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CARTOGRAPHY OF SEAGRASS BEDS USING HYDRO-ACOUSTIC METHODS

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ABSTRACT

Cartography of seagrass beds is very important for management and conservation of sound littoral ecosystems and sustainable fisheries in the coastal waters. The cartographical methods to map spatial distribution of seagrass beds are reviewed. They are classified into two categories. One is a direct method by visual observation and the other is an indirect method using a remote sensing apparatus. Indirect methods are divided into optical or hydro-acoustic methods. Indirect methods require sea truth by direct methods. Optical methods are image analysis of aerial photography or satellite imagery. They are effective for mapping broad areas but limited to shallow waters due to light attenuation in waters. Hydro-acoustic methods such as echosounder and side scan sonar have no limitation of turbidity. The echosounder is practical to map vertically density and height distributions of seagrass beds. The side scan sonar and multi-beam sonar are appropriate for mapping broad horizontal distributions. Coupling of several indirect mapping methods is more useful than using only one method.

Keywords: seagrass, seaweed, mapping, remote sensing, hydro-acoustic

INTRODUCTION

Seagrass beds play an important role for marine coastal ecosystems. They support flora and fauna including epiphytic organisms, and coastal fisheries productivity (Orth, 1984; Coles et al., 1993). Seagrass beds contribute to marine environment, for example, stabilizing bottom sediments, and maintaining coastal water quality and clarity (Ward et al., 1984; de Grissac and Bodouresque, 1985; Komatsu and Nakaoka, 2000; Komatsu and Yamano, 2000). Seaweed forests also have the following influences on marine environment: Buffering effect on water flow (Komatsu and Murakami, 1994; Mork, 1996), pH distributions (Komatsu and Kawai, 1986), dissolved oxygen distributions (Komatsu, 1989; Komatsu et al., 1990), water temperature distribution and change (Komatsu et al., 1982; Komatsu, 1985; Komatsu et al., 1994). It is possible that seagrass beds serve such influences as seaweed beds on marine environments. Many important species spawn in the beds, for example, sea urchins, balaos, cuttlefish, etc. Their larvae and juveniles use the beds as a nursery ground (Arasaki and Arasaki, 1978). Dugongs feed on seagrass species. In this way, the seagrass serve as an important habitat for marine animals and support biodiversity.

An increase in seafloor reclamation and sewage from industries and agricultures has decreased large areas of seagrass beds in the coastal zone during economic development in Japan (Hoshino, 1972) and U.S.A. (Short and Willie-Echeverria, 1996). Since the seagrass beds are sensitive to pollutions and water quality deterioration, they serve as a "bio-indicator". Change of seagrass depth distribution in Chesapeake Bay (Dennison et al., 1993) was the "bio-indicator" when runoff-impacts on water quality caused changes in light penetration and consequently affected seagrass abundance and distribution patterns. Using the lower bottom depth limit of *Posidonia oceanica* (L.) Delile as the "bio-indicator", a monitoring program has also been carried

out at 24-33 survey sites along the Provence and French Riviera coasts since 1984 (Boudouresque et al., 2000). Cartography of seagrass beds is a practical method to know a condition of coastal environment.

Preservation, restoration and creation of seagrass beds are, thus, necessary to recover coastal environment, biodiversity and bio-resources for sustainable development of fisheries. For this purpose, it is urgently required to establish precise and reliable techniques to map and monitor seagrass beds in quantitative and efficient ways (Lee Long et al., 1996).

CLASSIFICATION OF MAPPING METHODS

Mapping methods of seagrass beds are classified into two categories. One is a direct observation or measurement by researchers. The other is an indirect method using a remote sensing apparatus. Direct methods are ground surveys (walking, diving or grabs). In France, observation from a submarine was used to map lower bottom depth limit of P. oceanica beds along the French Riviera Coast (Meinesz and Laurent, 1978) because P. oceanica beds extend to bottom depths of 30-40 m. Direct methods are not efficient because they need time and persons to perform field surveys.

Indirect methods are classified into two groups by apparatuses for remote sensing: an optical remote sensing and acoustic remote sensing. In applying these two methods for mapping seagrass and seaweed beds, indirect methods essentially need ground truth (Lee Long et al., 1996).

OPTICAL REMOTE SENSING METHODS

To map spatial distributions of seagrass beds, aerial photography and satellite imagery are generally used. Satellite images are of value for large-scale localization investigations (Belsher, 1989; Fredj et al., 1990). Aerial photographs can provide more detailed data for studying the horizontal distribution, monitoring the long-term change or estimating the biomass of seagrass beds (Meulstee et al., 1986; Meinesz et al., 1988). The aerial photographs and satellite imagery are efficient for mapping where dense seagrasses can be identified on very large scales (Belsher, 1989; Belsher et al., 1988; Kirkman, 1990; Long et al., 1994), but cannot always be used successfully to map seagrass or seaweed biomass or find those of low density or small patches, or in water too turbid or too deep for remote sensing (Pasqualini and Pergent-Martini, 1996). Recently, towing video camera system has been developed (Norris et al., 1997). The camera is mounted in a 'down-looking' orientation on a towfish, which was deployed directly off the stern of the vessel using the cargo boom. However, it is also sensitive to turbidity.

