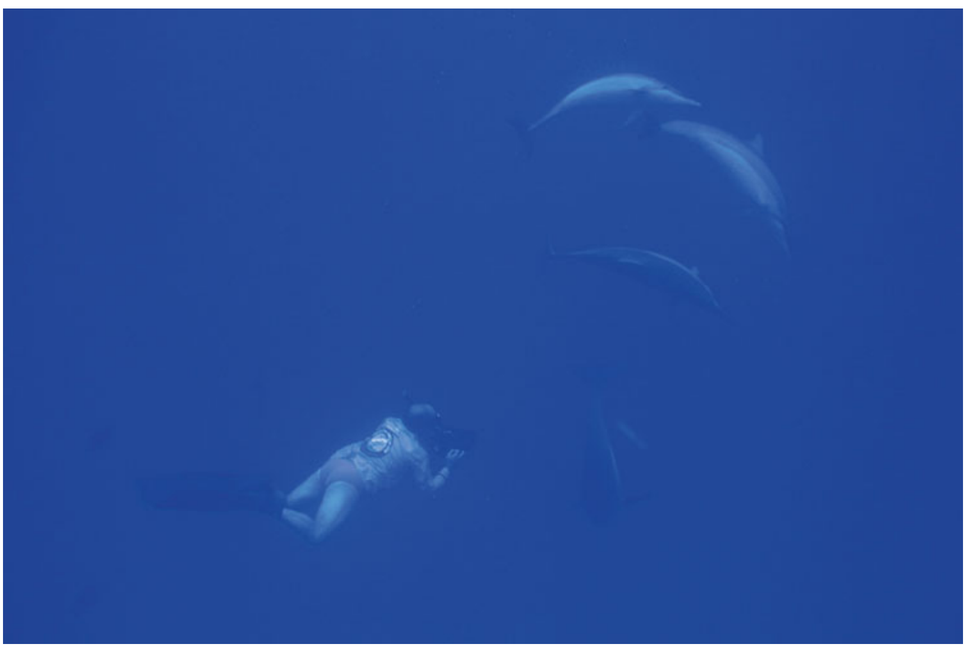

Fig. 6.6 The underwater photo and video recordings may contribute with the understanding of the cetacean life, once the surface time, when they are usually observed, is just a small part of their behavior. The clear waters, such as in the Fernando de Noronha Archipelago, is a requirement for this technique (Photo: Marcos Rossi-Santos)

frequency spectrum (or just spectrum) of the signal (Au and Hastings 2008).

Spectrum analyzers are often used to observe the spectral characteristics of continuous or long-duration (on the order of several seconds) signals. A spectrogram (Fig. 6.7) is a visual representation of the spectrum of frequencies in a sound or other signal as they vary with time or some other variable (Rossing 2007).

Among other advantages, these time-frequency portraits, generated by the spectrograms seem to correlate well

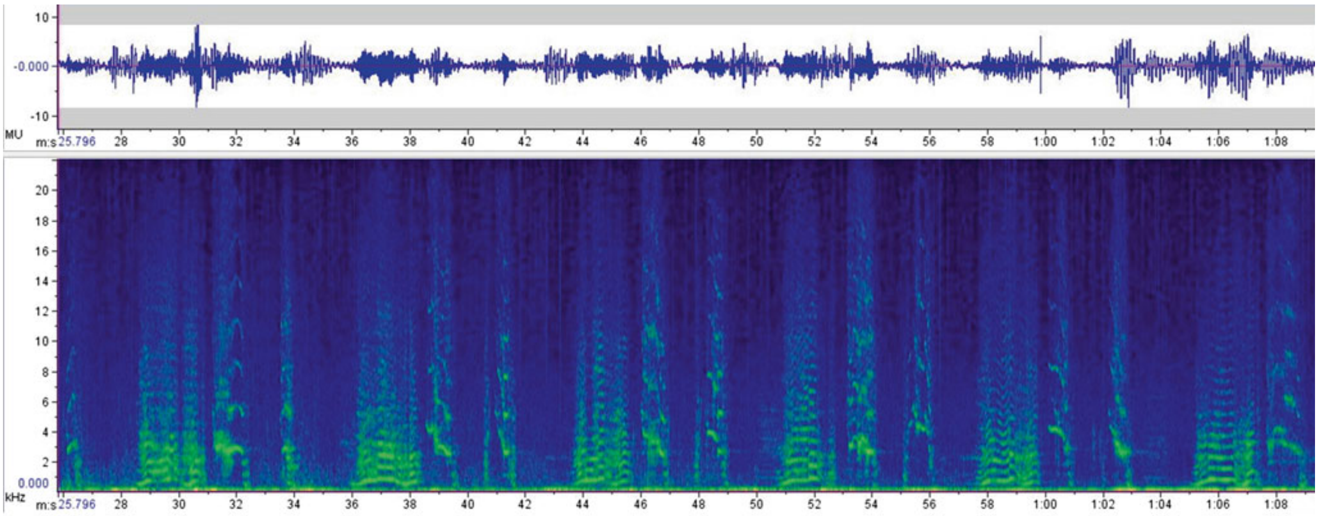

Fig. 6.7 A spectrogram is an important graphic visualization of the time (x axis) and frequency (y axis) relation in the acoustic analysis. Here it is presented for the song of the Humpback whale (*Megaptera novaeangliae*), even described as "the most elaborate single display of any animal species" (Wilson 1975). Structured sound patterns, in *green*, alternate and repeat again along time, with the marine background soundscape is the *blue* at the bottom

with our perceptions, providing important discrimination between different sounds characteristics (Alm and Walker 2002).

Early analog spectrograms were applied to a wide range of areas including the study of bird calls, with current research continuing using modern digital equipment and applied to all animal sounds (Pijanowsky et al. 2011; Hoffman 2012; Krause 2012; Brumm 2013).

Contemporary use of the digital spectrogram is especially useful for studying frequency modulation (FM) in animal calls. Specifically, the distinguishing characteristics of FM chirps, broadband clicks, and social harmonizing are most easily visualized with the spectrogram. It is also employed in the development of the diverse fields of music, sonar, radar, speech processing and seismology (Alm and Walker 2002; Rossing 2007; Krause 2012; Brumm 2013).

6.3.3 Target Cetacean Species

In order to develop an effort on modeling the cetacean soundscape ecology for the Brazilian continental shelf, combining Ecological Niche Models (ENM), we choose five representative cetacean species, described below, known as the best registered and studied for the Brazilian waters and with a larger publication number available nowadays (Lodi and Borobia 2013).

6.3.3.1 The Bottlenose Dolphin

The bottlenose dolphin, *Tursiops truncatus*, (Gervais 1855) (Odontoceti, Delphinidae) (Fig. 6.8) has been studied intensively in numerous locations around the world, and today is one of the best known cetacean species (Shane et al. 1986; Wells and Scott 1999; Reynolds et al. 2000; Bearzi et al. 2008). They live in tropical and temperate waters throughout the world, in socially-complex groups (Connor et al. 2000; Wells 2003) and are found even in pelagic environments and also in harbors, bays, gulfs and estuaries.

Taxonomy within this genus remains confused. In the past more than 20 species were described (Lodi and Borobia 2013). However, as a common sense, there are at least two recognizable forms, a coastal or inshore and another one pelagic or offshore.

