Monitoring dugong feeding behavior in a tidal flat by visual and acoustic observation

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ABSTRACT
Dugongs (*Dugong dugon*) are herbivorous marine mammals and an endangered species. Unfortunately, the lack of basic research especially on the use of seagrass patches by dugongs prevents us from taking any effective countermeasures for their conservation. In this study, to monitor the feeding behavior of dugongs in the seagrass bed of a tidal flat, we conducted automatic visual observation and passive acoustic observation using a digital camera and automatic underwater sound monitoring systems for Dugong (AUSOMS-D). These observation methods were tested around Talibong Island, Trang Province, Thailand. The increase in the number of dugong feeding trails was observed by the automatic visual observation. Dugong feeding sounds were observed by the passive acoustic observation. In this study, the term of dugongs feeding in this site was identified by automatic visual observation, and in addition, the time of dugongs feeding in this site was identified by the passive acoustic observation. Therefore, we propose to combine these two observations. The visual-acoustic combined observation method is effective in monitoring feeding behavior of dugongs. This method has technical benefits with no impact on either the dugongs or the seagrass beds.

KEYWORDS: Dugong, automatic visual observation, passive acoustic observation, digital camera, AUSOMS-D,

INTRODUCTION

Dugongs (*Dugong dugon*) are herbivorous marine mammal which are distributed in the tropical and subtropical shallow waters of the Indian and Pacific Oceans. The main Okinawa Island in Japan is the northern limit of the range of dugongs in the world. The World Conservation Union (IUCN) ranked this species as vulnerable to extinction in the Red List. The dugongs are also listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). The dugong population in Japan is classified as Critically Endangered, in that the number of mature individuals is less than 50, by the Mammalogical Society of Japan (1997). Threats to dugongs include by-catch, habitat loss and degradation, hunting, strikes and acoustic disturbances by vessels, and so on. In particular, the dugong mortality by incidental catch in fisheries is a major in many countries (Marsh *et al.*, 2002). Sixteen dead dugongs have been formally recorded in Japan in the past 30 years (Marsh *et al.*, 2002). Six of these dugongs were killed in trap nets, three in gill nets, one in an unspecified fishery, and six were found on the beach (Marsh *et al.*, 2002). Because the dugong population of Japan is in danger of extermination, this number of dead dugongs is extensive.

Dugongs are vulnerable to anthropogenic influences because of their life history and their dependence on seagrasses that are restricted to coastal habitats, and which are often under pressure from human activities (Marsh *et al.*, 2002). Co-existence of human beings and dugongs is currently considered to be a very important issue. Unfortunately, the lack of basic knowledge about dugongs prevents us from taking any effective countermeasures for their conservation. In particular, dugong feeding behavior is the key information to be accumulated in order to actualize the co-existence in the shallow waters where local people live on the coastal fisheries. Conventional studies on dugong feeding behavior were mainly conducted by observation of dugong feeding trails by eye sight. These studies have contributed to clarify dugong feeding behavior (Mukai *et al.*, 2000; De Iongh *et al.*, 1995, 1997). However, this method has serious problems. Firstly, this method needs a large amount of labor at frequent intervals. The observations have to be conducted over long intervals and the frequent observation has an adverse effect to the seagrass beds.

Secondly, it is difficult to observe dugong feeding trails by eye sight in night time.

Acoustic observation is an effective method to detect the animal under water. The acoustic observation has several advantages compared with visual observation. The acoustic observation can operate automatically and carry out constant detection efficiency. Although the visual observation in night time is difficult, the acoustic observation enables a day and night operation. Ichikawa *et al.* (2005) first tried to establish a monitoring method for dugong by applying the passive acoustic observation. An underwater sound monitoring system for dugong (AUSOMS-D) was developed for this research by System Intech Co., Ltd (Shinke *et al.*, 2004). From this research, this monitoring method is a powerful technique for the behavioral observation of dugongs.

