Dugong vocalization in relation to ambient noise

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ABSTRACT
Ocean noise has a possibility to interfere with acoustic communication of marine mammals by masking biological signals. Some species of marine mammals change their vocalization (*e.g.*, increasing amplitude, duration, repetition and shifting frequency) with elevated ambient noise level to avoid acoustic interference. We studied the dial pattern of ambient noise and dugong calls. We used the underwater sound data recorded off the south coast of Talibong Island, Trang, Thailand, by Automatic Underwater SOund Monitoring System for Dugong (AUSOMS-D). We used the data recorded from 10:00h on November 16 to 9:00h November 23, 2006. To quantify the dial pattern of the ambient noise, hourly ambient noise levels were analyzed. Then, we counted the number of dugong calls and analyzed their acoustic characteristics. Finally, we tested the relationship between the peak frequency of calls and the ambient noise level to investigate whether and how dugongs change their vocalizations. We found high ambient noise levels in the morning through noon (6:00-12:00h) and evening (18:00-21:00h). Dugongs calls were frequently observed at night as described in previous studies. Dugongs call showed the high frequency (6-9 kHz) with elevated level of the ambient noise, while they usually use 3-6 kHz call. Dugongs may adapt their vocalization in relation to the continuous ambient noise.

KEYWORDS: dugong, vocal behavior, ambient noise, AUSOMS-D

INTRODUCTION
Over the past few decades, ocean noise has drastically increased around the world (Andrew *et al.,* 2002; McDonald *et al.,* 2008). Especially in the coastal environment, the noise generated by human activities has been increased. The anthropogenic noise generated by human activities has a potential impact on the marine animals. Many animals use sound as an important information for communication, prey detection and predator avoidance. However, the noise from natural and anthropogenic sources has a possibility to interfere with the use of these signal sounds (Richardson e*t al*., 1995).

Animals use various strategies to avoid acoustic interference by noise. They sometimes change their vocalization with elevated ambient noise level. These vocal changes are represented as the increasing call amplitude, shortened or lengthened duration, repetition and shifting frequency of calls. In some marine mammals, these vocal changes have been also reported. Humpback whales (*Megaptera novaeangliae*) lengthen their song duration when they were exposed to sonar (Miller *et al.,* 2000). Killer whales (*Orcinus orca*) lengthen their call duration in noisy environment which is correlated with the number of whale watching boats (Foote *et al.,* 2004). Beluga whales (*Delphinapterus leucas*) increase the call amplitude with the presence of noise related to shipping (Scheifele *et al*., 2005). Manatee (*Trichechus manatus*) modified their vocalizations with noise in specific behavior (Miksis-Olds and Tyack, 2009). Thus marine mammals may adapt their vocalizations with environmental noise to overcome the acoustic interference.

Dugong (*Dugong dugon*) is listed as vulnerable by The World Conservation Union (IUCN). They are herbivorous mammals which live in the coastal shallow waters. Dugong and their habitat seagrass are easily influenced by human activities such as boat traffic and coastal fisheries. Human activities may lead to direct and indirect impacts to dugong. Hodgson and Marsh (2007) reported that dugong shows behavioral response to some situations of boats approaching. However acoustic impacts on dugong have been little known. We have questioned whether and how environmental noise affects the vocal behavior of dugong.

Previous studies on dugong vocalization showed that there are several types of calls (chirps, trills, and barks) in Australia and Thai population (Anderson and Barcray 1995; Ichikawa *et al*., 2003). They occasionally vocalized and their calls were detected frequently at night (Ichikawa *et al*., 2006). Captive male usually vocalize with active behavior (Hishimoto *et al.*, 2005). Sakamoto *et al.* (2006) suggested that dugong change their vocalization (higher frequency and shorter duration on calls) in response to boat noise. They focused on the vocal response against temporal anthropogenic noise. We speculate that dugong change their vocalization against continuous noisiness in their habitat. In general, environmental noise has changed during the day due to natural and anthropogenic noise sources. In our study, the dial pattern of the ambient noise and the dugong calls were analyzed. And we investigated whether and how ambient noise affects dugong vocalization.