Bottlenose dolphins usually are found in groups of fewer than ten until less than 80 to the coastal form and several hundreds to the offshore regions. In many areas they have adapted their feeding strategies to take advantage of local ecological conditions and also of human activities, even interacting with many fishing techniques, allow them to feed on netted fish, discarded fish by fishermen and fish attracted to vessels and fixed platforms (Reeves and Leatherwood 1983; Simões-Lopes 1991), while in shallow waters they perform a large variety of feeding strategies, as diverse as herding fish in different cooperative positions (Shane et al. 1986; Bel'kovich et al. 1991) until individual up-side-down techniques, presumably to aid in echolocation by reducing noise from surface echoes (Reeves and Leatherwood 1983).

Despite the large distribution range, the species commonly faces the same threats than other cetacean in general, such as habitat loss, fish stock depletion and diverse pollution incoming in the marine ecosystem, all of then provided by anthropogenic activities.

Fig. 6.8 The bottlenose dolphin, *Tursiops truncatus*, photographed in the southeast waters of the Brazilian continental shelf (Photo: Marcos Rossi-Santos)

6.3.3.2 The Rough-Toothed Dolphin

The rough-toothed dolphin, *Steno bredanensis*, (Cuvier 1823) (Odontoceti, Delphinidae) is found worldwide with reports from the Atlantic, Pacific, and Indian oceans, typically in warm temperate, subtropical, or tropical waters (West et al. 2011) (Fig. 6.9). In the southwestern Atlantic the species is reported on many occasions from Brazil (Pinedo and Castello 1980; Lodi and Hetzel 1999; Flores and Ximenez 1997; Wedekin et al. 2004).

The rough-toothed dolphin may be solitary but is often found in groups of various sizes. The largest report of group size was estimated at 160 individuals in the Mediterranean (Watkins et al. 1987). It is commonly found in shallow near-shore, deep offshore, and oceanic waters. There are many reports from shallow waters of coastal Brazil and Honduras (Flores and Ximenez 1997; Kuczaj and Yeater 2007; Lodi and Hetzel 1999). However, *S. bredanensis* is reported to dive as deep as 70 m, where a few individuals rubbed against a hydrophone at this depth (Watkins et al. 1987).

Diet has been inferred from stomach contents or from field observations of suspected foraging. Stomach contents from strandings in Brazilian waters consisted primarily of near-shore species, including the slender inshore squid (*Loligo plei*) (dos Santos 2001) and a cutlass fish (*Trichiurus lepturus*) (Ott and Danilewicz 1996; Di Beneditto et al. 2001). In the southwestern Atlantic off the Brazilian coast, in the Abrolhos Bank breeding ground, *S. bredanensis* was observed catching a diskfish (Echeneidae) (Wedekin et al. 2004).

6.3.3.3 The Guiana Dolphin

The Guiana dolphin (*Sotalia guianensis*) (Van Bénedén 1864) (Odontoceti, Delphinidae) is a small coastal species endemic to the Atlantic coast, from southern Brazil to Honduras, Central America (Simões-Lopes 1988; Carr and Bonde 2000; Flores and Da Silva 2009), inhabiting bays and estuaries generally related to large mangrove systems (Fig. 6.10). As the Brazilian coast represents more than the half of its distribution, this species is the most studied along the Brazilian continental shelf.

S. guianensis is also found in complex social aggregations (Monteiro-Filho and Monteiro 2008; Santos and Rosso 2008; Cantor et al. 2012), mostly following the fusion-fission patterns described for other dolphin species (e.g., Connor et al. 2000) and group size varies from few individuals to few hundred animals in different local environments along the Brazilian coast (Lodi and Borobia 2013).

The natural history of the Guiana dolphin is revised by Rosas et al. (2010), bringing important information on general biology, including food habits, reproduction, age and health of these dolphins. At least 25 teleost fish families, 5 cephalopod families and 1 crustacean family are included in the diet of the Guiana dolphin (*S. guianensis*). The schooling fish, such as *Sardinella brasiliensis*, *Trichiurus lepturus* and *Micropogonias furnieri* were identified as the most common consumed, however, due to the completely different ecosystems used by them, prey species consumed by the species varies along the Brazilian coast.

Fig. 6.9 The rough-toothed dolphin, *Steno bredanensis*, photographed in the underwater mountain range of Vitoria-Trindade, Brazilian continental shelf (Photo: Enrico Marcovaldi/Inst. Baleia Jubarte)

Fig. 6.10 The Guiana Dolphin, *Sotalia guianensis*, is one of the best studied cetacean in Brazilian waters, mainly because its coastal distribution along the continental shelf, like this population in Praia da Pipa, Rio Grande do Norte state, Northeastern Brazil (Photo: Marcos Rossi-Santos)

Daura-Jorge et al. (2007) studied the behavioral patterns (travelling and foraging) of the Guiana dolphin, comparing two populations in the Brazilian coast: Caravelas (Bahia state), along the eastern coast, and Norte Bay (Santa Catarina state), along the southern coast. Geographic positions were used to calculate the total distance traveled by dolphin groups on each day, using the daily mean speed of the dolphin as an index of movement intensity and identifying a variation in the behavior of the Guiana dolphin consistent with variations in environmental factors, such as water temperature.

Few papers report on foraging strategies of the Guiana dolphin. Rossi-Santos and Flores (2009) found great variety of cooperative feeding in a coastal bay of southern Brazil, while Tardin et al. (2011) quantified a large presence of calves in coordinated feeding tactic in Rio de Janeiro state, southeastern Brazil, suggesting that this behavior would be a involved in social learning in dolphins, especially between the mother and her calf.

Recently, it was found that, during evolution, the vibrissal system located in the dolphin rostrum, has functionally transformed from an originally mechano-receptive system into an electro-receptive system (Czech-Damal et al. 2012), allowing dolphins to explore their preys and the environment through electro-perception.

6.3.3.4 The Southern Right Whale

The southern Right whale, *Eubalaena australis*, (Desmoulins 1822) (Mysticeti, Balaenidae) is the only southern hemisphere representative of the mysticete (baleen) whale family Balaenidae. It is a large whale with no dorsal fin on its flat, shiny back (Fig. 6.11). This species is unique in having pale horny callosities on the head, chin and variably on the top edge of the lower jaw. The number, size and arrangement of these callosities can be used to identify individuals (Payne et al. 1983).

Most individuals are predominantly black in colour, except for scars, parasites and head callosities and some individuals have conspicuous white belly patches. Southern Right whales are considered to be sexually mature when 9–10 years of age, and approximately 12–13 m in length. An adult whale averages about 50 tonnes in weight and 16 m in length; males are generally slightly smaller than females. The maximum size recorded is 80 tonnes and 17.5 m (Cummings 1985).

Southern Right whales frequent sub-Antarctic and the lower Antarctic latitudes during the summer and feed on species that are abundant at that time. They rarely feed on Krill *Euphausia superba*, which is the key food of other baleen whales, leaving Antarctic waters – between 40° S and 60° S – and heading north as winter approaches to their breeding areas, along the southern coasts of Australia, South America and South Africa (Best et al. 1983; Bannister 2001; IWC 2001). It is thought that there may be up to seven more or less geographically isolated populations in the southern hemisphere, of which some are believed to concentrate in the vicinity of sub-Antarctic islands such as Macquarie, Heard and the Chathams (IWC 2001).

