Kuroshio Science **2**-1, 15-20, 2008

Coastal Environment and Seaweed-bed Ecology in Japan

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Abstract
Seaweed beds are communities consisting of large benthic plants and distributed widely along Japanese coasts. Species constituting seaweed beds in Japan vary depending on localities because of the influence of cold and warm currents. Seaweed beds are important producers along coastal ecosystems in the world, but they have been reduced remarkably in Japan. Not only artificial constructions in seashores but also the Phenomenon called “isoyake” have led to the deterioration of coastal environments. To figure out what is going on in nature, Japanese Government began the nationwide survey of seaweed beds. Although trials to recover seaweed communities have been also carrying out, they are not always the solution of subjects. We should think of harmonious coexistence between nature and human being so that problems might not happen.

Introduction

Through four billion years of evolution, life on earth has expanded to almost infinite diversity, with each species interacting with others and molding itself to its habitat until a global ecosystem developed. This diversity of life forms is commonly referred to as biodiversity. Biodiversity is not only crucial to ecosystem balance, but also brings great benefit to human lives. In recent years, however, human activities have caused a rapid decline in biodiversity, such as through the destruction of habitats and environmental pollution. This is true of Japan as much as anywhere else, where changes to the natural environment threaten many species that have developed over millions of years.

Seaweed beds are communities consisting of large benthic plants as primary producers, and they form rich marine meadows and forests. They play an important role in the ecosystem of the coastal areas, serving as nursery grounds for fish and shellfish, such as egg-laying sites and feeding grounds. Therefore, seaweed beds may contribute to the maintenance of both biodiversity and natural environments on earth.

In this paper, I focus on the present status of seaweed beds in Japan and describe the following subjects: 1) Diversity and distribution of seaweed beds in Japan; 2) The roles of seaweed beds; 3) Causes for the deterioration of seaweed communities; 4) Efforts to restore seaweed beds and coastal environments; and 5) Towards the sustainable coexistence between nature and human beings

1. Diversity and distribution of seaweed beds in Japan

Japan has wide range of climate zones from cold temperate to subtropical, reflecting its wide geographical extent from north to south, as well as the influence of two major warm and cold currents, the Kuroshio and Oyashio, respectively. In addition, there are also very diverse nutrient conditions including oligotrophic and highly eutrophic waters and different degrees of waves.

Corresponding to such environmental diversity, the Japanese coast has remarkably diverse macroalgal flora and algal communities. There are four distinct macroalgal florae in Japan. In north-east coasts, cold water and cool temperate algal florae along the cold Oyashio current. Warm temperate and subtropical algal florae extend, along the Kuroshio and its branch currents. Each macroalgal flora shows a characteristic community consisting of distinct species constituents including animals. These algal communities as well as seagrass meadows constitute seaweed beds, which are the bases of rich coastal ecosystems in Japan.

Seaweed beds are mainly classified into three groups, a seagrass bed, a kelp forest and a *Sargassum* bed. These beds grow right along the Japanese coast from Hokkaido, Honshu, Shikoku and Kyushu to the Rryukyu Islands.

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According to Yokohama and Aioi (1994), the total area of distributed seaweed beds in Japan in 1989-92 was 201,212 ha.

Seagrass beds developed in shallow water where sand and mud were piled up. Seagrass grow in bays where wave hits are not strong, such as sandy beaches or tidal flats near river mouths. Various small animals live in the calm area formed by seagrass beds, and many fishery products visit here to lay eggs. Seagrass beds occupy 15.7% of the total area of seaweed beds present in Japan.

Seagrass beds are distributed most abundantly in Hokkaido which accounts for 35% of total seagrass beds in Japan, which is followed by Aomori-prefecture (15%) at the north part of Honshu, and then comes Okinawa-prefecture (14%) at the south part of Japan.

Species making seagrass beds known in Japan are: *Zostera asiatica, Z. caulenscens, Z. caespitosa, Z. japonica; Phyllospadix iwatensis, P. japonicus; Cymodocea rotundata, C. serrulata; Syringodium isoetifolium; Halodule uninervis, H. pinifolia; Halophila ovalis, H. decipiens, H. minor, H. australis; Enhalus acoroides; Thalassia hemprichii*. Among them, species belonging to the genera *Zostera* and *Phyllospadix* occur in cold and temprate water, whereas species of *Halophila* and *Thalassia* grow in subtropical regions.