MATERIALS AND METHODS

Acoustic data

We used underwater sound data from 10:00h November 16 to 9:00h November 23, 2006, recorded off the south coast of Talibong Island, Trang, Thailand (Fig.1). The sound data was recorded by the Automatic Underwater SOund Monitoring System for Dugong version 2.0 (AUSOMS-D, System Intec, Co. Ltd., Tokyo, Japan. Details are described in Shinke, 2007). This recording device was developed for passive acoustical monitoring of marine mammals. The sampling frequency is 44.1 kHz with a 16 bit solution. Sound data sets are stored on a removable hard disk (120 GB) in uncompressed format (.wav). The AUSOMS-D version 2.0 records continuously for 168 hours. By the acoustic observations using the AUSOMS-Ds, dugong vocalization and feeding behavior have been investigated (*e.g.*, Ichikawa *et al*., 2006; Tsutsumi *et al*., 2006).

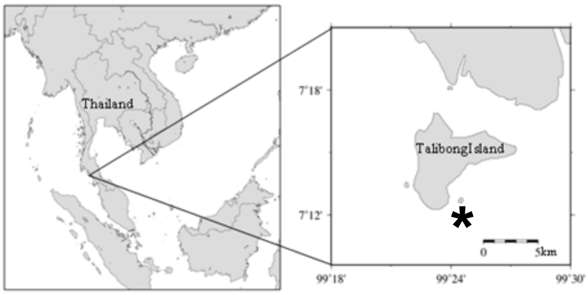

Fig. 1 Study area around the Talibong Island, Trang, Thailand. * recording site

Ambient noise analysis

Sound data for ambient noise analysis was extracted using 1min time bin per hour. If some anthropogenic sounds obviously exist in the time bin, another 1min time bin was then chosen. A Fast Fourier Transform (FFT) was performed on the time bin to obtain power spectra (1024 pt, 75% overlap, hamming window). Overall spectrum density of ambient noise were measured and compared every 3 hours. The dial change of ambient noise level was statistically tested using Kruskal-Wallis test.

Characteristics on dugong call

The first author in this paper detected dugong calls by listening and reading on spectrograms using Cool Edit Pro 2.0. The time, duration, peak frequency and received sound pressure level (SPL) on each call were noted. The number of calls was counted to determine the dial pattern of vocal activity.

Vocal correlation with ambient noise level

Dugong calls are usually represented as tonal sound and sometimes show a several harmonics structure (Fig.2). However the harmonic structure of dugong calls is still unknown. We classified the peak frequencies into five categories, <3, 3 – 6, 6 – 9, 9 – 12, and >12 kHz in convenience. We analyzed the proportion of peak frequency (3 –6, 6 – 9, and 9 – 12 kHz) with different ambient noise levels to quantify whether and how dugong change their vocalization with elevated ambient noise level. Fisher's exact test and adjusted residual analysis were used for statistic analysis.

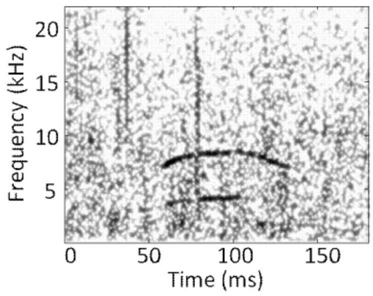

Fig. 2 Spectrogram of a dugong call

RESULTS

Dial pattern of ambient noise levels

Hourly ambient noise levels ranges from 72.5 to 77.9 dB (n = 159, average level 75.9 ± 0.72 dB). Ambient noise levels were significantly different during the day (χ^2 = 27.4, df = 6, p <0.001, Fig.3). The noise levels between 3:00 – 6:00h and 18:00 – 21:00h were significantly different.