In Brazil, Southern Right whales are found along the southern coastline, mainly in Santa Catarina State, which is a breeding area for the species from July to November, approaching very much to the coastline and allowing researchers to conduct shore-based surveys and promote conservation actions, integrating local communities (Groch et al. 2005; Palazzo Jr. 2007; Santos et al. 2011).

6.3.3.5 The Humpback Whale

The humpback whale, *Megaptera novaeangliae* (Borowsky 1781) (Mysticeti, Balaenopteridae) (Fig. 6.12), is a cosmopolitan species distributed along all the oceans worldwide, moving every year from high latitude feeding areas, staying

Fig. 6.11 The southern Right whale, *Eubalaena australis*, received this common name because it was very easy to approach during the whaling period, becoming the "right whale" to shoot. Today this species is a target only for photographic shooting from a whale-watching vessel in Santa Catarina state, southern Brazil (Photo: Marcos Rossi-Santos)

Fig. 6.12 The humpback whale, *Megaptera novaeangliae*, is also known as the singer whale because its complex acoustic sound production, which was the trigger to the 1970s "Save the Whales" pop conservation campaign. The species has a breeding area in the Brazilian continental shelf, concentrated in the Abrolhos Bank (Photo: Enrico Marcovaldi/Inst. Baleia Jubarte)

during the autumn and summer, to the breeding areas in the tropics, staying during the spring and summer (Clapham and Mead 1999). These breeding areas are typically between islands and/or associated with coral systems (Whitehead and Moore 1982). In the feeding and breeding area, the humpback whale present a social organization characterized by unstable and small groups (two to three animals). However, larger groups can be found during the feeding behavior or related to the aggressive competition between males during the breeding season (Clapham 1996).

Nowadays, there are seven humpback whale subpopulations (or stocks) in the southern hemisphere (IWC 1998), and the "Breeding Stock A/BSA" migrates to the Brazilian coast, where they breed from July to November. Despite their occurrence along a large range in Brazil, from Rio Grande do Sul state, southern Brazil, to the Fernando de Noronha Archipelago, northeastern Brazil, (Lodi and Borobia 2013), its core breeding area is the Abrolhos Bank, Bahia state (Wedekin et al. 2010). However, the increase of humpback whale sightings northwards from the Abrolhos Bank, suggest the population recovery in this historical area, occupied by the whales prior the whaling period (Rossi-Santos et al. 2008b).

The humpback whale is also known as singer whale because its unique characteristic of to exhibit a singing behavior, performed only by males, during the breeding season. Since the 1970th, many studies described the physic structure of the songs (e.g., Payne and Mc Vay 1971; Helweg et al. 1998; Arraut and Vielliard 2004; Au et al. 2006; Darling et al. 2014) and even their probable functions at the population ecology level, such as female attraction, male-male competition and cultural exchange (e.g., McSweeney et al. 1989; Dawbin and Eyre 1991; Darling and Sousa-Lima 2005; Herman et al. 2013).

6.3.4 Cetacean Records and Environmental Data

After select the cetacean target-species, we would like to verify their distribution along the Brazilian coast with different oceanographic parameters to evaluate possible relations among environmental characteristics and sound fitness and performance during cetacean occurrence. The cetacean records were compiled from the scientific literature using ISI Web of Knowledge (http://apps.webofknowledge.com). The words for search were the cetacean specific and common names in Latin and English and the words Brazil and Brazilian coast.

We overlaid the Brazilian continental shelf with 9965 grid cells of 0.5° spatial resolution to model species ecological niche by associating species records and environmental layers (see below). We obtained the environmental layers for the ocean from Bio-ORACLE – Ocean Rasters for Analysis for Climate and Environment (available at: http://www.oracle.ugent.be).

We further downloaded eight environmental variables that may influence in the medium density and, consequently, in the sound transmission (mean calcite concentration, mean chlorophyll A, mean cloud cover, mean pH, mean salinity, mean silicate, mean sea surface temperature, and range sea surface temperature) to model species niche. These variables were downscaled to the same grid and choose by the minimum overlap between them (see Tyberghein et al. 2012).

6.3.5 Ecological Niche Models (ENM)

Ensemble methodologies for modeling species' ecological niche (Araújo and New 2007) were implemented following Diniz-Filho et al. (2009, 2010) and Terribile et al. (2012). Twelve different ENMs were used, including five presence-only or presence-background methods (i.e. BIOCLIM, Euclidian, Gower, Mahalanobis distances, and MAXENT) and seven presence-absence methods (i.e. GLM, Random forest, GAM, FDA, MARS, ENFA, and neural network) (see Franklin (2009) and Peterson et al. (2011) for a general descriptions of methods). Notice that for model comparisons in both type of ENM, presence-only and presence-absence, we used the same pseudo-absence data, in presence-only ENMs pseudo-absences were used as background (sensu de Oliveira et al. 2014).

We randomly divided cetacean species records, and their pseudo-absences (randomly selected on background region with the same proportion of species records), into 75 % for calibration and 25 % for evaluation and repeated this process 50 times. As we did not correct the presences records for spatial autocorrelation (e.g., spatial or environmental filtering, see de Oliveira et al. 2014; Varela et al. 2014) we opt to select the pseudo-absences data randomly on background.

The 600 resulting models (i.e., 50 cross-validation × 12 ENMs) were used to generate consensual occurrence maps based on thresholds established by the ROC curve, for which the species frequency of occurrence in each grid cell was obtained from each ENM (i.e., resulting 12 frequency maps from 12 ENMs) (see Terribile et al. 2012 for methodological details).

The mean of these 12 frequencies of occurrence was used as a measure of environmental suitability for all cetacean species across Brazilian coast. We conducted the analyses using the computational platform BioEnsembles (Diniz-Filho et al. 2009; Terribile et al. 2012; Collevatti et al. 2013; de Oliveira et al. 2014).

6.4 Results

6.4.1 Soundscape Ecology

From 240 analyzed papers for the chosen cetacean species, only 22 (9 %) reported on bioacoustics, summarized in the Table 6.1, demonstrating the immense size of this still open field. Beyond the bioacoustics results, here we make an overview of other relevant behavioral ecology studies conducted in the Brazilian continental shelf, describing the main findings these works relate on how cetaceans percept, map and behave to different environments, many times in close interactions with human utilization of the same environments, within the soundscape ecology perspective.

The bioacoustical studies as a tool in cetacean behavioral ecology and conservation are recent in Brazil, initiated in the field during the 1990s, but only after 2000 the first studies had been published, showing different applications, from repertoire descriptions along the Brazilian coast (e.g., Monteiro-Filho and Monteiro 2001; Azevedo and Simão 2002; Erber and Simão 2004) and its associations with surface behavior (Pivari and Rosso 2005) and nocturnal activity (Monteiro-Filho and Monteiro 2008), to comparisons among population and geographic variation of dolphin whistles (Azevedo and Van Sluys 2005; Rossi-Santos and Podos 2006; May-Collado and Wartzok 2009), and more recently the characterization of anthropogenic noise in some key habitats for the Guiana Dolphin (Monteiro-Filho and Monteiro 2008; Rossi-Santos et al. 2009). Along the time, all these studies have been using spectrographic analyzes (Fig. 6.13) to describe and compare dolphin vocalizations.