Kelp forest consist of members of brown algae belonging to the class Laminariales. They are classified into three groups, *Laminaria* beds, *Eisenia*/*Ecklonia* beds and *Undaria* beds. Kelp forest may become good food for shellfish like abalones and top shell and sea urchins.

Among kelp forests, *Laminaria* beds appear predominantly in the north part of Japan. About 75% of *Laminaria* beds are localized in Hokkaido. Other kelps than *Laminaria* include species of *Alaria, Undaria, Agarum, Costaria* and so on. Some of these *Laminaria* species are harvested for the use of seafood.

Eisenia/*Ecklonia* beds are distributed in a temprate zone from Kyushu to Honshu and account for 24% of the total area of seaweed beds in Japan. *Eisenia*/*Ecklonia* beds consist of *Ecklonia cava, E. kurome, E. stolonifera; Eckloniopsis radicosa; Eisenia arborea, E. bicyclis; Streptophyllopsis kuroshioensis*. Shizuoka prefecture located at the mid-Honshu has the most abundant *Eisenia*/*Ecklonia* beds (18%), followed by Yamaguchi (15%) and Nagasaki (11%) prefectures in the western part of Japan.

Sargassum beds are the largest in kelp forest in Japan and consist of many species of the genera *Sargassum, Hizikia* and *Turbinaria,* which include *Sargassum alternato-pinnatum, S. ammophilum, S. araii, S. assimile, S. autumnale, S. berberifolium, S. brevifolium, S. bulbiferum, S. carpophyllum, S. confusum, S. crassifolium, S. crispifolium, S. cristaefolium, S. duplicatum, S. filicinum, S. fulvellum, S. giganteifolium, S. glaucescens, S. hemiphyllum, S. horneri, S. ilicifolium, S. ilicifolium, S. incanum, S. kashiwajimanum, S. kushimotense, S. longifructum, S. macrocarpum, S. micracanthum, S. microceratium, S. miyabei, S. muticum, S. myriocystum, S. nigrifolium, S. nipponicum, S. okamurae, S. oligocystum, S. pallidum, S. patens, S. piluliferum, S. pinnatifidum, S. polycystum, S. polyporum, S. ringgoldianum, S. ringgoldianum, S. ringgoldianum, S. sagamianum, S. salicifolioides, S. sandei, S. segii, S. serratifolium, S. siliquastrum, S. siliquosum, S. tenuifolium, S. thunbergii, S. tosaense, S. trichophyllum, S. wakayamaense, S. yamadae, S. yamamotoi, S. yendoi, S. yezoense; Coccophora langsdorfii; Cystoseira crassipes, C. geminata, C. hakodatensis; Hormophysa cuneiformis; Myagropsis myagroides; Hizikia (Sargassum) fusiformis*.

These species have air bladders by which their bodies can be erect and form a jungle underwater. *Sargassum* beds develop from a low tide level to about 10 meters in depth, where enough sunlight for photosynthesis reaches. *Sargassum* beds are distributed all over the Japanese coast except in Fukushima and Okinawa prefectures and represent 27% of the total area of seaweed beds in Japan. The prefectures that have more than 10% of total area of *Sargassum* beds are Ishikawa facing the Sea of Japan, Nagasaki at the side of the East China Sea and Shizuoka along the coast of the Pacific Ocean. Recently, it has been pointed out that temprate species of Sargassum tend to be replaced by tropical species or corals (Haraguchi *et al*. 2007).

Fig.1 *Sargassum* bed near St. Ana in the Philippines

2. The roles of seaweed beds

Seaweed beds have high primary production capability, equal to terrestrial plants and land forest. Through these photosynthetic products, seaweed beds are an important part of the marine food web: Seaweed beds play a vital role in the ecology of the aquatic ecosystems giving structure and complexity; providing substrate, food and shelter to many marine organisms; and contributing to the nutrient cycling of both beaches and the surrounding coastal waters.

