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Current status and problems of isoyake in Japan

Daisuke FUJITA [*1]

Abstract: In Japan, decrease of seaweed beds has been noticed by fishermen for more than a century and called isoyake. In the modern context, isoyake is defined as decrease or disappearance of upright seaweed beds resulting in the formation and maintenance of poorly vegetated area on the shallow bedrock and stony beds, other than seasonal and slight yearly fluctuations. Seaweeds decrease when they were grazed / browsed by herbivores (e.g., sea urchins and/or herbivorous fish), withered in waters with high water temperature, inhibited for germlings to attach and grow by sedimentation, and/or detached in storms. Some are natural, but the others are highly anthropogenic. The resultant poorly vegetated areas occur most often offshore of seaweed beds, sometimes zoned between shallow and deep beds or patched among the beds. Isoyake has increased during the 20th century; now most of coastal prefectures have more or less isoyake areas. The restoration of seaweed beds has often been unsuccessful because (1)drastic changes in coastal environments, (2) misunderstanding of isoyake, (3) inappropriate selection of restoration method, (4) decrease of young fishermen, (5) limited information on planning and measures, (6) short of social support system, (7) limited commercial usages for priceless herbivores. In 2007, Fisheries Agency published an official guideline for promoting restoration of seaweeds. The principle shown in the guideline is the removal of factor(s) inhibiting formation of seaweed beds; the recommended actions include the adaptive management and collaboration among fishermen, administrative, specialists and citizen. The guideline has been popularized by local meetings and demonstrated in restoration trials lead by supporters, i.e., experienced specialists. Now urchin barrens are highly recoverable to seaweed beds by removing sea urchins, but further technical developments are needed to restore seaweed beds when barren maintains by other factors, e.g., herbivorous fish, high density of snails or sedimentation.

Introduction

Recently, seaweeds have been used much more than before for the construction of 'healthy society' because of multifunctional aspects of the seaweed beds as well as useful constituents of seaweeds such as phycocolloids and tasty amino acids. However, further expectations (e.g., energy source, CO_2 sink) for utilization of the seaweeds and their beds have been much more difficult because seaweed beds have decreased all over the coasts in Japan. The decrease of seaweed beds has been known for more than a century as isoyake or isogare and not only the recent problem (Fujita 2002, 2009). The cause, process, period and extension of the isoyake are different from coast to coast and also changing from age to age (Fujita 2009). In old days, many researchers avoid studying isoyake because of its chaotic nature. Even now, although the number of articles and reports have increased (Kuwahara *et al.,* 2005), extensive and sustainable recovery of seaweed beds have not yet succeeded; aforestation methods by stone piling and deployment of concrete blocks, which intensively change coastal habitats, have been promoted without enough monitoring and discussions (Fujita *et al.,* 2010). In the present paper,

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[*1] Tokyo University of Marine Science and Technology , 4-5-7 Konan, Minato, Tokyo 108-8477, Japan

the author introduced the current status of 'seaweed beds and 'Isoyake' and discussed the problems from various points of views.

What is 'Isoyake'?

As stated above, decrease and disappearance of seaweed beds have been called isoyake or isogare (Yendo 1903), and the resultant barren bottoms, yakeiso or yakene in an old paper (Kishinoue 1894). Once seaweed beds have reduced, production of coastal fisheries have drastically reduced (Yendo 1903) because of suppressed growth ('e.g., meat of abalone, gonad of sea urchins) and reduction of commercial seaweed (e.g, *Gelidium*, *Saccharina, Eisenia, Ecklonia, Sargassum*) and related fish and shellfishes (e.g., rockfish, lobster) (Fujita 2002, 2009, Fisheries Agency 2007). Chronology of isoyake in Japan will be discussed elsewhere (Fujita, in prep.).The decrease of fishermen's income is most serious with the additional influence such as decrease of wild resource and damage of seascape resulting in the disappearance of regional attraction, i.e., decrease of sight seekers.