Effects of geographical location on the structure of *S. guianensis* whistles for ten populations in the Brazilian coast were revealed (Azevedo and Van Sluys 2005; Rossi-Santos and Podos 2006). Some features, like starting frequency, minimum frequency, and duration, were found to be more similar between adjacent sites than between more distant sites. Some whistle features, such as starting and minimum frequencies, also tended to be most distinct at one or both ends of the north – south transect. Other whistle features, however, did not appear to vary geographically, but may reflect the broad overlap in acoustic features across coastal sites, and an absence of any features that varied consistently and gradually across the studied range (Rossi-Santos and Podos 2006).

The geographic discontinuity in starting and minimum frequencies observed by Rossi-Santos and Podos (2006) might arise from multiple ecological and evolutionary causes (e.g., Van Parijs et al. 2000), such as a dispersal barrier between *Sotalia* populations that are on disparate evolutionary trajectories. One possible cause for a dispersal barrier would be the eastern flowing South Equatorial Current, which separates at the Eastern reach of Brazil into the south-flowing 'Brazil current' and the 'North Brazil Current'.

It is also possible that habitat preferences do diminish dispersal and lead to some isolation among northern and southern localities. It is noted that *Sotalia* in the southern and southeast regions tend to reside in protected bays and estuary systems, whereas in the northeast they reside sometimes in estuary systems but more often along open coasts and beaches. Perhaps there are broad differences among these acoustic or social environments that favor signals at disparate frequencies (e.g., Morisaka et al. 2005).

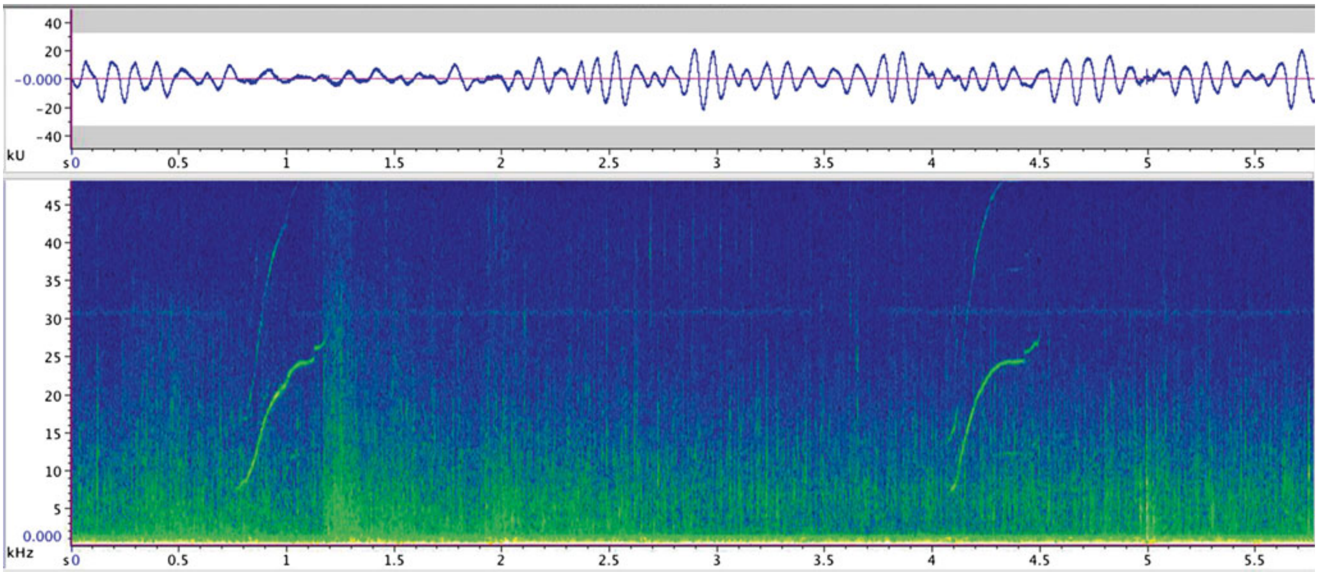

Fig. 6.13 A spectrogram showing whistles recorded for the Guiana dolphin, *Sotalia guianensis*, in Northeastern Brazil. This analysis is the first step to take numerical measurements of frequency and time, in order to describe cetacean sounds and to include them in a soundscape ecology approach

For the bottlenose dolphin, *Tursiops truncatus*, Azevedo et al. (2007) reported whistles parameters in the Patos Lagoon estuary, Southern Brazil. In that location, bottlenose dolphins emitted a varied repertoire of whistles, in which those with more than one inflection point were the most frequent, showing a great frequency range, despite quite similar to published frequency ranges for the species.

Whistle duration analyzed by Azevedo et al. (2007) differed significantly from those values previously reported for bottlenose dolphins and the authors argue that the variation of acoustic whistle parameters may be related to adaptation to background noise, as previously exampled by Ding et al. (1995) who suggested that in bottlenose dolphin whistles, higher frequencies, longer durations, and greater numbers of inflections are associated with localities of higher background noise.

Hoffmann et al. (2012) collected acoustic data since 2000–2009 from two bottlenose dolphin populations: a coastal group inhabiting the Tramandaí channel (29°58′ S 50°07′ W), southern Brazil, and an oceanic group occurring in the surrounding waters of the Saint Peter and Saint Paul (SPSP) Archipelago, 1010 km offshore from the northern coast of Brazil (0°56′ N 29°22′ W). The differences between the areas were significant for all whistle parameters except for final frequency. The whistles from the SPSP archipelago presented bigger values for maximal, minimal, initial frequencies, duration and frequency variation (maximum = 18.701 kHz; average = 8.631 ± 3.011 kHz) compared with the values from the coastal Tramandaí.

Ecologic explanations for the geographic variations include that whistle structure may vary according to the environment, where the dolphins seem to alter some parameters to adapt to specific environmental noise levels (Ding et al. 1995). The absence of interfering obstacles in open waters seems to favor the use of higher frequencies in pelagic species, given that such characteristics allow a better use of the binaural clues (Hoffmann et al. 2012). Then, in the SPSP archipelago dolphin group lives in a region with low noise levels, great depth (up to 1400 m), and transparent waters (visibility can reach 30 m), unlike the coastal group that occupies a shallow channel (5 m) with low visibility and anthropogenic activities.

In Brazil, changes in *T. truncatus* social organization seem to respond mainly to the local marine landscape. In Tramandaí, the predominance of lone dolphins inside the channel was related to the facility of prey capture without the necessity of associations (Hoffmann et al. 2012). In the SPSP archipelago, the depth, food offering, water currents, and presence of predators are completely diverse; thus it is expected that such differences would be reflected in their vocalizations, considering that their use is related to social organization and prey capture.

Lima et al. (2012) is the only paper found for the Brazilian continental shelf reporting on bioacoustics of the rough-toothed dolphins. Authors reported low values for all frequency parameters of the whistles emitted by *S. bredanensis* in Guanabara Bay, Rio de Janeiro, commonly characterized by a simple contour with low number of inflection points, as found in other areas (Belikov and Bel'Kovich 2007; May-Collado et al. 2007).

