Development of mapping techniques for small seagrass meadows: a case study of *Zostera marina* and *Halodule pinifolia*

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**Abstract:** The present research seeks an appropriate method of monitoring both submerged and exposed seagrasses. A seagrass mapping technique was developed using combination data sets from satellite images, digital maps, SONAR imagery and handheld-GPS data collected from seagrass meadows (*Zostera marina*) at Shinkawa–Kasugagawa estuary, the Seto Inland Sea, Japan, in September 2011. The entire coverage area of 123,000 m² was calculated from 638 captured SONAR images. *Zostera* meadows were observed at water depths of 1.6–5.0 m, over sandy sediments. *Zostera* was not found at water depths greater than 5.0 m, where the sediments are muddy. The canopy height of *Z. marina* was estimated to vary between 14 and 87 cm. Additional mapping of intertidal seagrass meadows of *Halodule pinifolia* was also carried out in Rayong Province, Thailand, by GPS tracking during April 2009 and December 2010. Coverage areas varied between 33,498 and 76,207 m², and the highest coverage area was found in April 2009. The present study demonstrates that the entire area of both submerged and exposed seagrass meadows can be calculated by simple methods in a short time with acceptable accuracy.

**Key words:** *Halodule pinifolia*, seagrass, seagrass mapping, seagrass monitoring, *Zostera marina*

**Introduction**

Seagrass meadows play an important role in coastal environments, especially as a nursery ground for juvenile fishes and other marine organisms. Increasing urbanization has caused a reduction of seagrass meadows in Asian countries. Accurate measurement of the coverage area of seagrass meadows is important for trend analysis of the reduction and/or increase of seagrass standing stock.

Generally, seagrass mappings have been reported by using a remote sensing technique. Kuriandewa & Supriyadi (2006) demonstrated seagrass mapping by use of satellite photography in East Bintan coastal area, Riau Archipelago, Indonesia. Seagrass meadow mapping of the Gulf of Mannar biosphere reserve, India, was later demonstrated by IRS ID satellite imagery (Umamaheswari et al. 2009). These techniques also used satellite image data to identify seagrass meadows features, and to estimate the coverage areas. Between 1988 and 1996, aerial photography was widely used as the basic mapping process, because at that time remote sensing methods appeared to be inaccurate for calculating seagrass area. An accuracy of 90% is required for polygons greater than 1.0 acre (4,046.86 m²). Because of the high cost of producing highly accurate maps, remapping of the entire study area is impossible (Kurz et al. 2000, Kurz 2002). Since seagrass meadows were usually found in shallow areas with turbid water, it was believed that the high level of particulate matter in the water col-
umn could be interfering with the satellite signal, resulting in reduced accuracy of coverage area estimation. This problem can be solved by using data collected by a handheld-GPS unit, in conjunction with a digital map.

The present study mapped the seagrass meadows of Zostera marina L. (eelgrass) and Halodule pinifolia (Miki) den Hartog (fiber-stand grass), by combining data from an Echo-sounder (fish finder), a handheld-GPS, an underwater TV camera, and tide tables. The canopy height of eelgrass was also estimated. Exposed periods of fiber-stand grass were calculated by combining data from a handheld-GPS with tide tables for Thai waters. The goal of the present study was to establish a coverage area estimation procedure with acceptable accuracy for the mapping of small seagrass meadows, where the covered areas range between 4,000 and 200,000 m².

Materials and Methods

Study area

The study areas were a submerged seagrass meadow of Zostera marina in the subtidal zone around Shinkawa–Kasugagawa estuary, Kagawa prefecture, Japan (34°21′1″–34°21′34″N, 134°4′48″–134°5′19″E; Fig. 1a) and a monospecific meadow of Halodule pinifolia in Prasare estuary, Rayong Province, eastern Thailand (12°40′39″–12°41′45″N, 101°40′12″–101°41′34″E; Fig. 1b).

Digital map preparation

Digital maps of submerged and exposed seagrasses were illustrated using Surfer ver. 8 (Golden Software, Colorado, USA), based on satellite images (Fig. 2). The accuracy of digital maps was verified by using landmark track data sets (of at least 5 m intervals) obtained from a handheld-GPS unit (Garmin, e-trex Legend model). All landmarks were posted on the digital maps to calculate the X and Y axis errors of the digital maps and handheld-GPS, as shown in Fig. 2a for Japanese seagrass meadow, and Fig. 2b for Thai seagrass meadow. Boundary, distribution, and coverage areas of seagrass were computed using these digital maps.

