Revista da Gestão Costeira Integrada 11(4):409-419 (2011)
Journal of Integrated Coastal Zone Management 11(4):409-419 (2011)

ASSOCIAÇÃO PORTUGUESA DOS RECURSOS HÍDRICOS
UNIVALI
http://www.aprh.pt/rgci/pdf/rgci-251_Parente.pdf
DOI:10.5894/rgci251
GESTÃO COSTEIRA INTEGRADA
Journal of Integrated Coastal Zone Management

Effectiveness of Monitoring Marine Mammals during Marine Seismic Surveys off Northeast Brazil *

Efetividade do Monitoramento de Mamíferos Marinhos durante Prospecções Sísmicas no Nordeste do Brasil

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ABSTRACT

The possible behavioral and physical problems involving marine mammals and marine seismic surveys have attracted the interest and concern of several authors. The Brazilian government has required Geophysical Companies to monitor marine mammals in order to: 1) avoid colisions with cetaceans and manatees; 2) record the effects of noise sources on the temporal and spatial distribution and abundance of marine mammals in the area of seismic survey; and 3) record the individual behavior response of cetaceans and manatees to seismic air-gun shots. As a consequence of this requirement, the effectiveness of monitoring marine mammals was evaluated during ocean-bottom-cable seismic surveys carried out during 2002 and 2003 of the northeastern coast of Brazil. This evaluation was based on the analysis of results from visual surveys and applied methodology considering the monitoring effort, visibility conditions, observers' experience, and observed marine mammal behaviors as indicator of its effectiveness. The monitoring procedures were not effective in addressing the concerns of the Brazilian government, and the following adaptations are recommended: more intensive training of marine mammal observers; development of a rigorous quantitative survey protocol; evaluate the functionality of acoustic monitoring techniques as an alternative for the night period; and independent baseline studies and analyses of marine mammal population distribution, density and behavior.

Keywords: Marine mammals; marine seismic survey; effectiveness of visual surveys; environmental management; South America; Northeast Brazil

RESUMO

Muitos autores têm apresentado interesse e preocupação com os possíveis efeitos das prospecções sísmicas no comportamento e fisiologia dos mamíferos marinhos. Por esse motivo o Governo brasileiro tem exigido às Empresas de Geofísica a realização de monitoramento das espécies para: 1) evitar colisões de embarcações com cetáceos e sirênios; 2) registrar os efeitos dos sons na distribuição espaço-temporal e abundância relativa de mamíferos marinhos na área de prospecção e 3) registrar a resposta comportamental individual de cetáceos e sirênios em relação aos disparos dos canhões de ar. Como conseqüência dessas exigências, foi realizada uma avaliação da efetividade do monitoramento de mamíferos marinhos ocorridos durante prospecções sísmicas no nordeste do Brasil entre 2002 e 2003. Esta avaliação foi baseada nos resultados das observações visuais e metodologia aplicada. O esforço de monitoramento, as condições de visibilidade, a experiência dos observadores e as avistagens e comportamentos

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** Submission: February 18, 2011; Evaluation: April, 11, 2011; Reception of revised version: June 17, 2011; Accepted: August 15, 2011; Available on-line: October 19, 2011*

registrados foram considerados como indicadores. Os resultados indicam que os procedimentos adotados para o monitoramento não foram efetivos para responder aos questionamentos do Governo brasileiro, sendo necessárias as seguintes adaptações: intensificar o treinamento das equipes de observadores, desenvolver protocolo de monitoramento, avaliar técnicas acústicas de monitoramento como alternativa para o período noturno, assim como a realização de estudos independentes para o conhecimento das densidades populacionais e análises do comportamento das espécies.

Palavras-chave: *mamíferos marinhos; sísmica marítima; monitoramentos visuais; gerenciamento ambiental; Nordeste do Brasil; América do Sul.*

1. INTRODUCTION

Seismic surveys are a fundamental process used to recognize and map geological structures that may yield oil or gas in amounts that can be economically extracted. Seismic surveys involve the emission of high-energy sound pulses through the water column to analyze geophysical features of the sea sub-surface (Jones 1999). Seismic pulses are generated through the collapse of air bubbles produced by one or more air guns. These air-gun pulses are captured after reflection or refraction either by arrangements of floating hydrophones when streamers are used or hydrophones arranged on the seafloor when ocean-bottom cables (OBC) are used. Seismic surveys can also vary according to the technology used i.e. 2-dimensional (2D) when conducted in single lines and 3-dimensional (3D) when conducted in net-lines that cover a patch of the ocean floor (Jones 1999).

The possible behavioral and physical problems in marine mammals caused by emissions of sound pulses during seismic surveys have been investigated by several authors. Except for the study carried out by Madsen *et al.* (2002), many pieces of research have documented the negative effects of loud anthropogenic noises on cetaceans (*e.g.* Evans *et al.,* 1993, Goold, 1994, Mate et al., 1994, McCauley *et al.,* 2000, Mallakoff 2002, Gordon *et al.,* 2004). Regarding manatees, there is no report of seismic survey impacts on this group of marine mammals (Richardson *et al.,* 1995), but the movements of boats in extremely shallow waters, characteristic of OBC seismic surveys, is a possible source of collision risk for these slow-moving animals (Gerstein 2002).

Governments of several countries have adopted measures to monitor and mitigate the impacts of seismic surveys on marine mammals. Seismic surveys on the Brazilian continental shelf were intensified in 1999 when the Brazilian government allowed private petroleum companies to explore for oil and gas. However, because of concern about the possible negative effects of noise generated by seismic air guns on marine mammals, the Brazilian government has required geophysical companies to minimize the impacts of seismic surveys. These requirements include the use of marine mammal observers during seismic surveys to ensure that: 1) accidents (collisions, entanglements) with cetaceans and manatees are avoided; 2) the effects of noise sources on the temporal and spatial distribution and relative abundance of marine mammals in the seismic survey area; and 3) the individual behavior response of cetaceans and manatees to air-gun shots are recorded (Brazilian Institute of the Environment and the Renewable Natural Resources – IBAMA 2003).

Some recent studies have focused on a possible methodological bias in the monitoring of marine mammals (*e.g.:* Gómez de Segura *et al.,* 2006, Mann 1999, MacLeod *et al.,* 2004), but evaluating the effectiveness of monitoring techniques is an uncommon scientific field with respect to seismic surveys. An important measure of the effectiveness of scientific research is the capacity of a study and its methods to address the study objective. In the case of monitoring procedures adopted during seismic surveys, effectiveness would be measured by the capacity of these procedures to meet the three objectives outlined above. This paper evaluates the effectiveness of monitoring cetaceans and manatees during OBC seismic surveys off northeastern Brazil in 2002 and 2003.