Other important characteristics of the repertoire of the rough-toothed dolphins in Rio de Janeiro was the emission of repeated whistle types and a great amount of segmented whis-

Table 6.1 Commonest descriptive acoustic parameters, often presented by mean and standard deviation – Start, Minimum, Maximum frequencies, Frequency Amplitude (kilohertz) and Duration (seconds) – found in the revised literature on the knowledge of bioacoustics for the cetacean species of the present study, in the Brazilian continental shelf

Source	Species/area/type	Start Frq (kHz)	Min Frq (kHz)	Max Frq (kHz)	Frq Ampl (kHz)	Duration (sec)
Arraut and Vielliard (2004)	*M. novaeangliae* (AbrolhosBank) song	–	0.1	3	3	–
Simão and Moreira (2005)	*M. novaeangliae* (Cabo Frio) female/calf call	4.90 ± 1.0	–	–	–	0.97 ± 0.10
Sousa-Lima (2007)	*M. novaeangliae* (AbrolhosBank) song	–	–	–	70.8–3.55 (interval)	–
Rossi-Santos (2012)	*M. novaeangliae* (North Coast Bahia) song	–	0.24 ± 0.39	4.42 ± 4.69	4.19 ± 4.65	1.06 ± 0.73
Rossi-Santos (2015)	*M. novaeangliae* (North Coast Bahia) song	–	220	3.27	3.05	1.82
Parks et al. (2013)	*E. australis* (S. Catarina) upcalls		68.2 ± 18.6 70.1 ± 24.8			
Figueiredo (2014)	*B. Edeni* (Cabo Frio) multiple	–	8.5–225	19–671	11–330	0.78–1.53
Azevedo et al. (2007)	*T. truncatus* (Patos Lagoon) whistles	8.28 ± 3.11	5.96 ± 2.15	12.21 ± 3.20	6.25 ± 3.34	0.55 ± 0.33
Hoffmann et al. (2012)	*T. truncatus* (ASPSP) whistles	9.81 ± 5.13	6.40 ± 2.07	15.03 ± 3.4	8.63 ± 3.01	0.80 ± 0.40
Hoffmann et al. (2012)	*T. truncatus* (Tramandaí) whistles	5.64	4.72	10.37	5.64	0.392
Azevedo et al. (2010)	*S. frontalis* (I. Grande Bay) whistles	8.85 ± 3.21	8.04 ± 2.51	13.58 ± 3.64	6.25 ± 3.34	0.36 ± 0.29
Lima et al. (2012)	*S. bredanensis* (Guanabara Bay) whistles	6.83 ± 1.53	6.02 ± 1.31	8.14 ± 1.33	2.13 ± 0.98	0.40 ± 0.23
Figueiredo (2014)	*Delphinus* spp. (Cabo Frio) whistles	13.11 ± 4.55	8.73 ± 1.75	16.45 ± 3.72	7.74 ± 3.93	0.71 ± 0.45
Camargo et al. (2006)	*S. longirostris* (FNoronha) whistles	10.78 ± 4.08	9.03 ± 2.79	14.48 ± 3.87	5.44 ± 3.44	0.49 ± 0.39
Rossi-Santos et al. (2008)	*S. longirostris* (FNoronha) calls	–	0.22–1.80	0.46–9.31	0.13–2.01	0.046–2.08
Cremer (2007)	*P. blainvillei* (Babitonga Bay) whistles	9.7 ± 3.0	–	–	0.3–7.2 (interval)	0.13 ± 0.09
Monteiro-Filho and Monteiro (2001)	*S. guianensis* (Cananéia) whistles				2.8–6.0 (interval)	0.21 ± 0.02
Monteiro-Filho and Monteiro (2001)	*S. guianensis* (Cananéia) calls				0.3–5 (interval)	0.10–0.73 (interval)
Azevedo and Simão (2002)	*S. guianensis* (Guanabara Bay) whistles	7.90 ± 2.90	7.60 ± 2.90	13.0 ± 4.10	–	0.10 ± 0.81
Erber and Simão (2004)	*S. guianensis* (Sepetiba Bay) whistles	10.70 ± 4.97	10.52 ± 4.51	13.31 ± 4.85	–	0.78 ± 0.31
Rossi-Santos and Podos (2006)	*S. guianensis* (from Santa Catarina to Ceara) whistles	8.0–11.49	7.7–11	12–18	7–9,5	0.17–0.33
Pivari and Rosso (2005)	*S. guianensis* (Cananéia) whistles	8.15 ± 3.0	9.97 ± 2.89	14.46 ± 2.88	6.48 ± 3.13	0.23 ± 0.10
Simão and Moreira (2007)	*S. guianensis* (Sepetiba Bay) whistles		39.9 (max)		31.1 (max)	
Andrade et al. (2015)	*S. guianensis* (Guanabara Bay) whistles	6.20 ± 2.70	6.00 ± 2.50	45.3 ± 1.50	39.3 ± 2.70	0.28 ± 0.10

tles, also reported for the species in the central Pacific Ocean and in the northeastern Atlantic Ocean (Lima et al. 2012).

The production of repeated whistle types has been observed for other species of delphinids and several authors have suggested that they may indicate the use of specific whistles to groups or individuals (Caldwell and Caldwell 1965; Janik 2000; Tyack 2000a, b; Shapiro 2010). Therefore, a species' whistle repertoire may present specific characteristics and reflect adaptation to specific habitat conditions.

There are many gaps in knowledge regarding cetacean behavioral ecology, mostly because oceanic waters are difficult to assess. Wedekin et al. (2014) collected systematic visual and acoustic information in the Vitória-Trindade seamounts in a dedicated survey expedition, reporting 19 groups of cetaceans along a 1300-km trackline, with 6 species being identified: the humpback whale (*Megaptera novaeangliae*, N=9 groups), the fin whale (*Balaenoptera physalus*, N=1), the Antarctic minke whale (*Balaenoptera bonaerensis*, N=1), the rough-toothed dolphin (*Steno bredanensis*, N=1), the bottlenose dolphin (*Tursiops truncatus*, N=2), and the killer whale (*Orcinus orca*, N=1).

In addition to visual surveys, acoustic stations were sampled to record male humpback whale songs (Fig. 6.14). Authors were able to aurally identify whether more than one singer was present when different song themes overlapped, resulting in a number of singers data point for each station.

From a total of 28 acoustic stations, humpback whale songs were only detected near the seamounts close to the Abrolhos Bank, where most groups of this species were visually detected. Songs were not heard during the trip over oceanic waters from Caravelas to Trindade Island or in the surroundings of the Martin Vaz and Trindade Islands, where few groups were visually detected.

The presence of humpback whales at the Trindade Island and surroundings is most likely occasional, with few sightings and low density, but there were observed a significant number of humpback whales along the seamounts close to the Abrolhos Bank, confirming its main function as a breeding habitat for this species.

Aiming to integrate the soundscape perspective to the bioacoustical studies of cetaceans in Brazil, Rossi-Santos (2015) was the first study to bring systematic information about the soundscape ecology, including oil and gas platforms, in a humpback whale breeding ground in the South Atlantic Ocean. The results of this study showed that oil and gas platforms contribute to oceanic noise pollution by producing sound over a broad range of frequencies – including all frequencies in our measured acoustic range (0–48 kHz).

The registered noises are concentrated in lower and mean frequencies (0–10 kHz), which is a large part of the humpback whale acoustic niche. Thus a potential frequency overlapping between the humpback whale song and the anthropogenic noise originated from the Oil Industry in the Brazilian breeding ground was evidenced.

Spectrograms may clearly illustrate the amount of anthropogenic noise discharged in the oceans and absorbed by cetaceans, as shown, for example, by Clark et al. (2009). When comparing two spectrograms, being one without any man-made noise (fig. 6.15) and another showing a noise from an oil platform (fig. 6.16), becomes easy to understand that cetacean may have their signals masked by human activities, such as the oil and gas exploitation along the Brazilian continental shelf (Fig. 6.12).

