OTSUCHI MARINE SCIENCE 28: 72–79 (2003)

Hydro-acoustic methods as a practical tool for cartography of seagrass beds

Teruhisa Komatsu[1] *, Atsuko Mikami[1], Sayeeda Sultana[1], Kenichi Ishida[1], Tomonori Hiraishi[2]
and Ken-ichi Tatsukawa[1]

[1] *Ocean Research Institute, The University of Tokyo, 1–15–1, Minamidai, Nakano-ku, Tokyo, 164–8639, Japan*
** E-mail: komatsu@ori.u-tokyo.ac.jp*
[2] *Graduate School of Fisheries Science, Hokkaido University,*
3–1–1, Minatocho, Hakodate 041–8611, Japan

Received: 4 January 2003
Accepted: 17 February 2003

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 an echosounder and a 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.

Key words: seagrass, cartography, 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 temperatue distribution and change (Komatsu et al., 1982; Komatsu, 1985; Komatsu et al., 1994). It is possble that seagrass beds excert 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). Dugons 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 30–50 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 obtained by the side-scan sonar. The patch structure are 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 content in 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 al., 1981; Hatakeyama and Maniwa, 1978),

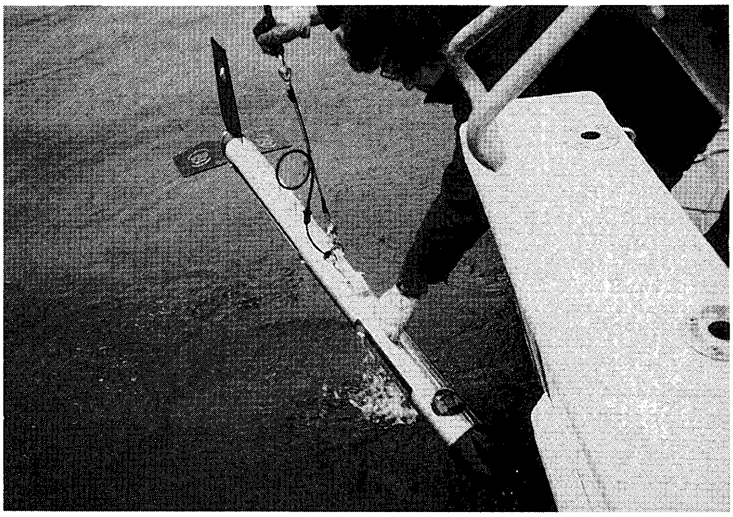

Fig. 1. Picture showing towing transducer of side-scan sonar photographed by T. Komatsu.