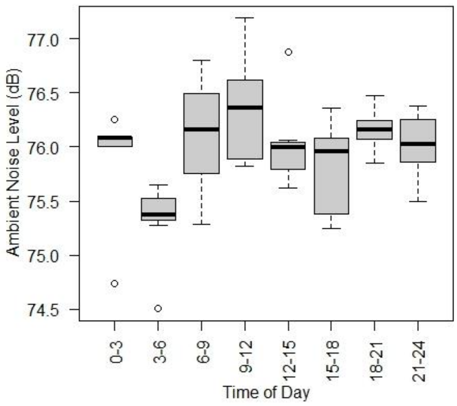

Fig.3 Ambient noise levels with overall frequency bands every 3 hours

For the frequency spectra of ambient noise, low-mid frequencies are much different between the calm and the loud hours (Fig.4). Boat noise spanned a wide range of frequencies, especially dominating at low frequency.

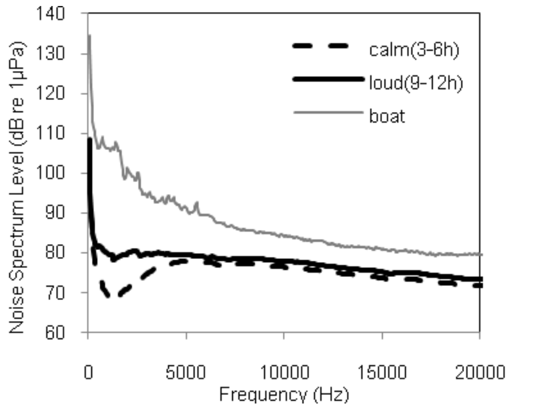

Fig. 4 Frequency spectra of ambient noise (calm and loud hours) and a boat noise

Dial pattern of dugong vocal activity

Approximately 160 hours of sound data, a total of 13,939 dugong calls were detected. We selected the calls which had high signal to noise ratio over 85 dB in received SPL (n = 8431). The calls were roughly categorized into two types; short- and long-duration calls as described in Ichikawa *et al.* (2003). Short-duration calls, which are defined as <300 ms in duration, were mainly detected in our data (96.5%, 8193 calls). In this study, we analyzed only short-duration calls to remove ambiguity depending on the functional difference of call types. The average numbers of calls were variously different during the day, but not significant (χ^2 = 11.92, df = 7, p = 0.102, Fig.5). Calls were detected frequently at night.

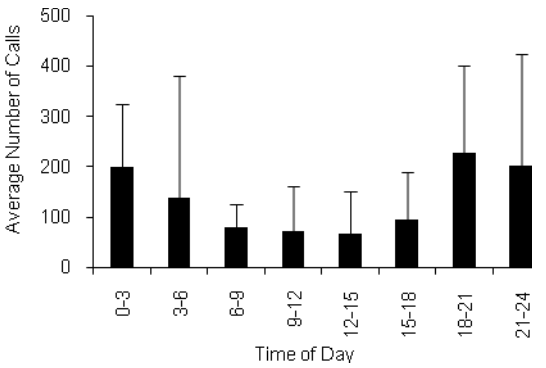

Fig. 5 The number of dugong calls (n = 8193)

Call frequency vs. ambient noise level

The peak frequency of dugong calls ranged from 1-16 kHz. The 3-6 kHz call dominated in all the calls (64 %, 5387calls). Based on the histogram of hourly ambient noise levels, we classified them into 4 categories for convenience: <75, <76, <77, and <78 dB (n = 7, 55, 47, and 9, respectively). The proportion of peak frequency showed a significant difference with ambient noise level (χ^2 = 27.892, df = 9, p <0.001, Fig.6). At the highest ambient noise levels < 78 dB, the proportion of 6 – 9 kHz call was increased significantly, while that of 3 – 6 kHz frequency call was decreased (p <0.01). We compared the signal to noise ratio (SNR) between the low and high ambient noise levels (Fig.7). SNR tended to be higher in higher call frequency. And at the high ambient noise <78 dB, SNR of 3 – 6 kHz was significantly low (t = 1.65, df = 289, p <0.001)