2. MATERIALS AND METHOD

This study was based on the results of marine mammal observations during seismic surveys in the following states: Sergipe (10°S - 37°W), Rio Grande do Norte (05°S - 35°W) and Ceará (03°S - 38°W), all in Northeast Brazil, between July 2002 and August 2003 (Table 1 and Figure 1). The characteristics of the seismic surveys and observations of marine mammals are described as follows:

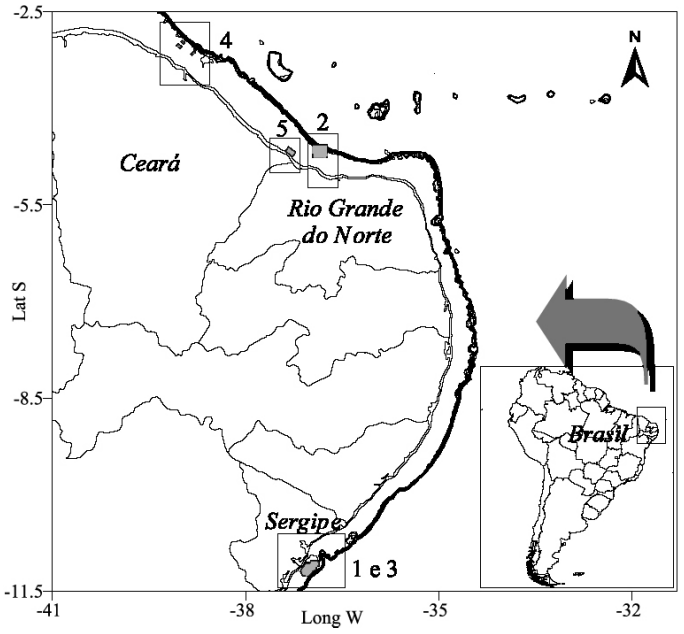

Figure 1. Brazilian northeastern region with distinction for the states and studied areas (1.Caioba-Camurim, 2. RNS-144, 3. Guaricema-Dourado, 4. Atum-Xaréu-Espada-Curimã e 5. CES-134).

Figura 1. Região nordeste do Brasil com destaque para os Estados e áreas de estudo (1.Caioba-Camurim, 2. RNS-144, 3. Guaricema-Dourado, 4. Atum-Xaréu-Espada-Curimã e 5. CES-134).

Table 1. Main characteristics of the OBC seismic surveys carried out in the northeast of Brazil between 2002 and 2003.
Tabela 1. Principais características da sísmica com cabos de fundo realizadas no nordeste do Brasil entre 2002 e 2003.

Project	Technology	Time	Duration (days)	Distance from coast Minimum – Maximum (Km)	Depth Minimum – Maximum (meter)	No. *air-guns*
Caioba – Camurim	3D	June to August, 2002	52	4,1 - 21,0	6 – 30	8
RNS-144	2D	August to October, 2002	42	25,4 - 45,1	15 - 50	4
Guaricema – Dourado	3D	October, 2002 to February, 2003	105	4,8 - 24,7	20 - 50	8
Atum-Xaréu-Curimã-Espada (AXEC)	3D	March to July, 2003	107	32,8 - 42,5	25 - 58	8
CES-134	2D	July to August, 2003	14	0,0 - 9,3	2 - 10	4

2.1 Seismic surveys

The OBC seismic survey method used 4 to 6 boats (lengths: 6m) to lay the cables. The boats were responsible for the deployment and withdrawal of the bottom cables with hydrophones. These cables were connected to the Record Boat and the Gunboat (lengths: 35m), to which the air guns were connected. The sound pulse generation system used by the Gunboat consisted of four to eight Generator-Injector (GI) air-guns with a capacity of 1,410psi each. Air was supplied by a compressor generating 2,000psi.

2.2 Marine mammal observations

Marine mammals were monitored during the seismic surveys through visual survey by on board marine mammal observers. Species occurrence and behavior were recorded on "Biota Records and Occurrence Forms" proposed by the geophysical company and approved by IBAMA. The information presented on the forms was as follows: Boat (identification, activity, geographical position and direction); Seismic survey [date, time, depth , sea state, weather conditions visibility and wind direction and strength - and observer´s name]; Animal [species, anatomical description, number of specimens (total, adult and calves), identification level (definite, probable and possible), behavior (swimming, feeding, courting, stationary, playing, other) and distance from the air-guns]; air-gun state (turned on or off) and other comments. The visibility was classified according to sea conditions associated with the Beaufort scale and luminosity as follows: Good – intense brightness with Beaufort 0 or 1;

Moderate – little brightness with Beaufort 1 or intense brightness associated with Beaufort 2;Poor – Beaufort 3 or little brightness with Beaufort 2.

There were no seismic surveys or marine mammal monitoring when sea conditions reached or exceeded Beaufort 4 because it was difficult to spread the hydrophone cables and to observe marine mammals.

During the *Caioba-Camurim* Project (Table 1), there was only one observer on the Gunboat. In the next three projects there was one observer on the Gunboat and another on the Monitoring Boat. In the last project (*CES-134*), conducted off *Ceará*, there were seven observers distributed among all the boats involved in the seismic survey (Gunboat, Monitoring Boat and the five Lay-Out Boats).

2.3 Data analysis

The information from the "Biota Records and Occurrence Forms" was analyzed to evaluate whether the objectives of the Environmental Management Plan, as proposed by the geophysical company responsible for the monitoring of marine mammals, had been achieved. The following indicators were used to measure the effectiveness of monitoring regarding each objective:

To avoid boat collisions with marine mammals

Records of collisions between boats and marine mammals in the five environmental reports and its forms were reviewed and analyzed. The number of animals was categorized by effort to establish a sighting index (marine mammal/hour), and these records were organized in class intervals of two hours. This procedure helped in evaluating the influence of time on the ability to record marine mammals as well as verifying the synchronicity of observation and seismic survey efforts. The Kruskal-Wallis statistical test was used to determine whether there was a significant difference among the class intervals.

To measure the effects of noise sources on the relative-abundance and distribution of marine mammals

Visual surveys were used to quantify the effects of the noise sources on marine mammal behavior. As well as the synchronicity analyzed above, these surveys verified the distance between marine mammals and boats; the effect of the observer's experience (classified as: beginner, capable and expert) on the sighting indices; the identification level

(definite, probable and possible) and the effect of visibility conditions (good, moderate or poor) on the marine mammal records.

A Principal Component Analysis (PCA) using the Bray-Curtis coefficient, following data normalization with a double-center post-transformation procedure, was used to verify the relationship between visibility conditions and number of marine mammals recorded by the seismic survey. The Kruskal-Wallis statistical test was also applied to evaluate the influence of visibility conditions on the sighting indices during the seismic surveys.