The objective of this study is to establish observation methodology for the monitoring of dugong feeding behavior. Our study was conducted in the tidal flat's seagrass beds. We conducted automatic visual observation and passive acoustic observation. In automatic visual observation, we set up digital cameras at 5 m above the level of the sea, and conducted interval photography. Such observation can monitor at frequent intervals with little labor and minimum impact to the seagrass bed. However, this observation has one problem in that it can not monitor at night time. To solve the problem, we set up an AUSOMS-D on the sea floor in seagrass beds to perform a passive acoustic observation. This observation has the purpose to record dugong feeding sounds. Dugong feeding sounds are direct evidence of dugong feeding so that the monitoring of the feeding sounds will contribute greatly to clarify dugongs feeding behavior. This observation can be conducted in day and night.

MATERIALS AND METHODS

1. *Study site*

We decided on a study site on seagrass beds off Talibong Island, Trang Province, Thailand (longitude: N07^{o}13.970' latitude: E99^{o}26.799', Fig. 1), where many dugongs have been sighted. We conducted the survey from February 21 to March 4 in 2005. A seagrass bed off Talibong Island is one of the largest seagrass beds with the highest species diversity in Thailand. In particular, in the southeast of Talibong Island, seagrass beds were distributed continuously up to around 3 km offshore (Nakanishi *et al.*, 2005). Ten species of seagrasses were identified around Talibong Island (Nakanishi *et al.*, 2005).

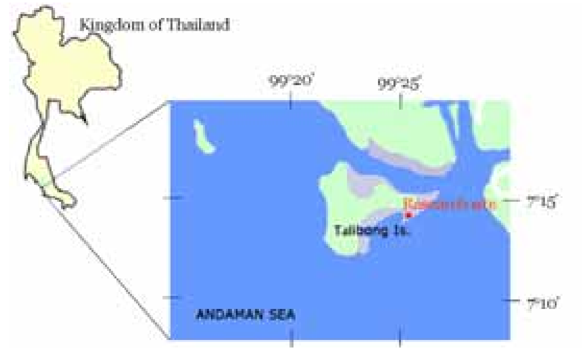

Fig. 1. Study site. Shaded area shows the seagrass beds in tidal flats.

2. *Automatic visual observation*

In automatic visual observation, we used a digital camera (Canon Power Shot S60). The camera has a function for interval photography. The interval can be set from one minute up to 60 minutes. In this survey, we had to change the battery and the memory of the digital camera at low tide in daytime every day because these had limited capacity. This observation was conducted during daytime every day. For these reasons, the following intervals were set (Table 1).

Table 1. Photographing time, photographing interval and the number of photographs in visual observation.

Date (2005/day/month)	22/2	23/2	24/2	25/2	27/2	28/2	1/3	2/3	3/3
Starting time	16:33	6:33	6:22	7:46	9:22	8:31	8:41	9:10	8:24
Ending time	18:39	18:42	15:42	17:34	18:52	18:19	18:29	18:46	18:12
Interval (min)	14	14	14	6	6	6	6	6	6
Number of photos	10	49	41	99	96	99	99	98	99

The digital image had 2592 pixels x 1944 pixels. We fixed the camera on the top of an iron pipe installed at the seafloor. The height of the camera was about 5m with a simple framework and with adequate strength and stability (Fig 2a, b).

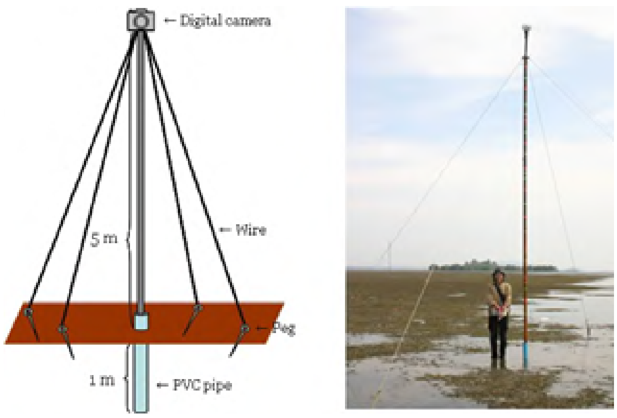

Fig. 2. (a) The design of the installed base, (b) The installed base in research site

Considering the height of the camera (5 m) and field angle of the camera (65.5^{o}), we set the photography area 30 m x 50 m and 9 m away from the installed base to omit dead areas. This observation was performed only in daytime because the flash could not cover the whole survey area in night time. The installed base was set up in Site A where the dominant species was *Halophila ovalis* (Fig. 3).