Up to now, the term isoyake has been defined in various ways, including following of old literature, distorted interpretation which neglects the history and mention of the other intertidal phenomenon (Fujita 2002). After reviewing, the author (Fujita 2002) defined as follows; a phenomena of decrease or disappearance of beds of upright seaweed (moba in Japanese) resulting in the formation and maintenance of poorly vegetated area on the shallow bedrock and stony beds, other than seasonal and slight yearly fluctuations. Isoyake includes some urchin barrens but not stable ones often found at offshore of seaweed beds. The definition was adopted in the 'Isoyake Taisaku Guideline' (Fisheries Agency 2007). The definition should not include items such as which factor(s) cause isoyake, how the resultant area look like, how much degree the related commercial resources are influenced, and how long time is needed because they are highly dependent on the topography, oceanography, biota and the history of utilization and development in coastal areas (Fujita 2002, 2009, Fisheries Agency 2007).

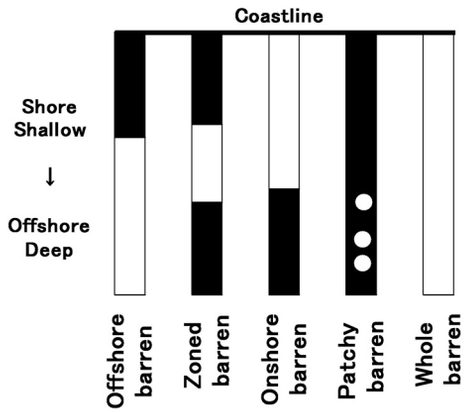

Fig. 1. Location of isoyake in seaweed beds from shore to the lower limit of its bed. (Fujita 2002)

The bottom status of poorly vegetated area after deforestation includes high coverage of crustose coralline algae, denuded rock, survival of tolerant algae or proximal parts of grazed/browsed/withered upright algae, and/or accumulation of soft sediments, all of which remind us barren scenery, something like fired housings and forests as 'yake' in the word isoyake means burnt. Most of isoyake occurs as a zone in the offshore or middle of seaweed beds parallel to the coastline; the latter includes two types, zoned and patchy barrens as shown in Fig. 1 (Fujita 2002, 2009, Fisheries Agency 2007). The most important in the further discussion on isoyake is to pay more attention to the current decrease of seaweed beds, to stop the trend and to start restoration of seaweed beds. However, we now know that each type schemed in Fig. 1 can be also recognized in wild vegetation pattern other than isoyake. For example, the offshore communities in areas deeper than seaweed beds often look like isoyake because of limited light intensity and water motion, accumulation of sediments and/or abundance of herbivores (mainly sea urchins). Therefore the use of the word isoyake should be restricted to mention the 'decrease of the stable seaweed beds' but not to include the stable permanent barrens. Of course, the definition of isoyake is too much comprehensive to treat each local phenomenon and to build working hypothesis there because the biota and environmental conditions are quite different from site to site in Japan elongated from subtropical to cold temperate, comprising of exposed and sheltered, or eutrophic and oligotrophic coasts. It is