Seaweed beds are localized zones of high biodiversity where pelagic and benthic ecosystems interact. The high biodiversity contributes to high biological productivity. Seaweed beds are critical for the recruitment and protection of many commercially important finfish and shellfish fisheries. Attached seaweeds are structurally important components of the marine environment and support high biodiversity by providing habitat, shelter and food, as well as affecting wave flow and energy. Free-floating seaweeds also play an important role in the recruitment and dispersal of other pelagic organisms. Even beach-cast seaweeds provide habitat and food for a diverse ecology of marine and terrestrial organisms such as amphipods, isopods and copepods. These invertebrates are an important food source for some birds and reptiles. Not only fish and shellfish but also people in East Asia, including the Japanese, consume seaweeds as healthy food.

Seaweed beds have photosynthetic activities, absorbing carbon dioxide and discharging oxgen. Inorganic nutrients are absorbed by seagrass from their roots and by algae from the whole surfaces of their bodies. Seaweed beds play a significant role in the removal of nutrients and organic materials especially from eutrophicated water, serving as buffers of coastal water quality.

On the other hand, human activities have led to considerable emissions of carbon dioxide that may cause global warming. It is estimated that 7.1 billion tons of carbon have been released per year, from which, the ocean has taken up 2 billion tons of carbon a year according to the Intergovernmental Panel on Climate Change in 1994. Since the global production of seaweed beds is estimated to be 460 million tons of carbon a year, seaweed beds absorb one-fourth of the total amount of carbon dioxide that the ocean uptakes per year. Annual carbon absorption by seaweed beds growing along the Japanese coast is about 2.7 million tons, equivalent to 1.4% of the carbon dioxide the ocean uptakes (Muraoka 2004). Thus, seaweed beds may function as a great carbon sink.

Fig.2 ***Halimeda*** **community in Green Island, Taiwan**

3. Causes for the deterioration of seaweed communities

Although seaweed beds are very important for the global ecosystem, about 6400 ha of seaweed beds disappeared from the Japanese coastal area during the period between 1978 and 1992 (Kikuchi 1994). In those 13 years, 20% of seagrass beds, 22% of *Sargassum* beds and 36% of kelp forest have gone. Most of such loss seems to be caused by land filling reclamation and other human impact, some of which include the influence of eutrophication and the lowering of water transparency.

One of the most serious causes of deterioration in the quality of Japanese coastal waters is the loss of tidal flats. The loss of tidal flats corresponds with the decline of seaweed beds. Coastal engineering works such as reclamation projects and dredging are mainly responsible for the loss of these areas. For example, more than 80 percent of the coastline of Tokyo Bay has been reclaimed since the Second World War (between 1950 and 1988) mainly for industrial development, and the remainder is still threatened by development.

Changes of coastal lines by reclamation or construction of seawalls resulted in serious affects on seaweed habitats. Seaweeds need enough sunlight for growth and development. Reclamation has extensively taken away shallow water environments in which sunlight easily reaches seaweed beds through seawater. Since seaweeds, unlike free-floating flagellates, cannot live on ground deeper than the light compensation point-depth, areas in which seaweed beds can develop were reduced.

Furthermore, the lowering of water transparency and turbidity due to muddy water from rivers make this situation even worse. When the transparent water area is narrower, the light compensation point-depth for photosynthesis becomes shallower. This means that algae are unable to live on deep ground where they used to grow. Thus, reclamation and increases in water turbidity lead to the deterioration of seaweed beds.

The other serious problem is what we call barren ground, sea desert or denudation of rocks. In recent decades, some of the shallow seas along the Japanese coast have been suffering from a phenomenon known as barren ground or denudation of rocks, which in Japanese we call “isoyake”. Barren ground occurs when sublittoral marine algae such as *Eisenia*, *Ecklonia* and *Sargassum* species are replaced by dense crustose coralline red algae, resulting in rapid reduction in productivity and biodiversity. Therefore, barren ground is defined as the condition where seaweed beds that used to grow are decreased or extinct, and then crustose coralline red algae containing calcium carbonate components cover rock substrata.