Using bottom-mounted archival acoustic recorders for study of boat impact to the humpback whales in the Abrolhos Bank, Sousa-Lima and Clark (2009) found that whales were repelled by boats, moving away from their approaching routes, and changing their dive and singing behavior.

Parks et al. (2013) described the vocal behavior of southern right whales in Brazilian waters, assessing the difference in vocalizations between areas with low and high human activity. Bottom-mounted archival acoustic recorders were deployed in two coastal locations in central Santa Catarina State, southern Brazil. One recorder was placed off Gamboa

Fig. 6.14 Acoustic sampling during a field expedition over the Vitória-Trindade seamounts, adding information about cetacean occurrence, distribution and abundance when applied together with visual sampling survey (Photo: Leonardo Wedekin/Inst. Baleia Jubarte)

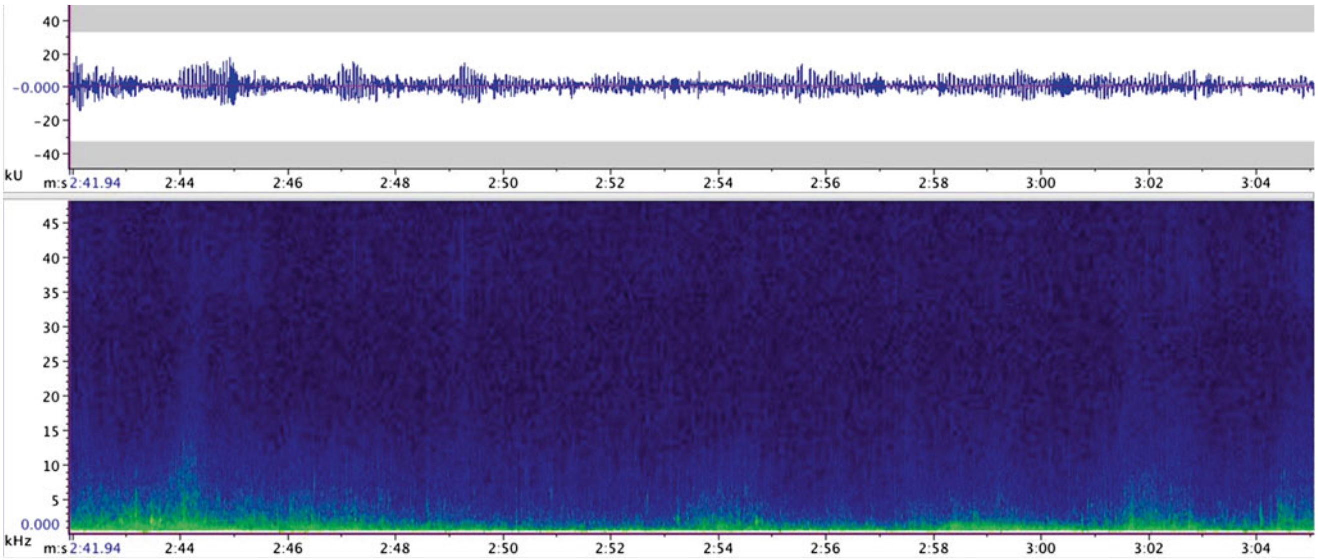

Fig. 6.15 A relatively "silent" marine soundscape, recorded in this spectrogram from the Abrolhos Bank, Eastern Brazil. Is possible to note that only occasional sea-wave soft noise can be shown with more energy (*green colour*), meaning that is a "natural" marine soundscape for cetaceans along the continental shelf

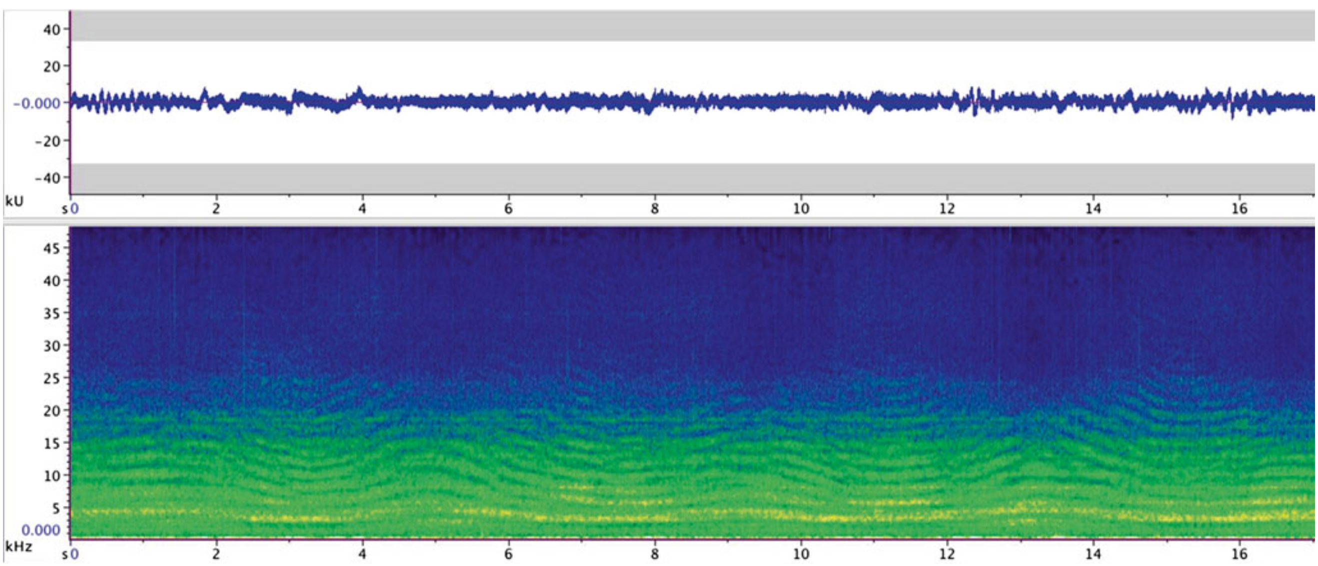

Fig. 6.16 In opposite to the previous figure, this spectrogram shows a "noisy" marine soundscape, recorded around an oil platform in the Bahia state, northeastern Brazil. All the *green colour* represents more energy spent in the acoustic signal, in this case the drilling operation of this platform. Is possible to note that noise overcome the sonic band (up to 20 kHz) and easily have the potential to mask cetacean communication

(27°56′S and 48°39′W, low traffic) and a second off Ribanceira (28°11′S and 48°37′W, high traffic). Authors focused on a particular call type, the right whale upcall (Clark 1982) with a signal to noise ratio >10 dB. The mean minimum frequency from Gamboa was 68.2 ± 18.6 Hz and from Ribanceira was 70.1 ± 24.8 Hz.

The noise levels measured in the two Brazilian locations showed different ranges and different slopes in the ECDF (Empirical cumulative density function) when compared to sites in the North Atlantic (Parks et al. 2013). Identified background noise sources included small vessels and a significant biotic source of sound from chorusing fish. The minimum frequency of right whale upcalls recorded in Brazil was notably lower than minimum frequency recorded from the North Atlantic right whales in the Cape Cod Bay habitat in 2005 of 103 ± 18 (Parks et al. 2009) and lower, but similar, to the frequency range of Southern right whales reported for Argentina in 2000 (78 ± 15) (Parks et al. 2007).