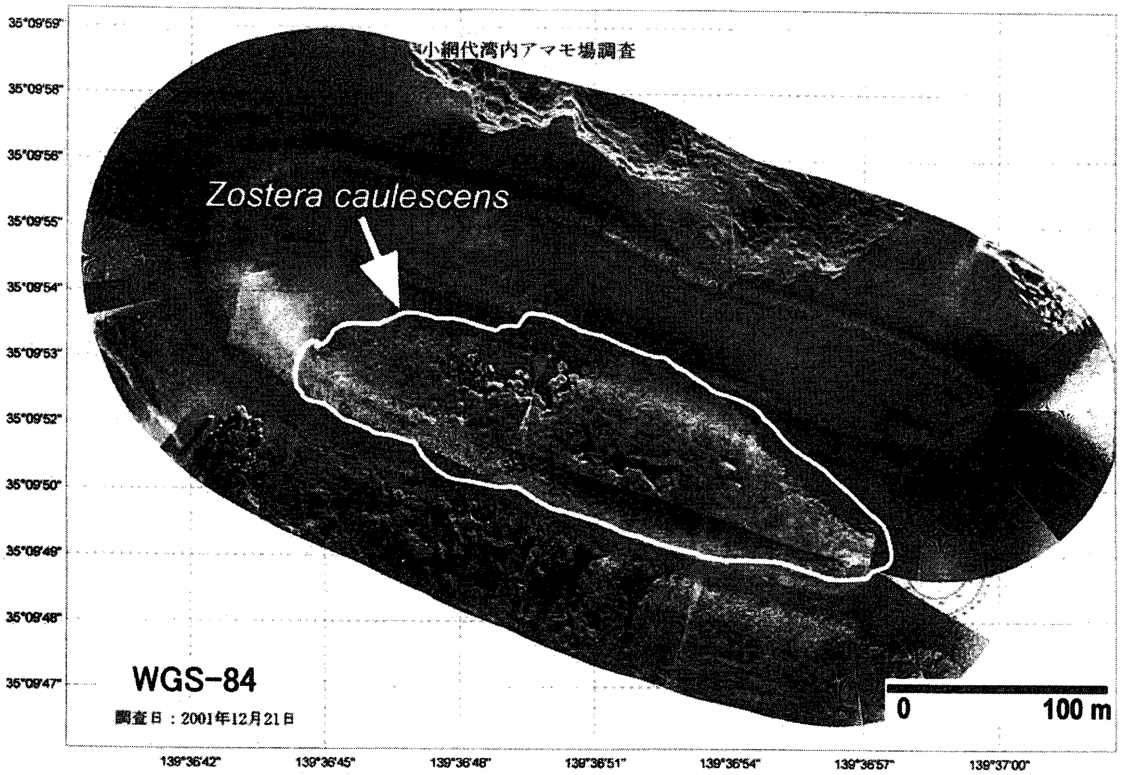

Fig. 2. Map showing horizontal distribution of *Zostera caulsecens* surveyed with side-scan sonar by T. Komatsu.

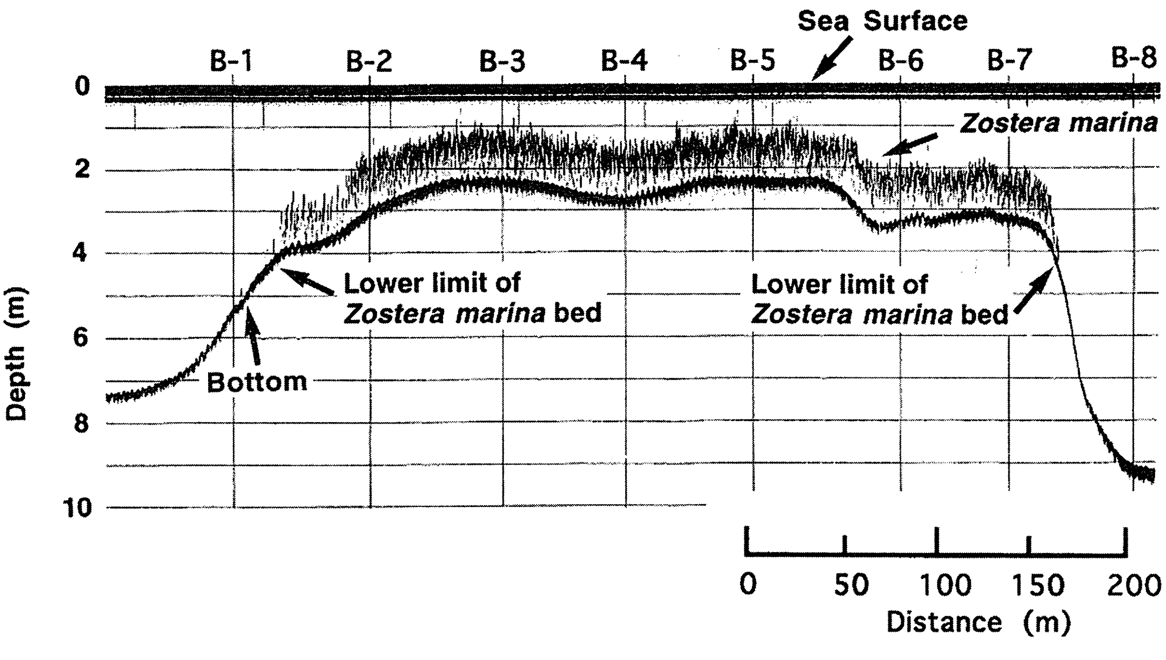

Fig. 3. Raw records of echo trace along a transact in Ajino Bay, Japan cited from Komatsu and Tatsukawa (1998). A depth of 0 m is the sea surface, which is not standardized to the depth relative to the mean sea level.