To record the behavioral responses of cetaceans and manatees to air-gun shots

The behaviors recorded during the surveys were analyzed in confrontation with those published in previous studies concerning behavioral responses of marine mammals to anthropogenic noises. The Mann-Whitney non-parametric statistical test was used to detect any significant difference between the record indices of the main behaviors during the different states of functionality of the air-guns (switched on or switched off). A probability of (p) < 0.05 was considered statistically significant.

3. RESULTS

A total of 2,028 hours of marine mammal monitoring was carried out during 4,263.75 hours of seismic surveys. This marine mammal monitoring corresponded to 47.6% of the total duration of the seismic surveys and was not synchronized with the operation of the air-guns. The air-guns were not shooting continuously, but were switched on and off at different intervals throughout the projects, generally starting around midday and stopping at night (Figure 2). Despite this, accidents between boats and marine mammals were not recorded during the seismic surveys. The only "accident" recorded by the observers was a collision of the Gunboat during project CES-134 (Ceará State) with some fixed wood used to build fishing traps.

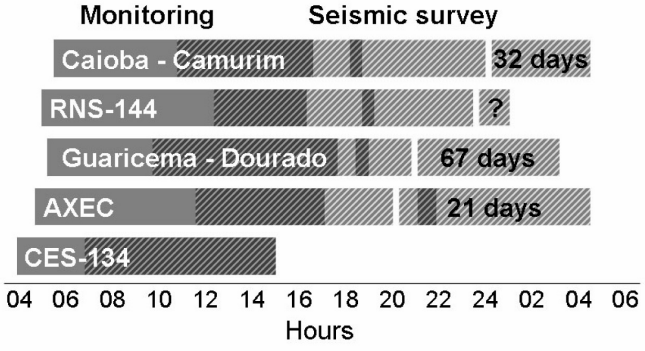

Figure 2. Effort of the monitoring of marine mammals and seismic survey with the limits representing the average of hour of the beginning and final of the activities.
Figura 2. Horário médio de início e final do monitoramento de mamíferos marinhos e dos disparos dos canhões de ar nos projetos sísmicos.

The marine mammal monitoring programs recorded 83 sightings of 311 specimens of cetaceans and manatees, including *Megaptera novaeangliae*, *Tursiops truncatus*, *Sotalia guianensis*, *Stenella frontalis*, *Stenella* sp., *Steno bredanensis* and *Trichechus manatus*. Thirty-four sightings were of Odontoceti (toothed whales). Information on the diversity, occurrence and distribution of species are discussed in a separate study (Parente 2005).

All sightings of marine mammals occurred between 04:00 and 18:00 hours, which correspond to the daylight period on northeastern off Brazil (Figure 3). The Kruskal-Wallis non-parametric test (H=19.36) relating sightings of marine mammals to the hour class interval was highly significant (p=0.0036). There was a significantly higher probability of observing marine mammals between 0800 and 1600 hours i.e. during daylight hours.

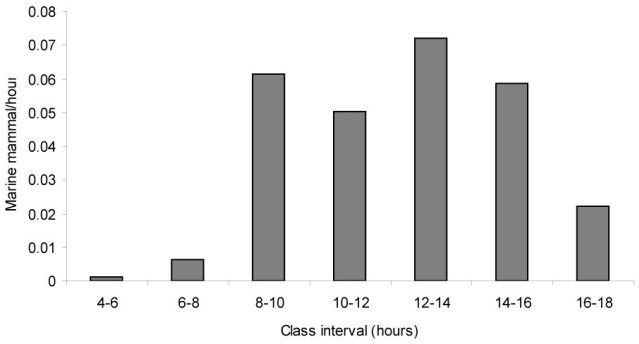

Figure 3. Marine mammals sighted according to class interval of hour.
Figura 3. Mamíferos marinhos observados conforme intervalos de horário.

The Operation Licenses demanded that marine mammal monitoring should be carried out during the entire period of air-gun activity. Considering this requirement, and considering that air-gun operations extended through the period of night in four of the five projects (except for project *CES-134)*, night vision binoculars (model Gen 1 Pathfinder®) were used to help observers at night. Nevertheless, there was no regular frequency of night monitoring due to the risk of accident with the observers and no marine mammal was recorded during these periods of darkness. According to observers, during good sea conditions (Beaufort 0 or 1), with a cloudless sky and full moon, the night vision binoculars offered satisfactory visual accuracy, although they caused discomfort when used for long periods.

3.1 Marine mammal observers

The number of marine mammal observers, their degree of experience and level of monitoring effort varied throughout the seismic surveys. During the *Caioba-Camorim* Project (which consisted of 356 hours of monitoring effort), there was only one observer and he was classified as a "Beginner" due to his lack of experience with marine mammals

sightings. This observer underwent a training program that included sighting methodology, safety procedures and the most likely species to been seen in the area. The training program lasted eight hours, after which the observer was able to remain active in the project until its conclusion. During the subsequent two projects, *RNS-144* (255 hours of monitoring) and *Guaricema-Dourado* (803.25 hours), two other observers were contracted and neither had previous experience in monitoring marine mammals, both being classified at the end of the study as "Beginners". As with the first observer, both were marine science professionals and both participated in the same training program. In summary, the geophysical company used three "Beginners" that rotated between two boats (Gunboat and Monitoring boat). During the *AXEC* seismic survey (450 hours), a new observer with more than ten years of experience and classified in this study as an "Expert" was contracted. This observer also rotated between the same boats with two other observers classified as "Capable" during this work due to their two previously experience in monitoring marine mammals. Finally, on the *CES-134* Project (163.75 hours) four new observers with previous experience and classified as "Experts" and three new observers classified as "Capable" were distributed among seven boats (Gunboat, Monitoring boat and five Lay-out boats).

Considering all the seismic surveys together, the "Beginners" observed more marine mammals than the "Capable" and "Expert" observers (Figure 4). This result could be consequence of the difference in the abundance of cetaceans between the areas or as consequence of higher levels of false-positive observations by the "Beginners" working on the first three seismic projects. Additionally, a higher frequency of "definite" vs. "possible" identifications was noted among the "Capable" and "Expert" observers when compared with the "Beginners".