Submerged seagrass mapping

Mapping process

Zostera mapping was conducted at the subtidal zone around Shinkawa–Kasugagawa estuary in September 2011. Eelgrass during this period was in a steady state. First, the waypoints (A to R) in each line transect were fixed on the digital map to define a boat route. Afterward, the boat passed along the transect line (L1 to L17), at a velocity of about 3 knots, to ensure accurate detection of the small seagrasses boundary (Fig. 2a). A video recorder was used to capture the data from an echo-sounder (GP-3500F, Furuno, 200 kHz, measurement rate 25 times sec⁻¹, vertical resolution ±2%, sound speed 1,500 m sec⁻¹) to determine depth at each specific GPS position. At the same time, the seagrass boundary was verified by an underwater VDO-camera. These recordings were made during neap tide, to minimize the effects of tidal fluctuations on depth measurements. Finally, depth and GPS position were classified by sonar images captured from VDO-camera files. The types of bottom were also identified as seagrasses or sediments in each transect line.

Canopy height calculation

The captured data were used to calculate the bottom base line and canopy height (CH) of Zostera as shown in Fig. 3.

Zostera CH was calculated using the following equations:
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22) \[ D(B_s-B_d) = \sqrt{(a_{B_s}-a_{B_d})^2 + (b_{B_s}-b_{B_d})^2} \] (1)

22) \[ D(B_s-S_{ni}) = \sqrt{(a_{B_s}-a_{S_{ni}})^2 + (b_{B_s}-b_{S_{ni}})^2} \] (2)

\[ BL_{ni} = \left( \frac{\Delta(FB_s-FB_d) x D(B_s-S_{ni})}{D(B_s-B_d)} \right) + FB_s \] (3)

\[ CH_{ni} = \Delta(BL_{ni}-FC_{ni}) \] (4)

Where

\[ D(B_s-B_d) \] is distance \( B_s \) to \( B_d \).
\[ a_{B_s} \] is east (E) or west (W) UTM value of \( B_s \).
\[ b_{B_s} \] is north (N) or south (S) UTM value of \( B_s \).
\[ a_{S_{ni}} \] is east (E) or west (W) UTM value of \( S_{ni} \).
\[ b_{S_{ni}} \] is north (N) or south (S) UTM value of \( S_{ni} \).
\[ BL_{ni} \] is the calculated depth of the seagrass bottom baseline on each line transect \( (L_{ni}) \).
\[ FB_s \] is the depth (m) recorded from the fish finder at \( B_s \).
\[ FB_d \] is the depth recorded from the fish finder at \( B_d \).
\[ CH_{ni} \] is the canopy height of seagrass from the bottom baseline \( (BL_{ni}) \) on each line transect \( (L_{ni}) \), and
\[ FC_{ni} \] is the depth (m) from the fish finder (seagrass canopy depth) of \( S_{ni} \) on each line transect \( (L_{ni}) \).

Accuracy of canopy height calculation and seagrass boundary

Once mapping of submerged seagrass and calculation of the seagrass coverage area were completed, the Zostera boundary was confirmed at 5 zones as lower bare zone (LB), lower edge zone (LE), middle zone (MD), upper edge zone (UE), and upper bare zone (UB) in October 2011. These confirmation stations were overlaid at the M-N transect line. To analyze CH at each of these stations, \( Z. \) marina shoots were taken for direct measurement on board. Subsequently, variation in CH between the observed, actual values and the expected, estimated values was calculated. These results verified the accuracy of the seagrass boundary and CH equations.

Exposed seagrasses mapping

Mapping process

The study area was divided into 18 grids (250×350 m) covering the entire seagrass meadow. The optimum grid size was estimated based on visual estimation (Fig. 2b). For in situ mapping of \( Halodule \) pinifolia, all landmarks were tracked at the patchy boundaries using handheld-GPS and all data were posted on the appropriate digital map. Observations for seagrass coverage area at Prasare estuary were conducted in April, July, September and December in 2009 and 2010. Dates were chosen to include both wet (July to September) and dry (December to April) seasons.

Distribution and expanded coverage area of seagrass

Expanding and shrinking areas were evaluated by analyzing the various coverage areas of all grids at each of the selected time periods. Contour images of coverage areas were produced using Surfer. Differences in the contour areas among time periods were considered as measures of expansion and shrinkage from the center of each meadow, the latter defined as the grid area where the highest coverage was most frequently observed.

Habitat topography

Topographic features, such as sand dunes or tide pools, and duration of the exposed period were tracked by handheld-GPS in July 2010. This date was selected because it is the lowest tide level period of the year, based on data from tide tables (Hydrographic Department Royal Thai Navy 2009 and 2010). The exposed boundary during this period was then used as a base line to calculate the exposed position and the exposed period. The tide level affecting seagrass variation was calculated by subsequent data analysis.