ACOUSTIC REMOTE SENSING METHODS

One acoustic method to map seagrass beds using a side scan sonar, which is more efficient than that of the ground surveys, has been developed since 1970s in the Mediterranean Sea. It scanned sea bottom at a width ranging 50-500 m, and could distinguish seagrass bed distributions and the others successfully (Newton and Stefanon, 1975; Meinesz et al., 1981; Lefevre et al., 1984; Gloux, 1984; Ramos and Ramos-Espla, 1989; Pasqualini et al., 1998). Figures 1 and 2 show towing apparatus of side-scan sonar and the distribution map of *Zostera caulescens* Miki in Koajiro Bay in Sagami Bay obatined by the side-scan sonar. The patch structure is clearly depicted. However, it is difficult for this method to measure densities and heights of plants along a transect. Great disadvantages are (1) expensiveness of the system, (2) difficult treatment of the

system on the small boat in shallow waters and (3) difficult processing of horizontal distribution data to mapping data through position data of the ship. Echosounders have been developed to detect distributions of fish schools and to measure underwater bottom topographies. They send out ultrasonic waves of a certain frequency in the water and measure their reflection by bottoms and objects in the sea. Because the reflection coefficient of ultrasonic depends on materials of objects, especially air contentin leaves, we can identify the objects in clear cases. The echosounders have advantages not only to continuously measure biomass distributions and bottom topographies, but also to be used at a low cost and easy treatment. This method has been applied to several studies in phanerogam beds in lakes (Duarte, 1987), Zostera marina L. beds (Hakakeyama and Maniwa, 1978; Komatsu and Tatsukawa, 1998) and P. oceanica meadows (Colantoni et al., 1982; Rey and Diaz del Rio, 1989).

Colantoni et al. (1982) tried to use a low frequency echosounder (3.5 kHz); it proved to be rather ineffective to discriminate the acoustic character between P. oceanica bed and the bottom. Although the high-resolution continuous seismic reflection (3.5 kHz) could distinguish the P. oceanica and others (Rey and Diaz del Rio, 1989), long wavelength of ultrasonic brings worse vertical precision of echosounder. Echosounders with an ultrasonic wave of 200 kHz is more appropriate for detecting seagrass beds (Fig. 3) (Hatakeyama and Maniwa, 1978; Komatsu and Tatsukawa, 1998).

The echosounder can scan seagrass beds when traveling at about 1.0-1.5 m/s (2-3 knots). It is possible to investigate 37 km per day when a ship with an echosounder travels at 1 m/s (2 knots) for ten hours (Komatsu and Tatsukawa, 1998). In this way, the echosounder is a very useful apparatus to map seagrass beds.

LOCALIZATION USING GPS SYSTEM

Most of the studies mentioned in the previous section did not refer to a density distribution of plants along a transect by the echosounder in the sea, and have not been used for mapping so often. It is estimated that one of the reasons is that localization of vessels equipped with an echosounder was not easy with good precision. Two transit theodlites (Meinesz et a., 1981; Hatakeyama and Maniwa, 1978), DECCA(Meinesz et a., 1981), or a radio positioning system (Rey and Diaz del Rio, 1989; Calvo et al., 1993) have been used as a localization system. The Global Positioning System (GPS) became available in 1980s. It permits us to localize instantaneously the place scanned by the echosounder. The accuracy of GPS has been ameliorated from ±36 m (95%) to ±6 m (95%) since 2000 because of the removal of Selective Availability (SA) from GPS (stopping the intentional degradation of the GPS signals) on 2 May 2000. In the world, 34 countries have already installed Differential GPS radio beacon networks in territory of each country, and more are considering the adoption of this navigation standard. The improvement of the basic GPS signal through elimination of SA may allow the DGPS radio beacons to transmit fewer error corrections and more accurate localization. Accuracy of DGPS is about several decadal centimeters. The GPS is inexpensive system and more convenient and more available at any place for localization. The GPS or DGPS contribute in situ remote sensing and direct observation for cartography of seagrass beds.

QUANTIFICATION USING AN ECHOSOUNDER

Hatakeyama and Maniwa (1978) used the echosounder for mapping a Zostera bed, but they calculated only an index of biomass: sum of canopy heights by unit sector along transects scanned by the echosounder. Since it is necessary to estimate seagrass or

seaweed biomass for a quantitative comprehension of the their ecosystems, Komatsu and Tatsukawa (1998) proposed a simple converting method from the shading grades of seagrass on echograms to above-ground biomass based on quadrate samplings (Fig. 4). Area of grade distribution can be converted to biomass (Fig. 5).

DETECTION OF VERTICAL DISTRIBUTION

The position of the lower bottom depth limit of seagrass beds is related to the light extinction coefficient influencing the minimum degree of light required for growth of seagrass (Duarte, 1991). Thus, it can be used for an indicator of water quality. In France, the lower bottom depth limit of *P. oceanica* was monitored by placing concrete markers (Meinesz, 1977). In this case, obtained results are very precise, but the observed area is limited. The echosounder can be used to define the vertical distribution of seagrass bed and the lower bottom depth limit of seagrass beds by correcting depths measured by the echosounder to the mean sea level. Therefore, monitoring of the lower bottom depth by the echosounder is useful for detecting the lower bottom depth limit of seagrass beds not precisely but roughly in a wide area. When these two types of monitoring are coupled, they complement each other to obtain lower bottom depth limits.

Komatsu and Tatsukwa (1998) clarified that the canopy height was nearly proportional to the maximum blade length (Fig. 6). By cropping blades of seagrass, the height of seagrass canopies on the echo-traces can be used as an indicator of the maximum blade length of seagrass when the current speeds were not greatly different over the beds. Tanaka and Tanaka (1985) also reported a similar proportional relation between the canopy height and maximum frond lengths of *Sargassum* species. Komatsu et al. (submitted) developed mapping methods using a multi-beam sonar that can send several decadal beams from the transducer and measure the bottom depths (Fig. 7). They can measure height distribution of seagrass beds (Fig. 8). Volume occupied by the seagrass canopy is also estimated by this method.

CONCLUSION

Seagrass distributions are linked to physical, chemical and social environments or human impacts. Geographical Information Systems (GIS), the computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information are practical tools for analyzing spatial and temporal change of seagrass bed distributions.