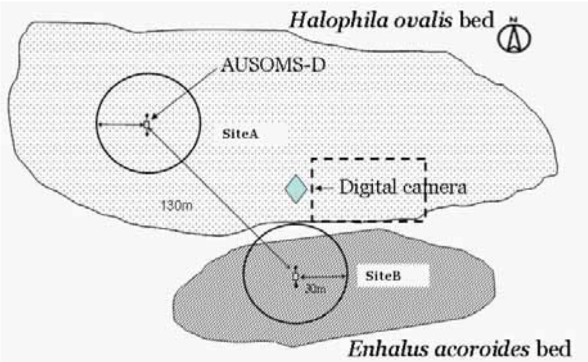

Fig. 3. Map of research sites near Talibong Island, Trang Province, Thailand. The dotted area shows site A (dominant species: Halophila ovalis); the shaded area shows site B (dominant species: Enhalus acoroides). The square enclosed with a dotted line is the area of photography and seagrass survey (30 m x 50 m).

3. *Passive acoustic observation*

For initial assessment of dugong feeding sounds, we recorded the underwater feeding sounds of a captive male dugong at Toba Aquarium, Toba City, Mie Prefecture, Japan (Fig. 4). The dugong fed every day on whole eelgrass (*Zostera marina*) anchored in a net plate. A hydrophone (ST 1020; Oki Electric Industry Co., Tokyo Japan) was suspended in the tank at a depth of 1 m. During feeding, sounds were recorded by a digital audio tape recorder (TCD-D8; Sony Corp., Tokyo, Japan). The mouth movement of the feeding dugong was recorded by a camcorder simultaneously. Later, mouth movements and recorded sounds were compared to ensure that the sounds corresponded to the feeding events.

We conducted a passive acoustic survey in two seagrass grounds off Talibong Island, Trang Province, Thailand. We selected a tidal flat dominated by *H. ovalis* as site A and a site dominated by *E. acoroides* as site B (Fig. 3). We deployed the AUSOMS-D Ver.1.5 at site A on 21-22 February (Fig. 5). We then moved the AUSOMS-D to the *E. acoroides* site B on 22 February and performed recording experiments until 4 March. On 26 February, we recovered the AUSOMS-D to change the battery cells and to carry out maintenance. The AUSOMS-D consists of a set of hydrophones, which are set 2 m apart from each other and housed in a pressure tight case. The sampling frequency was 44.1 kHz, and the dynamic range was 74-140 dB (re: 1 µ Pa) with a 16-bit resolution. The device also had an 80-GB hard disk and could be operated up to 124 hours.

↑ *Fig.4* ↑ *Fig.5*

Fig. 4. A male dugong in Toba aquarium
Fig. 5. AUSOMS-D Ver.1.5

3. *Seagrass observation*

The seagrass survey area was the same as the photography area (rectangular land with 30 m length and 50 m breadth, Fig. 3). We conducted this survey on February 23 and March 3, 2005. On February 23, we observed the seagrass species composition and coverage, and mapped dugong feeding trails, and measured length and width of the trails. On March 3, we mapped the increased dugong feeding trails, and measured length and width of the trails. We observed the seagrass species composition and coverage in 9 stations of the survey area (Fig. 6). In each station, we randomly selected a 50 cm x 50 cm quadrant, and we observed the seagrass species composition and coverage (0-100%). We delimited the survey area every 5 m x 5 m, and conducted the mapping using two observers.

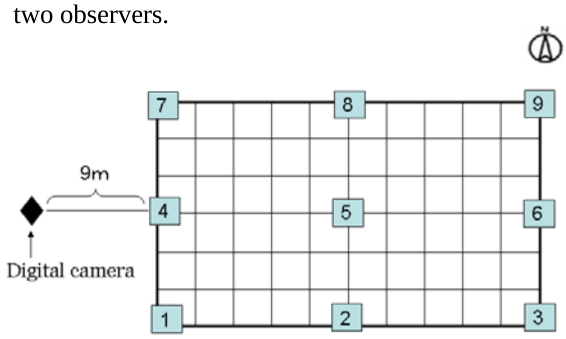

Fig. 6. The observation stations of the seagrass species composition and coverage

RESULTS

1. *Automatic visual observation*

In total, 690 photos were taken by the digital camera (Table 1). Comparing these photos in time-series order did not indicate the appearance of dugongs in survey area. However, when we compared the photo taken at 6:19 pm on February 28 with the photo taken at 8:41 am on March 1, we found two new dugong feeding trails (Fig. 7). The former time was the ending time of the observation on February 28, and the later time was the starting time of the observation on March 1.