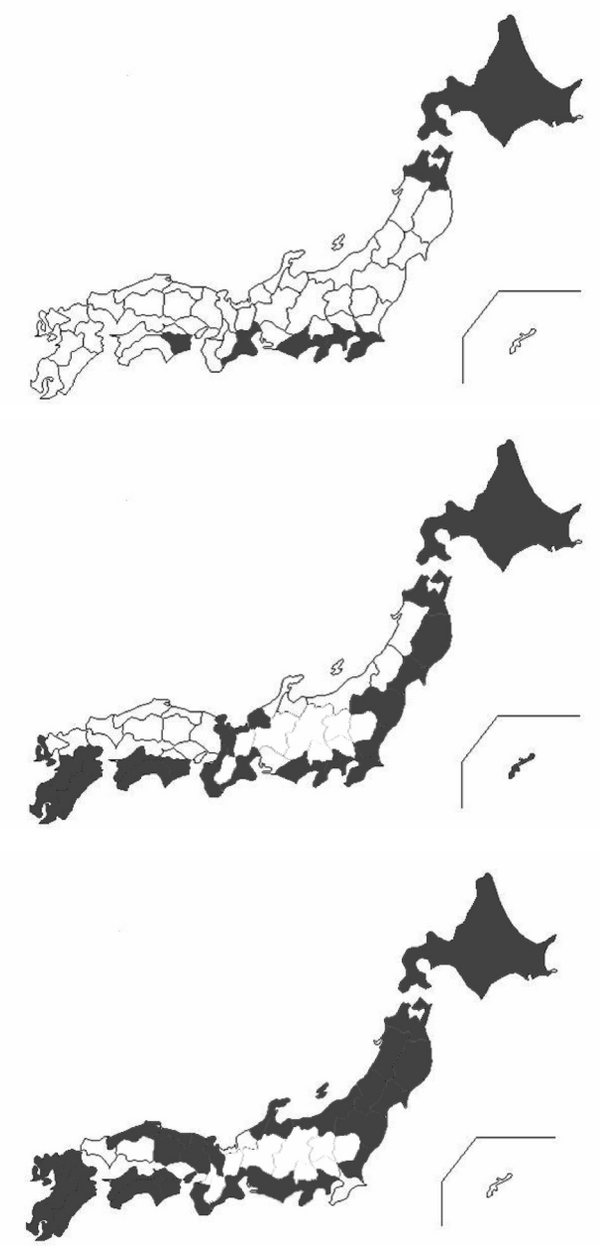

Fig.2. Chronological increase of isoyake at prefectural level in Japan.
Top: early 20th century; middle: late 20th century; bottom; early 21st century.

desirable for each coastal prefecture to positively promote the seaweed restoration projects by delineating the local isoyake phenomena and setting the practical definition to which administrative can treat the project as done in Kochi Prefecture (Kochi Prefecture 2008).

Current status of 'Isoyake' and causative agents in Japan

Fig.2 shows the changes in distribution of isoyake at the prefectural level in Japan. As shown in the figure, number of prefectures with isoyake increased from the beginning of 20th century, through the latter (1980's) of the century, to the beginning (2005) of the 21st century; most prefectures suffered from the phenomena. Figs. 2 (bottom) and 3 to 5 are based on the data of hearing to all coastal prefectures by Fisheries Agency in 2005. Although presence of isoyake was not reported from some prefectures (not pasted in Fig. 2 (bottom)), more or less seaweed beds have actually decreased even in these prefectures. Akimoto *et al.*, (2009) confirmed the presence of 83,798 ha (41.6%) of 201,212 ha reported in 1994 (data obtained in 1989 to 1991 were used), among which 18,538 ha (22.1%) was lost until 2006-2008.

The major decreasing bed-forming seaweeds are cold temperate kelp *Saccharina* in Hokkaido and Northeast coast of Honshu, warm temperate kelps such as *Ecklonia* and *Eisenia* and *Sargassum* in Honshu, and *Gelidium* in some local areas in Honshu and Shikoku Islands (Fig. 3).

The reasons thought to cause and/or maintain isoyake are, though some of them are not popular, 1) changes in oceanographic conditions, 2) deficiency of nutrients, 3) outflow of freshwater, 4) changes in climatic conditions, 5) grazing or browsing by herbivores, 6) Competition for space with attached organisms, 7) sedimentation, and 8) public nuisances including industrial wastes (Table 1). The extension and duration of isoyake are highly variable in these phenomena and the causative agents listed above often damage seaweed beds in combination. Seaweeds decrease when thalli are 1) grazed or browsed by herbivores (Grazing-type), 2) when thalli are withered (Withering-type), 3) when reproductive cells (including dispersal propagules and germlings) cannot attach to the substrata or germinate (settlement inhibition-type) and/or 4) when thalli are dislodged in storms (dislodgement-type). (Fujita 2002, 2009; Fisheries Agency 2007). All of these processes are common in healthy seaweed beds; the beds decrease when they exceed each usual range by the reasons listed above.

