OTSUCHI MARINE SCIENCE 27: 23–27 (2002)

Preliminary study on shoot density and biomass of seagrass, *Zostera caulescens*, in Funakoshi Bay off Sanriku Coast, Japan.

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The world's longest seagrass, *Zostera caulescens* Miki, is distributed in Funakoshi Bay in Sanriku Coast off Honshu Island facing the North-western Pacific. Shoot density, shoot length and biomass of *Z. caulescens* were measured taking samples on a quadrat of 0.5 m×0.5 m at depths of 4.4 m, 10.9 m, 13.3 m, 14.3 m and 15.3 m in Funakoshi Bay on 4 July 2000 when the *Z. caulescens* was luxuriant. Shoot density of *Z. caulescens* ranged between 36 and 180 shoots/m^2. Density of shoots with lengths of 80 cm and below were much greater than that above 80 cm. The former densisty was negatively correlated with bottom depth. The longest shoot was observed to be 545 cm at the depth of 13.3 m. Above-ground biomass of the seagrass ranged between 33.57 and 187.31 gDW/m^2, while below-ground biomass ranged between 6.08 and 66.71 gDW/m^2. Above- and below-ground biomass had a peak at the bottom depth of 10.9 m. Above-ground biomass of shoots with lengths above 80 cm was much greater than that with lengths of 80 cm and below. Ratio of below-ground to above ground biomass was negatively correlated with bottom depth.

Key words: *Zostera caulescens*, seagrass, biomass, shoot density, shoot length, bottom depth

INTRODUCTION

Seagrass are known as prominent components of coastal ecosystems, where they sustain high primary production (Duarte 1989, Hilman et al. 1989, Duarte and Chiscano 1999, Vermaat et al. 1995, Agawin et al. 1996), and host a wide variety of associated fauna including commercially important fishes and endangered marine mammals such as dugongs and manatees (Heinsohn et al. 1977, Bell and Pollard 1989). They provide nursery habitats for fishes (Orth et al. 1984). Seagrass beds also contribute to marine environments; for example, stabilizing bottom sediments and maintaining coastal water quality and clarity (Ward et al. 1984). They are vulnerable to physical perturbations caused by severe climatic conditions or human activities (*e.g.* eutrophication) and therefore vary in aerial cover due to shoots mortality (Shepherd et al. 1989). Recent die-offs occurring throughout the world have caused concern (Robblee et al. 1991, Quammen and Onuf 1993).

In Japan, 16 species of seagrass have been recorded from different parts (Aioi 1998). Among them eelgrass, *Zostera marina* L. is one of the most important due to its distributional area. However, in Seto Inland Sea, more than 70% of *Z. marina* beds have been lost since 1977, which seriously affected coastal fisheries (Komatsu 1997, Aioi 1998). Aioi et al. (1998) found *Zostera caulescens*, one of the eelgrasses, which is an endemic species, in Funakoshi Bay, in Sanriku Coast off Honshu Island facing the North-western Pacific. They reported that it was the world's longest (7 m) seagrass. *Z. caulescens* is distributed from a depth of 5 m to 15 m (Tatsukawa et al. 1996). There are, however, no reports on shoot density and biomass of this species in this habitat of Funakoshi Bay. To conserve the seagrass, it is necessary to understand its ecological characteristics. Thus we made an attempt to examine shoot and biomass of the seagrass at different depths in Funakoshi Bay.

MATERIALS AND METHODS

Biomass of above-ground part of *Z. caulescens* in Funakoshi Bay (39°22.5′N, 141°57′E) was maximal in summer and minimal in winter (Nakaoka et al. 2000). In order to know about shoot and biomass of the seagrass and their relation with a bottom depth, we made a quadrat sampling of the plants by SCUBA diving at depths of 4.4 m, 10.9 m, 13.3 m, 14.3 m, and 15.3 m in Funakoshi Bay on 4 July 2000 during the luxuriant growth season of *Z. caulescens*. The area of the quadrat was 0.5 m×0.5 m. Bottom depths of sampling stations were measured by a depth gauge for diving. Mean bottom depths were calculated using the tide tables (Anon. 2000). The seagrass samples were stored in 5% formalin in plastic bags.

