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Effect of ship sound on the vocal behavior of dugongs

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ABSTRACT
Effects of man-made, low-frequency sounds on the behavior of the dugong are discussed in this paper. We developed a monitoring system of power-driven vessel to assess the impact of man-made noise on dugongs. Ship navigation was monitored by questionnaire for boaters and visual observations from an anchored vessel. We used automatic under water sound monitoring systems for dugongs (AUSOMS-D) to record under water sound and to track ship navigations acoustically. The visual observations were performed for a total of 10 hours and 20 minutes and 72 ships were detected. The acoustic monitoring was conducted for over 81 hours and detected 258 ships. Shortest distance between the visual-observation platform and the power-driven vessels ranged from 18 to 500 m or more. We calculated the monitoring range of the system by comparing the result of the visual observation and the acoustic survey. The system detected 51.4 % of noise-making ships within 500 meters from the observation platform, and 78.1 %, 89.5 %, and 100 % within 300, 200, and 100 meters, respectively. The ship navigation showed bimodal occurrence during 6:00-7:00 and during 15:00-17:00. We could position the sound source of ship sounds and draw the pathway of a ship by using AUSOMS-D. Based on this result, we calculated the position-fix accuracy of ship sound, which was 17.1±8.71 m. This study provided information on detailed techniques for tracking the noise-making vessels and will lead to tracking the vocalizing animal, such as the dugong.

KEYWORDS: Dugong, AUSOMS-D, man-made noise, ship monitoring system

INTRODUCTION

In Thailand there was a watercraft collision of dugong (*Dugong dugon*) (Adulyanukosol et al., 2005). Some of the stranded dugongs may have been victims of boat propeller strikes (Sigurdsson, 1990; Jaaman, 2000). Eleven dugong mortalities from boat strikes have been recorded in the Queensland Wildlife Stranding and Mortality Data Base since 1996 (Haines, 2000). In Australia based on the results from the 18 dugong stranding and mortality cases for which the cause of mortality could be identified, 88.8% of the identified sources of mortality during 2004 (n=16) were linked to human activity (Jennifer, 2004). Watercraft collisions caused 83 % of dugong deaths from all human-related causes (1986-92) and 37 % of all deaths from identified causes (Ackerman, 1995).

There are many navigating ships in the sea area where dugongs live, but there are only a few studies about the response of dugongs to ships. Anderson (Anderson, 1981) reported that relatively slow moving vessels (5–8 kn.) initiate an evasive response in dugongs at a distance of 150 m. On the other hand, there are several responses caused by navigating ships (Jennifer, 2006). A herd of dugongs detected and responded to two speedboats traveling at approximately 20 kn, from a distance of 1000 m (Preen, 1992). In another situation, Anderson (1981) was unable to detect any anticipatory or evasive action by a group of dugongs that was bisected by a fast (27 kn.) speedboat. The boat passed within 1 m of some animals, causing the experiment to be abandoned. Vincent (1996) suggested that dugongs may be avoiding boats and divers and may only be coming close to the shore to feed when the divers are absent.

There are some regulations for protecting dugongs in Australia. The Australian and Queensland governments agreed to several measures aimed at arresting the decline of dugong's population in 1997, including a resolution not to issue permits for the indigenous hunting of dugongs in the region (Marsh, 2000). Also in Japan, fishing of dugongs is quite limited by the legal structure. The dugongs are occasionally caught by nets, therefore it is necessary to enforce protection measures for them.

Preventing watercraft from running into the dugongs needs regulations on ship traffic. But it is still not clear why the collisions occur. If the reason for the collisions has not yet been cleared, it is impossible to force the fishermen or the people who work in the sea area to bear the burden. It is required to understand in detail the reaction of behavior of dugongs on ship navigations in order to effectively regulate ship navigation for the protection of dugongs and for coexistence of human and dugongs. In this study ship navigations and also dugong vocalizations were examined by acoustical analyses. Ship traffic was examined in terms of traffic density during daytime and nighttime and also the vocal response of dugongs to ship sound was examined.