Although the exact cause of barren ground has not yet been identified, there are some possible candidates. One hypothesis is that it may be brought about through overgrazing by some hervivorous invertebrates and fish like siganids. Herbivorous invertebrates such as gastropods and sea urchins can graze heavily on new fronds and broken-ends of old fronds of brown algae. Dense aggregations of sea urchins as well as masses of grazing fish may have drastic effects on kelp assemblages and may remove large tracts of seaweed beds, creating barren ground.

Other hypotheses include competition with other algae for substrata and hydrographic changes such as damage by typhoons. Temperature changes brought about Kuroshio meander, and global warming may affect the physiological conditions of seaweed beds.

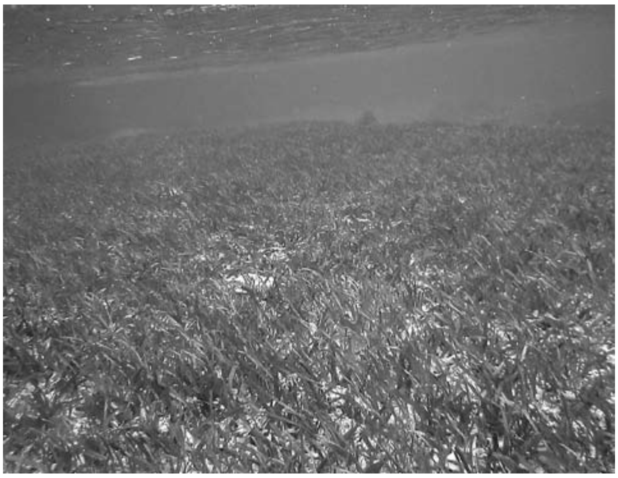

Fig.3 Seagrass bed in Ishigaki Island, Japan.

4. Efforts for restoring seaweed beds and coastal environments

Several projects that aim to restore or create fishery industry-related coastal habitats are being carried out in Japan. It is expected that these activities may lead to the recovery and enhancement of the proper ecological functioning of aquatic environments and seaweed communities. Techniques have been developed for the construction of artificial seaweed beds.

One of them is the spore dispersal or spore-bag technique. Gametophytes developed from zoospores or embryonic sporophytes obtained by fertilization are allowed to setttle on substrata, and then placed on rocks suitable for kelp habitats. Reproductive cells released from the gametophytes or sporophytes are dispersed densely, so that new kelp forests may develop around the rocks. A similar technique is the rope-seeding technique, where ropes with zoospores discharged from fertile sporophytes in indoor tanks are immersed into the sea. The zoospores may be germinated on the ropes to develop new tufts of fronds.

Transplantation of the kelp alga *Ecklonia* is carried out, where adult plants are attached to concrete blocks with strong rubber bands or ropes. The holdfasts of *Ecklonia* generate to attach to the blocks after some months of growth, new blades from the adult plants form around the blocks. In the case of seagrass, the way of transplantation is more drastic. A section of seagrass bed is collected with the ground in a box, shipped out to a different place and transplanted to create a new habitat.

The reform of seawalls is also performed, an example is seen in the case of Kansai International Airport (http://eem.pcc.gov.tw/eemeng/?q=node/1308). A gentle slope is constructed along vertical seawalls, so that seaweeds may grow on the slope to restore fish and other animal habitats.

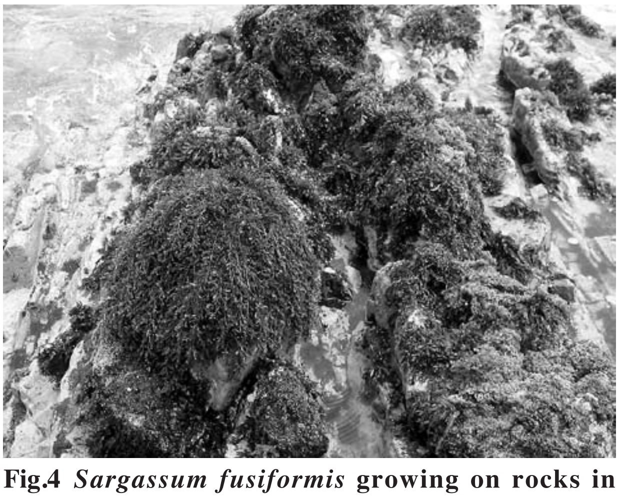

Fig.4 *Sargassum fusiformis* growing on rocks in Kochi, Japan.