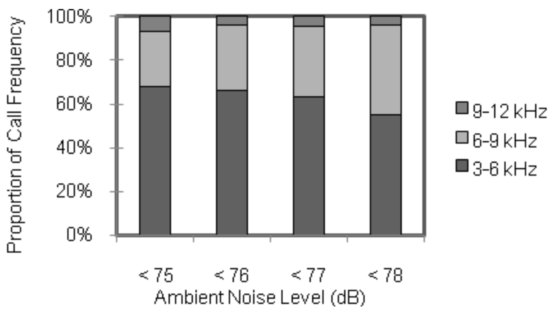

Fig. 6 Proportion of call frequencies with ambient noise levels (n = 118)

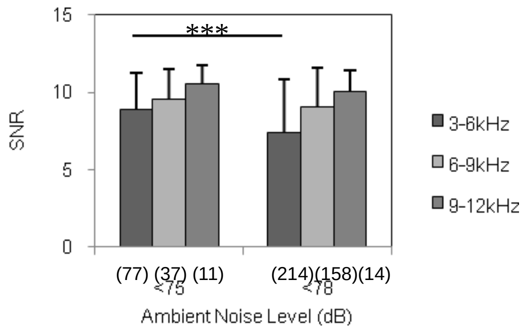

Fig. 7 Signal to noise ratio (SNR) in each frequency with different ambient noise levels, <75 dB and <78 dB. Each sample sizes are in parentheses. ** p <0.001

DISCUSSION

Ambient noise levels were high in the daytime. They were lowest at 3:00 – 6:00h and gradually increased at 6:00 – 12:00h. Many boat noises were recorded especially in the morning in our acoustic data (unpublished data). In fact, small-scale fishery boats had passed frequently at certain hours in the recording site. This boat traffic would contribute to ambient noise levels at the local scale. Biological sound generated by snapping shrimp contains broad-band frequencies, it may also contribute to the ambient noise level. To define what sound sources contribute to the ambient noise, we need further spectrum analysis in various frequency ranges.

We compared the proportion of peak

frequency among the different ambient noise levels. The short-duration calls of dugong usually represented as 3 – 6 kHz tonal calls. Our results showed that the proportion of 6 – 9 kHz calls increased with the highest ambient noise. Some possible explanations are: 1) dugong changed call frequency, 2) harmonic structure of the dugong calls were recorded because a) dugong increased call amplitude or b) the dugongs vocalized closer to the recorder, 3) other dugongs vocalized, and 4) change of physical environment.

In the first case, dugongs may shift the calls with higher frequency to avoid acoustic interference by overlapped noise. As show in fig.7, SNR of higher frequency would be better to detect calls in the noisy environment. The high frequency component of the harmonic structure of the dugong calls usually attenuates greater than the fundamental component. In the second case, the harmonic structures might have been observed more clearly as the result of increasing the sound level of call. Sound level of calls were increased in higher ambient noise level (unpublished data), though it is unknown whether dugong increased the source level of call or vocalized more close to the recording device. Anyway if dugongs use the vocal strategies mentioned above, it requires more energy than the usual condition. It may affect negatively the individual physiology and population level in future. In the third case, the results might depend on individual vocal characteristics. It is difficult to distinguish the individual calls when two or more dugongs vocalize. In the last case, call characteristics might be affected by physical environment such as water depth. Sound propagation in shallow water is complicated. To clarify our uncertainness, acoustic study including applying a recording tag on the animal will be desirable.

In future works, we need further understanding not only the acoustic characteristics of ambient noise but also the substantial human activities in the local region. For example, the number of boats may relate to the fishery activities. Acoustic characteristics of ambient noise would be an important parameter for environmental noise assessment. Information about noise occurrence would contribute to the conservation and management plans of dugongs and their environment.

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