MATERIALS AND METHODS

Study area

Visual observation of ships and acoustical observation was conducted by recording underwater sounds using an acoustical array which consisted of three recording systems, in the southern part of Talibong Island, Trang, Thailand (Fig. 1). In the visual observation, ships passing near the recording site were observed from 10:00 to 14:00 on 28th October, from 9:40 to 13:00 on 29th October and from 10:30 to 13:30 on 30th October 2005.

In the visual observation, ships of which distances from the observation ship were less than or equal to 500 m were observed and the time of the ship navigation, the GPS of the observation ship, distance and direction to the ship, ship type, speed, and moving direction of the ship were recorded. Distance of the ship was recorded by macrometer which could measure the distance below 500 m, and direction to the ship was measured by an electronic compass. 3 types of ships were identified; fishing boats, pleasure boats and others. Photos of the ships were taken to record the ship type. The moving direction of the ship was recorded according to the classification shown in Table 1.

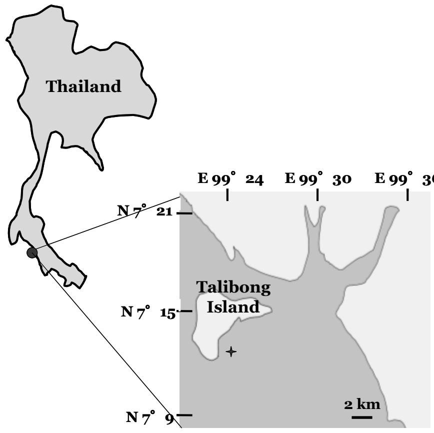

Fig. 1. The study site. Ship traffic was observed in the marked area in the map.

Equipments

The recording was made by using the automatic underwater sound monitoring systems for dugongs version 1.0, known as AUSOMS-D for short (Fig.2). The recording system was developed by System Intech Co., Ltd. around acoustical characteristics of dugong calls (Ichikawa et al. 2003).

The main features of the AUSOMS-D are stereophonic recording for over 117 hours, sampling frequency at 44.1 kHz and dynamic recording range from 74 to 120 dB with 16 bit resolution. The stereophonic recording enabled us to calculate the sound source direction by analyzing the time difference between the hydrophones.

Table 1. Classification of the moving direction of ships

Classification	Moving direction
1	Navigating for shore along coastline
2	Navigating for offshore along coastline
3	Navigating for shore
4	Navigating for offshore
5	Situated off of observation ship and navigating for shore
6	Situated off of observation ship and navigating for offshore
7	Other

Fig. 2. AUSOMS-D version 1.5.

Visual observation of ships

We conducted visual observation also in the study area during the survey period. In the visual observation, we observed ships passing near the acoustical array and wrote down the time when we found a ship, ship speed, ship type, distance and direction to the ship. We also recorded the relative position of the ship (Fig.3).

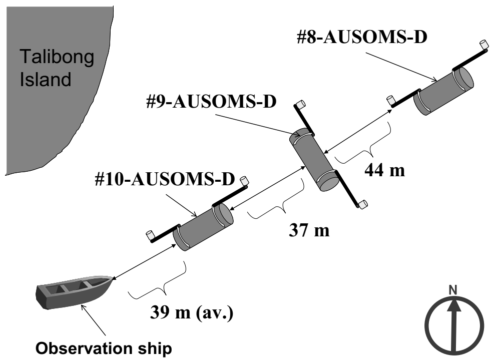

Fig. 3. We set up 3 AUSOMS-Ds as indicated in this figure. From own ship we conducted visual observation of ships.

Detecting ships by acoustical analyses

By using an acoustic filter for ship detection, we calculated the time difference, frequency and sound pressure level. Based on the continuity of the time lag, we determined the start time and the end time of ship sound. We calculated the sound source direction from the time difference.

Positioning of ship pathways by sound analyses

The sound source direction could be calculated by using acoustical data of AUSOMS-D. Time difference was converted into sound source direction using trigonometric function as Eq (4.1), (4.2). The calculation was done under the basic assumption that the sound source comes from *S* and the sound source was far away enough to identify the sound wave as plane (Fig. 4).

$$c = \frac{d \times 1000}{\max AT}, \quad (4.1)$$

$$\delta = ar\cos(\frac{ct}{d}), \quad (4.2)$$

where c is undersea sound speed, d is the distance between the stereo hydrophones (2.93 m), *maxAT* is maximum of the difference of arrival time (1.9048 ms), δ is the arrival direction of the sound source, and t is the arrival time difference.

