Kuroshio Science **3**-1, 39-44, 2009

Status of Seagrass Ecosystems in the Kuroshio Region – Seagrass decline and challenges for future conservation –

Yohei Nakamura*
Graduate School of Kuroshio Science, Kochi University
(200 Monobe, Nankoku, Kochi 783-8502, Japan)

Abstract
Seagrass beds, a major feature of shallow marine and estuarine areas in tropical and temperate zones worldwide, play important ecological roles, including provision of oxygen, sediment stabilization, seawater purification, and provision of nursery habitats for many fishes and crustaceans, including some commercially important species. In recent years, however, seagrass beds have drastically declined worldwide, mainly due to anthropogenic impacts (e.g. marine pollution) resulting from increased coastal populations. The decline of a seagrass bed often affects not only immediate populations of seagrass bed-associated organisms but also those in other habitats, thereby having potentially negative influences on biodiversity and local fisheries. In order to protect seagrass ecosystems, environmental education, management of human activities that stress seagrass ecosystems, and establishment of appropriately protected areas, are urgently required.

Key words: conservation, fish, habitat connectivity, human impacts, seagrass decline

Introduction

Seagrasses are vascular plants that grow on shallow sandy substrates along coastal margins in tropical, temperate and subarctic marine waters. About 60 species are known to date, 21 having been recorded from the Kuroshio region, ranging from the Philippines to Japan (Green and Short, 2003; Kuo et al., 2006). Such a high species richness is probably related to the Kuroshio current that extends from the centre of seagrass origin in Malaysian/Indonesian waters (Mukai, 1993).

Seagrass beds function variously in coastal ecosystems (see reviews by Hemminga and Duarte, 2000; Duarte, 2002). Seagrasses absorb carbon dioxide from and provide oxygen to water and sediments through photosynthesis, in addition to the roots stabilizing sediments and the leaves preventing eutrophication of sea water by trapping suspended solids and absorbing inorganic salts, thereby contributing to water purification in coastal regions. Seagrasses also constitute important food resources for herbivores, such as fishes, sea urchins, turtles and dugongs. Furthermore, seagrass beds are used as habitats by various animals, such as crabs, shrimps and fishes, including some commercially important species.

Although seagrass ecosystems are widely recognized as important features of coastal zones, seagrass decline is a common worldwide phenomenon, including in the Kuroshio region. Accordingly, an understanding of seagrass ecosystems and the impacts of anthropogenic stressors on them is urgently required, being a basic requirement for effective management and conservation of such ecosystems and regional fisheries resources. This paper provides a review of recent research on seagrass ecosystems, with special reference to the Kuroshio region, and discusses future challenges for their conservation.

1. Seagrass Ecosystems in the Kuroshio region

Seagrasses, which can form dense submerged vegetation, increase the available substrate surface for inhabiting fauna, such provision of shelter and living space being amongst the most important functions of the bed (Nakaoka, 2005). Differentiation of the plant body into leaves, stems, rhizomes and roots increases the microhabitat diversity, enabling the support of a greater diversity of animals compared to unvegetated bare substrata (e.g., Connolly, 1994; Edgar and Shaw, 1995a; Horinouchi and Sano, 1999; Nakamura and Sano, 2004). In general,

*Corresponding author: e-mail ynakamura@kochi-u.ac.jp

polychaetes and small crustaceans, such as harpacticoid copepods, gammaridean amphipods and tanaids are dominant invertebrates in seagrass beds in American and Australian waters (e.g., Howard *et al*., 1989; Edgar and Shaw, 1995a), and similarly so off Japan (e.g., Kikuchi, 1966; Nakaoka *et al*., 2001; Nakamura and Sano, 2005; Yamada et al., 2007).

The diets of fish assemblages in seagrass beds have been examined at numerous locations worldwide (e.g., Bell and Pollard, 1989; Edgar and Shaw, 1995b), including a few in the Kuroshio region. Kikuchi (1966) and Horinouchi and Sano (2000) investigated the food habits of fishes collected in *Zostera marina* beds, and found that small crustacean feeders and planktonic-animal feeders were the most abundant by number, the most important food item for the seagrass fish assemblage being gammaridean amphipods, calanoid copepods and errant polychaetes. Nakamura *et al*. (2003) also found a dominance of small-crustacean feeders in an *Enhalus acoroides*-dominated bed in the southern Ryukyu Islands. However, compared with the *Zostera* bed fishes, the latter fish assemblage was characterized by higher species numbers of detritivores, herbivores and piscivores, and fewer planktonic-animal feeders.