DECCA (Meinesz et al., 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

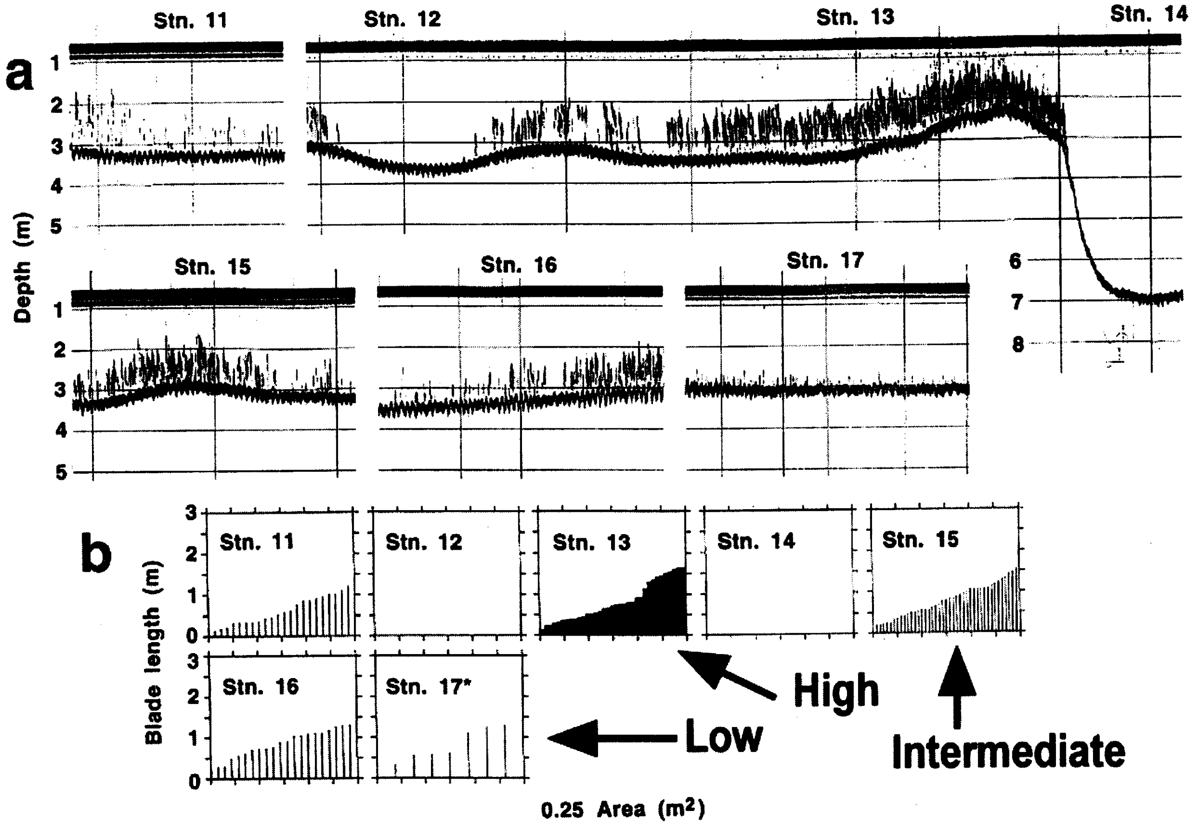

Fig. 4. Echogram (upper panels) and blade length distribution (lower panels) obtained by a quadrat sampling at Stations 10–17 (Komatsu and Tatsukawa, 1998). Blades lengths per 0.25 m^2 are shown as vertical lines from the smallest one to the largest one in order in each figure at the stations (lower panels). *: Blade length distribution per m^2. No seagrass was found at Stations 12 and 14. Arrows with "High, intermediate and low" show blade densities.

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 quadrat 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.