Data analysis

Handheld-GPS data were used to estimate coverage areas and shape of seagrass meadows, topography of sea bottom, and accuracy of digital maps were compared to satellite imagery maps using Surfer.
Results

Submerged seagrass mapping

Coverage area of seagrass

The coverage area of *Zostera* meadows at Shinkawa–Kasugagawa estuary was calculated to be 123,000 m² from 638 captured sonar images (Fig. 4a & b).

Habitat topography

*Zostera* meadows were located on sandy substrate at 1.6–5.0 m depth, and were never found at >5.0 m depth, where the topography dropped away sharply to much deeper waters and the substrate was mud (Fig. 4d).

Canopy height

Analysis of the fish finder depth data set and of the seagrasses and sediments from captured images were used to calculate the bottom baseline and CH of *Z. marina* within each zonation of seagrass (Fig. 4a & c). In order to verify the accuracy of the canopy equation, the study area was separated into three zones: lower (L, >4 m depth), middle (M, 3–4 m depth) and upper (U, <3 m depth).

The mean CH ranges (±SD) were: 20±12 to 53±19 cm in the L zone; 16±3 to 87±10 cm in the M zone; and 14±3 to 77±12 cm in the U zone. The calculated CH of the middle zone showed a higher value than that of the lower zone and upper zone in each transect line (Table 1).

Fig. 3. Calculation model of canopy height and bottom base line depth; planar view (a) and cross section view (b).
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Accuracy verification

Accuracy of Handheld-GPS and Digital maps

The X and Y-axis errors were calculated by comparing the distance between the position of in situ tracks and two landmarks, as shown on the digital maps. On the Japanese digital map (for submerged seagrasses), the calculated distance errors of the handheld-GPS on the X-axis and Y-axis were \(-6\) and \(-13\) m, respectively; compared with the corresponding displayed GPS accuracy of 3 to 5 m. On the Thailand digital map (exposed seagrasses), the corresponding distance error ranges were \(-11\) to \(-34\) m and \(-49\) to \(-72\) m, respectively, with observed GPS accuracy of 7 to 12 m. Although the handheld-GPS differed from the digital maps, both the in situ tracks and landmarks on digital maps showed the seagrass coverage areas to have the same shape (Fig. 5). All positions were recalculated with reference to the digital maps and actual observed positions of the grasses, before calculation of the seagrass coverage area.

Accuracy of canopy height calculation and seagrass boundaries

Confirming the location of various sections of the Zostera meadows resulted in accurate mapping of the seagrass and sediment boundaries. Mean canopy heights

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Table 1. Average canopy height (mean±SD) of Zostera marina in each transection line on lower (L), middle (M), and upper zone (U).

| Line | Lower zone (L) | Middle zone (M) | Upper zone (U) |
|------|----------------|-----------------|----------------|
|      | Average (cm)   | n               | Average (cm)   | n               | Average (cm)   | n               |
| A–B  | 40±14          | 7               | 66±19          | 17              | 59±25          | 12              |
| B–C  | 45±17          | 9               | 76±9           | 10              | 62±3           | 5               |
| C–D  | 41±17          | 8               | 87±10          | 13              | 55±24          | 11              |
| D–E  | 23±13          | 6               | 52±12          | 9               | 22±6           | 5               |
| E–F  | 32±13          | 7               | 76±16          | 11              | 19±10          | 10              |
| F–G  | 52±14          | 5               | 67±14          | 11              | 40±2           | 11              |
| G–H  | 37±14          | 7               | 76±11          | 12              | 30±11          | 9               |
| H–I  | 53±19          | 6               | 75±11          | 11              | 37±12          | 5               |
| I–J  | 29±21          | 7               | 77±13          | 12              | 54±13          | 4               |
| J–K  | 31±17          | 3               | 63±9           | 10              | 24±9           | 4               |
| K–L  | 39±12          | 6               | 84±10          | 9               | 51±22          | 6               |
| L–M  | 52±22          | 6               | 77±12          | 7               | 41±15          | 6               |
| M–N  | 36±15          | 6               | 75±4           | 10              | 35±21          | 9               |
| N–O  | 27±11          | 4               | 30±11          | 8               | 14±3           | 3               |
| O–P  | 72±16          | 15              | —              | —               | 77±12          | 7               |
| P–Q  | 20±12          | 4               | 16±3           | 6               | —              | —               |

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Fig. 4. Mapping process: identified SONAR image tracks and seagrass boundary with zonation of seagrass canopy (a), analyzed planar map with countercheck station (b), depth of bottom baseline and seagrass canopy (c), and 3-D habitat topography (d).
(±SD) from LE, MD, and UE stations were 31±8 (n=14), 31±7 (n=24), and 28±1 (n=3) cm, respectively. Calculated canopy heights (mean±SD) along the M-N transect line presented L, M and U values of 36±15, 75±4, and 35±21 cm, respectively. Comparisons between LE and L, MD and M, and UE and U resulted in calculated equation accuracies (CH variation) of 86%, −45%, and 74%, respectively.