A mapping method using an echosounder is a simple, laborsaving and efficient one to detect their canopy height and above-ground biomass and their upper and lower depth limits. Since a newly developed GPS system makes positioning of a boat more accurate, scanning of the beds becomes highly precise. Incorporating the cropping of plants in situ, we can estimate vertical and horizontal distributions of the beds, plant density, and a biomass distribution of the beds. On the other hand, a side scan sonar is very effective to horizontal mapping of seagrass beds while it is complicated and expensive. It is expected that the acoustic mapping methods will become more effective by combining of not only those acoustic methods but also other direct and other optical remote sensing methods.

ACKNOWLEDGMENT

REFERENCE

Arasaki, M. & T. Arasaki. 1978. Compilation of stories on algae. Tokai University Press, Tokyo. Pp. 1-228.

Belsher, T. 1989. Apports du satellite SPOT à la cartographie des végétaux marins. La Mer, 27: 144-145.

Belsher, T., Meinesz, A., Lefèvre J.R. & C-F, Boudoureque. 1988. Simulation of SPOT satellite for charting shallow-water benthic communities in the Mediterranean. Marine Ecology P.S.Z.N., 9: 157-165.

Boudouresque, C-F., Charbonel, E., Meinesz, A., Pergent, G., Pergent-Martini, C., Cadiou, G., Bertrandy, M.C., Foret, P., Ragazzi, M. & V. Rico-Raimondino. 2000. A monitoring network based on the seagrass *Posidonia oceanica* in the northwestern Mediterranean Sea. Biologia Marina Mediterranea, 7: 328-331.

Calvo, S., Frada Osterano, C. & P. Abbadessa. 1993 The suitability of a topographical instrument for an integrated approach to the cartography of *Posidonia oceanica* meadows. Oceanologica Acta, 16: 273-278.

Colantoni, P., Gallignani, P., Fresi, E. & F. Cinelli. 1982. Patterns of *Posidonia oceanica* (L.) Delile beds around the Island of Ischia (Gulf of Naples) and in adjacent waters. Marine Ecology P.S.Z.N., 3: 53-74.

Coles, R.G., Lee Long, W.J., Watson, R.A. & K.J. Derbyshire. 1993. Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns Harbour, a tropical estuary, northern Queensland, Australia. Aust. J. Mar. Freshwater. Res., 44: 193-210.

Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S, Bergstrom, P.W. & R.A. Batiuk. 1993 Assessing water quality with submerged aquatic vegetation: Habitat requirements as barometers of Chesapeak Bay health. BioScience, 43: 86-94.

Duarte, C. M. 1987. Use of echosounder tracings to estimate the above ground biomass of submerged plant in lakes. Can. J. Fish. Aquat. Sci., 44: 732-735.

Duarte, C.M. 1991. Seagrass depth limits. Aquat. Bot., 40: 363-377.

Fredj, G., Meinardi, M., Pierrot, S. & P. Roy. 1990. Cartographie par le satellite SPOT 1 de communautés benthiques littorales en Méditerranée occidentale. Bull. Inst. Oceanogr., 6: 71-85.

Gloux, B. 1984. Méthode acoustiques et informatiques appliquées à la cartographie rapide et détaillée des herbiers. In Boudouresques C.-F., Jeudy de Grissac A, Olivier J. (eds.) International Workshop on *Posidonia oceanica* Beds. GIS Posidonie Press, Marseille. Pp. 45-48.

Hashimoto, T. & M. Nishimura. 1953. Sounding of artificial schools, rocksand, sea plants fields by fish finder. Tech. Rep. Fishing Boat, 4: 138-142 (In Japanese).

Hashimoto, T. & M. Nishimura. 1953. Study on detection of Japanese tang field by the ultrasonic fish-finder. Tech. Rep. Fishing Boat, 5: 187-194 (In Japanese).

Hatakeyama, Y. & Y. Maniwa. 1978. On the investigation of seaweed distribution by utilizing the fish finder. Tech. Rep. Fishing Boat, 73: 155-168 (In Japanese).

Hoshino, Y. 1972. Pollution in the Seto Inland Sea. Iwanami, Tokyo. Pp.1-202 (In Japanese).

Jeudy de Grissac, A. & C-F Boudoureque. 1985. Rôle des herbiers de Phanérogames marines dans les mouvements des sédiments côtiers : les herbiers à *Posidonia oceanica*. In Ceccaldi HJ, Champalbert G. (eds.) Acte du colloque pluridisciplinaire franco-japonais d'Océanographie Fiscicule 1, Société Franco-japonaise d'Océanographie, Marseille. Pp.143-151.

Kirkman, H. 1990. Seagrass distribution and mapping. In Phillips RC, McRoy CP (eds.) Seagrass research methods. Monographs on oceanographic methodology, UNESCO, Paris. Pp.19-25.

Kitoh, H. 1983. Seaweed beds research by a scientific echosounder. Seikai Reg. Fish. Res. Inst. News, 43: 2-4 (In Japanese).

Komatsu, T. 1985. Temporal fluctuations of water temperature in a Sargassum forest, J. Oceanogr. Soc. Japan, 41: 235-243.

Komatsu, T. 1989. Day-night reversion in the horizontal distributions of dissolved oxygen content and pH in a *Sargassum* forest. J. Oceanogr. Soc. Japan, 45: 106-115.

Komatsu, T. & H. Kawai. 1986. Diurnal changes of pH distributions and the cascading of shore water in a *Sargassum* forest. J. Oceanogr. Soc. Japan, 42: 447-458.

Komatsu, T. & S. Murakami. 1994. Influence of a *Sargassum* forest on the spatial distribution of water flow, Fish. Oceanogr., 3: 256-266.

Komatsu, T. & M. Nakaoka. 2000. Water flow and sedimentation rate in seagrass beds off Khao Bae Na in Trang Province, Thailand. Biologia Marina Mediterranea, 7: 240-242.