On the basis of the relative abundance and occurrence of fish species in *Zostera marina* beds in Japan, Kikuchi (1966) classified species as (1) permanent residents – fishes residing all year, (2) seasonal residents – fishes residing only for a season or life history stage, (3) transients – fishes occurring in the bed in the course of foraging over a variety of habitats, and (4) casual species – fishes appearing only occasionally in the seagrass habitat. Similar classifications were adopted to describe fish-seagrass associations elsewhere in temperate (see reviews by Kikuchi, 1982; Horinouchi, 2003) and tropical seagrass beds (Kochzius, 1999; Nakamura and Tsuchiya, 2008) (Fig. 1) in the Kuroshio region.

Many of the seasonal residents that use seagrass beds as nursery or juvenile habitats (Beck *et al*., 2001) are important commercial species (Jackson *et al*., 2001). In the Kuroshio region, seagrass beds in the Ryukyu Islands are clearly utilized temporally for juvenile habitats by a number of coral reef fishes, including commercially valuable species of Scaridae, Siganidae, Lutjanidae and Lethrinidae (Kanashiro *et al*., 1999; Nakamura and Tsuchiya, 2008). Similar circumstances exist in the Philippines seagrass beds (Kochzius, 1999). On the other hand, temperate zone seagrass beds off the Japanese coast provide nursery areas for commercial species such as *Pagrus major*, *Sebastes oblongus*, and *Lateolabrax japonicus* (Kikuchi, 1974, 1982). These phenomena illustrate the importance of seagrass beds for the production of fishery resources in the Kuroshio region.

2. Seagrass Decline in the Kuroshio Region

Seagrass beds are presently declining in tropical and temperate zones worldwide (Orth *et al*., 2006), the documented loss of seagrass from direct and indirect human impact amounting to 33,000 km^2 (18% of the documented global seagrass area) over the last two decades (Walker *et al*., 2006). The main factor in the destruction of seagrass beds around the world is human disturbance, including coastal development and the worsening of water quality (Orth *et al*. 2006), amounting to more than 70% of total global seagrass bed loss during 1970-1994 (Short and Wyllie-Echeverria, 1996).

The Environmental Agency and Marine Parks Center of Japan (1994) reported seagrass areas in Japan as extending over 51,541 ha in 1978, reducing to 49,464 ha by 1991. Such decline was mainly due to the direct changes made to the coastal environment through land-

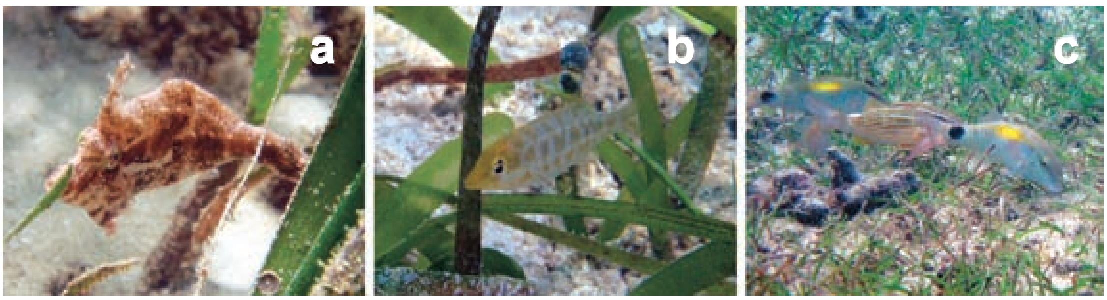

Fig. 1 Patterns of seagrass habitat use by fishes in the Ryukyu Islands
(a) permanent residents; *Acreichthys tomentosus* in *Enhalus acoroides*-dominated beds at Iriomote Island, (b) seasonal residents; *Lethrinus obsoletus* in *Thalassia hemprichii*-dominated beds at Ishigaki Island, (c) transients; *Parupeneus ciliatus* (center) and *Parupeneus indicus* in *Halodule uninervis*-dominated beds at Amami Oshima Island