Mapping of exposed seagrass meadows

Distribution and expanded coverage area of seagrass

A map of the Prasare estuary seagrass meadow is shown in Fig. 6a. All 3,869 in situ landmarks (in April 2009) were posted on the digital map to illustrate the boundaries of seagrass patches. Halodule pinifolia and Halophila ovalis were found together only during the first observation, in April 2009. Thereafter, H. pinifolia was the only species found in this seagrass meadow. The total coverage area of H. ovalis was only 280 m² from 12 small patches in grids G2, G3, G6, G7, and G10. Coverage area and patch numbers of H. pinifolia in all observations (April 2009 to December 2010) ranged from 33,498 to 76,207 m² and 25 to 99 patches, respectively. Total coverage area of H. pinifolia was largest in April and smallest in July. This seasonal variation occurred in both 2009 and 2010 (Fig. 6b).
Table 2. Percentage of seagrass coverage in G1 to G18 during 2009 and 2010.

| Grid No. | 2009 | 2010 |
|----------|------|------|
|          | April | July | September | December | April | July | September | December |
| G1       | 7.57  | 6.06 | 6.05      | 8.70     | 6.47  | 4.11 | 4.49      | 9.62     |
| G2       | 24.79 | 9.86 | 10.07     | 23.33    | 20.45 | 9.10 | 12.96     | 16.45    |
| G3       | 0.64  | 0.56 | 0.94      | 2.45     | 3.39  | 1.11 | 1.18      | 1.52     |
| G4       | 0.40  | 0.32 | 0.23      | 0.93     | 1.42  | 1.12 | 0.72      | 0.00     |
| G5       | 4.28  | 4.84 | 4.40      | 4.81     | 3.16  | 2.12 | 2.00      | 2.97     |
| G6       | 45.64 | 36.63| 38.90     | 47.31    | 40.96 | 21.91| 30.17     | 35.15    |
| G7       | 17.26 | 15.17| 16.06     | 18.79    | 18.58 | 11.12| 8.06      | 9.42     |
| G8       | 2.97  | 1.13 | 1.82      | 0.16     | 7.08  | 1.50 | 1.01      | 0.00     |
| G9       | 0.59  | 0.19 | 0.13      | 0.06     | 0.00  | 0.00 | 0.00      | 0.00     |
| G10      | 5.30  | 2.22 | 1.22      | 0.31     | 0.00  | 0.00 | 0.00      | 0.00     |
| G11      | 0.00  | 0.00 | 0.00      | 0.02     | 0.15  | 0.00 | 0.00      | 0.01     |
| G12      | 0.00  | 0.00 | 0.00      | 0.00     | 0.01  | 0.00 | 0.00      | 0.00     |
| G13      | 0.00  | 0.00 | 0.74      | 0.00     | 1.63  | 0.00 | 0.00      | 0.00     |
| G14      | 0.00  | 0.00 | 0.00      | 0.00     | 0.00  | 0.00 | 0.00      | 0.00     |
| G15      | 0.00  | 0.59 | 0.48      | 0.39     | 0.00  | 0.00 | 0.00      | 0.00     |
| G16      | 0.00  | 0.00 | 0.00      | 0.00     | 0.00  | 0.00 | 0.00      | 0.00     |
| G17      | 0.00  | 0.00 | 0.00      | 0.00     | 0.00  | 0.00 | 0.00      | 0.00     |
| G18      | 0.00  | 0.00 | 0.00      | 0.00     | 0.00  | 0.00 | 0.00      | 0.00     |

Fig. 7. Maps and contour expanding and shrinking coverage of *Halodule pinifolia* area.
Seagrass occurred consistently on grids G1 to G12, but was not found on grids G13 to G18, except for some months at G13 and G15. Table 2 shows the percentage variations in seagrass coverage area for each grid. Coverage of grids G2, G6, and G7 ranged from 9.10 to 24.79%, 21.91 to 47.31%, and 8.06 to 18.79%, respectively. These grids showed higher coverage values than the others grids. The highest coverage area was frequently observed at G6, which was located at the center of the seagrass meadow.