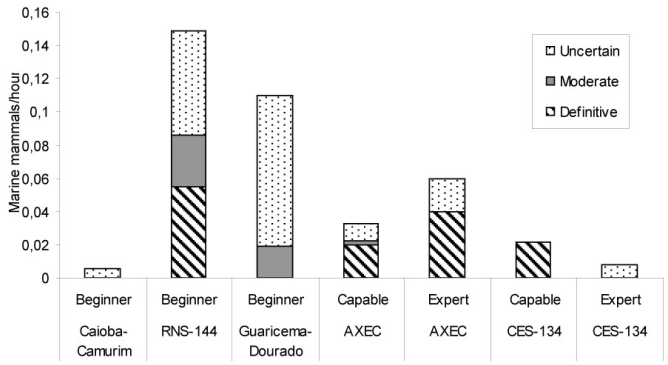

Figure 4. Quality of the sightings of marine mammals (Definitive, Moderate, Uncertain) according to the observers' experience (Beginner, Capable, Expert) during the seismic surveys.
Figura 4. Qualidade dos registros de mamíferos marinhos (Definitiva, Moderada, Ruim) conforme experiência dos observadores (Iniciante, Apto, Experiente) durante todos os estudos sísmicos.

3.2 Effects of visibility conditions on marine mammal sightings

Marine mammals sightings were more frequent when visibility conditions were considered "good". This was confirmed by the results of the Kruskal-Wallis non-parametric test, which showed a highly significant value (H=10.88; p=0.0043,) confirming the influence of visibility conditions on recording rate among the seismic surveys. It is important to emphasize that the observers only recorded the visibility conditions during the monitoring effort when marine mammals were observed.

The PCA using the Bray-Curtis dissimilarity index provided excellent adjustment and addressed 97.4% of the variables. It showed a direct and statistically significant relationship between "moderate" and "good" visibility conditions and the number of marine mammals observed (Figure 5).

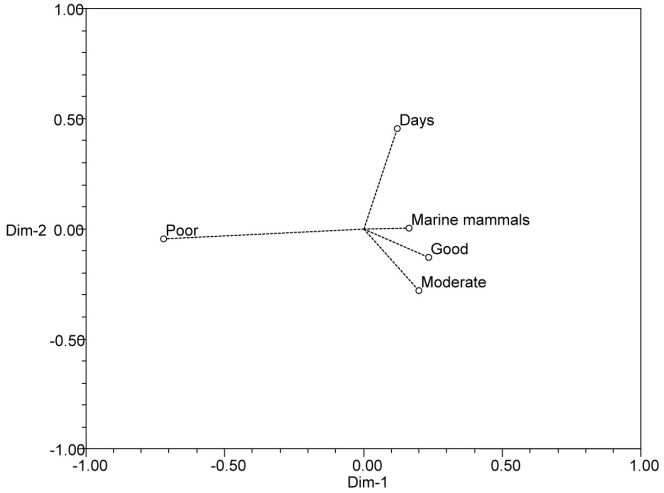

Figure 5. Relationship among visibility condition (Good, Moderate, Bad), days of monitoring and the total number of marine mammals sighted in the projects (Animal).
Figura 5. Relação entre condição de visibilidade (Bom, Moderado, Ruim), dias de monitoramento e o número total de mamíferos marinhos observados nos projetos (Animais).

3.3 Marine mammal distance from boats

According to the Environmental Management Plans presented by the Geophysical Company to IBAMA (which is responsible for authorizing seismic surveys), the air-guns should be switched off every time a marine mammal was observed within a radius of 500 meters from the Gunboat. In fact, only 34 of 83 forms analyzed (40.9%) actually showed information regarding the distance of the marine mammal in relation to the corresponding air-guns. Among these 34, 28 documented observations within a radius of 500 meters, 5 between 500 and 1,000 meters and only one beyond 1,000 meters. According to the forms and reports analyzed, the air guns were switched off in all cases when marine mammals were recorded within a radius of 500 meters.

3.4 Observed marine mammal behaviors

The observed behaviors were: swimming (83.3%), playing (13.2%), feeding (1.5%) and stationary (1.5%) (Figure 6). Behavior observations only exceeded 10 minutes when the marine mammals were seen within a distance of 500 meters from the Gunboat, whilst observations longer than 15 minutes were never recorded by observers.

Figure 6. Observation frequency of behaviors according to air-guns operation state.
Figura 6. Freqüência de comportamentos observados conforme funcionamento dos airguns.

During the periods when air-guns were "switched on", only swimming (0.061 marine mammal/hour) and playing (0.015) behaviors were recorded. The frequency of swimming behavior was greater when the air-guns were "switched off" (0.115), however the Mann-Whitney statistical test showed that this difference regarding the air-gun operational state was not statistically significant [U=16.50; $Z(U)$=1.022; p=0.3067]. This result suggests that swimming behavior was independent of air-gun operational state.

4. DISCUSSION

The monitoring of marine mammals showed a great variation among the number and degree of experience of marine mammal observers, as well as sighting effort and air gun operation time. However, the visual survey methodology was constant in all projects, thus allowing us to analyze the effectiveness of marine mammal monitoring according to the indicators used in this study.

4.1 Avoiding accidents with marine mammals

Because of their inability to detect or possibly recognize certain moving vessels, cetaceans and manatees can be struck by boats. Collisions between marine mammals and boats, which were defined in this study as "accidents", are the main cause of death of some marine mammals, such as North Atlantic Right Whales (*Eubalaena glacialis*) and West Indian Manatees (*Trichechus manatus*); vessel collisions with odontocetes are less common (Klinowska, 1991; Wells & Scott, 1997; Clapham *et al.,* 1999; Gerstein, 2002), presumably because these animals can better heard vessels due to its sensitivity to high frequency noise. This study did not record any accidents involving boats and marine mammals, although this absence could not be attributed to the mitigation and monitoring procedures. Marine mammal observers did not make observations during the entire period when seismic surveys were occurring in all projects, due to environmental conditions or night time. However, there was no evidence of collision risk between boats and sighted species.

4.2 To attenuate the effects of noise sources on the temporal and spatial distribution and abundance of marine mammals

The possible effects of noise from seismic air-gun pulses on marine mammals are numerous, including physiological impacts (i.e. alteration of hearing sensitivity and stabilization of gas bubbles in body tissue), plus behavior impacts and changes in vocal patterns, breathing and avoidance of certain areas (Jepson *et al.,* 2003, N.R.C, 2003). Changes in physiology and vocal behavior were not possible to detect using the monitoring method adopted in this study. Studies to identify physiological changes caused by noise from air guns should be conducted continuously and systematically by researchers with in-depth knowledge of marine mammal anatomy and physiology, and independent from Geophysical Companies.