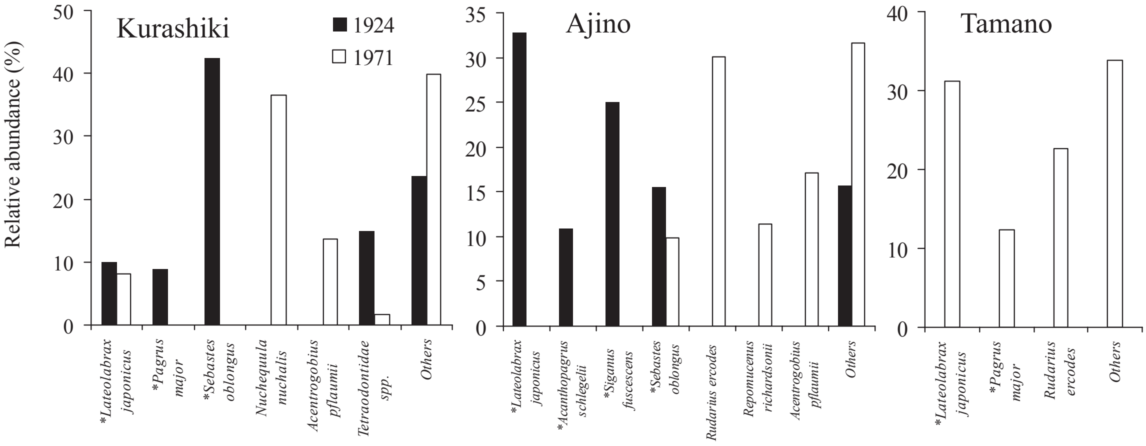

Fig. 2 Relative abundance (%) of dominant fishes in the seagrass beds at Kurashiki, Ajino and Tamano Bays, Okayama Prefecture, Central Japan in 1924 and 1971
1924 data for Tamano Bay unavailable; Asterisk indicates fishery important species.

fills. In the Philippines, thousands of hectares of seagrass beds have been lost as a result of eutrophication, pollution and dragging, and land reclamation for housing, airports and shipping facilities (Green and Short, 2003).

The decline of seagrass beds has had a negative influence on seagrass-associated organisms. Azuma (1981) compared the fish fauna in seagrass beds in three bays in Okayama Prefecture, Central Japan (Kurashiki, Ajino, Tamano), which differed in the degree of seagrass growth due to differing degrees of human disturbance, such as water pollution. In 1924, Ajino and Kurashiki had broad seagrass beds. However, the seagrass area had halved in Ajino and almost disappeared in Kurashiki by 1971. Figure 2 shows the ratio of dominant species occurring in the seagrass beds in Kurashiki, Ajino and Tamano in 1924 and 1971. Tamano, which alone had healthy seagrass beds, harbored many permanent residents such as *Rudarius ercodes*, and seasonal residents such as *Lateolabrax japonicus*, in 1971, fishes which had been dominant in seagrass beds in Kurashiki and Ajino in 1924. However, such fishes had disappeared from the latter locations by 1971, being replaced by mud fishes, such as *Acentrogobius pflaumii*. This demonstrated that most seagrass-associated fishes disappear with seagrass habitat degradation and the accompanying loss of living space and food resources, the fish assemblage structure instead becoming similar to that of sandy-mud bottom habitats (Fig. 3, see also Horinouchi, 2007). In addition, invertebrate density was lowest in Kurashiki in 1971 (Azuma, 1981).

Seagrass bed loss also leads to declining densities of adult fishes in other habitats, but dependent upon a seagrass habitat nursery period (Nagelkerken *et al*., 2002). Dorenbosch et al. (2006) found higher adult densities of the commercial species *Cheilinus undulates* on coral reefs adjacent to seagrass beds than on coral reefs without the latter, evidence for the importance of seagrass beds as a nursery habitat for coral reef fishes. Nakamura and Tsuchiya (2008) also suggested that the presence of extensive seagrasss habitats enhances adult densities of *Lethrinus* species on adjacent coral reefs in the Ryukyu Islands. Because *Lethrinus* species are very important commercially in the southern Kuroshio region (Carpenter and Allen, 1989), the loss of seagrass nursery areas could have significant negative impacts on regional fisheries as well as coral reef biodiversity.