Fig. 7. New dugong feeding trails (white arrow). The photo taken by the camera at 8:41am of March 1 was zoomed in.

2. *Passive acoustic observation*

In total, 237.5 hours of data were recorded at the study site. Only data collected when the AUSOMS-D was submerged were used for analysis to exclude wave noises at low tide. After excluding this data, 205 hours of effective recordings remained for analysis. The feeding sounds were categorized into two types: tearing and mastication sounds (Fig. 8). Tearing was characterized by pulse sounds. Mastication was characterized by wideband and fricative sounds. The feeding sounds began with several successive tearing sounds followed by mastication sounds. In many cases, only mastication sounds could be heard. In total, 175 feeding sounds events were identified. The sound characteristics of potential tearing and mastication sounds recorded in the wild were similar to the feeding sounds observed in captivity.

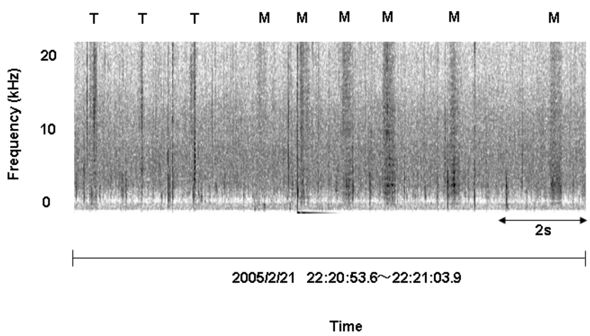

Fig. 8. Sonogram of a typical sequence of dugong feeding sounds. T indicates tearing sounds, and M indicates mastication sounds.

The occurrence frequencies of sound intervals for mastication were compared for wild and captive recordings. The most frequent interval of mastication sounds was 0.9 s (S.D. =0.35) in the wild and 0.8 s (S.D. =0.08) in captivity, respectively. Irregular sound intervals were observed in 8 events. Figure 9a shows the time interval sequence of mastication sounds. This figure was divided into two separate periodical interval sequences (Fig. 9b, c). The average interval of each sequence was 0.8 and 0.9 s, respectively.

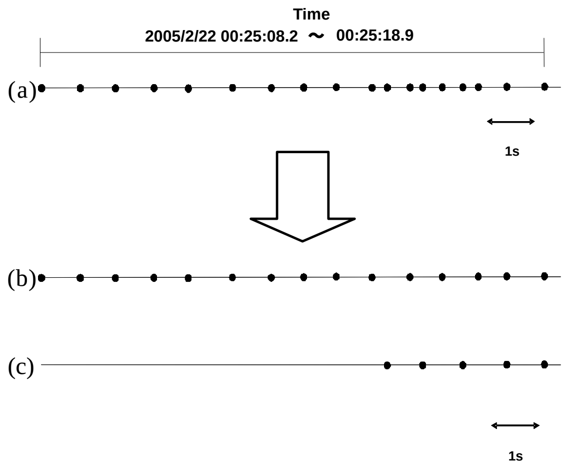

Fig. 9. Diagram (a) indicates the incommensurate intervals of mastication sounds. (a) was divided into two separate regular interval sequences (b) and (c). The solid circle indicates a mastication sound.

3. *Seagrass observation*

The result of seagrass species composition and coverage is shown in Fig. 10. In the station number 1, 2 and 3, seagrasses were poor or did not exist. In other stations, seagrasses were abundant. The dominant species was *Halophila ovalis* in all stations excluding the station number 1 and 3.