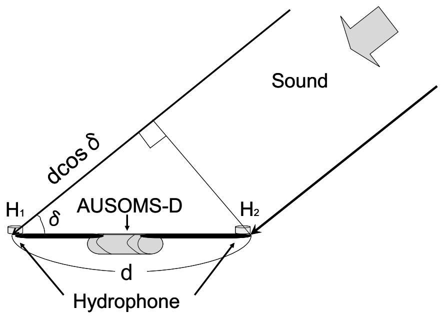

Fig. 4. Geometry of sound source localization using trigonometry. The two hydrophones are H_1 and H_2, d is the distance between the stereo hydrophones (2.93 m), *maxAT* is maximum of the difference of arrival time (1.9048 ms), and δ is the arrival direction of the sound source.

δ was converted into θ using expression (4.3). The bearing azimuth of H_1 both #8 and #10 AUSOMS-Ds was 203-degree, the direction of H_1 was 247-degree on X-Y coordinate (Fig. 5).

$$\theta = 247 \pm \delta, \quad (4.3)$$

the tangent value of θ was calculated.

The position of the sound source could be calculated by using three AUSOMS-Ds. There is one ambiguity in this method of calculation. The sound source and the mirrored image would be located at the sides of the AUSOMS-Ds array, for the arrival direction θ would be exactly the same value in each case (Fig. 6).

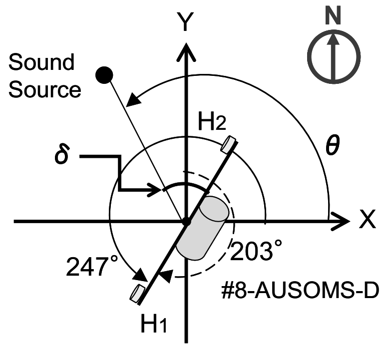

Fig. 5. Geometry of sound source direction. The two hydrophones are H_1 and H_2, θ is angle from X axis to sound source and δ is the arrival direction of the sound source. δ was converted into θ in X-Y coordinate to calculate angle of the sound source geometrically.

$$X = \frac{-\tan\theta_{10} X_{10} + Y_{10}}{\tan\theta_8 - \tan\theta_{10}}, \quad (4.4)$$

$$Y = \tan\theta_8 X, \quad (4.5)$$

where *#8 (0, 0)* and *#10* (X_{10}, Y_{10}) are the positions of #8-AUSOMS-D and #10-AUSOMS-D. The position of the sound source is *S* (X, Y) and the position of the mirrored image is *M* (X_M, Y_M). The angles of θ_8, θ_9 *and* θ_{10} are the arrival directions of the sound source at #8-AUSOMS-D, #9-AUSOMS-D and #10-AUSOMS-D, respectively. The sound source and the mirrored image are detected with two hydrophones at each of *#8 (0, 0)* and *#10* (X_{10}, Y_{10}). The correct position of the sound source was determined as *S (X, Y)* by using the angle of θ_9.

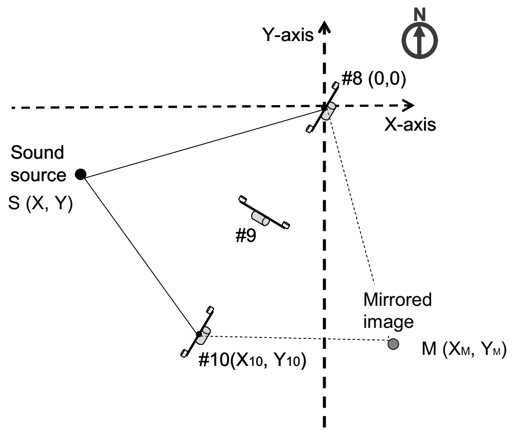

Fig. 6. Geometry of sound source and mirrored image localization. *#8 (0, 0)* and *#10* (X_{10}, Y_{10}) are the positions of #8-AUSOMS-D and #10-AUSOMS-D. The position of the sound source is *S* (X, Y) and the position of the mirrored image is *M* (X_M, Y_M). The sound source and the mirrored image are detected with two hydrophones at each of *#8 (0, 0)* and *#10* (X_{10}, Y_{10}). The correct position of the sound source was determined as *S (X, Y)* by using the angle of θ_9.