Monitoring from either fixed or mobile observation platforms has been widely used to study populations and behaviors of marine mammals (*e.g.* Santos *et al.,* 2000, Carretta *et al.,* 2001). The utilization of visual techniques to study the potential effects of anthropogenic activities on behavioral changes and habitat use by whales is now commonplace (Ng & Leung, 2003). These studies generally compare observations made before, during and after the anthropogenic activity to detect changes in marine mammals (*e.g.* Goold, 1996; McCauley *et al.,* 2000; Monteiro-Neto *et al.,* 2004). Some researchers observe marine mammals only during the anthropogenic activity and measure the distance and direction of movement patterns to identify changes (Harris et al., 2001).

The monitoring effort during this study occurred only during seismic surveys, no prior or subsequent observations being made. In addition, the sighting effort covered less than 50% of the seismic survey period and was focused on the daylight period due to the low efficacy of night sightings. For these reasons, factors such as the distance of animals from the noise source and behaviors during seismic surveys were the only possible indicators of any anthropogenic effects on the marine mammals.

Sighting distance

The West Australian Department of Mineral Resources and Petroleum demands the interruption of air-gun shots when whales are observed within 3 km for female/calf pairs and 1.5 km for other cases not involving females and calves. The Australians impose no restrictions for odontocetes

(DoIR, 1998). On the other hand, during seal observations carried out from a Gunboat working in the Beaufort Sea, Alaska, 79% of seals were within the "risk zone" defined as a radius of 250 meters (Harris *et al.,* 2001). Studies off the west coast of the British Isles have shown that dolphins responded to air-gun noise at distances greater than 1 km from the source (Goold & Fish, 1998).

For seismic surveys conducted in Brazilian waters, the "risk zone" adopted for marine mammals is 500 meters from the noise source (Gunboat). This distance was applied according to theoretical models of sound diffusion presented by Geophysical Companies during the licensing process: They are based on the assumption that at this distance the noise is less than 180dB re 1 µPa (RMS) and, according to previous studies (Richardson *et al.,* 1995; McCauley *et al.,* 2000), this level would not cause lethal damage to marine mammals. Although sightings of marine mammals close to vessels might be interpreted as zero or minimal impact on their populations (Harris *et al.,* 2001), some researchers have associated cetacean stranding with seismic surveys (*e.g.* Malakoff, 2002; Engel *et al.,* 2004) and others have documented alterations in behavior due to noise from air-guns (*e.g.* Richadson et al., 1995, Goold, 1996). In this study, the more frequent sightings of marine mammals within 500 meters of the seismic source suggests that the visual surveys may not have been effective in detecting species before they reached the "risk zone" defined for seismic surveys in Brazilian waters. Likewise, the absence of information about the distance of whales from the sound source in more than 50% of the records suggests that the marine mammal observers may have had difficulty estimating distances. The small proportion of sightings may also have been associated with the height of the observation point on the boats, which was no greater than five meters. These difficulties may have reduced the effectiveness of the monitoring method in answering key questions concerning the effects of seismic surveys on marine mammals. Theoretical models from previous works presented the possibility that sound may stabilize micro-bubbles in the tissues of marine mammals, which can block capillary and blood vessels when the animals are exposed to a sound intensity of 150-220 dB re 1 µPa (Crum & Mao, 1999). Lesions similar to these were found in cetaceans stranded during military tests of low-frequency sonar (Jepson *et al.,* 2003). Based on this information, it is possible that although whales sighted at short distances from air-guns may not feel ear pain, other body tissues may be affected. In such circumstances, visual observation may be ineffective in avoiding impact on whales. One suggestion to improve the current surveys would be to conduct bioacoustic monitoring studies simultaneously with marine mammal observation on seismic surveys to generate a database and evaluate alterations in the vocal repertoires of manatees and cetaceans when under the influence of air-gun impulses.

Visibility conditions

It was expected that reflection or glare and sea state would interfere in sighting marine mammals. However, there is little information on this subject relative to seismic surveys. Regarding glare, reflection of light on the sea surface is greater during the first and final hours of the day (Thurman, 1997). It was therefore expected that sightings of cetaceans and manatees would be reduced during these hours. Sightings of seals during seismic surveys in the Alaskan Beaufort Sea were not effective during the night and most sightings were near the Gunboat (Harris *et al.,* 2001). Similar results were observed during the current research; sightings of marine mammals were more frequent between 08:00 and 16:00 hours, corresponding to the time interval of highest solar light intensity in Northeast Brazil. Considering this, the effectiveness of visual surveys may have been reduced during the early hours of the morning and the final hours of the afternoon. Visual surveys were ineffective during the night, even when night-vision binoculars were used.

Regarding sea state, during aerial surveys of beluga whales (*Delphinapterus leucas*) in Alaska, researchers observed that the highest densities were recorded when the sea state was BF 1 (DeMaster *et al.,* 2001). In the present research, the Principal Components Analysis correlated the number of sightings with visibility conditions classified as "moderate" and "good", associated with BF 0-2. Similar to the Alaska results, the result of our statistical analysis showed that the effectiveness of visual surveys was reduced when conditions were classified as "moderate" and "poor". When considering reflectance (glare) and sea state together as "visibility", both factors influenced the effectiveness of the mitigation and monitoring studies of marine mammals.

The possibility of detecting marine mammals by hydrophone arrays linked to special software (Passive Acoustic Monitoring – PAM) has shown promise as a monitoring tool for some species of marine mammal with frequent vocalization (*e.g.* Swartz *et al.,* 2002; Mellinger, 2004). PAM has been suggested as an alternative or additional technique to improve the effectiveness of monitoring marine mammals (Lewis *et al.,* 1998). This acoustic technique has been used to complement visual surveys during periods of darkness and may have advantages over the visual technique in areas with strong wind and poor visibility (Swartz *et al.,* 2003). Considering all of these factors, it is recommended to start experiments with PAM in Brazilian waters as an auxiliary tool to document the presence of marine mammals during seismic surveys.

Experience of the observers

The experience of marine mammal observers is a very important factor in the detection and identification of marine mammals. During previous visual surveys of marine mammals off Northeast Brazil, in which all the observers were experts, they had been extensively trained and had conducted simulations of marine mammal sightings (Zerbini *et al.,* 2004).

In the present research, most observation effort during the first three seismic surveys was by "Beginner" observers. "Expert" and "Capable" observers were present only during the two last projects. It is noteworthy that a higher sighting index was generated by the "Beginners" compared to the "Expert" and "Capable" observers. Another important result was that the highest number of cetaceans recorded during project RNS-144 in Rio Grande do Norte State was when only "Beginners" were observing and the lowest number of marine mammals recorded was during the last two projects

in the State of Ceará when only "Experts" and "Capable" observers were recording. Although it was not possible to statistically distinguish the effects of observers' level of experience on the sighting indexes, it is evident that there was a positive effect in the quality of identification of species when the observers were "Experts". This result indicates the importance of training observers in sighting and identifying marine mammals. Another factor that indicates the need for training was the high index of "possible" records by all observers, despite the known influences of visibility conditions. Therefore, one major recommendation of this paper that would be likely to improve the effectiveness of marine mammal mitigation and monitoring programs during seismic surveys in Brazilian seawaters is that all marine mammal observers have sufficient training and experience before going to sea.