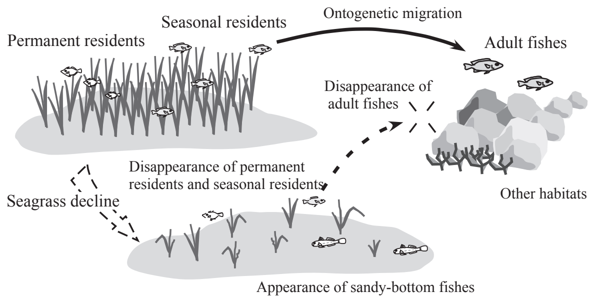

Fig. 3 Transition process of a seagrass fish assemblage structure with progressive seagrass decline

3. Challenges for Seagrass Conservation

The main large scale threats to seagrass ecosystems will continue to result from human activities, through direct disruption of coastal zones, changes in land use, and continuing inputs of silt, nutrients and sewage to the coastal zone (Duarte, 2002). It is important, therefore, to determine how to apply the findings of basic scientific research in such a way as to resolve the present crisis of seagrass ecosystems (Kenworthy *et al*., 2006). The following three proposals should provide for effective management and conservation of seagrass ecosystems:

(1) *Education*–It is important for local residents to "understand" and "be aware" that the protection of seagrass beds is strongly linked to the maintenance of their livelihood. The lack of appreciation of the role of seagrass beds and the effects of various activities result in many of the latter being done without due regard to possible social and economic consequences, even though such activities are not usually aimed at the direct destruction of the beds. For example, emperor fishes (family Lethrinidae), which use seagrass beds as nursery habitats, are the most commonly landed commercial species in Okinawa Prefecture, southern Japan (Ohta, 2008). Loss of the local seagrass beds would deprive Okinawa of its main fishery resource. The highlighting of such risks through environmental education targeted at local residents is the first step for preserving seagrass ecosystems, and is important for gaining a consensus from local residents in conservation and management actions.

(2) *Management of human activities*–It is important to specify measures for countering human activities that produce burdens on seagrass ecosystems. For example, since the 1970s, Okinawa Prefecture has implemented intensive public projects, including the development of roads, ports and agricultural land. As a result, considerable sedimentation has accumulated in several coastal areas (Omija, 2006). Seagrasses in shallow protected coastal waters directly affected by such sedimentation are highly susceptible to such input. Indeed, the environmental effects of excess nutrients or sedimentation are the most significant causes of seagrass decline (Orth et al., 2006). Although reports on the considerable decrease of Okinawan seagrass beds are lacking, some seagrass beds are declining due to sedimentation (Toma *et al*., 1991; The Environmental Agency and Marine Parks Center of Japan, 1994). Therefore, it is necessary to minimize sediment loss to the sea. One of the best examples of water quality management in such a case is in Chesapeake Bay, the largest estuary in the United States, where scientists, managers and the public have collaborated to conserve seagrasses through heightened water quality criteria and protection (Dennison *et al*., 1993).

(3) *Marine Protected Areas*–The number of marine protected areas (MPAs) including seagrass beds has increased rapidly in recent years (Green and Short, 2003). However, in the majority of them, seagrasses are neither acknowledged nor directly protected. Although a few MPAs have been established to directly protect seagrass beds, other associated habitats have not been afforded concurrent protection. For instance, the protection of seagrass beds that may be significantly affected by coastal developments requires appropriate foreshore conservation and management. The Egyptian coral reef management technique, in which an MPA includes not only the sea but also the adjacent land, is a good example of this (Jobbins, 2006). In addition, seagrass beds are linked to adjacent fish habitats through feeding and ontogenetic migration. Clearly, any assessment of future protective measures for seagrass habitats should necessarily include assessments of adjacent habitats, including the connectivity among them (see also Mumby and Harborne, 2006).

Acknowledgments

I appreciate the financial support of National Sun Yat-sen University (NSYSU) and the leadership of Drs. H.K. Mok and Y. Morooka in organizing and leading the symposium "Kuroshio biodiversity research" held at the NSYSU, which provided the opportunity to present this paper. Constructive comments on the manuscript from G. Hardy were much appreciated. This study was supported in part by a Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists (No. 18·10371) to Y. Nakamura

References

Azuma, M. 1981. Seagrass beds as fish nursery. In "Seaweed beds", ed. by The Japanese Society of Fisheries Science, pp. 34-56. Kouseisha-kouseikaku, Tokyo.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F., and Weinstein, M.P. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51, 633-641.

Bell, J.D. and Pollard, D.A. 1989. Ecology of fish assemblages and fisheries associated with seagrasses. In "Biology of seagrasses", ed. by Larkum, A.W.D., McComb, A.J., and Shepherd, S.A., pp. 565-597. Elesevier, Amsterdam.