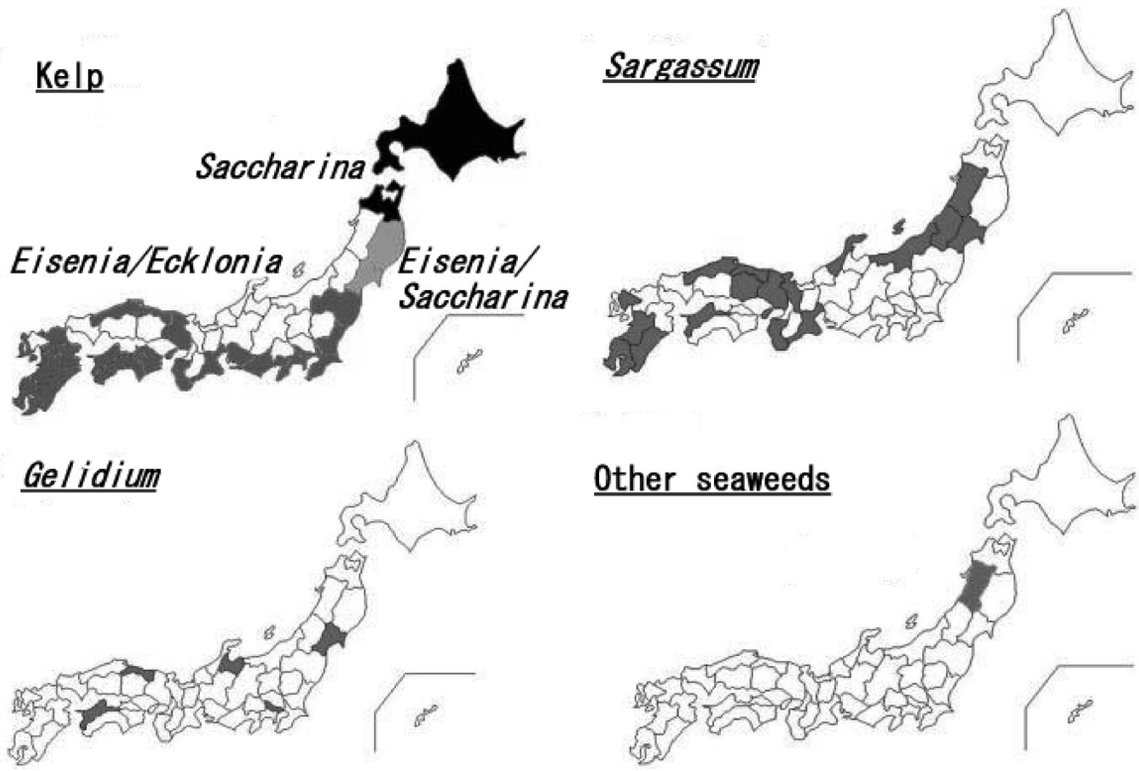

Fig. 3. Distribution of major decreasing bed-forming seaweeds in Japan.

The most important among the four types is the grazing/browsing type (Fisheries Agency 2007). The herbivores which intensively and extensively affect the distribution of seaweed beds are sea urchins (Fujita *et al.*, 2008) and herbivorous fish (Fujita *et al.*, 2006). Local reduction of seaweed beds are often brought by the grazing by gastropods such as horned turban *Turbo cornutus,* small snails (e.g., *Chlorostoma*), and sea hares *Aplysia kurodai* and *A. Juliana.* Among the herbivores, grazing by sea urchins has been paid attention as structuring force in the world (Lawrence 1975, Harrold & Pearese 1987): the domestic dominant causative species are *Strongylocnetrotus nudus* in northern Japan and *Anthocidaris crassispina* and *Diadema setosum* in southern Japan (Fig. 4). The strongylocentrotids and diadematids are dominant in cold/warm temperate waters in northern hemisphere and tropical to subtropical waters, respectively (Lessois *et al.*, 2001, Biernmann *et al.*, 2003), both of which affect the seaweed vegetation and its distribution (Lawrence 1975, Fujita *et al.*, 2008).

On the other hand, notable herbivorous fish are tropical/subtropical species such as *Siganus fuscescens, Calotomus japonicus*, *Kyphosus bigibbus* and *Prionurus scalprum*, which damage seaweed beds in southern to central coasts of Japan (Fig. 5). Among them, *S. fuscescens* is recorded from all over the domestic warm temperate coasts (up to 41° N, i.e., except Hokkaido, but quite rare in northeastern coasts of Honshu) and its browsing on seaweeds are detected in the highest latitude (at least 38 °N) among the four species (Fujita *et al.*, 2006).