MAPPING OF 3-DIMENSIONAL DISTRIBUTION

Usually multi-beam sonar has been used to sound bottom topography, especially, harbors and channels. Komatsu et al. (submitted) developed mapping methods using multibeam sonar that can send several decadal beams from the transducer and measure the bottom depths (Fig. 7). Since computer processing removes acoustic signals reflected by the seagrass on a basis of the height difference between the sand bottom and seagrass (Fig. 8), they obatin distributions of seagrass beds by subtracting the bottom topography without seagrass from that with seagrass (Fig. 9). It is the first time to calculate volume occupied by the seagrass. In

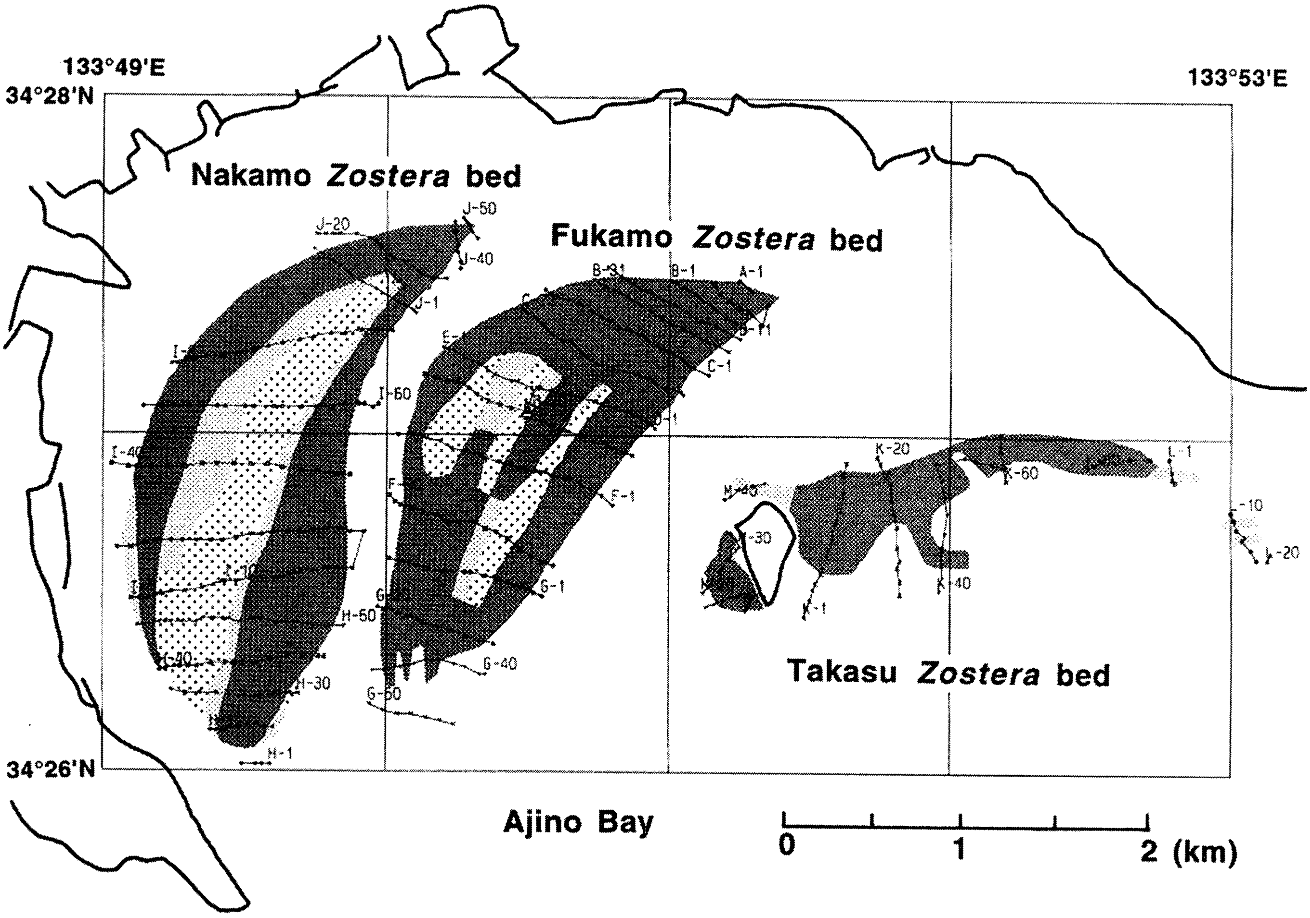