Carpenter, K.E. and Allen, G.R. 1989. FAO species catalogue, Vol. 9 Emperor fishes and large-eye breams of the world (family Lethrinidae). An annotated and illustrated catalogue of lethrinid species known to date. FAO Fish. Synop. No. 125, Vol. 9. FAO, Rome.

Connolly, R.M. 1994. A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. Aust. J. Mar. Freshw. Res. 45, 1033–1044.

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 submersed aquatic vegetation. BioScience 43, 86-94.

Dorenbosch, M., Grol, M.G.G., Nagelkerken, I., and van der Velde, G. 2006. Seagrass beds and mangroves as potential nurseries for the threatened Indo-Pacific humphead wrasse, *Cheilinus undulatus* and Caribbean raimbow parrotfish, *Scarus guacamaia*. Biol. Conserv. 129, 277-282.

Duarte, C.M. 2002. The future of seagrass meadows. Environ. Conserv. 29, 192-206.

Edgar, G.J. and Shaw, C. 1995a. The production and trophic ecology of shallow-water fish assemblage in southern Australia III. General relationships between sediments, seasgrasses, invertebrates and fishes. J. Exp. Mar. Biol. Ecol. 194, 107-131.

Edgar, G.J. and Shaw, C. 1995b. The production and trophic ecology of shallow-water fish assemblage in southern Australia II. Diets of fishes and trophic relationships between fishes and benthos at Western Port, Victoria. J. Exp. Mar. Biol. Ecol. 194, 83-106.

Environmental Agency and Marine Parks Center of Japan (Eds.). 1994. The report of the marine biotic environment survey in the 4th national survey on the natural environment. Vol. 2 (algal and seagrass beds).

Green, E.P. and Short, F.T. (Eds.). 2003. World atlas of seagrasses. University of Calirounia Press, California.

Hemminga, M.A. and Duarte, C.M. 2000. Seagrass ecology. Cambridge University Press, New York.

Horinouchi, M. 2003. Seagrass fish research methods. In "Encyclopedia of measurement and analysis on global environment, vol.3", ed. by Takeuchi, H., pp. 723-732. Fuji-technosystem, Tokyo.

Horinouchi, M. 2007. Review of the effects of within-patch scale structural complexity on seagrass fishes. J. Exp. Mar. Biol. Ecol. 350, 111-129.

Horinouchi, M. and Sano, M. 1999. Effects of changes in seagrass shoot density and leaf height on abundances and distribution patterns of juveniles of three gobiid fishes in a *Zostera marina* bed. Mar. Ecol. Prog. Ser. 183, 87-94.

Horinouchi, M. and Sano, M. 2000. Food habits of fishes in a *Zostera marina* bed at Aburatsubo, central Japan. Ichthyol. Res. 47, 163-173.

Howard, R.K., Edgar, G.J., and Hutchings, P.A. 1989. Faunal assemblages of seagrass beds. In "Biology of seagrasses", ed. by Larkum, A.W.D., McComb, A.J., and Shepherd, S.A., pp. 536-558. Elesevier, Amsterdam.

Jackson, E.L., Rowden, A.A., Attrill, M.J., Bossey, S.J., and Jones, M.B. 2001. The importance of seagrass beds as a habitat for fishery species. Oceanog. Mar. Biol.: an Annual Rev. 39, 269-303.

Jobbins, G. 2006. Tourism and coral-reef-based conservation: can they coexist? In "Coral reef conservation", ed. by Cote, I.M. and Reynolds, J.D., pp 237–263. Cambridge University Press, Cambridge.

Kanashiro, K., Motonaga, F., and Kimura, M. 1999. Settlement of white-spotted spinefoot, *Siganus canaliculatus* (Pisces: Siganidae), in the coastal waters off Okinawa Island, Japan. Nippon Suisan Gakkaishi 65, 19-25.

Kenworthy, W.J., Wyllie-Echeverria S., and Coles R.G. 2006. Seagrass conservation biology: an interdisciplinary science for protection of the seagrass biome. In "Seagrasses: biology, ecology and conservation", ed. by Larkum, A.W.D., Orth, R.J., and Duarte, C.M., pp 595-623. Springer, Dordrecht.

Kikuchi, T. 1966. An ecological study on animal communities of the *Zostera marina* belt in Tomioka Bay, Amakusa, Kyushyu. Publ. Amakusa Mar. Biol. Lab. 1, 1-106.