4.3 To register the behavioral response of cetaceans and manatees to air-gun shots

The interpretation of behavioral responses of marine mammals during seismic surveys is complex and little studied. Nevertheless, quantitative behavioral studies are an important tool used to investigate potential human impacts on the marine environment (*e.g.* Richardson *et al.,* 1995, Ng & Leung, 2003). It is also essential to observe and evaluate the methodologies used to investigate these potential human impacts.

A critical analysis of the methodologies applied in marine mammal behavior research concluded that they can be classified according to the "follow protocol" and "sampling method". The first refers to how long an observation extends and to whether researchers follow a group or an individual animal, whilst the second refers to the procedures used to sample the behavior of the individuals or groups (Mann, 1999).

The protocol used in this study can be classified as a "survey", in which individuals or groups are observed for 30 min or less. Surveys provide only a "snapshot" of animal life, and are used mainly to address population-level questions such as density and distribution (Mann, 1999). In other words, surveys are not recommended for observations of behavioral response unless they are conducted before, during and after the anthropogenic event being investigated.

The sampling methods used in this research could be classified as "incident sampling" because of the short duration of sightings when only the behavior presented at the instant of detection is recorded (Mann, 1999). Therefore, without previous experience and knowledge of the behavioral repertoire of the species exhibited during a seismic survey, it could be argued that it is not possible to infer an accurate response to human activity during that instantaneous observation.

Considering the above, we suggest that the methodology used to identify behavioral responses of marine mammals during marine seismic surveys off Northeast Brazil was inadequate to meet the stated objectives. To adequately document real changes in the density and distribution of marine mammals during seismic surveys, it would have been necessary to compare results of marine mammal surveys conducted before, during and after the seismic surveys, following established protocols used in previous studies (Richardson *et al.,* 1995, Goold, 1996, McCauley *et al.,* 2000).

Another recommendation that should be considered is the adoption of an established behavioral repertoire classification scheme to be used during observations. Studies of the potential effects of boat traffic on the behavior of the bottlenose dolphin (*Tursiops truncatus*) used eight behavior categories and applied the focal group following protocol (Constantine *et al*., 2004). Similarly, the United Kingdom Joint Nature Conservation Committee (JNCC) recommends the use of the *ad libitum* sampling method and suggests that twelve behavioral categories plus the direction of movement be used for surveys of marine mammals during seismic surveys (JNCC 2004).

The behaviors recorded on the forms used during this research include only five general characteristics and there is no consideration of movement direction. These shortcomings preclude accurate inferences about the effects of air-gun noise on marine mammals and do not allow useful comparisons of this study with previous similar studies (*e.g.* Goold, 1996; McCauley *et al.,* 2000). For example, "swimming" behavior, which was the behavior observed most often during the seismic surveys, is the most common behavior among all marine mammals and may be categorized according to speed as "slow", "normal", and "fast", depending on whether the animal is resting, feeding, migrating or escaping (Frohoff, 2000). Because no information was recorded regarding swimming speed and direction during the sightings, it was not possible to relate this important behavioral criterion to information about air-gun operations and possible effects on cetaceans and manatees. We recommend revisions to the monitoring protocol, including the structure of the data recording forms, so that detailed information about marine mammal behavior can be recorded, which may then allow an assessment of the effects of air-gun operations on marine mammals.

In addition, it is important to understand that the use of visual techniques to observe the behavior of marine mammals, which may only be visible for a fraction of total daylight hours, is complicated because the animals are only observed when they are on the surface and not when they are underwater (Mann, 1999). Accurate interpretation of marine mammal behavior therefore depends greatly on the previous experience and knowledge of the observer regarding expected behaviors of cetaceans or manatees. Considering that most of the observers from this study were not experts, the accuracy of marine mammal behaviors recorded during the seismic surveys and the effectiveness of the monitoring and mitigation programs could be questioned.

4.4 Final considerations

This analysis of methods used to monitor marine mammals during seismic surveys off Northeast Brazil seeks to provide a better understanding of the effectiveness of such work. It is our opinion that the monitoring programs reviewed in this paper were ineffective and would not answer the key questions about the effects of seismic surveys on marine mammals.

This was mainly due to the fact that the methodologies implemented, although appropriate to the measurement of density and distribution, were not conducted before, during and after the seismic surveys. Similarly, the monitoring was not implemented continuously during the seismic surveys and was strongly influenced by visibility conditions, as well as by the level of experience of the observers. We conclude that the methodology used to observe marine mammals during the OBC seismic surveys in marine waters off Northeast Brazil was not effective in addressing the following issues: measuring the effects of seismic survey noise sources on the presence and distribution of marine mammals; and assessing the behavioral response of cetaceans and manatees to air-gun shots. Furthermore, the absence of records of collisions between boats and marine mammals during the monitoring program could have been a result of difficulties in recording data at night or during poor visibility conditions.

We recommend several lines of action to improve the effectiveness of marine mammal monitoring programs, starting with a review of the monitoring protocol, including observations before and/or after the seismic effort to allow analysis of changes in distribution. Other actions include revising the data collection forms focused mainly in the group behavior such as swimming speed, approach or avoidance behavior and abrupt changes in direction. Since 2005 some of these suggestions was incorporated by the Brazilian Environmental Agency but this form should have include space for a complete description of sighted species. A final important action is to establish a training program for observers before the surveys, which would enable them to correctly identify species and behaviors. We feel that these recommendations would better prepare the marine mammal observers from the Geophysical Companies and greatly improve the protocol for monitoring marine mammals during marine seismic surveys. Even these analyses have been done on the scope of the monitoring of seismic survey impacts, its results and concepts could be extended to all monitoring programs of marine mammals developed on coastal zone contributing to its improvement.

We also recommend that different monitoring techniques *(e.g.* acoustic monitoring, aerial surveys and telemetry) should be conducted by researchers independent of the Geophysical Companies regarding the effects of seismic surveys on the density, distribution and behavior of cetaceans and manatees. This independent acoustic monitoring should be conducted mainly during seismic surveys carried out at night or when visibility conditions are not favorable.