Komatsu, T. & K. Tatsukawa. 1998. Mapping of Zostera marina L. beds in Ajino Bay, Seto Inland Sea, Japan, by using echosounder and global positioning systems. J. Recherche Océanogr., 23: 39-46.

Komatsu, T. & H. Yamano. 2000. Influence of seagrass vegetation on bottom topography and sediment distribution on a small spatial scale in the Dravuni Island Lagoon, Fiji. Biologia Marina Mediterranea, 7: 243-246.

Komatsu, T., H. Ariyama, H. Nakahara & W. Sakamoto. 1982. Spatial and temporal distributions of water temperature in a *Sargassum* forest, J. Oceanogr. Soc. Japan, 38, 63-72.

Komatsu, T., Igarashi, C., Tatsukawa, K. & Y. Matuoka. (Submitted). Mapping seagrass meadows using a multi-beam sonar.

Komatsu, T., Kawai, H. & W. Sakamoto. 1990. Influences of *Sargassum* forest on marine environments. Bull. Costal Oceanogr., 27: 115-126 (In Japanese with English abstract).

Komatsu, T., S. Murakami & H. Kawai. 1994. Some features of jump of water temperature in a *Sargassum* forest, J. Oceanogr., 52, 109-124.

Lee Long, W.J., Mckenzie, L.J., Rasheed, M.A. & R.G. Coles. Monitoring seagrasses in tropical ports and harbours. In Kuo J, Phillips RC, Walker DI, Kirkman H (eds.) Seagrass biology: Proceedings of an international workshop Rottnest Island, Western Australia, 25-29 January 1996. Fac. Sci. Univ. West., Australia, Western Australia, Nedlands. Pp. 345-350.

Lefèvre, J.R., Meinesz, A. & B. Gloux. 1984. Premières données sur la comparaison de trois méthôdes de cartographie des biocénoses marines. Rapport PV Reun. Comm. Internation. Explor. Sci. Medit., 29: 209-211.

Long, B.G., Skews, I.D. & I.R. Pointer, I.R. 1994. An efficient method for estimating seagrass biomass. Aquat. Bot., 47: 277-292.

Meinesz, A. 1977. Balisage de la limite inférieure de l'herbier de *Posidonia oceanica* en rade de Villefranche-sur-Mer (Alpes-Maritimes, France) Rapport P. V. Réunion Comm. Int. Explor. Sci. Medit., 24: 143-144.

Meinesz, A., & R. Laurent. 1978. Cartographie et état de la limite inférieure de l'herbier de *Posidonia oceanica* dans les Alpes-maritimes (France) -Campagne Poseidon 1976-. Botanica Marina, 21: 513-526.

Meinesz, A. Cuvelier, M. & R. Laurent. 1981. Méthode récentes de cartographie et de surveillance des herviers de Phanérogames marines. Vie et Milieu, 31: 27-34.

Meinesz, A., Boudouresque, C-F. & J.R. Lefèvre. 1988. A map of the *Posidonia oceanica* beds of Marina d'Elbu (Corsica, Mediterranean). Marine Ecology P.S.Z.N., 9: 243-252.

Meulstee, C., Nienhuis, P.H. & T.C. Van Stokkom. 1986. Biomass assessment of estuarine macrophytobenthos using aerial photography. Mar. Biol., 91: 331-335.

Mork, M. 1996. The effect of kelp in wave damping. SARSIA, 80: 323-327.

Newton, R.S. & A. Stefanon. 1975. Application of side scan sonar in marine biology. Mar. Biol., 31: 287-291.

Norris, J.G., Wyllie-Echeverria, S., Mumford, T., Bauley, A. & T. Turner. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquat. Bot., 58: 269-287.

Orth, R.J., Heck, K.L.J. & J. Van Monfrans. 1984. Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predatory-prey relationships. Estuaries, 7: 339-350.

Pasqualini, V. & C. Pergent-Martini. 1996. Monitoring of *Posidonia oceanica* meadows using image processing. In Kuo J, Phillips RC, Walker DI, Kirkman H (eds.) Seagrass biology: Proceedings of an international workshop Rottnest Island, Western Australia, 25-29 January 1996. Fac. Sci. Univ. West., Australia, Western Australia, Nedlands. Pp. 351-358.

Pasqualini, V., Pergent-Martini, C., Clabaut, P. & G. Pergent. 1998. Mapping of *Posidonia oceanica* using aerial photographs and side scan sonar: Application off Island of Corsica (France). Estuarine Coast. Shelf Sci., 47: 359-367.

Ramos, M.A. & A. Ramos-Espla. 1989. Utilization of acoustic methods in the cartography of the *Posidonia oceanica* bed in the bay of Alicante (SE, Spain). Posidonia Newsletter, 2: 17-19.

Rey, J. & V. Diaz del Rio. 1989. Cartographia de los fondos marinos de la Bachia de Palma (Baleares, Espana): Distribution de las praderas vegetales y sedimentos superficiales. In Boudouresques C-F, Meinesz A, Fresi E, Gravez V (eds.), International Workshop on Posidonia beds 2 GIS. Posidonie Press, Marseille. Pp. 29-41.

Short, F. & S. Willie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation, 23: 17-27.

Tanaka, M. & K. Tanaka. 1985. On the estimation of the abundance of seaweed in coastal area I, estimation by echosounder. Fisheries Civil Engineering, 21: 17-23 (In Japanese).