Other cetacean species, besides those five described, with bioacoustics records and analyzes for the Brazilian continental shelf include the Spinner dolphin (*Stenella longirostris*) (Camargo et al. 2006; Rossi-Santos et al. 2008a, b), the Franciscana or La Plata dolphin (*Pontoporia Blainvillei*) (Cremer 2007), the Atlantic spotted dolphin (*Stenella frontalis*) (Azevedo et al. 2010), the Bryde Whale (*Balaenoptera edeni*) and the common dolphins (*Delphinus* spp.) (Figueiredo 2014).

6.4.2 Ecological Niche Models

The spatial pattern of environmental suitability for *Sotalia guianensis* and *Eubalaena australis* were similar and narrower than the other species showing environmental suitable habitats on the Southeast Brazilian shelf (Fig. 6.17 c, e). The spatial pattern for *Tursiops truncatus*, *Steno bredanensis* and *Megaptera novaeangliae* were spread but showed a concentration of environmental suitable habitats from Northeast to Southeast Brazilian shelf (Fig. 6.17 a, b, d).

6.5 Discussion

6.5.1 Soundscape Ecology

With this overview we would like to obtain a broad comparison on the cetacean distribution patterns along the Brazilian continental shelf. Taking in consideration the specific environmental requirements to perform a certain acoustic signal, as well as the different hearing adaptation in each species is possible to make a comparison on how acoustically unique species are using their marine landscape.

It is easily seen that whales and dolphins utilize different frequency ranges for their acoustic signals that interact with the environment. For example, in the humpback whale that presents more flexible sound patterns composing their song, the fundamental frequencies are concentrated in a low range, up to 4 kHz (Table 6.1), while dolphins, in general, use high frequency ranges, even reaching ultrasonic bands (Simão and Moreira 2007; Andrade et al. 2014).

It is clear that the composition of the acoustic environment and the relative contribution of each sound type differed from site to site, demonstrating the potential effects of the landscape in sound diffusion and of the local scale characteristics in sound origin.

Along the Brazilian continental shelf the increase of human activities such as oil and gas exploitation may substantially change the soundscape, with potential to mask important cetacean signals, either in short or long acoustic range, such as breeding and contact calls as commented for the area (Rossi-Santos 2015) and worldwide (e.g., Tyack 2000a, b; Hildebrand 2009; Clark et al. 2009).

6.5.2 Ecological Niche Modeling

The ENM evidenced the similarity of very coastal distribution to complete different acoustic niches, such as the low frequency range for the right whales and medium and high frequency range for the Guiana dolphin, in a possible example of acoustic partitioning, as already evidenced, throughout spectrographic analyzes for terrestrial and marine habitats worldwide (Krause 2012).

The modeling results also showed that the cetacean species with more coastal habitat suitability, such as *S. guianensis* and *E. australis*, also increase the chances with human interaction, consequently it is a good method to identify potential sources for acoustic anthropogenic impacts along their distribution. Efforts to characterize marine background sounds present in the cetacean environment and incorporate in the ENM should be conducted to add a fine-scale information to the soundscape ecology approach and could lead to the description of the marine soundscape ecology of the Brazilian coast, throughout a cetacean perspective, as an important group in the ecological chain.

To reflect about cetacean distribution related to complex shelf habitats, a special mention should be given to the Abrolhos Bank, because all particularities this place adds in the ecology of the studied cetacean species. The Abrolhos Bank represents the biggest enlargement of the Brazilian continental shelf, located off the southern Bahia State, eastern Brazil The continental shelf may be as wide as 240 km (east of Caravelas city), and beyond the shelf depth increases abruptly to ~ 2000 m. The Abrolhos Bank can be divided into northern and southern regions, which have distinct physiographic characteristics. While in the south the marine environment is more dynamic, deeper and with stronger currents, the north is protected by the largest coral reef aggregation (Fig. 6.18) for the entire south Atlantic Ocean (Freitas 2000).

The Abrolhos Bank is also the core area in the breeding ground of the humpbacks in Brazil (Martins et al. 2001; Andriolo et al. 2010; Wedekin 2011), a population estimated in about 10,000 animals, that faces today many anthropogenic threats, such as accidental catches in fishing nets, boat collisions chemical and noise pollution (e.g., Perrin et al. 2009).

Rossi-Santos et al. (2006) suggested a distinct habitat use patterns by the three dolphin species of the present study, in the Abrolhos Bank. The extensive overlap of distribution of the Guiana, Bottlenose and Rough-toothed dolphins in the northern Abrolhos Bank region may result from the heterogeneity of habitats observed in the area, especially bottom physiography.