Some people, even researchers consider that recent elevation of water temperatures (global warming?) induced the tropical/subtropical herbivores such as *Diadema* and herbivorous fish to the warm temperate areas of Japan. However, this is not true because both of them have been known for more than a century. For example, *Diadema* was reported by the first Japanese echinoderm taxonomist Shigeyasu Yoshiwara (Yoshiwara 1898) in Boso, Miura and Izu Peninsulas at the end of 19th century and *Siganus fuscescens* was reported from northern Kyushu as early as 1708.

In the hearing in 2005, coastal prefectures also

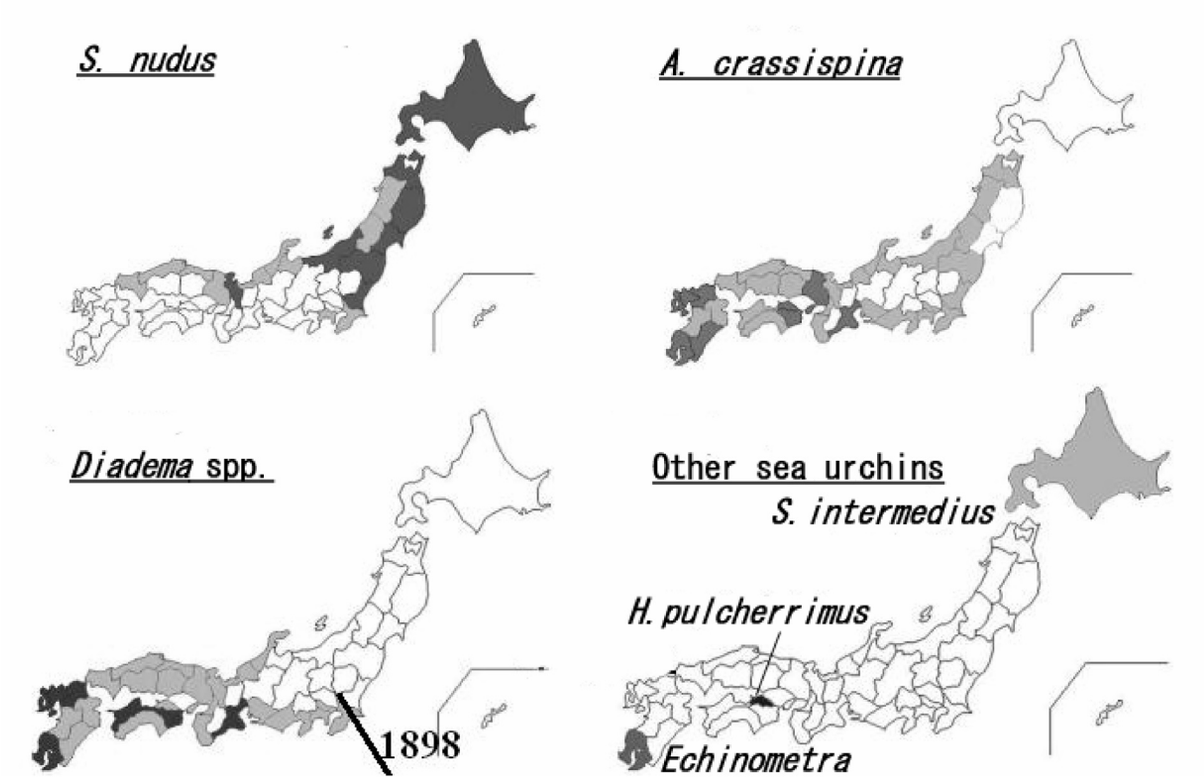

Fig.4. Distribution of major species of sea urchin causing deforestation of seaweed beds in Japan. Prefectures with thin and dark color show the occurrence of each species and the presence of intensively grazed areas, respectively, except the map of other sea urchins. Note that tropical/subtropical species *Diadema setosum* has been known since 1898 from Boso Peninsula, central Pacific Coast of Japan.