However, most of these projects focus mainly on engineering solutions to productivity enhancement, not ecological-based solutions. Among various future tasks related to habitat technology, priority should be given to the restoration and creation of coastal nurseries such as tidal flats and seaweed beds. These areas play a very important role in the reproductive potential of most valuable fisheries resources. In this respect, it is important to prioritize the investigation of the ecological features of the natural system before designing artificial habitats.

To investigate the real situation of the coastal ecosystem and environments in detail and precisely, it is essential for us to collect information on long-term changes in seaweed habitats and physico-chemical environmental factors.

Since 1973, the Japanese Ministry of Environment has carried out the National Survey of the Natural Environment every five years. This nationwide survey, which we call the Green Census, is designed to clarify the current state of Japan's natural environment and to monitor any changes in the biological situation (http://www.biodic.go.jp/english/kiso/fnd_f.html). It covers land, surface water and coastal areas and is subdivided into such categories as animals, plants, rivers/lakes/marshes, and tidal flats/seaweed beds/coral reefs. As for coastal areas, investigation is now put in practice (from 2002-2007) to clarify the status of flora and fauna of benthic communities at 129 marine forests and 145 tidal lands all along the Japanese coasts. The survey is implemented by local governments, with the cooperation of researchers, experts and volunteers across the nation. The Biodiversity Center of Japan now has responsibility for it and plans to expand the survey network and to continue monitoring the nation's ecosystems.

5. Towards the sustainable coexistence between nature and human beings

The present situation in Japanese coastal waters does not provide an optimistic view of the possibility of the regional seas of Northeast Asia being a greatly enhanced food resource in the future (Nakata 1998). Influence of the ocean environment such as water temperature, coastal development such as the reclamation of seaweed beds and tidal flats, and increases in fishing capacity due to improved efficiency of fishing gear and boats are major factors that caused the deterioration of fishery resources. In addition, most areas are also suffering from severe degradation of water quality and rapid loss of the coastal habitat. During the period of high economic growth in the 1960s and 1970s, the Japanese coastal environment, particularly around urbanized areas, was severely damaged. Vast economic growth was accomplished, but a huge price was paid, in terms of the ecological degradation of coastal waters. However, times have changed now.

The Basic Environmental Plan, established by the Japanese government in 1994, outlines long-term policies through the middle of the 21st century for environmental conservation (http://www.env.go.jp/en/policy/plan/basic/index.html). This plan sets the following four long-term objectives:

1). To establish a socioeconomic system by which substances may cycle in natural environments.

2). To ensure harmonious coexistence between nature and human beings.

3). To build a society where all parties participate in environmental conservation activities.

4). To promote international environmental efforts.

These objectives can be applied to the conservation and restoration of the marine environment.

In order to achieve the goals outlined in the Basic Environmental Plan, it is absolutely essential to realize that human beings are an integral part of the biosphere, sharing its limited energy and resources with other living creatures. In this respect, Takahashi (1992) has pointed out that an evolutionary switch in socio-cultural thinking is required. He proposes a switch from rule by modern technocrats, who base their choices on advanced high technologies, to rule by a new generation of "ecocrats". Ecocrats prefer to maintain natural ecosystems on a sustainable basis in conjunction with utilizing their productivity. Most of the people who try to restore the natural environment concentrate on directly solving problems that have already happened. This is distinct from the way of thinking and behaving as ecocrats. As ecocrats we should think of how we can harmonize human activities with global ecosystems on the earth and of what policies and devices are essential to achieve it from multiple scientific and sociological standpoints, so that problems might not occur. A technology and social system based on an understanding of ecosystems will advance the goal of realizing sustainable exploitation of the blessings of the marine environment. Our global is to create a harmonious and everlasting coexistence between nature and human beings.

Acknowledgment

I would like to thank Professor H. Kawai of Kobe University, Japan, for useful suggestions and advice. This research was supported by a Grant-in-Aid for Scientific Research (No. 19310030) from the Ministry of Education, Culture, Sports, Science and Technology,

Japan.

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