Plant material was rinsed in fresh water and cleaned of sand and shells in the laboratory. Shoot density and length of foliar portions were measured. Shoot density refers only to the above-ground foliar portions of the plant. Shoot length (*i.e.* length from the bottom end of shoot to the top of the blade the highest from the root) was measured by a centimeter scale. Samples were also sorted into above- and below-ground parts. The epiphytic plants and animals living on leaves were scarped off by using a spatula. Dry weight of every shoot and root of the samples were taken after drying them at 60°C for 48 hrs by using hot air oven (DX300, Yamato Scientific Co. Ltd.) to obtain above- and below-ground biomass. Biomass is expressed as dry weight (g) in unit area (hereafter, we use gDW/m^2), which is the most widely used expression for Biomass (Westlake 1965).

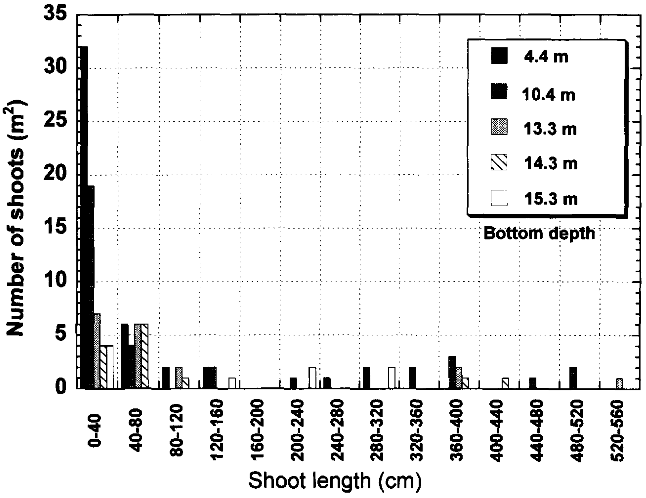

Figure 1. Shoot length frequency of *Zostera caulescens* at five different bottom depths in Funakoshi Bay on 4 July 2000.

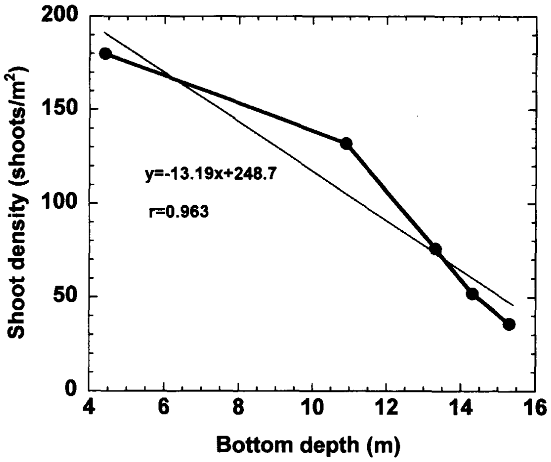

Figure 2. Shoot density of *Zostera caulescens* at five different bottom depths. Closed circles show the stations where the samples were taken. Regression line of shoot density to a bottom depth is represented with a straight line (r=0.963).