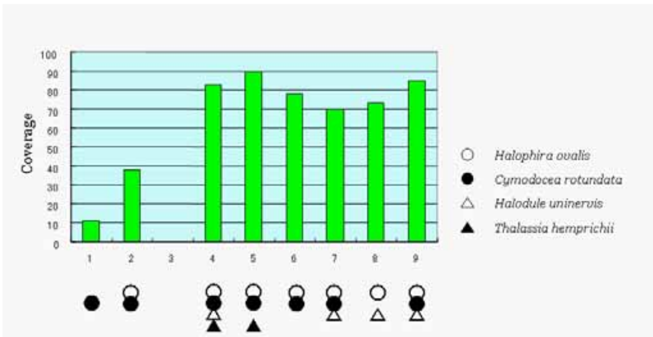

Fig. 10. The seagrass species composition and coverage

The result of mapping of dugong feeding trails is shown in Fig. 11. On February 23, we mapped a total of 77 existing feeding trails. The average length of the feeding trails was 149.0±80.4 cm and the average width of the feeding trails was 15.0±2.7 cm. On March 1, we mapped new 4 feeding trails (Fig. 11). The newly-created trails A were photographed using automatic visual observation. The newly-created trails B were not photographed because they were outside the photography area. The lengths of the newly-created trails A were 105 and 280 cm, respectively and the widths were 10 and 15 cm, respectively. The distance between these two feeding trails was 85 cm. The lengths of the newly-created trails B were 230 and 62, respectively and the widths were 15 and 12 cm, respectively.

Comparing the map of dugong feeding trails with the photos at low tide taken by the digital camera, we estimated the reach of identifiable feeding trails. The reach of identifiable feeding trails was 13m (the shorter parallel side) x 63m (the longer parallel side) x 40m (altitude) trapezoid area (Fig. 11).

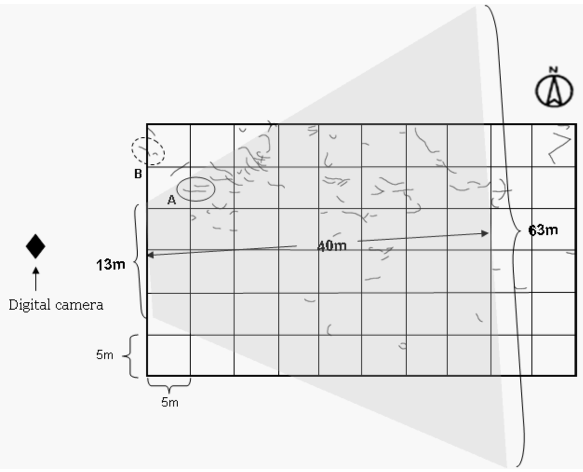

Fig. 11. The map of dugong feeding trails. A and B are newly-created trails. Gray area is the reach of identifiable feeding trails.

DISCUSSION

In the automatic visual observation, by comparing photos at low tide, the increase of dugong feeding trails was found. In this observation, it became clear that two dugong feeding trails had increased between 6:19 pm on February 28 and 8:41 am on March 1. To sum up the matter, dugongs fed on seagrasses in nighttime in the survey area. Adulyanukosol *et al.* (2003) studied the feeding trails of a cow-calf pair. They measured 16 feeding trails of the mother dugong and 15 feeding trails of the calf, respectively. The average length of the former was 5.35±1.85 m and the average width was 0.174±0.0198 m. The average length of the latter was 1.00±0.66 m and the average width was 0.09±0.0143 m. The average distance between the mother trail and the calf trail was 1.05±0.20 m. The data of two newly-created trails confirmed by automatic visual observation (the lengths: 105 and 280 cm, the width: 10 and 15 cm, the distance: 85 cm) agree well with those data. Furthermore, the data of two newly-created trails not confirmed by automatic visual observation (the lengths: 230 and 62 cm, the width: 15 and 12 cm, no data on the average distance) also agree well with those data. This suggested that these two newly-created trails had increased in the same period and were the feeding trails of a cow-calf pair.

The automatic visual observation can confirm the increase of dugong feeding trails. However, it was difficult to obtain detailed information from this observation. We should improve this observation, for example, by use of a high resolution camera. The automatic visual observation can reduce the disturbance to the seagrass bed by observers' feet. From the results of the experiment, the automatic visual observation is a useful method to measure the dugong feeding behavior in the seagrass bed in the shallow waters.

