Clumped distribution of vocalising dugongs (*Dugong dugon*) monitored by passive acoustic and visual observations in Thai waters

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ABSTRACT

Distribution pattern of dugongs is a key component for space-based managements. Vocal interaction of dugongs may result in a distinctive distribution pattern. This study described the distribution patterns of vocalising dugongs, solitary and cow-calf pairs of dugongs. Total of 31 hours and 24 minutes of aerial surveys over southern Thai waters were conducted to observe distribution of the dugongs in 2006, 2008 and 2010. We also conducted towed acoustic surveys to observe the distribution of vocalising dugongs. Total of 473 adult dugongs and 122 calves and 223 vocalizations were found. The distribution of vocalising dugongs was clumped with the range of about 1 km^2. Groups with cow-calf pairs (9 animals on average) were also clumped. Their distribution range was about 3 km^2 and did not overlap that of vocalising dugongs. Average number of individuals in groups without cow-calf pairs was about 1, indicating that the most of the group members were solitary. They distributed widely throughout the focal area with the distribution range of about 41 km^2.

INTRODUCTION

The dugong, *Dugong dugon*, is one of four extant species in the mammalian order Sirenia, all of which are aquatic herbivores (e.g. Marsh et al. 2002 among many others). Over much of their range, dugongs are believed to be represented by separate, relict populations, many close to extinction or extinct (Marsh et al. 2002). World Conservation Union (IUCN) ranked this species as vulnerable to extinction in the Red List criteria and trade in products is regulated or banned by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES appendix I).

Distribution pattern of such highly social animal as dugongs is a key component for space-based managements. Different social behaviours affect their distribution patterns, because there is evidence that dugongs use specialised habitats for various activities. Shallow waters, such as on tidal sandbanks (Marsh et al., 1984), and shallow channel between an island and mainland (Adulyanukosol et al., 2007) have been reported as sites for calving. Mating behaviour was also observed by Adulyanukosol et al. (2007) in a shallow channel (2-3 m deep at high tides) between an island and mainland. Lanyon (2003) found that solitary dugongs use the same locations repeatedly, indicating different distribution pattern as compared to that of calving herds.

Acoustic signals produced by dugongs are used for interindividual acoustic communication (Ichikawa et al., 2011). Dugong vocalizations were roughly classified into three types: Chirps, trills and barks by Anderson and Barclay (1995). Chirps are frequency-modulated signals in the 3 to 18 kHz range lasting ca. 60 ms. Trills last as long as 2,200 ms, are frequency-modulated over a bandwidth of 740 Hz within the 3 – 18 kHz band, and have two to more harmonics. Barks are broadband signals of 500 to 2,200 Hz lasting 30- 120 ms with up to five harmonics. Frequency modulation of chirps suggested a ranging function. Trills were more appropriate for affiliative function and barks for aggressive behavior (Anderson and Barclay 1995). We applied the passive acoustic observation to study dugong behaviour in Thai waters. Previous surveys using automatic underwater sound monitoring systems for dugongs (AUSOMS-D for short) showed that dugong calls in southern Thailand have been roughly categorized into short-duration and long-duration calls (Fig. 1, Ichikawa et al., 2003). Short duration calls, referred to as chirps, have a mean frequency of 4521 ± 1615 Hz and a mean duration of 126 ± 87 ms (n = 704). Long-duration calls, which seem to correspond to the trills in the study by Anderson and Barclay (1995), are characterized by a frequency of 4152 ± 1111 Hz and a duration of 1737 ± 1049 ms (n = 74) (Ichikawa et al., 2003). Chirps are the calls detected most frequently both in the wild population and between two captive individuals maintained at the Toba Aquarium in Japan. They account for approximately 90% of all calls recorded in previous surveys (Ichikawa et al., 2003, 2006, 2011; Okumura et al., 2007; Hishimoto et al., 2005). Barks as described in Anderson and Barclay (1995) had not been identified in the recordings from Thai waters. Passive acoustic observations performed using the AUSOMS-Ds revealed that the vocal activities of the dugongs showed circadian and/or circatidal rhythms (Ichikawa et al., 2006).