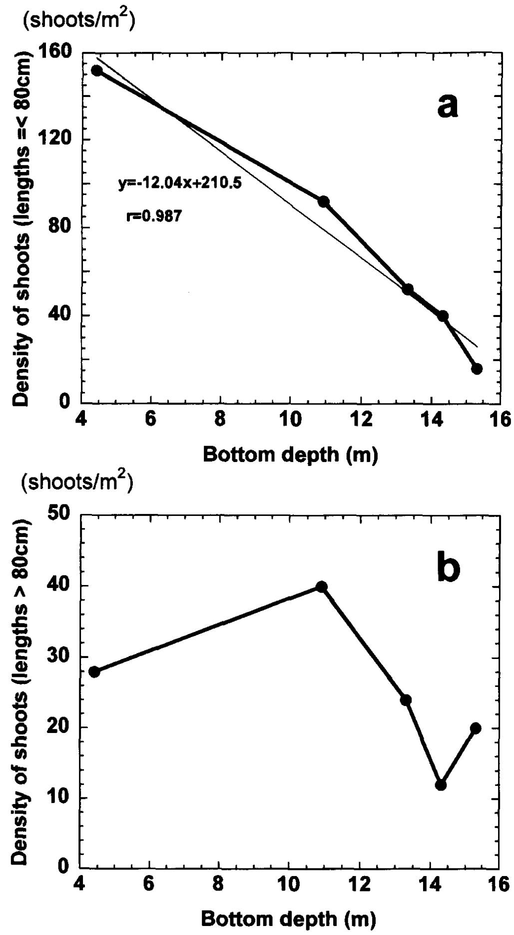

Figure 3. Densities of shoots (shoots/m^2) with lengths of 80 cm and below in the upper panel (a) and those above 80 cm in the lower panel (b) at five different bottom depths. The regression line between densities of shoots with lengths of 80 cm and below and bottom depth is expressed by a straight line in the upper panel.

RESULT

Frequency distributions of shoot lengths of *Z. caulescens* at five different sampling depths is shown in Fig. 1. The shoot lengths ranged from 4 cm to 546 cm. The longest shoot was 546 cm at a depth of 13.3 m. The number of shoots was the greatest at a class of shoot length less than 40 cm at all depths except at a depth of 14.3 m, where a class between 40 and 80 cm was the greatest. We found the difference of shoot number distribution between below and above 80 cm (Fig. 1). Nakaoka et al. (2000) examined relation between lengths of flowering and vegetative shoots in Funakoshi Bay. They reported that length range of vegetative shoots and flowering shoots were 19–98 cm and 96–445 cm in July and 24–87 cm and 84–471 cm in August, respectively. Based on the size distribution of shoots in Fig. 1 and Nakaoka et al. (2000), we grouped shoots into two categories of shoots with length above and below 80 cm for further analysis. We assume that they roughly correspond to flowering and vegetative shoots.

The shoot density of all shoots of *Z caulescens* ranged between 36 and 180 shoots/m^2 (Fig. 2). Shoot density was the greatest (i.e. 180 shoots/m^2) at the shallowest bottom depth (4.4 m) of sampling and the lowest (36 shoots/m^2) at the deepest bottom depth (15.3 m) in Funakoshi Bay. Densities of shoots with lengths of 80 cm and below ranged between 16 and 152 shoots/m^2 and those above 80 cm did between 12 and 40 shoots/m^2 (Fig. 3). Shoot densities of all shoots and those with lengths of 80 cm and below were negatively correlated with bottom depth.

The above- and below-ground biomass were the greatest 187.31 gDW/m^2 and 66.71 gDW/m^2 at a bottom depth of 10.9 m and the lowest 33.57 gDW/m^2 and 6.03 gDW/m^2 at a bottom depth of 14.3 m (Fig. 4a). Biomass decreased with increasing of bottom depth under a bottom depth of 10.9 m. Ratio of below-ground biomass to above-ground was the greatest (54.46%) at the shallowest depth (4.4 m) and decreased with increasing of bottom depth (Fig. 4b). Biomass of shoots with lengths above 80 cm follows the same tendency of total above-ground biomass (Fig. 5 and 4a), while shoot with lengths of 80 cm and below decreased with increasing of bottom depth (Fig. 5). The former biomass was much greater than the latter (Fig. 5).

DISCUSSION

Among the five species of seagrass belonging to *Zostera* genus, *Z. marina* is generally found in shallow subtidal bot-