Ward, L.G., Kemp, W.M. & W.R. Boyton. 1984. The influence of waves and seagrass communities on suspended particulates in an estuarine embayment. Mar. Geo., 59: 85-103.
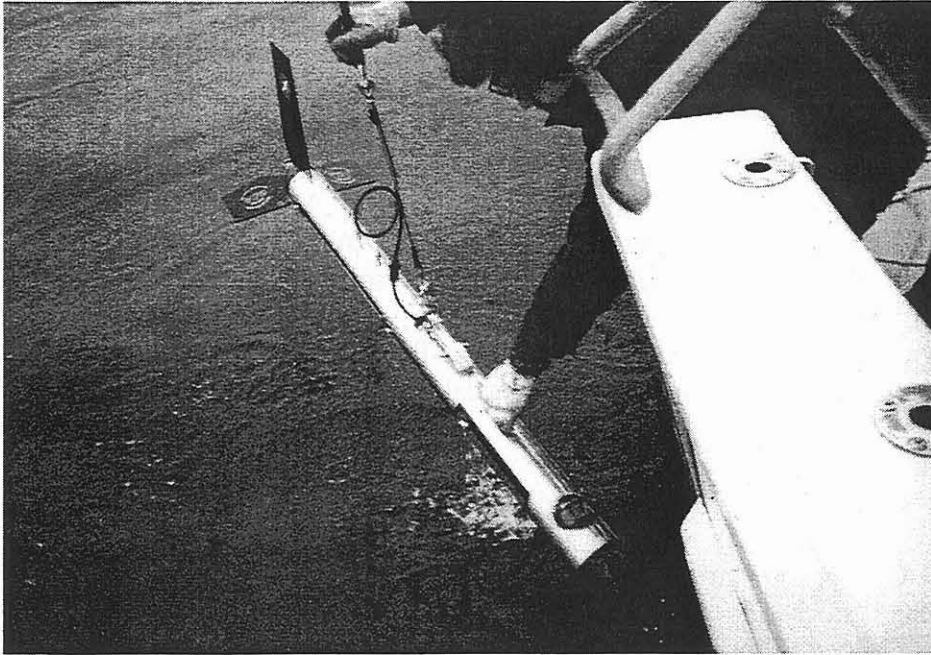
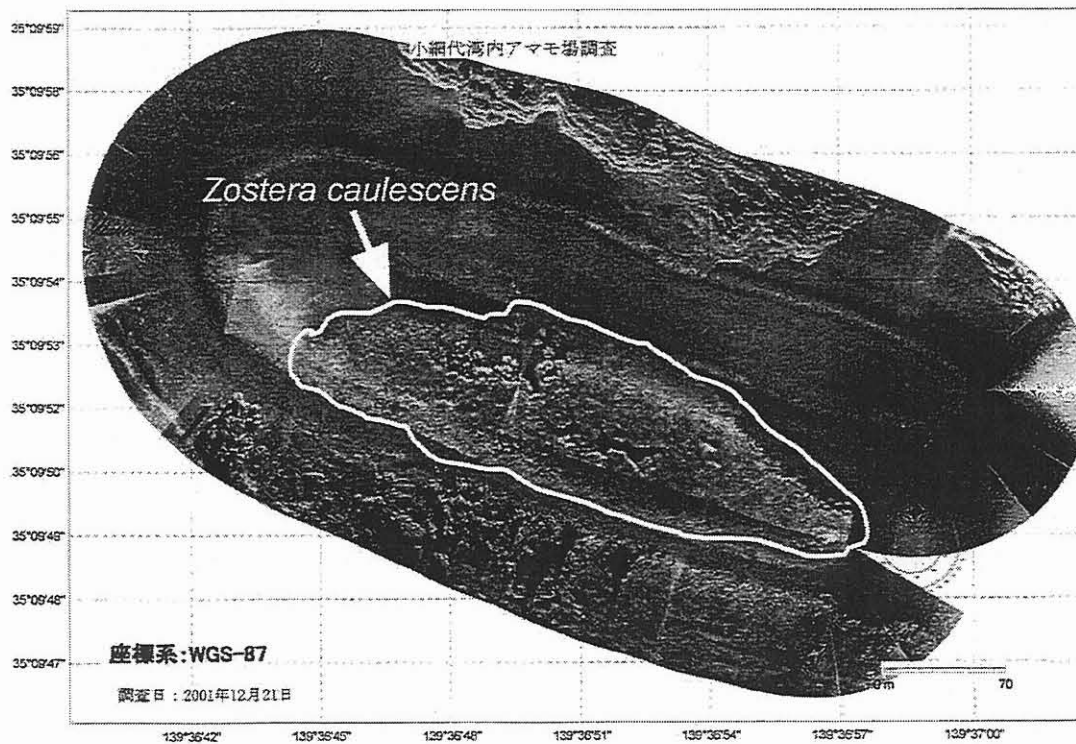Figure 1. Picture showing towing transducer of side-scan sonar photographed by Komatsu.