Evaluating effects of ship sound on dugong vocalization

Bottlenose dolphins in Sarasota Bay increased their whistle rate on approach by ships, and it is also known that they swim in tighter groups during approaches, much like a social defense response to predation (Kara, 2004).

To evaluate changes in dugong vocal characteristics after the ship sound, we listened to dugong calls around the ship sound. The characteristics were number of calls per minute, frequency of calls and duration of calls. Then, we counted dugong calls and recorded frequency and duration of dugong calls from 5 minutes before the ship sound to 5 minutes after ship sound. The ship sound must be separated by 5 minutes to study each case as an independent. We used the sound data of 15 ship sounds which we recorded by AUSOMS-D.

RESULTS

Visual observation of ships

In total, 72 ships were found during 10 hours and 20 minutes visual observation. Distance between ship traffic and the observation ship ranged from 18 m to 500 m. We observed only long tail boats between 10:00 – 13:00. The figure shows a typical long tail boat which had been observed the most (Fig.7).

Fig. 7. We observed only this type of ship during visual observation.

Detecting ships by acoustical analyses

We calculated the number of ships by acoustical analyses. The number of ships was 258 ships for 81 hours from 00:00 on 28th December to 09:00 on 1st November (Fig.8).

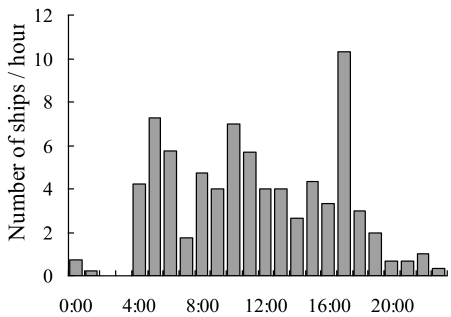

Fig. 8. Number of ships per 1 hour

We used the data of the visual observation of ships and sound data, and based on the sets of data, we calculated the monitoring range of ships by sound analyses. A ship navigation was detected when the relative sound pressure level exceeded 6 dB between 0.3-1.0 kHz range. Figure 9 shows the ship detection range of AUSOMS-D. The system detected 51.4 % of noise-making ships within 500 meters from the observation platform, and 78.1 %, 89.5 %, and 100 % within 300, 200, and 100 meters, respectively.

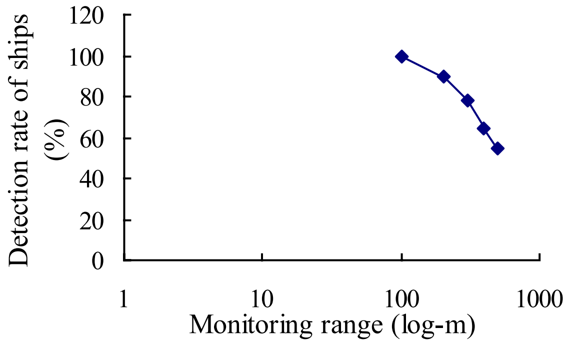

Fig. 9. This graph shows the ship detection range of AUSOMS-D. The horizontal axis is detection range. The vertical axis is the detection rate of ships.

Pathway of ship by sound analyses

We could position the sound source of ship sounds and draw the pathway of a ship by using AUSOMS-D. This graph shows the result of the positioning of sound source of a ship (Fig.10). The red line shows the GPS measurements of the ship. The blue line shows the result of the ship positioning. Based on this result, we calculated the position-fix accuracy of ship sound, which was 17.1±8.71 m.