The sound characteristics of potential tearing and mastication sounds recorded in the wild were similar to the feeding sounds observed in captivity. The intervals of mastication sounds in captive and wild data were well related. Therefore, we determined that the tearing and mastication sounds recorded in the wild were the feeding sounds of wild dugongs. Irregular sound intervals strongly suggested that two or more dugongs fed in the observation area at the same time (Fig. 9). The sound interval sequence was divided into two periodic sequences in this case. Each interval of these sequences (0.8 and 0.9 s) was close to the most frequent interval for the mastication sound (0.9 s and 0.8 s in the wild and captivity, respectively). Thus, the minimum number of feeding dugongs should also be observable acoustically. The acoustic monitoring system (AUSOMS-D) worked well in monitoring the feeding behavior of dugongs. The feeding sounds could provide not only information on the attendance of feeding dugongs but also duration of a feeding session, and periodic attendance at the feeding ground.

Both observations are very useful methods, respectively. We now propose to combine these two observations. Automatic visual observation can confirm the increase of dugong feeding trails so that the frequent seagrass survey by observers is not necessary. However, it is difficult to observe dugong feeding behavior at night time. Passive acoustic observation can be operated 24 hours a day, seven days a week. The visual-acoustic combined observation method is a key to better understand dugong habitat use and thus facilitate their conservation.

ACKNOWLEDGEMENTS

We thank all members of the National Research Council in Thailand, Phuket Marine Biological Center, Chaomai National Park (National Park, Wildlife and Plant Department), System Intech Co. Ltd., Metocean Environment Inc., and Okinawa Environmental Research Co., Ltd. who helped support these field experiments. We also thank Mr. Anuwat Prasittipornkun, Ms. Pantaruk Buakaew, and Mr. Sumain Panpum of the Phuket Marine Biological Center, Mr. Hideharu Tamori and Mr. Kazuo

Takeuchi of the Japan Fisheries Resource Conservation Association, and Mr. Akihiko Matsuda of the National Research Institute of Fisheries Engineering for their assistance in conducting the acoustical survey in Thailand. We thank Dr. Hiroshi Mukai of Hokkaido University for helpful comments and assistance in the seagrass survey. We further thank the staff and students in the laboratories of Biosphere Informatics, Graduate School of Informatics, Kyoto University. This study was partly supported by the Cabinet Office and the Ministry of Education, Culture, Sports, Science and Technology (Grants-in-Aid for Scientific Research 16255011 and 16658081, and Informatics Research Center for Development of Knowledge Society Infrastructure of the 21st Century Center of Excellence Program).

REFERENCES

Adulyanukosol, K. *et al.*, 2003. An observation of dugong behaviors from aerial survey and feeding trails of a cow-calf pair in seagrass habitat, Journal of Environment and Resource, Mahidol University, 1, pp. 112-118 (in Thai)

De Iongh, H.H. *et al.*, 1995. Seagrass distribution and seasonal biomass changes in relation to dugong grazing in the Moluccas, East Indonesia, Aquatic Botany, 50, pp. 1-19

De Iongh, H.H. *et al.*, 1997. Observations on the behaviour of the dugong (*Dugong dugon* Muller, 1776) from waters of the Lease Islands, eastern Indonesia, Contributions to Zoology, **67(1)**, 71-77

Ichikawa, K. *et al.*, 2005. Acoustic detection of dugong using automatic underwater sound monitoring systems: AUSOMS-D, Proceedings of the International Symposium on SEASTAR2000 and Bio-logging Science, pp. 64-68

Marsh, H. *et al.*, 2002. Dugong status report and action plans for countries and territories, UNEP Early Warning and Assessment Report Series 1, pp. 162

Mukai, H. *et al.*, 2000. Dugong grazing on *Halophila* beds in Haad Chao Mai National Park, Thailand, Biologia Marina Mediterranea , 7, 268-2

Nakanishi, Y. *et al.*, 2005. The distribution of dugong trenches in the seagrass beds of Libong Island, Thailand, Journal of Advanced Marine Science and Technology Society, 11, pp. 53-57 (in Japanese)

Shinke, T. *et al.*, 2004. Development of automatic underwater sound monitoring system version 1, Proceedings of The 2004FY Annual Meeting of the Marine Acoustics Society of Japan, pp. 33-36. (in Japanese)