Finally, we strongly recommend that a comprehensive assessment should be made of all marine mammal monitoring programs conducted during seismic surveys in Brazilian waters since 1997. This more comprehensive analysis would further support the preparation of a protocol and assist in the licensing and fiscal processes for petroleum exploration in marine areas of Brazil. The adoption of these recommendations will increase knowledge of the occurrence and distribution of marine mammals on the Brazilian continental shelf, as well as help address concerns regarding the effects of seismic surveys on these animals.

ACKNOWLEDGMENTS

This study was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES-MEC) and grants from The Cetacean Society International. The authors would like to thank Antonio Albuquerque, Douglas Araújo, Francisco Ávila, Guilherme Amado, Leo Bruno, Rommel Feitosa, Rose Emília, Tito Tsuji, Gisele Soares and all the 636 crew members and managers from Grant Geophysical for their fellowship and documentation needed in carrying out this study. The seismic surveys were authorized by the Petroleum and Nuclear Licensing Office (ELPN, in Portuguese) through Operation License (LO) Nº 224/2002 for the areas of *Caioba-Camurim-Guaricema-Dourado*, LO Nº 252/2002 for the area *RNS-144*, LO Nº 301/2003 for the areas of *Atum-Xaréu-Espada-Curimã* (AXEC) and LO Nº 243/2002 (Technical Opinion Nº 051/2003) for the area *CES-134*. The authors thanks also Luciano Dalla Rosa and other anonymous reviser for your valuable suggestions in this article.

BIBLIOGRAPHY

Carretta, J.V.; Taylor, B.L.; Chivers, S. J. (2001) - Abundance and depth distribution of harbor porpoise (*Phocoena phocoena*) in northern California determined from a 1995 ship survey. *Fishery Bulletin,* 99(1):29–39. http://fishbull.noaa.gov/991/3.pdf

Clapham, P.J.; Young, S.B.; Brownell Jr, R.L. (1999) - Baleen whales: conservation issues and the status of the most endangered populations. *Mammal Review*, 29(1):37–62. DOI: 10.1046/j.1365-2907.1999.00035.x.

Constantine, R.; Bruton, D.H.; Dennis, T. (2004) - Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. *Biological Conservation*, 117(3):299–307. DOI: 10.1016/j.biocon.2003.12.009

Crum, L.A.; Mao, Y. (1996) - Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *Journal of the Acoustical Society of America* (ISSN:0001-4966), 99(5):2898-2907, Melville, NY, U.S.A. DOI: 10.1121/1.414859.

DeMaster, D.P.; Lowry, L.F.; Frost, K.J.; Bengtson, R.A. (2001) - The effect of sea state on estimates of abundance for beluga whales (*Delphinapterus leucas*) in Norton Sound. Alaska. *Fishery Bulletin,* 99(1):197-201. http://fishbull.noaa.gov/991/17.pdf

DoIR - Department of Industry and Resources (1998) - *Guidelines on Minimizing Acoustic Disturbance to Marine Fauna.* 6p., East Perth, Western Australia, Australia.

Engel, M.H.; Marcondes, M.C.C.; Martins, C.C.A.; Luna, F.O.; Lima, R.P.; Campos, A. (2004) - Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult Humpback whales on the Abrolhos Bank, northeastern coast of Brazil. 7p., Paper SC/56/E28 presented to Scientific Committee of the 56th International Whaling Commission, Sorento, Italy. http://www.marineconnection.org/docs/humpback_stranding.pdf

Evans, P.G.H.; Lewis, E.J.; Fisher, P. (1993) - *A study of the possible effects of seismic testing upon cetaceans in the Irish Sea*. 36p., Report from Sea Watch Foundation to Marathon Oil, Oxford, U.K.

Frohoff, T.G. (2000) - Behavioral indicators of stress in odontocetes during interactions with humans: a preliminary review and discussion. 23p., Paper SC/52/WW2 presented to Scientific Committee of the 52nd International Whaling Commission, Adelaide, Australia.

Gerstein, E.R. (2002) - Manatees, bioacoustics and boats: Hearing tests, environmental measurements and acoustic phenomena may together explain why boats and animals collide. *American Scientist,* 90(2):154-163. DOI: 10.1511/2002.2.154. http://www.americanscientist.org/issues/feature/2002/2/manatees-bioacoustics-and-boats/1

Gómez de Segura, A., Crespo, E., Pedraza, S., Hammond, P. & Raga, J. (2006) - Abundance of small cetaceans in waters of the central Spanish Mediterranean. *Marine Biology*, 150(1):149-160. DOI: 10.1007/s00227-006-0334-0. http://www.springerlink.com/content/q7477k814223w7h5/fulltext.pdf.

Goold, J. C. (1996) - Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. *Journal of the Marine Biology Association of the United Kingdom*, 76(3):811-820. DOI: 10.1017/S0025315400031477.

Goold, J.C.; Fish, P.J. (1998) - Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. *Journal of the Acoustical Society of America* (ISSN:0001-4966), 103(4):2177-2184, Melville, NY, U.S.A. DOI: 10.1121/1.421363.

Gordon, J.; Gillespie, D.; Potter, J.; Frantzis, A.; Simmonds, A.P.; Swift, R.; Thompson, D. (2004) - A review of the effects of seismic surveys on marine mammals. *Marine Technology Society Journal* (ISSN: 0025-3324), 37(4):16-34, Columbia, MD, U.S.A. DOI: 10.4031/002533203787536998.

Harris, R.E.; Miller, G.W.; Richardson, W.J. (2001) - Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort sea. *Marine Mammal Science,* 17(4):795-812. DOI: 10.1111/j.1748-7692.2001.tb01299.x.

IBAMA (2003) - Guia para o licenciamento ambiental das atividades marítimas de exploração e produção de petróleo e gás natural. 28p., IBAMA - Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, Brasília, DF, Brasil.

Jepson, P.D.; Arbelo, M.,; Deaville, R.; Patterson, I.A.P.; Castro, P.; Baker, J.R.; Degollada, E.; Ross, H.M.; Herráez, P.; Pocknell, A.M.; Rodríguez, F.; Howie, F.E.; Espinosa, A.; Reid, R.J.; Jaber, J.R.; Martin, V.; Cunningham, A.A.; Fernández, A. (2003) - Gas-bubble lesions in stranded cetaceans: Was sonar responsible for a spate of whale deaths after an Atlantic military exercise? *Nature*, 425:575-576. DOI: 10.1038/425575a.

JNCC (2004) - Guidelines for minimizing acoustic disturbance to marine mammals from seismic surveys. JNCC - Joint Nature Conservation Committee, Aberdeen, U.K.. http://www.jncc.gov.uk/pdf/Seismic_survey_guidelines_200404.pdf.

Jones, E.J.W. (1999) - *Marine geophysics*. 474p., John Wiley and Sons Ltd., Chichester, England, U.K.. ISBN-13: 978-0471986942.