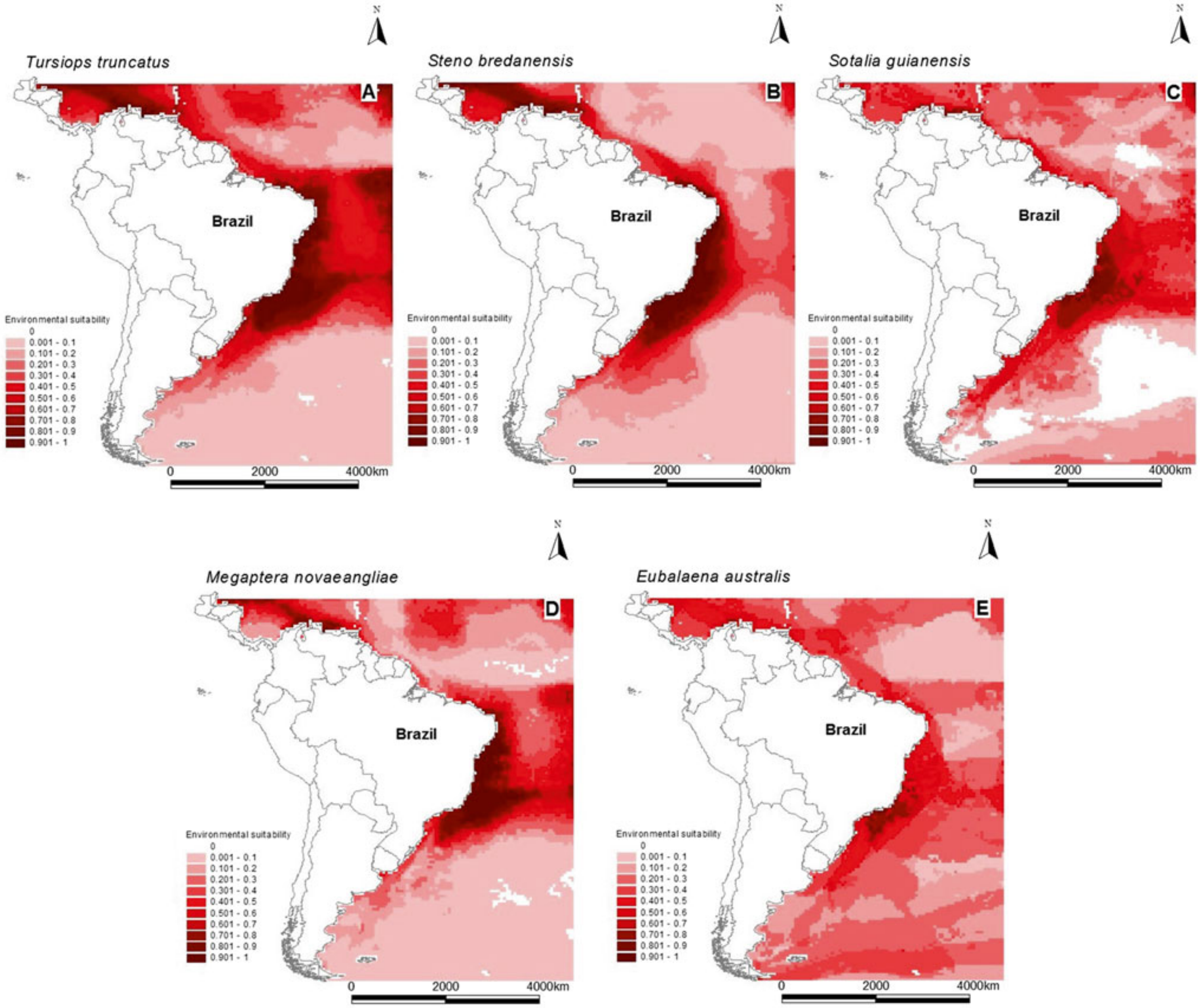

Fig. 6.17 Spatial patterns of environmental suitability for five cetacean species along the Brazilian continental shelf: the bottlenose dolphin (*Tursiops truncatus*), the rough-toothed dolphin (*Steno bredanensis*), the Guiana dolphin (*Sotalia guianensis*), the humpback whale (*Megaptera novaeangliae*) and the southern right whale (*Eubalaena australis*)

The offshore distribution of Guiana dolphins only ranged as far as the Abrolhos Archipelago region (Fig. 6.19), possibly because of the extension of shallow and warm waters in this area (Lodi and Borobia 2013). The species was commonly observed in coastal and productive riverine systems, such as the Caravelas estuarine mangrove system, and the Doce River mouth and its vicinities. Areas of estuaries, protected bays, large river discharges, and other habitat characteristics that induce coastal and localized productivity may serve as dispersal barriers, and/or may not support large populations of Guiana dolphins (Rossi-Santos et al. 2006).

The distribution of rough-toothed dolphins around the Abrolhos Archipelago and coral reef surroundings was likely due to the association of its potential prey items to coral reef communities, and the foraging strategies described for this species in Brazilian coastal waters (Lodi and Hetzel 1999). One of the prey items of rough-toothed dolphins captured while interacting with humpback whales in the Abrolhos Bank, the sharksucker (*Echeneis naucrates*) (Wedekin et al. 2004), is generally found in shallow reef sites such as those found in the northern region of the Abrolhos Bank (Reeves and Leatherwood 1983).

The bottlenose dolphin was the most generalist species in terms of habitat use, which corroborates the information reported in the literature. This species is a known generalist predator (Connor et al. 2000), which may account for its

Fig. 6.18 The Abrolhos Bank presents the largest coral reef aggregation for the entire south Atlantic Ocean, and constitute one of the most important marine national park in the Brazilian continental shelf (Photo: Enrico Marcovaldi/Inst. Baleia Jubarte)

Fig. 6.19 The Guiana dolphin, *Sotalia guianensis*, in a rare sight, photographed in an unusual habitat, the Abrolhos Archipelago, about 70 km from the mainland, a large extension of the Brazilian continental shelf (Photo: Marcos Rossi-Santos/Inst. Baleia Jubarte)

broader occurrence in the area. Both rough-toothed and bottlenose dolphins were not observed using coastal waters less than 12 km from shore. This pattern was similar to that observed for humpback whales, which appeared to avoid the chronic turbid coastal waters of the Abrolhos Bank, with high concentration of suspended material (Freitas 2000).

Knoppers et al. (1999) identified clear differences of mineral composition of suspended matter among inshore, coastal, and open reef waters of the Abrolhos Bank. A similar gradient was also verified in permanent and tidal currents and plankton composition (Knoppers et al. 1999). All these different environmental variables may have indirectly influenced small cetacean distribution as a result of their foraging ecology.

Cetaceans live in an aquatic environment strongly influenced by nearby activities on the mainland. Each environment has a unique soundscape or acoustic context. Dolphins and whales in Brazil have shown different sound patterns that could be associated with different ecologic conditions along a geographic gradient, such as the latitudinal extension of the Brazilian continental shelf. According to this assumption, May-Collado and Wartzog (2009) studying Guiana dolphins in Costa Rica, proposed that variation in whistle structure shows how dolphins adapt to local and changing habitat conditions, resulting in differences between populations at different geographic scales.

For the acoustic study of *T. truncatus* in different populations off Brazil, (Hoffmann et al. 2012) concluded that the differences in the whistle parameters between the areas seem to be related to differences in the environment and water characteristics, allowing the use of higher frequencies and longer vocalizations as well as whistles with a broader range of frequency variation.

Ecological differences between two habitats are usually the result of several interacting factors, such as water temperature, transparency, salinity, tides, currents, light, depth and habitat. As pointed out by Daura-Jorge et al. (2007), a better knowledge on the dynamics of prey abundance and distribution associated with cetacean feeding habitats and the influence of the diverse physical-chemical parameters of the water in the biotic components may help to unravel and explain processes involving the complex associations between the physical environment, prey and predators in different coastal areas.

It is show that diverse cetacean species poses a specific life history and for consequence react to the environmental features in distinct ways. Furthermore, cetacean distribution is associated with dynamic behavioral patterns that are mostly triggered by sound production, than it is expected that there is a close relation between environmental acoustic properties with evolutionary shaped mechanisms of sound production and reception (Ketten 1992).

Many important research questions could emerge from these observations, such as behavioral costs for masking compensation by marine mammals, physiological limits for noise exposure, local habitat degradation by excessive noise and other non-acoustic factors that are important in predicting adverse effects of noise, such as underwater visual cues for animal distribution.

It is also recommended for the Brazilian continental shelf to develop more studies, including experimental monitoring improvement with combined technological acoustic tools and geographic information system, to fully ascertain the sound patterns to build the soundscape ecology approach.

The integrative approach and interpretation of all these questions, such as performed with the soundscape ecology, may lead to a broad perspective to conciliate the modern human expansion with the conservation of natural environments, essential to a healthy and productive whole ecosystem.

6.6 Conclusions

The cetacean ecology study may contribute with a general characterization of the continental shelf, mainly because it is a result of a consistent dataset from long term monitoring using a multi-technique research on diverse ecologic and behavioral information about how animals utilize and react to different environmental features and this relation is intrinsic to their own evolution. This knowledge is very useful for a broad understanding of the continental shelf dynamic processes and for management to conservation purposes.

The value of bioacoustics for conservation strategies is growing. Acoustical tools have successfully been used to assess ecological population parameters as density and distribution of cetaceans. Studies investigating impacts of anthropogenic activities, such as ship traffic and whale watching activities, are fundamental to cetacean protection and may also focus on acoustics. Nevertheless, the applicability of bioacoustics in conservation depends on gathering baseline information, from long term monitoring, about the natural variation in acoustic behavior of the cetacean species.

Finally, using the integrative methods, we hope in the future to predict threats to cetacean populations along the Brazilian continental shelf and to provide useful scientific information to marine managers and conservation groups. Future management strategies must consider the possible influence of noise pollution on the communication system and long-term fitness of cetacean populations along the continental shelves worldwide.

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