Fig. 5. Estimated bed distribution of seagrass beds in Ajino Bay (Komatsu and Tatsukawa, 1998). Density of seagrass beds is indicated by the following patterns: open area: no seagrass; coarse dotted area: sparse seagrass with low blade density; intermediate dense dotted area: intermediate dense seagrass with intermediate blade density; dense dotted area: dense seagrass with high blade density.

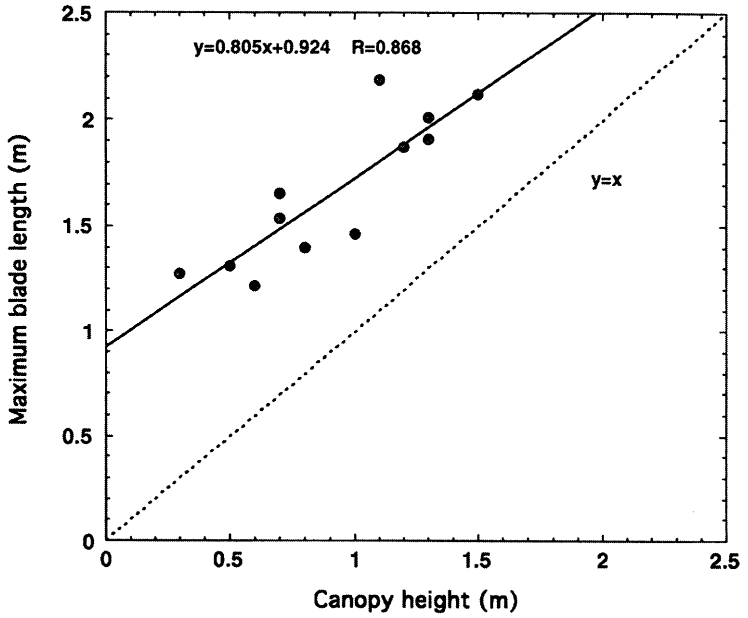

Fig. 6. Regression between the canopy height and the maximum blade length at the stations where the quadrat sampling of seagrass was done (Komatsu and Tatsukawa, 1998). Solid line and broken line represent linear regression line and a line with a slope of 1.0 and an intercept of 0, respectively.