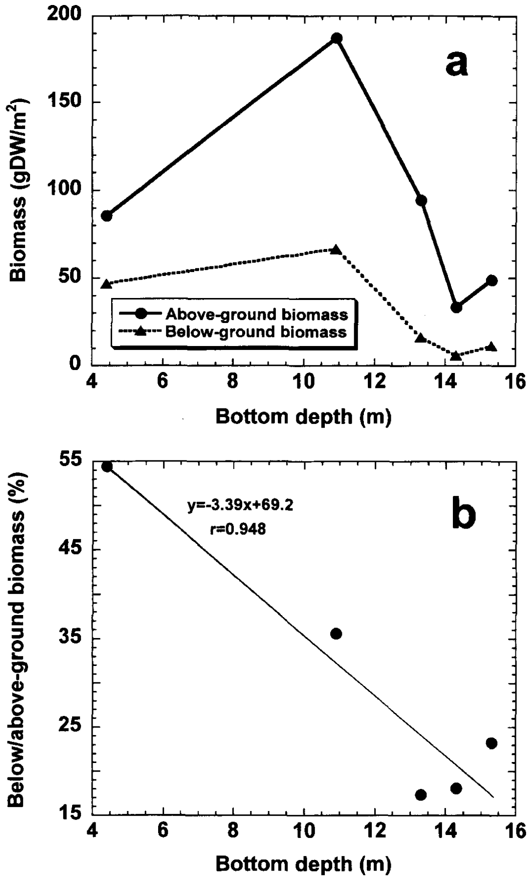

Figure 4. Upper panel (a) shows above- and below-ground biomass (gDW/m^2) of *Zostera caulscens* at five different bottom depths and lower panel (b) ratio of below-ground biomass to above-ground one. Regression line between ratios of below- to above-ground biomass to bottom depths is represented with a straight line ($r=0.948$) in lower panel (b).

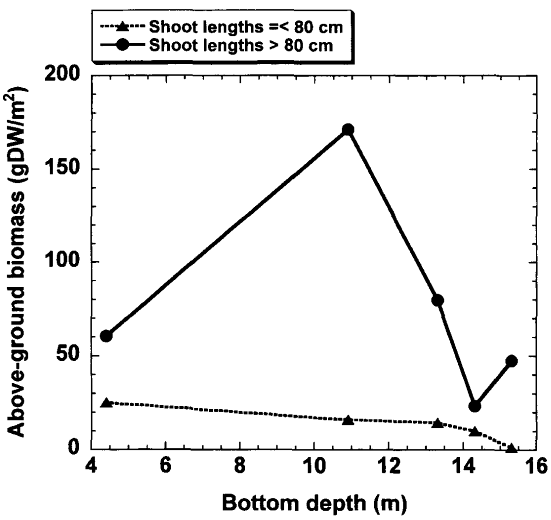

Figure 5. Above-ground biomass of shoots with lengths 80 cm and below (closed triangles and dotted line) and above 80 cm (closed circles and fat line) at five different bottom depths.

tom between depths of 1 m and 5 m. *Zostera japonica* grows in shallower intertidal habitats, and the other three species, *Zostera asciatica*, *Zostera caespitosa* and *Zostera caulescens*, in subtidal habitats (Nakaoka and Aioi 2001). Miki (1933) reported that a habitat of *Z. caulescens* was at bottom depths of 6 m to 10 m in a closed inlet with muddy substratum. Tatsukawa et al. (1996) showed that a vertical distribution of *Z. caulescens* extended to a bottom depth of 16 m in Funakoshi Bay by an echo-sounder. On the other hand, Aioi et al. (1998) stated that the mean depth of the habitat of this species in the Bay was about 5 m. Samples of *Z. caulescens* were found on a bottom depth of 4.4 m to 15.3 m in Funakoshi Bay in July 2000. Therefore our samples covered the whole vertical distribution of *Z. caulescens* in Funakoshi Bay.

In summer it is likely that light is very low for *Z. caulescens* growing at lower bottom depths in Funakoshi Bay in August when a secchi depth at the bay mouth of adjacent Otsuchi Bay was 4.5 m and the minimum in a year, (Otobe et al. 1995). However, flowering shoot height from the bottom is maximum during the summer (Nakaoka et al. 2000). Our results show that flowering shoots were about 5-6 m long from a depth of 10 m to 14 m. The top of the shoots attains to the depth of about 10 m. Since the shoot density was low at the most offshore station at 15.3 m deep, it is suggested that flowering shoots can receive enough light to survive due to low density and high water clarity of offshore waters. Therefore *Z. caulescens* can survive during the summer when the light is limited.