enumerated factors other than grazing/browsing by sea urchins (see Fujita *et al.,* 2008) and herbivorous fish (see Fujita *et al.,* 2006), namely, stagnation/turbidity of waters accompanied with sedimentation, oceanographic fluctuations/elevation of water temperatures, typhoon, grazing by gastropods, deployment of coastal structures (breakwater, long piers, artificial reefs etc.), warm waste discharged from power plants, and excretes from fish aquaculture cages (see Fujita *et al.,* 2010). However, the discussions on effects of coastal structures, power plants and aquacultures are often neglected or tabooed by coastal prefectures, resulting in insufficient answers in the hearing. Therefore the nation-wide survey is needed to detect any effects of the coastal structures and activities on the seaweed beds. These are sometimes unavoidable for protection of coastlines as well as the development of local economy, but their effects are much more intensive and extensive than expected; further cautions are needed for the renewal plan. We have to note that plural causative agents co-affect on seaweed beds and causative agents are often different from maintenance factor in isoyake. Generally, in Japan, water pollution by mine and industrial wastes were much more serious until 1970's than now. The pollution has been removed because of movement of the factories from domestic to abroad and replaced by river improvements and shore protection, which were promoted publicly to recover the sluggish economy and to create hiring labors as well as to keep residential ease, safe and richness. The fishermen have lowered their interests and capabilities in seaweed bed managements because of changes in fisheries (i.e., catch of wild rocky resource to aquaculture), resulting in the less maintenance of seaweed beds (i.e., removing herbivores and competitive algae). Recent elevation of water temperatures and behavioral changes of coastal currents as well as increasing abnormal climatic events, accompanied with global warming, can also be a threat although little reliable studies (only as

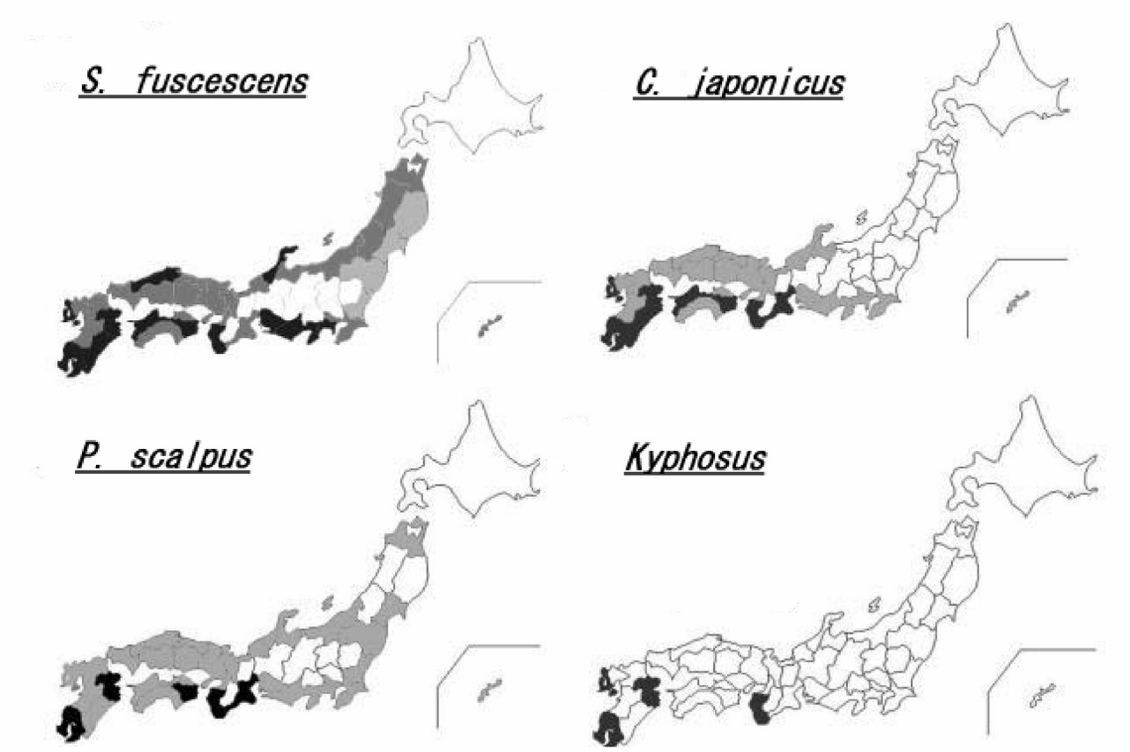

Fig.5. Distribution of major species of herbivorous fish causing deforestation of seaweed beds in Japan. Prefectures with thin and dark color show the occurrence of each species and the presence of intensively browsed areas, respectively. The prefectures with thinnest color in the map of *S. fuscescens* show the episodic record as a rare case of occurrence of the species. Note that *S. fuscescens* was reported as early as 18 century from northern Kyushu.