Klinowska, M. (compiler) (1991) - Dolphins, Porpoises and Whales of the World. The IUCN Red Data Book. 438p., IUCN, Cambridge, U.K. ISBN: 2880329361.

Lewis, T.P.; Swift, R.; Gonzalbes, P.; Butler, J.; Gordon, J. G. (1998) - *Passive Accoustic Monitoring of Cetacean Distribution North-west of the Hebrides*. 75p., Hebridean Whale and Dolphin Trust, Isle of Mull, Scotland, U.K. http://www.whaledolphintrust.co.uk/cust_images/research%20publications/Cetacean-survey98.pdf

MacLeod, C. D., Hauser, N. & Peckham, H. (2004) - Diversity, relative density and structure of the cetacean community in summer months east of Great Abaco, Bahamas. *Journal of the Marine Biological Association of the UK*, 84(2):469-474 DOI: 10.1017/S0025315404009476h.

Madsen, P.T.,; Møhl, B.; Nielsen, B.K.; Wahlberg, M. (2002) - Male sperm whale behaviour during exposures to distant seismic survey pulses. *Aquatic Mammals*, 28(3):231-240. http://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/2002/AquaticMammals_28-03/28-03_Madsen.pdf

Malakoff, D. (2002) - Suit ties whale death to research cruise, *Science*, 298(5594):722-723. DOI: 10.1126/science.298.5594.722.

Mann, J. (1999) - Behavioral sampling methods for cetaceans: a review and critique. *Marine Mammal Science,* 15 (1):102-122. DOI: 10.1111/j.1748-7692.1999.tb00784.x.

Mate, B.R.; Stafford, K.M.; Ljungblad, D.K. (1994) - A change in sperm whale (*Physeter macroephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. *Journal of the Acoustical Society of America* (ISSN:0001-4966), 96(5):3268-3269, Melville, NY, U.S.A. DOI: 10.1121/1.410971.

McCauley, R.D.; Fewtrell, J.; Duncan, A.J.; Jenner, C.; Jenner, M.-N.; Penrose, J.D.; Prince, R.I.T.; Adhitya, A.; Murdoch, J.; Mccabe, K. (2000) - Marine seismic surveys: a study of environmental implications. *APPEA Journal* (ISSN: 1326-4966), 40: 692-708, Australian Petroleum Production and Exploration Association, Camberra, Australia.

Mellinger, D.K. (2004) - A comparison of methods for detecting right whale calls. *Canadian Acoustics* (ISSN: 0711-6659), 32(2):55-65, Canadian Acoustical Assocition, Toronto, Ontário, Canada.

Monteiro-Neto, C.; Ávila, F.J.C.; Alves Jr., T.T.; Araújo, D.S.; Campos, A.A.; Martins, A.M.A.; Parente, C.L.; Furtado-Neto, M.A.A.; Lien, J. (2004) - Behavioral responses of *Sotalia fluviatilis* (Cetacea, Delphinidae) to acoustic pingers, Fortaleza, Brazil. *Marine Mammal Science,* 20(1):145-151. DOI: 10.1111/j.1748-7692.2004.tb01145.x.

N.R.C (National Research Council) (2003) - *Ocean noise and marine mammals*. 204p., National Research Council of the National Academies,_Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals, Ocean Studies Board (OSB) & Earth and Life Studies (DELS), National Academies Press, Washington, DC, U.S.A. ISBN-13: 978-0309085366. http://www.nap.edu/openbook.php?record_id=10564&page=R1

Ng, S.L.; Leung, S. (2003) - Behavioral response of Indo-Pacific humpback dolphin (*Sousa chinensis*) to vessel traffic. *Marine Environmental Research*, 56(5):555–567. DOI: 10.1016/S0141-1136(03)00041-2.

Parente, C.L. (2005) - *Monitoramento de mamíferos marinhos durante estudos sísmicos no nordeste do Brasil*. 72p., Tese de Mestrado (Masters Thesis), Universidade Federal de Pernambuco, Recife, PE, Brazil.

Richardson, W.J.; Greene-Jr, C.R.; Malme, C.I.; Thomson, D.H. (1995) - *Marine Mammals and Noise*. 576p., Academic Press, San Diego, CA, U.S.A. ISBN: 0125884400.

Santos, M.C.O.; Rosso, S.; Siciliano, S.; Zerbini, A.; Zampirolli, E.; Vicente, A.; Alvarenga, F. (2000) - Behavioral observations on the marine tucuxi dolphin (*Sotalia fluviatilis*) in São Paulo estuarine waters, southeastern Brazil. *Aquatic Mammals*, 26(**3**):260-267. http://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/2000/AquaticMammals_26-03/26-03_Santos.pdf

Swartz, S.L.; Cole, T.; Mcdonald, M.A.; Hildebrand, J.A.; Oleson, E.M.; Martinez, A.; Clapham, P.J.; Barlow, J.; Jones, M. L. (2003) - Acoustic and visual survey of humpback whale (*Megaptera novaeangliae*) distribution in the eastern and southeastern Caribbean Sea. *Caribbean Journal of Science* (ISSN: 0008-6452), 39(2):195–208, College of Arts and Sciences of the University of Puerto Rico, Mayagüez, Puerto Rico.

Swartz, S.L.; Martinez, A.; Stamates, J.; Burks, C.; Mignucci-Giannoni, A. A. (2002) - *Acoustic and visual survey of cetaceans in the waters of Puerto Rico and the Virgin Islands: February-March 2001*. 62 p., volume 463 of NOAA Technical Memorandum NMFS-SEFSC, Miami, Fl, U.S.A. http://manatipr.org/wp-content/uploads/2010/01/Swartz2001NOAA.pdf

Thurman, H.V. (1997) - *Introductory oceanography*. 544p., Prentice-Hall. Englewood Cliffs, NJ, U.S.A. ISBN: 0132620723.

Wells, R.S.; Scott, M.D. (1997) - Seasonal incidence of boat strikes on bottlenose dolphins near Sarasota, Florida. *Marine Mammal Science*, 13(3):475-480. DOI: 10.1111/j.1748-7692.1997.tb00654.x.

Zerbini, A.N.; Andriolo, A.; da Rocha, J.M.; Simões-Lopes, P.C.; Siciliano, S.; Pizzorno, J.L.; Waite, J.M.; DeMaster, D.P.; Vanblaricom, G.R. (2004) - Winter distribution and abundance of humpback whales (*Megaptera novaeangliae*) off Northeastern Brazil. *Journal of the Cetacean Research and Management* (ISSN: 1561-0713), 6(1):101–107, International Whaling Commission, Cambridge, U.K.