Although there are some previous reports on the dugong vocalizations, no research has succeeded in examining spatial distribution of vocalising dugongs. It is particularly important to examine and compare the distribution between social groups, because different social acitivities may result in different distribution patterns. In this study, social groups of the dugongs is categorized into 1) calving herds, 2) non-calvinjg herds (includes solitary dugongs) and 3) vocalising dugngs (includes both 1 and 2). Then the distribution pattern of each of the social group is compared.

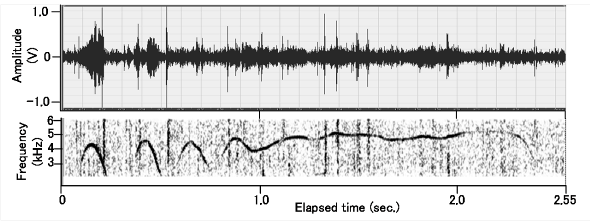

Fig. 1. A sonogram (bottom inset) and a waveform (upper inset) of typical dugong calls, including three chirp calls and a trill call, recorded in the study area. Chirp calls were the most frequent vocalization in the study area.

MATERIALS AND METHODS

Study site

A series of aerial surveys and towed acoustic surveys were conducted around Talibong Island, Thailand (N 07°13', E 99°24'; Fig. 2) in 2006, 2008 and 2010. Previous surveys estimated a population of 120 dugongs in the focal area, which accounts for 60 % of the total estimation of 200 individuals in Thailand (Adulyanukosol 1999; Hines et al., 2005). Most dugongs are sighted in or around seagrass beds (Nakanishi et al., 2005; Hines et al., 2005).Calving and mating activities are frequently seen around the Talibong Island (Adulyanukosol et al., 2007).

Aerial survey

Total of 31 hours and 24 minutes of aerial surveys using a microlite over Talibong Island were conducted to observe distribution of the dugongs from November 15 to 23, 2006, January 13 to 15, 2008 and on January 21, 2010 (Table 1). The microlite took off from and landed on Chao Mai Beach nearby the focal area. The survey crew comprised the pilot and an observer. The aircraft was flown at an altitude of 212 m on average at an average ground speed of 83.25 km/h (45 knots), starting from 1 to 1.5 hours prior to the high tide. The high tide was determined based on tide tables published by Hydrographic Department, Royal Thai Navy). Average flight time was 2 hours and 45 minutes. We followed the same survey methods as described in Hines et al. (2005) and used transect surveys to record locations of dugongs in the focal area. The transect lines were perpendicular to the shoreline and parallel to each other with about 1-km separation. Precise navigation along transects was achieved with Global Positioning System (GPS; GPS 76s, Gamin, USA) in combination with visual navigation using fixed landmarks. Latitude and longitude of all dugong sighting along with the flight paths were recorded using GPS. The observer recorded the time, group size, number of calves, weather, tidal level and Beaufort sea state. Body lengths of adult dugongs and calves are about 3 m and less than 1.5 m, respectively (Adulyanukosol et al., 2007). According to this report, a calf was discriminated by its body length.

Towed acoustic survey

Dugong vocalizations have been captured mostly around Talibong Island (Ichikawa et al., 2009). The flat sea floor (mean depth, 4.82 ± 0.09 m) and a mixed-layer profile of the water column (mean water temperature, 29.2 ± 0.1^{o}C) suggested a uniform propagation horizontally in any direction from the sound source. Details of the towed acoustic survey are also described in Ichikawa et al. (2009).

A towed stereo hydrophone system (Towed Aquafeeler, System Intech Co.Ltd., Japan) was operated from January 11 to 23, 2008. We operated a wooden boat (11.3 m in length and 2.4 m in width) for daily trips around the focal area. The distance of this trip was 60 km, and took 6 hours a day at a towing speed of 10 km/h. The cruise lines from north to south were separated by approximately 1 km in order to cover a wider range of the focal area, specifically inshore and offshore lines. Each day, we randomly selected either an inshore or offshore line to begin surveys.