physiological experiments in simplified conditions or *in situ* monitoring, but not including tests to reject other factors, such as structural changes in coastline and stock levels of predators (as controller of herbivores) and herbivores (Fujita *et al.,* 2010). Now, even in areas in which climatic and oceanographic changes had been mentioned for the decrease of seaweeds in older days, anthropogenic factors are becoming more serious than before, which can affect directly on the physiology of seaweeds and indirectly on the activity of herbivorous sea urchins and fish (Table 1). The question mark on global warming (elevation of water temperatures) in Table 1 is not because of doubting its effects to seaweed beds but to keep in mind the necessity of discussion whether it is the true or major causative agent. The feeding activity of herbivores is not only dependent on water temperatures but food condition (i.e., seaweed vegetation), water motion and anthropogenic factors. For example, intensive grazing on seaweed by sea urchins can be caused by a variety of reasons, including baby boom, release of juveniles and transplantation from deep to shallow waters, decrease of drifting seaweeds (cease of seaweed culture, overexploitation, yearly bad growth etc.), decrease of sea urchin fishery, decrease of predators on sea urchins (crabs, rockfish etc.), increase of habitats (piled stones, deployed concrete blocks, etc.) and stagnation of waters as well as elevation of water temperatures (Fujita *et al.,* 2008).

Publish of a guideline and the subsequent activities

Although the studies and projects on isoyake have been increased (Nakatsu 2005, Kuwahara *et al.,* 2006), success in recovery of seaweed beds are quite limited because of the reasons as follows; (1)drastic changes in coastal environments,.(2) misunderstanding of isoyake, (3) inappropriate selection of method, (4) decrease of young fishermen,

Table 1. Causing or maintenance factors (including tentative) of isoyake in Japan

Factor	Example	Note
1..Oceanographic changes	Dominance or shoring of Kuroshiwo and Tsushima Current, Ashoring of the first branch of Oyashiwo, Shoring of floating ice.	Elevation of water temperature in winter or summer (accompanied with short of nutrients). Floating ice also plays role in clearance of weed on rocks.
2. Short of nutrients	Prohibition of dumping squid viscera, increase of land-slide barrier, decrease of river flow and disturbed dispersal	Short of N and P (and Fe?) can reduce the growth and/or maturation of seaweeds. Alteration in coasts and watershed as well as loss of feedback of nutrients into coastal community can enlarge the geographical unbalance of eutrophic and oligotrophic areas.
3.Inflow of fresh waters	Deforestation in land forests (causing flood, periodical discharge of freshwaters, cultivation in open fields, heavy or prolonged rain,	Reduction of salinity has been thought to cause decrease of seaweeds; turbidity and/or accumulation of organic silts are more serious in modern context.
4.Climatic factors	Typhoon, warm winter	Extensive deforestation was known only when Kitty Typhoon (1949) attacked west coast of Sagami Bay.
5.Grazing or browsing by herbivores	Sea urchins (*S. nudus*, *D. setosum*, *A. crassispina*), gastropods such as *T. cornutus*, aplysian sea hare, herbivorous fishes (*S. fusges cens*, *C. japonicus*, *P. scalous* and *K. bigibbus.*)	Sea urchins and herbivorous fish are most important; *T. cornutus* and *Aplysia* often overgraze *Gelidium* and *Undaria* beds, respectively,
6.Occupation of hard substrata	Crustose coralline algae, polycheates	Crustose coralline algae (CCA) can live even poor-vegetated area (including deforested area) because of its high tolerance to grazing, wave, turbidity and accumulation of silts. The dominance of CCA is a result of Isoyake rather than the cause of the phenomenon.
7. Burial of hard substrata	Volcanic ash, drift sand, silt & floc	Damage by volcanic ash was reported around Mt. Komagatate, Mt. Fugen- dake and Miyake Island. Drift sand and silt & floc are highly linked with alteration of coasts and watersheds.
8.Public nuisance	Mine or industrial wastes, sewage, warm waste from power plant, river improvement, enlarging ports, breakwater coastal road, cultivation on upstream land, agricultural chemicals.	After closing domestic mines and improving water quality comparative to economical high growth period, increase of coastal structures facilitate stagnation of waters and accumulation of silt & floc.
9. Fisheries and aquaculture	Hard use as fishery ground, overharvest of seaweeds, deployment of concrete blocks, release and transplantation of herbivores such as sea urchins, excretes and unfed pellets in fish culture, stagnation caused by crowded culture cages or rafts	Some barrens have experienced the overharvest of commercial products including abalone, agar weeds and kelp. Unsuccessful improvements of fishery ground and transplantation of sea urchins from deep barren to shallow algal refuge has enlarged deforested areas.
10. Others	Hot spring, decrease of seepage caused by pumping underground water, virus or bacterial disease etc.	Some has not been scientifically elucidated, others are superstitions.