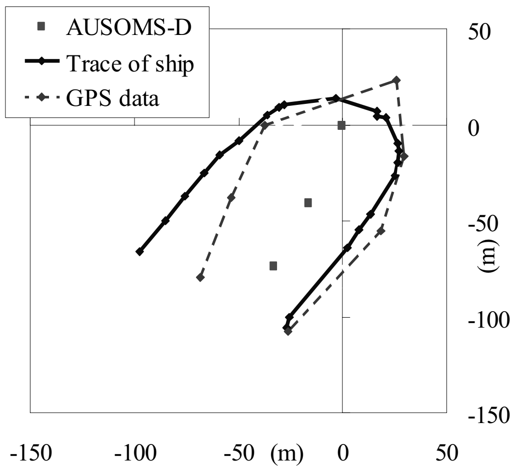

Fig. 10. This graph shows the result of the positioning of sound source of a ship. The units of both horizontal axis and vertical axis are m. The dotted line shows the GPS measurements of the ship. The solid line shows the result of the ship positioning.

Evaluating effects of ship sound on dugong vocalization

Figure 11 (a) shows the change in the number of calls per minute. Changes in call number were examined in 15 encounters of the ships and the dugongs. The number of calls per one minute decreased from 3.87 to 1.49. The decrease was observed on 9 occasions out of 15 encounters in total. There was no significant difference. The dominant frequency increased from 4080 to 5237 after the ship sound (Fig. 11 (b)). The increase was observed in 3 cases, which was 75 % of all encounters. However, we did not find any significant difference with this parameter, either. The call duration decreased from 167 to 67, which happened in all cases, although the change was not statistically significant (Fig. 11 (c)).

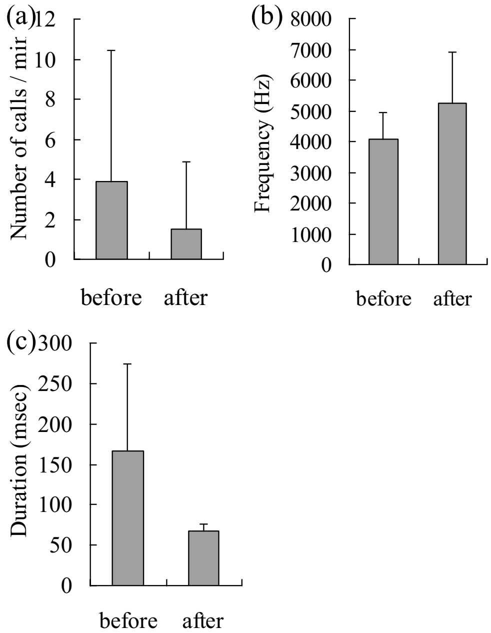

Fig. 11. (a) The number of dugong calls per 1 minute before ship sound heard and after ship sound. (b) Frequency of dugong calls before ship sound heard and after ship sound. (c) Duration of dugong calls before ship sound heard and after ship sound.

DISCUSSION

The position-fix accuracy of ship sound was calculated, which was 17.1±8.71 m as a result of comparison of the GPS measurements and localization of ship sound by acoustical observations. The position-fix accuracy of ship sound was calculated, which was 200.79±65.69 m and 31.40±21.56 ° as a result of comparison between the visual observation and localization of ship sound by acoustical observations. There were angular errors due to rolling of the observation ship and distance errors from inexperience of measurement of observation ships. As identified above, the localization by the visual observation at ship had a margin of error. Because localizing ships which navigate linearly without unexpected action had a margin of error, localizing dugongs which surface to take a breath by visual observation would have more margin of error.

The results of localizing ships by acoustical observation of which x-coordinates were positive tended to be further from the observation ship than the results of localization of ships by visual observation. But the results of localizing ships of which x-coordinate were positive by acoustical observation tended to be nearer from the observation ship than the results of localization of ships by visual observation.

Ships were detected and localized by acoustical observation. For the future, if ship navigations were to be detected by unmanned system, the location of ship navigations would be drawn by unmanned system. Now automatic detection of dugong calls was tried (Ichikawa, 2003). So by combining the automatic monitoring of ship navigations and automatic detection of dugong calls, it will be possible to take measures to protect dugongs from watercraft collisions.