Figure 2. Map showing horizontal distribution of Zostera caulsecens surveyed by side-scan sonar photographed by Komatsu.
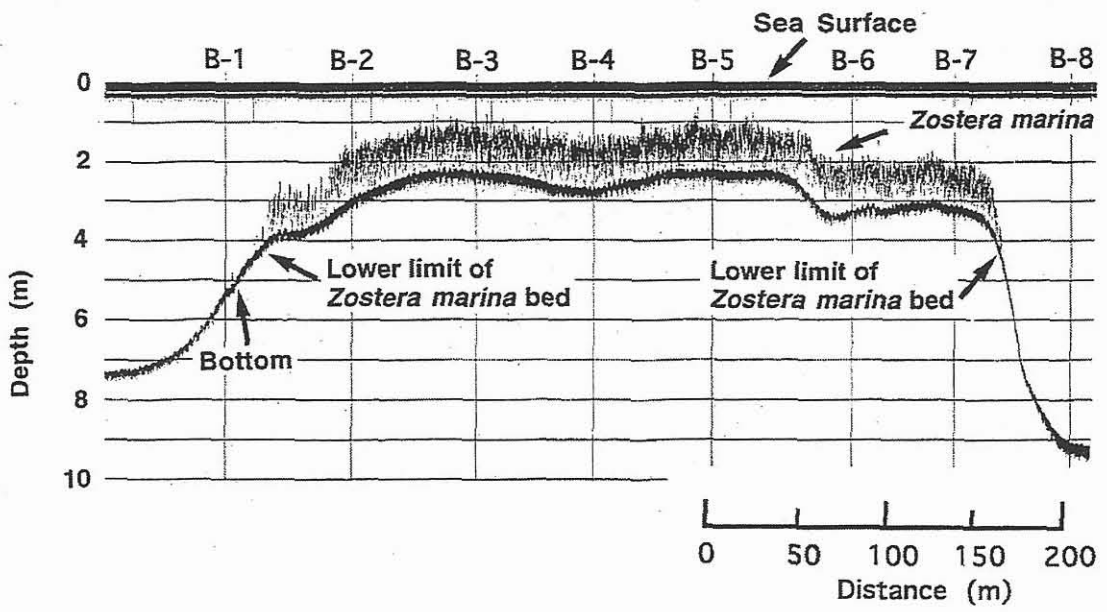
Figure 3. Raw records of echo trace along a transact in Ajino Bay, Japan cited from Komatsu and Tatsukawa (1998). A depth of 0 m is the sea surface, which is not standardized to the depth relative to the mean sea level.
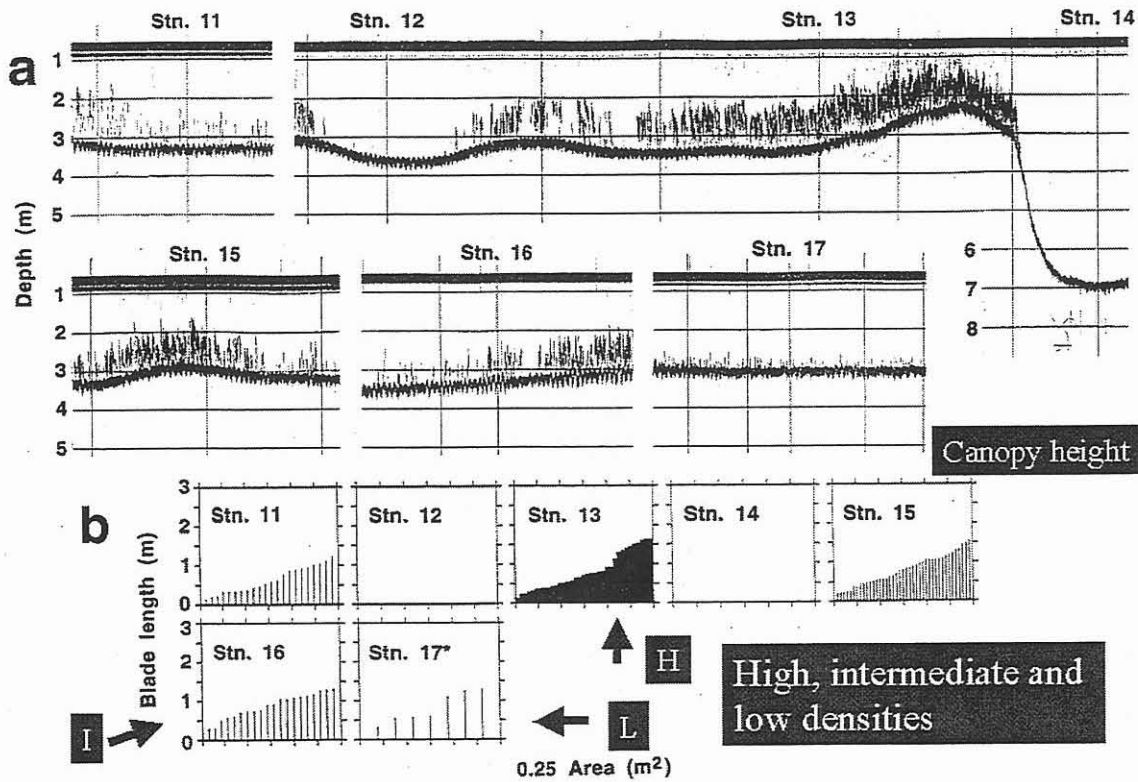
Figure 4. Echogram (upper panels) and blade length distribution (lower panels) obtained by a quadrat sampling at Stations 10-17 (Komatsu and Tatsukawa, 1998). *: Echograms are not shown due to no seagrass. Grades of echo traces of seagrass beds were shown at the lower part