Nakaoka and Aioi (2001) concluded that *Z. marina* had no consistent tendency between shoot density and bottom depth by comparing many data on bottom depths and shoot densities of *Z. marina* in Japan. The reason why there was no relation between shoot density and bottom depth in *Z. marina* is considered to be small difference in light intensity according to small differences in bottom depths of its vertical distribution (depth difference of about 3–5 m) at the same locality. Since the bottom depth of *Z. caulescens* ranged depths of 4.4 m to 15.3 m in Funakoshi Bay, light environment is varied in a wide range. Therefore shoot density of *Z. caulescens* consisted mainly of shoots equal to and below 80 cm is inversely correlated with the depth according to light availability for photosynthesis.

The shoots greater than 80 cm mainly contributed to above-ground biomass. Thus it is necessary to consider the flowering shoots during the luxuriant season of the seagrass. The flowering shoots at a depth of 4.4 m was less than those at a depth of 10.9 m, while light is not a limiting factor for development of *Z. caulescens* in the shallowest bottom at a depth of 4.4 m. Although the flowering shoots of *Z. caulescens* can grow up to about 6–7 m (Aioi et al. 1998), it is difficult for the flowering shoots to grow parallel to the sea surface due to drag forces by wind and waves in the surface layer to extract blades. In consequence, the biomass of flowering shoots at a depth of 4.4 m limited by the water depth is less than at a depth of 10.9 m. On the other hand, the flowering shoots are limited by light availability under a depth of 10 m. Thus they decrease with increase of bottom depth. Finally the above-ground biomass had a peak at a depth of 10.3 m.

The ratio of below-ground biomass to above-ground biomass was the greatest in the shallowest depth and decreased with the increase of bottom depth. Seagrass roots develop not only to absorb nutrients but also to hold shoots not to be extracted by drag forces caused by waves and currents. The shallower the bottom depth, the stronger water movement by wave and current. Because roots are developed in shallower bottom depth, the ratio of below-ground biomass to above-ground biomass becomes greater in shallower bottom depth.

This study shows that *Z. caulescens* adapts to physical environment such as light and water movement to survive by varying shoot density, shoot lengths and above-and below-ground biomass. This great adapting ability of *Z. caulescens* to environment enables this species to grow in a wide range of bottom depths from depths of 4–5 m to 15–16 m.

ACKNOWLEDGMENT

We thank Mr. Kouichi Morita and other staff of Otsuchi Marine Research Center, Ocean Research Institute, The University of Tokyo for their support for conducting field research. We also thank Ms. Hiroko Aoyama and Dr. Takaomi Arai of Ocean Research Institute for their help during this study. Finally we are grateful to Prof. Nobuyuki Miyazaki of Ocean Research Institute, The University of Tokyo for his warm encouragement. This study was partially supported by the Grant in Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (No. 12358008).

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三陸，船越湾産タチアマモのシュート密度とバイオマスに関する予察的研究

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世界最大の海草タチアマモ (*Zosetra caulescens* Miki) は三陸沿岸の船越湾に分布している．船越湾においてタチアマモの繁茂季にあたる2000年7月4日に0.5 m×0.5 mの方形枠による坪刈を4.4 m, 10.9 m, 13.3 m, 14.3 m, 15.3 mで行い，タチアマモのシュート密度，シュート長，バイオマスを調べた．シュート密度は36–180 shoots/m^2の範囲にあった．シュート長が80 cm以下のシュートの密度はそれよりも長いシュートの密度よりも大きく，また，80 cm以下のシュートの密度は深度と負の相関があった．得られたサンプル中，最大のシュートは13.3 m深の点の545 cmのものであった．地上部のバイオマスは33.57–187.31 gDW/m^2，地下部のバイオマスは6.08–66.71 gDW/m^2の範囲にあった．地上部および地下部のバイオマスは10.9 m深の点でピークを示した．80 cmよりも長いシュートのバイオマスは80 cm以下のシュートのバイオマスよりも大きかった．地上部に対する地下部の比率は底深に負の相関を示した．

Received: 25 January 2002
Accepted: 12 February 2002