In this study the change of the number of dugong calls and the change of the frequency of dugong calls after ship navigations provided an indication of the effects of ship sound. Though marine mammals show various reactions of acoustical behavior on each species (Kara, 2004), in the noisy environment during ship presence, marine mammals enhance detectability of calls in order to remain their batches i.e. a shift in frequency bands, kind and repetition of calls (Lesage, 1999) ; a shift in repetition of calls (Scarpaci, 2000; Van, 2001). However it is said that there are few occasions that dugongs form groups and there are many occasions that dugongs swim each other (Adulyanukosol, 2001). This was because dugongs did not need to raise repetition of calls and enhance detectability of calls in order to remain their batches. In this study individuals were not recognized by acoustical observation using calls, so the number of calls per min. per individual was not calculated. For the future, comparison of the change in call frequency before and after ship sound by combining visual observation and acoustical observation would be needed. This would help us understand the change of call frequency and behavior of dugongs and visual observation of dugongs and ships would help reveal reaction behavior without vocalization.

Secondly dugongs tended to raise the frequency of their calls after ship coming. The reason for this could be the dominant frequency of ships was 66.99 ± 22.70 Hz with the result that the sound source level during ships coming was more than the sound source level during ships not coming in less than 2000 Hz. So dugongs might use their high frequency calls in order to avoid overlapping of their calls and ship sounds.

Lastly dugongs showed significantly shorter call duration after one of the three ships coming. Because AUSOMS-D was the passive acoustical monitoring system and dugongs were not localized, the transmission loss was not calculated. So the correct durations of dugong calls were not to be known and it was possible that the duration of dugong calls could not provide an indication of the effects of ship sound. In order to use the duration of dugong calls as an indication of the effects of ship sound, localization of dugong calls or recording of dugong calls by placing the recording system directly against dugongs would be necessary.

Ships were detected and localized by acoustical observation. For the future monitoring ship navigations by unmanned systems would enable us to reveal reasons for watercraft collisions. Also fishermen and some state organizations could be given a factual suggestion for dugong protection. In this study ship sounds were localized, so correlation between ship sounds including ship speed, duration of ship sounds and energy of ship sounds, and the characteristics of dugong calls was investigated. The effects of ship navigations on dugongs would be investigated. Furthermore if dugong calls were to be localized, investigation would be made on the correlation between the distance of dugongs and ships and the characteristics of dugong calls, together with the distance of dugongs and ships and sound source level of ship sounds to which dugongs are exposed when the distance between dugongs and ships are shortest.

Reactions of Florida manatees which are marine mammals occurred at an average of distance of 50 ~ 60 m (Weigle, 1994). The position-fix accuracy of ship sounds more than 50 m was needed in order to evaluate the effects of ship sound on marine mammals. The position-fix accuracy of ship sound was calculated, which was 17.1±8.71 m as a result of comparing the GPS and localization of ship sound by acoustical observations. The position-fix accuracy of ship sound was calculated, which was 200.79±65.69 m as a result of comparing the visual observation and localization of ship sound by acoustical observations. Based on the above, the position-fix accuracy of ship sound by visual observations is not good enough to evaluate the effects of ships on marine mammals, and the importance of acoustical localization of ships was confirmed.

In order to achieve the co-existence of human beings and dugongs which are one of the endangered species, it is important to protect dugongs in the shallow waters where human beings and dugongs come the closest to each other. When ships are navigating, watercraft collisions occur. If the monitoring ship navigations and movements of dugongs could be conducted, watercraft collisions could be prevented. In this study, ship navigations could be detected, the peaks of the number of ships could be found, and the shipping routes could be revealed by the localization of ship navigations.

In addition, many dugong calls were recorded at night. It was possible that sea tide or time affected dugongs' behavior. If dugong behavior were to be monitored, the monitoring of ship navigations and dugong behavior could lead to the co-existence of human beings and dugongs by providing restrictions on shipping routes and fishing times, including keeping the ship traffics from the time and place of adjacent dugongs. The problems of the co-existence of human beings and dugongs will be solved by utilizing acoustical information. The monitoring ship navigations will contribute greatly to providing protection against collisions of marine lives and watercraft.

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