The Towed Aquafeeler consisted of a 10 m draw, a 4 m flexible polyvinyl chloride rubber tube with two hydrophone elements (100 Hz～100 kHz) inside, a 60 m towed electric cable, a receiving unit, and a 2-channel conditioning amplifier. The towed cable eliminated interfering noise from the towing boat. The cable had a neutral buoyancy that enabled towing even in shallow waters of 1 m depth, which is close to the minimum depth of 0.8 m that dugong forage in (Tsutsumi et al., 2006). The stereo hydrophone (two hydrophone elements) was separated by 2 m from the preamplifier near the hydrophone element. The receiving sensitivity of the hydrophone was -193 dB (re 1 V/μPa). The amplifier had a variable high-pass filter (cut-off frequencies of 200 Hz, 1 kHz, 4 kHz). In the present study, we selected a 1 kHz high-pass filter to eliminate flow noise interference. Stereo signals were recorded using a hard disk recorder (R-4 pro, Roland, Japan).

Two experienced audio listeners (TA and TS, authors of this paper) monitored underwater sounds using headphones (MDR-Z600, SONY, Japan). These listeners had experience in listening to several dozen hours of recorded sounds and identifying dugong vocalizations. The two listeners took turns listening, alternating every 30 minutes. The time at which dugong calls were received, with a one second resolution, was recorded by the listener. Two successive chirps or one long trill over a one second period were defined as a detection, and if these sounds were not heard, no record was made. Automatic track logging of the GPS was used to assess the location with respect to the detection time. Underwater sounds were amplified to a volume that prevented the listener from hearing the voice of the other observers on board. Onboard detections were confirmed by off-line listening. TA checked the recording of each detection with Cool Edit Pro software (Syntrillium Software Corp., AZ., USA) by listening to the sound and looking at the sonogram to exclude false positive detections. The detection threshold level was 90 dB rms re 1 μPa using a 1024-point fast Fourier transform. Source level of the dugong vocalizations are estimated to be approximately 134 to 138 dB using spherical spreading model assumption for the transmission loss (Ichikawa 2007; Ichikawa et al., 2011). Given the mode of the source level of dugong calls and the detection threshold level, the acoustic detection range was calculated to be 251.2 m.

Data analysis

Minimum convex polygon (50%, 75 % and 100%) and each area were calculated by using MATLAB to determine range of distribution to compare the distribution patterns among calving herds, non-calving herds and vocalising dugongs. The area of 75% convex polygon was taken as the distribution range. We segmented the surveyed area by 200-m sample blocks along the transect lines, and tallied both acoustic and visual detections for each block. Then, an analysis of dispersion using an I_δ-index was performed to examine the spatial distribution of dugong sightings. The I_δ-index was proposed by Morisita (1962) as an index for measuring dispersion of individuals within a population. The statistical significance of the index value was tested by F (b-1,∞; 0.01). The index value and F value for a given group of N individuals was computed as equation (1) and (2):

$$I_\delta = x_i (x_i - 1) / N (N - 1); \text{ and} \quad (1)$$

$$F = (I_\delta (N - 1) + b - N) / (b - 1), \quad (2)$$

where x_i is the number of individuals in the i-th sample block of the total b blocks (i=1,2,3,4,…,b). If the index is greater (smaller) than 1, then the distribution is clumped (uniform). An index equal to 1 indicates a random distribution. All of averages are provided with standard deviation.

RESULTS

Aerial survey

Total of 31 hours and 24 minutes of aerial surveys over Talibong Island were conducted and 473 adult dugongs and 111 calves were found during the flights. Average number of individuals in calving herds was 8.76 ± 11.10 (adult dugong: n = 318, calf: n = 111). Their distribution were clumped (I_δ = 6.41, F = 50.95, p < 0.01) off north-east of Talibong Island-with a range of about 3.40 km^2. Non-calving herds were mostly consisted of solitary dugongs (n = 107, 69 % of total 155 individuals) with average number of individuals of 1.21 ± 0.56 (n = 155). They distributed widely throughout the focal area (I_δ = 1.06, F = 1.07, No significance) with the distribution range of about 40.80 km^2 (Fig. 2).

Towed acoustic survey

Total of 120 hours of acoustic observation around Talibong Island were conducted and 223 vocalizations in 44 locations were detected. The distribution of vocalizing dugongs were clumped (I_δ = 14.69, F = 17.66, p < 0.01) off south-east of Talibong Island with the range of about 1.10 km2 and did not overlap that of calving herds (Fig. 2).