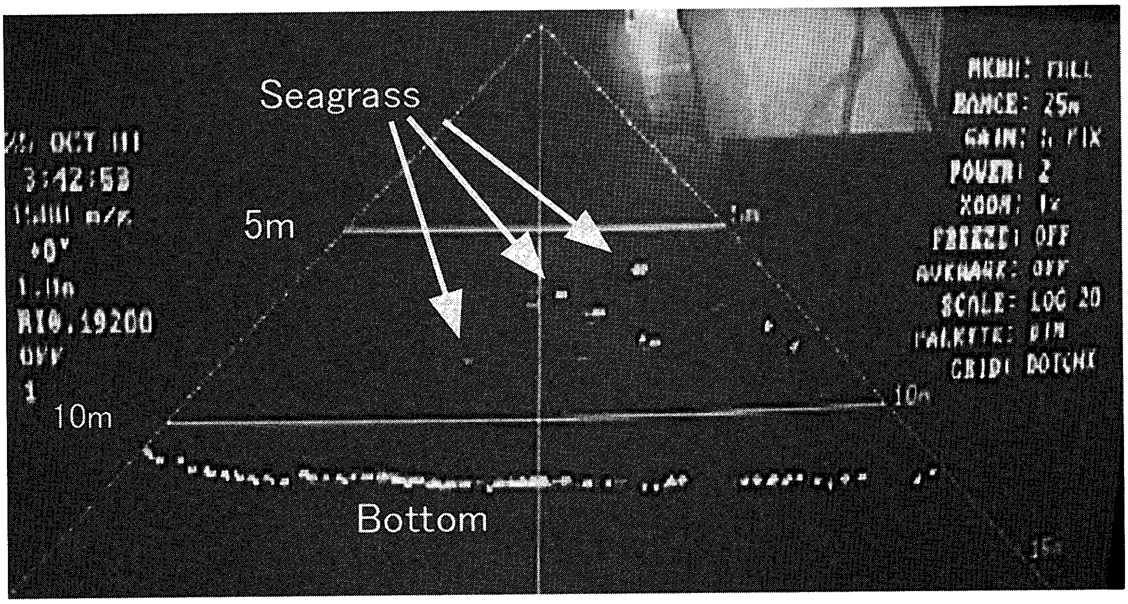

Fig. 7. Echo image of vertical profile of segrass beds scaned by the multi-beam sonar (Komatsu et al., submitted). White dots represent bottom and seagrass canopy.

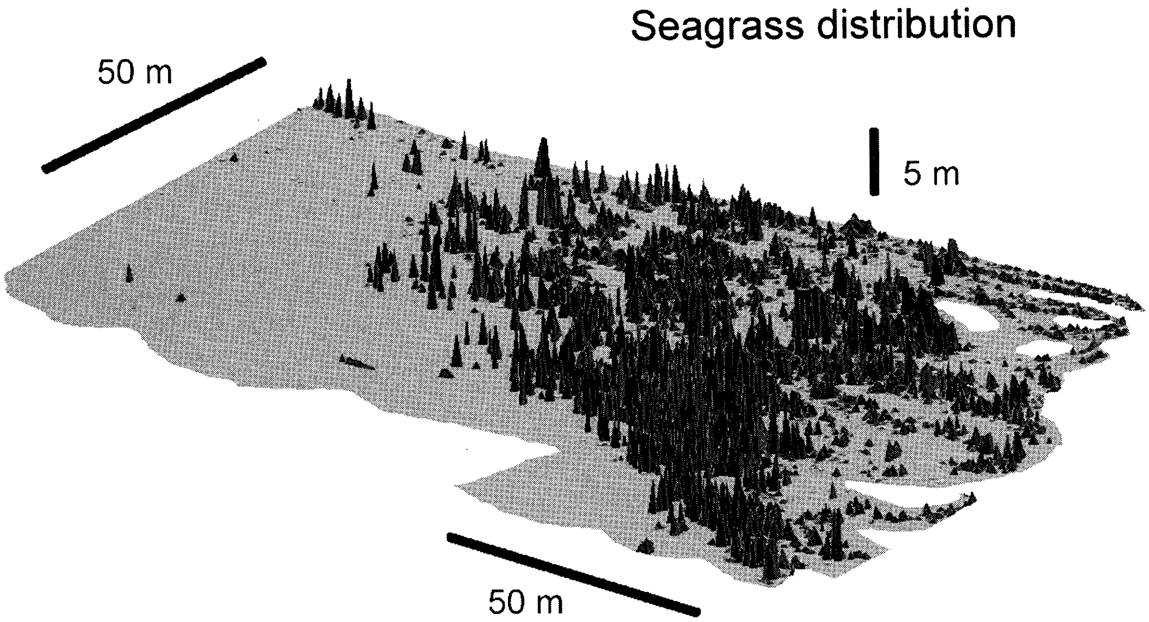

Fig. 8. Three-dimensional distribution of seagrass beds off Nebama in Otsuchi Bay (Komatsu et al., submitted).

corporated with quadrat sampling of seagrass, biomass of seagrass is also estimated.

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

We thank to Dr. T. Nishida of National Institute for Far Seas Fisheries for his critical reading of our manuscript.

REFERENCES

Arasaki, M. and Arasaki, T. 1978. Compilation of stories on algae.

Tokai University Press, Tokyo (in Japanese).

Belsher, T. 1988. Apports du satellite SPOT à la cartographie des végétaux marins. La Mer 27: 144–145.