Kikuchi, T. 1974. Japanese contributions on consumer ecology in eelgrass (*Zostera marine L.*) beds, with special reference to trophic relationships and resources in inshore fisheries. Aquaculture 4, 145-160.

Kikuchi, T. 1982. Habitat functions of seagrass beds for fishes. In "Seagrass beds and fishery species", ed. by Japan Fisheries Resource Conservation Association, pp. 49-105. Japan Fisheries Resource Conservation Association, Tokyo.

Kochzius, M. 1999. Interrelation of ichthyofauna from a seagrass meadow and coral reef in the Philippines. In "Proceedings of the 5th Indo-Pacific Fish Conference, Nouméa", ed. by Séret, B. and Sire, J-Y., pp 517-535. Société Française d'Ichthyologie and Institut de Recherche pou le

Développement, Paris.

Kuo, J., Kanamoto, Z., Iizumi, H., Aioi, K., and Mukai, H. 2006. Seagrasses from the Nansei Islands, southern Japanese Archipelago: species composition, distribution and biogeography. Mar. Ecol. 27, 290-298.

Mukai, H. 1993. Biogeography of the Tropical Seagrasses in the Western Pacific. Aust. J. Mar. Freshwater Res. 44, 1-17.

Mumby, P.J. and Harborne, A.R. 2006. A seascape-level perspective of coral reef ecosystems. In "Coral reef conservation", ed. by Cote, I.M. and Reynolds, J.D., pp 78–114. Cambridge University Press, Cambridge.

Nagelkerken, I., Roberts, C.M., van der Velde, G., Dorenbosch, M., van Riel, M.C., Cocheret de la Morinière, E., and Nienhuis, P.H. 2002. How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. Mar. Ecol. Prog. Ser. 244, 299–305.

Nakamura, Y., Horinouchi, M., Nakai, T., and Sano, M. 2003. Food habits of fishes in a seagrass bed on a fringing coral reef at Iriomote Island, southern Japan. Ichthyol. Res. 50, 15-22.

Nakamura, Y. and Sano, M. 2004. Overlaps in habitat use of fishes between a seagrass bed and adjacent coral and sand areas at Amitori Bay, Iriomote Island, Japan: Importance of the seagrass bed as juvenile habitat. Fish. Sci. 70, 788-803.

Nakamura, Y. and Sano, M. 2005. Comparison of invertebrate abundance in a seagrass bed and adjacent coral and sand areas at Amitori Bay, Iriomote Island, Japan. Fish. Sci. 71, 543-550.

Nakamura, Y. and Tsuchiya, M. 2008. Spatial and temporal patterns of seagrass habitat use by fishes at the Ryukyu Islands, Japan. Estuar. Coast. Shelf Sci. 76, 345–356.

Nakaoka, M., Toyohara, T., and Matsumasa, M. 2001. Seasonal and between-substrate variation in mobile epifaunal community in a multispecific seagrass bed of Otsuchi Bay, Japan. P.S.Z.N.I: Mar. Ecol. 22, 379-395.

Nakaoka, M. 2005. Plant-animal interactions in seagrass beds: ongoing and future challenges for understanding population and community dynamics. Popul. Ecol. 47, 167-177.

Ohta, I. 2008. Sustainable use of coral reef fish resources. Lagoon 10, 6-8.

Omija, T. 2006. Terrestrial inflow of soils and nutrients. In "Coral reefs of Japan", ed. by Ministry of the Environment and Japanese Coral Reef Society, pp. 64-68. Ministry of the Environment, Tokyo.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck Jr., K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., and Williams, S.L. 2006. A global crisis for seagrass ecosystems. BioScience 56, 987-996.

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

Toma, T., Tamaki, T., and Gushiken, T. 1991. Seagrass- and *Sargassum*-beds in Okinawa Islands. Annual Rep. Okinawa Pref. Fish. Exp. Stn., 131-142.

Walker, D.I., Kendrick, G.A., and McComb, A.J. 2006. Decline and recovery of seagrass ecosystems-The dynamics of change. In "Seagrasses: biology, ecology and conservation", ed. by Larkum, A.W.D., Orth, R.J., and Duarte, C.M., pp 551-565. Springer, Dordrecht.

Yamada, K., Hori, M., Tanaka, Y., Hasegawa, N., and Nakaoka, M. 2007. Temporal and spatial macrofaunal community changes along a salinity gradient in seagrass meadows of Akkeshi-ko estuary and Akkeshi Bay, northern Japan. Hydrobiologia 592, 345-358.