Table 1. Number of individuals found in the aerial surveys

		Number of individuals within herds		
		With calves		Without calves
Year	Date	Adult	Calves	Adult
2006	November 15-23	285	99	134
2008	January 13-15	4	3	25
2010	January 21	6	4	32

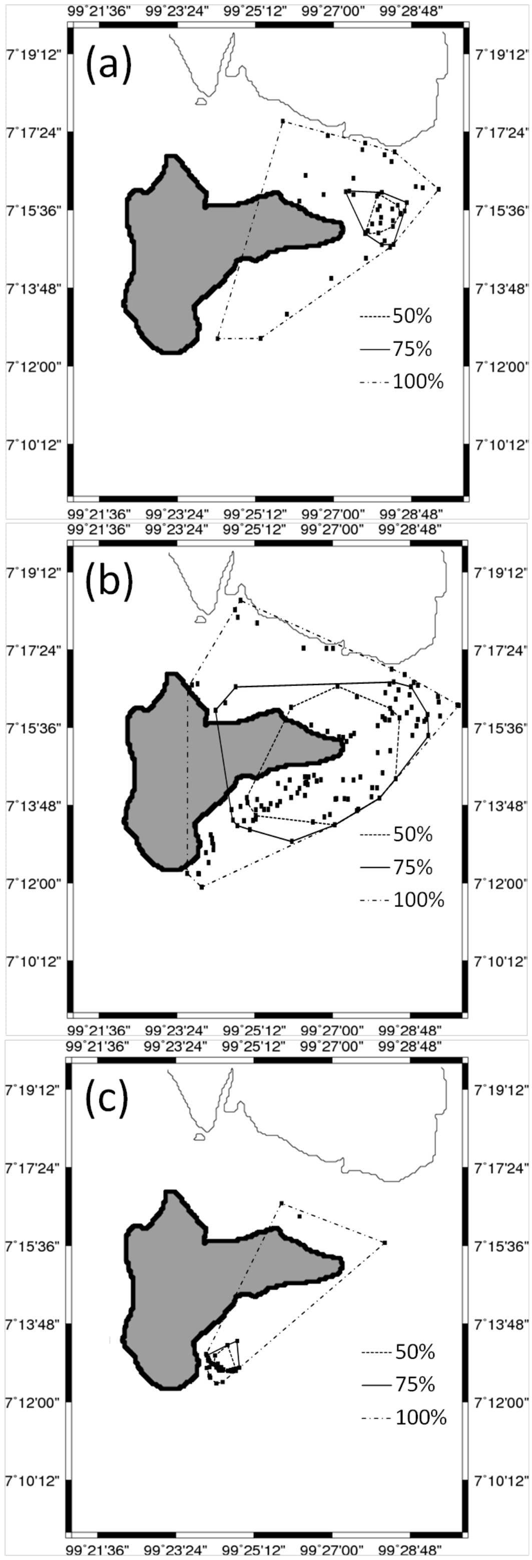

Fig. 2. Distribution patterns of (a) calving herds, (b) non-calving herds, (c) vocalizaing dugongs. The distribution of calving herds and vocalizing dugongs were clumped off Talibong Island while the non-calving herds (most of them were solitary) ranged randomly throughout the focal area. The distribution range (75% minimum convex polygon) of the vocalizing dugongs was mainly used by non-calving herds.

CONCLUSION AND DISCUSSION

Distinctive differences in the distribution patterns were found between calving herds, non-calving herds and vocalizing dugongs. The clumped distribution of vocalizing dugongs (vocal hotspot) was also determined by Ichikawa et al. (2009) using the dame data set. The vocal hotspot was mostly used by non-calving herds. This suggest that non-calving herds are more acoustically active compared to calving herds. Dugongs have strong cohesion between mother and its calf, with rearing period of about 18 months (Marsh et al., 2002). Vocal signals often facilitate the group cohesion as observed in Amazonian manatees (Sousa-Lima et al., 2002) and Florida manatees (O'Shea and Poché Jr. 2006). Mother and calf pairs of the dugongs may not use their vocalization to maintain cohesion.

This study demonstrated that distribution of calving herds is clumped within a small area. Because of a low reproduction rate, long generation time and high investment in each offspring, the population fluctuation is most sensitive to survivorship of calving adults (as described in Marsh et al., 2002). Such information on the calving hotspot contributes to effective management of space-based protection and conservation of dugongs.

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