of the vertical line representing the station by the following characters: G1: Grade 1 (no seagrass); G2: Grade 2 (sparse seagrass); G3: Grade 3 (intermediate dense seagrass); G4: Grade 4 (dense seagrass). Blades lengths are shown as vertical lines from the smallest one to the largest one in order in each figure at the stations (lower panels).
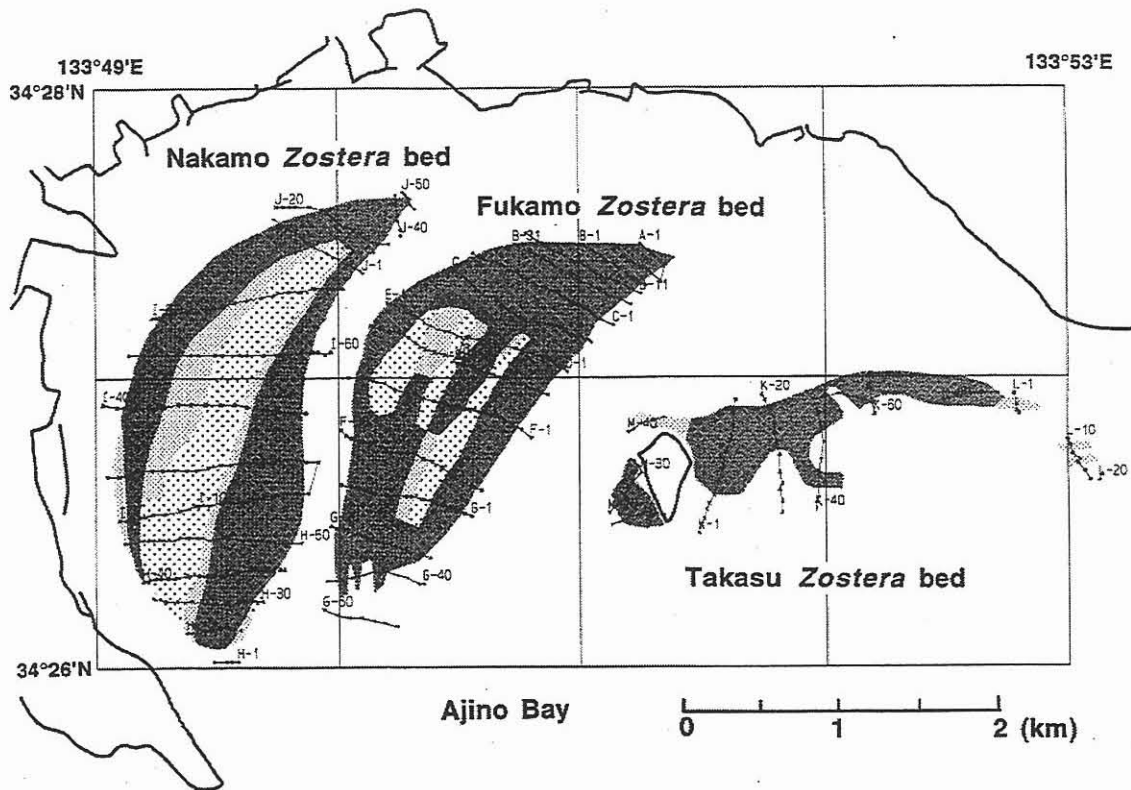
Figure 5. Estimated bed distribution of seagrass beds in Ajino Bay (Komatsu and Tatsukawa, 1998). Density of seagrass beds is indicated by the following patterns: open area: no seagrass (Grade 1); coarse dotted area: sparse seagrass (Grade 2); intermediate dense dotted area: intermediate dense seagrass (Grade 3); dense dotted area: dense seagrass (Grade 4).