Contours of the expanding and shrinking coverage area for G6 are shown in Fig. 7. In April and July, the seagrass coverage area was observed to be shrinking, while in September and December, expansion was observed. The rate of shrinkage or expansion ranged from $-12$ to $-213$ m² week⁻¹ and 18 to 103 m² week⁻¹, respectively.

**Habitat topography**

Exposed areas were observed in the southwestern part of the study area (Prasare estuary). The small tide pool and water channel were affected by seawater movement and effluent from shrimp culture ponds around G2, G3 and G4 (Fig. 8a). The habitat was mostly exposed in the daytime during April to July, with a mean of 294 ± 75 hr mo⁻¹, with exposure highest in May and July: 310 to 343 hr mo⁻¹, respectively. In all cases, ≤1.3 m of mean sea level (at 11°47’42.92″N, 99°47’31.40″E) was required when the exposed area was presented (Fig. 8b).

**Distribution and expanding of seagrass coverage area**

Because *Zostera marina* mapping was performed only once, its seasonal variation remains unknown. Coverage area, shape of meadows, and depth of seagrass habitat are presented based solely upon one observation. Long term monitoring of coverage area is an important process to predict the status of seagrass meadows. However, unaccurate data on the coverage area and status of seagrasses are considered to be cosmopolitan problems. Duarte (2002) has suggested that knowledge of present seagrass coverage globally is still uncertain for most nations with an extended coastline. These uncertainties preclude any reliable quantitative forecast of future seagrass coverage. For *Halophila pinifolia*, the coverage area based on the digital map showed an obvious tendency for seasonal variation. The patterns of change in the coverage area of the Prasare estuary seagrass meadow during 2009 and 2010 were almost identical from one year to the next (Fig. 6b). Therefore, the change in coverage area can be used to identify the trend of seagrass status. The present study found that a declining phase appeared from April to July, while the coverage area expansion appeared from September to December. All data demonstrated that the coverage area continuously decreased during the 2009 to 2010 monitoring period, indicating that the *H. pinifolia* meadow is de-
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teriorating. Area G6 consistently showed the highest percentage of coverage area, there is the center of the meadow (Fig. 7 & Table 2).

Accuracy of Handheld-GPS and Digital mapping

Using GPS mapping techniques for the detection and assessment of the expansion of seagrass coverage area is a new method. The shape and size of land marks (e.g. roads and breakwaters) were compared between in situ track positions and digital map positions based on satellite images, to ensure the accuracy of digital mapping, regarding the position and coverage area of the subject seagrass meadows. The circular error probability (CEP) of the GPS hand set refers to the radius of a circle in which 50% of the values occur (Novatel, 2003). Estimated X and Y errors between in situ track positions and digital map positions in Japan and Thailand resulted in additional CEP. To optimize accuracy, digital base maps were calibrated with X and Y error values of lowest CEP periods.

Comparisons of landmarks (shape and size) between in situ track positions and digital map positions confirmed the accuracy of the maps used, and each seagrass mapping process was completed within a day, maximizing the accuracy at each position.

Accuracies of canopy height calculation and seagrass boundaries

Physical countercheck of the Zostera marina boundary showed that the margins of this patch had been drawn correctly, confirming the accuracy of the adjusted digital map used in this study. Comparison of the CH observed in situ and that previously calculated showed high accuracy at the LE and UE zones. The higher accuracy for LE than UE is a property of the difference in sample number (n). However, the actual CH of the MD was 145% of the calculated value. This is considered to have resulted from the use of a horizontal substrate baseline (BL), which is not in accord with the natural topography of the sea bottom. This resulted in overestimation of middle BL depths, and probably also caused errors in the CH calculations. The BL of LE and UE were posted around meadow margins where BL depths were calculated with adjacent bottom depths of the LB and UB zones. Thus, the in situ values of CH of the LE, MD and UE zones were similar, and this study demonstrated that the estimated CH of the L and U zones were representative of whole meadow area. Consequently, the efficiency of the CH equation used was verified at 74% and 86% of LE and UE accuracies, respectively.

This study developed an accurate mapping technique for small seagrass meadows. The methods used provided qualitative and quantitative results (e.g. for coverage area, extension, canopy height, and seasonal variation of seagrass meadows) with high accuracy, using simple and readily available equipment (handheld-GPS, Fish finder echo sounder, and underwater video camera). These methods offer a low-cost, low-effort solution, with only a short working time required for each observation period, making the technique suitable for long term and continuous seagrass monitoring.

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