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

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

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

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

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

Dennison, W. C., Orth, R. J., Moore, K. A., Stevenson, J. C., Carter, V., Kollar, S, Bergstrom, P. W. and Batiuk, R. A. 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. and Roy, P. 1990. Cartographie par le satellite SPOT 1 de communautés benthiques littorales en Méditerranée occidentale. Bull. Inst. Oceanogr. Monaco. 6: 71–85.

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

Hatakeyama, Y. and Maniwa, Y. 1978. On the investigation of seaweed distribution by utilizing the fish finder. Tech. Rep. Fish. Boat 73: 155–168 (in Japanese).

Hoshino, Y. 1972. Pollution in the Seto Inland Sea. Iwanami, Tokyo (in Japanese).

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

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

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. Jpn. 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. and Kawai, H. 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. and Murakami, S. 1994. Influence of a *Sargassum* forest on the spatial distribution of water flow, Fish. Oceanogr. 3: 256–266.

Komatsu, T. and Nakaoka, M. 2000. Water flow and sedimentation rate in seagrass beds off Khao Bae Na in Trang Province, Thailand. Biol. Mar. Mediterr. 7: 240–242.

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

Komatsu, T. and Yamano, H. 2000. Influence of seagrass vegetation on bottom topography and sediment distribution on a small spatial scale in the Dravuni Island Lagoon, Fiji. Biol. Mar. Mediterr. 7: 243–246.

Komatsu, T., H. Ariyama, H. Nakahara and Sakamoto W. 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. and Matuoka, Y. (submitted) Mapping seagrass meadows using a multi-beam sonar.

Komatsu, T., Kawai, H. and Sakamoto, W. 1990. Influences of *Sargassum* forest on marine environments. Bull. Coast. Oceanogr. 27: 115–126 (in Japanese with English abstract).

Komatsu, T., Murakami, S., and Kawai, H. 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. and Coles, R. G. 1996. Monitoring seagrasses in tropical ports and harbours. *In* Seagrass biology: Proceedings of an international workshop Rottnest Island, Western Australia, 25–29 January 1996. Kuo, J, Phillips, RC, Walker DI. and Kirkman, H. (eds), pp. 345–350, Faculty of Science, The University of Western Australia, Nedlands.

Lefèvre, J. R., Meinesz, A. and Gloux, B. 1984. Premières données sur la comparaison de trois méthôdes de cartographie des biocénoses marines. Rapp. P. V. Réunion Comm. Int. Explor. Sci. Mer Mediterr. 29: 209–211.

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

Meinesz, A. 1997. Balisage de la limite inférieure de l'herbier de *Posidonia oceanica* en rade de Villefranche-sur-Mer (Alpes-Maritimes, France) Rapp. P. V. Réunion Comm. Int. Explor. Sci. Mer Mediterr. 24: 143–144.

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

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

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

Meulstee, C., Nienhuis, P. H. and Van Stokkom, T. C. 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. and Stefanon, A. 1975. Application of side scan sonar in marine biology. Mar. Biol. 31: 287–291.

Norris, J. G., Wyllie-Echeverria, S., Mumford, T., Bauley, A. and

Turner, T. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquat. Bot. 58: 269–287.

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

Pasqualini, V. and Pergent-Martini, C. 1996. Monitoring of *Posidonia oceanica* meadows using image processing. *In* Seagrass biology: Proceedings of an international workshop Rottnest Island, Western Australia, 25–29 January 1996. Kuo, J, Phillips, RC, Walker, DI. and Kirkman, H. (eds), pp. 351–358, Faculty of Science, The University of Western Australia, Nedlands.

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

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

Short, F. and Willie-Echeverria, S. 1996. Natural and human-induced disturbance of seagrasses. Environ. Conserv. 23: 17–27.

Tanaka, M. and Tanaka, K. 1985. On the estimation of the abundance of seaweed in coastal area I, estimation by echosounder. Fish. Civil Eng. 21: 17–23 (in Japanese).

Ward, L. G., Kemp, W. M. and Boyton, W. R. 1984. The influence of waves and seagrass communities on suspended particulates in an estuarine embayment. Mar. Geol. 59: 85–103.