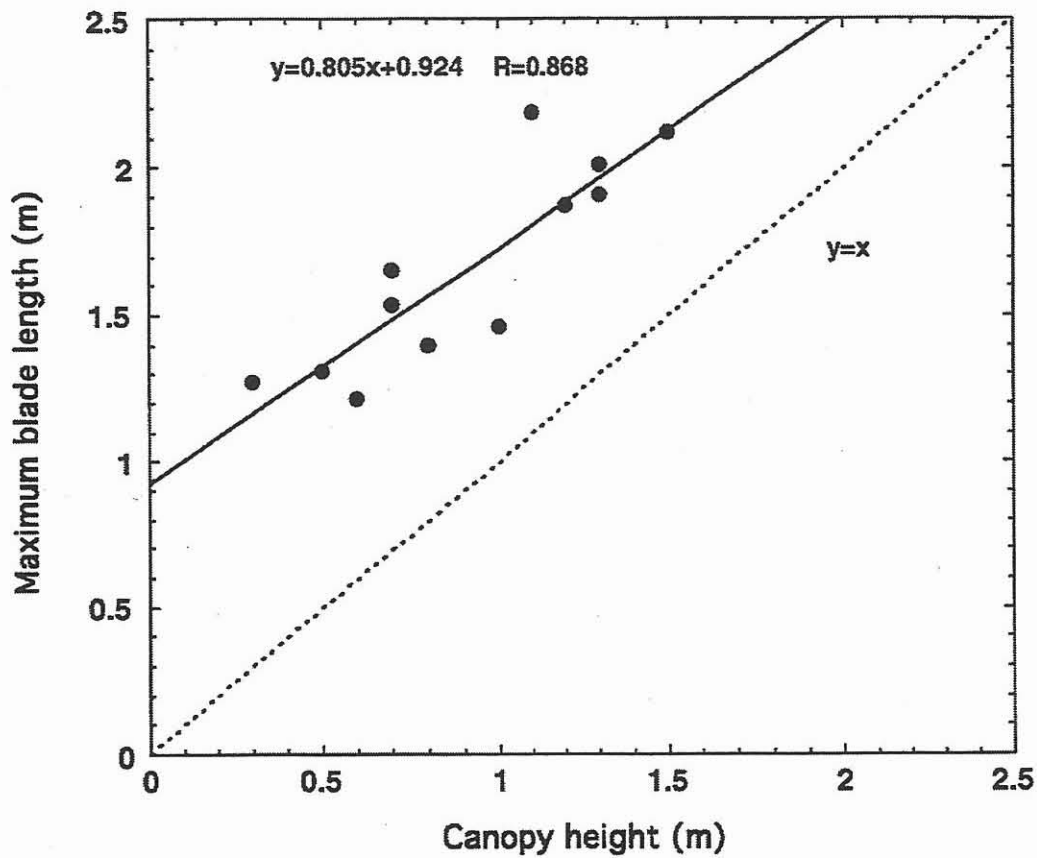
Figure 6. Regression between the canopy height and the maximum blade length at the stations where the quadrat sampling of seagrass was done (Komatsu and Tatsukawa, 1998). Solid line and broken line represent linear regression line and a line with a slope of 1.0 and an intercept of 0, respectively.
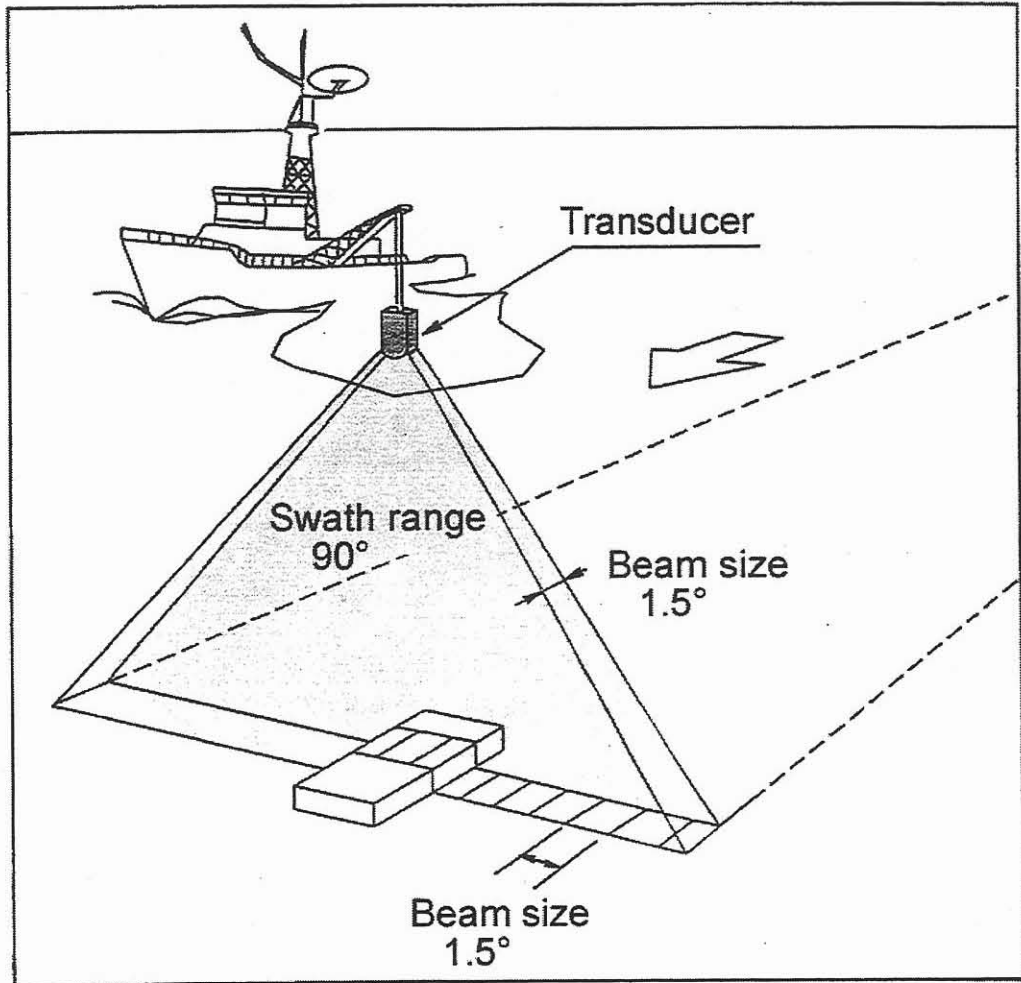
Figure 7. Multi-beam sonar system surveying precise bottom topography for mapping
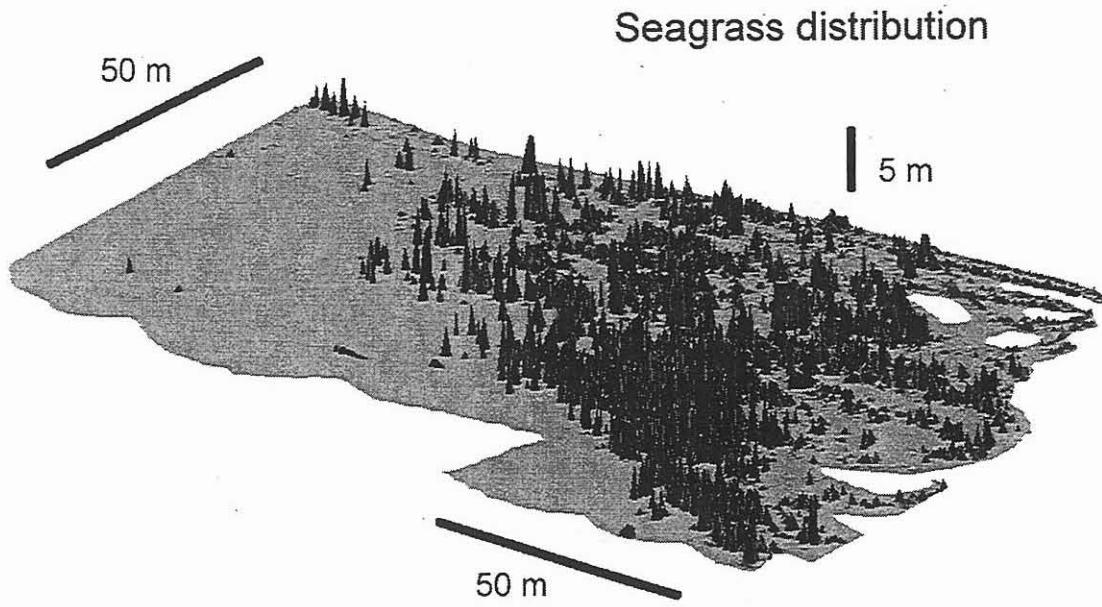seagrass beds (Komatsu et al., submitted).

Figure 8. Three-dimensional distribution of seagrass beds in Otsuchi Bay (Komatsu et al., submitted).