(5) limited information for planning and practice for the restoration, (6) short of social support system for promoting restoration, (7) limited commercial usages for priceless herbivores such as less gonad sea urchins and tasteless herbivorous fish. Details were discussed elsewhere (Fujita 2009).

At the end of fiscal year 2006, Fisheries Agency (Japan) officially published 'Isoyake Taisaku Guideline' (Taisaklu=measures) to practically restore seaweed beds from isoyake areas as a result

of 'Emergent Model Project for Recovering from Isoyake' (2004-2006). The principal in seaweed bed restoration should be the removal or reduction of major factor(s) which inhibit the formation (or recovery) of seaweed beds, in most cases, grazing /browsing pressure. Therefore the guideline emphasized the need to remove herbivores from bottoms desirably as fisheries because this is the only breakthrough which fishermen themselves can be a core of the restoration program as professionals. Collaboration among administrative boards, researchers and citizens (both local resident and municipals) as well as adaptive management are strongly recommended in the guideline. In the program, introduction of simple experiments to identify the inhibiting factor(s), monitoring of current status of seaweed beds and recording the results of any action for restoration are important to feedback and bring successful results. Furthermore, in order to induce secondary damage to seaweed beds, soft restoration techniques are preferable to hard techniques (i.e., piling of stones, deployment of concrete blocks). This is because artificial beds often provide habitats for sea urchins and herbivorous fish. Among the collaboration, introduction of citizen can be a key not only to provide an amount of labors in the depopulated or aged fishing village, but to activate the village by promoting practical human exchanges between cities and fishing villages. They will also be a power to inhibit undesirable destructive plans in coastal managements (e.g., land reclamation, overprotection) which should be dissolved as habitat problems and to avoid secret negotiation between local office and fishermen's cooperatives.

After publishing the guideline, Fisheries Agency started a subsequent project, 'Large-scale Project for Promotion of Recovery from Isoyake' (2007-2009). In the project, guidance was held in requested areas (more than 10 sites a year) and a training course (monitoring of seaweed beds, once a year) were opened to researchers in local fisheries institutes and teachers in fishery high schools. Furthermore, practical restoration programs were developed with the help of supporters (specialists of full experiences in restoration) at 10 sites. Unsolved problems including the defense from browsing by herbivorous fish are also continued to study in the project. Now, in most 'urchin barren', at which grazing by sea urchin (no escape, no hide out) solely contributes the maintenance of isoyake, continuous removal of sea urchins promises the restoration of seaweed beds. The effective and efficient system for the maintenance and enlargement of the beds should be established as the next step. On the contrary, seaweed beds are hardly recovered when browsing by herbivorous fish (professionally eat and escape) is dominant, when waters are stagnated and/or sedimentation of silts and turbidity are dominant, and when 'urchin barren' is accompanied with other herbivores (fish, snails, sea hares) or sedimentation.

Perspective and remained problems

The 'Isoyake Taisaku Guideline' (Fisheries Agency 2007) is a crystal of the knowledge of the participant prefectures and committee comprised of specialists, explaining principal concepts and 25 systematized component techniques. Following the landmark guideline, some prefectures published local version of the guideline (e.g., Kochi Prefecture 2008) and planned and practiced in ways more specified to the local environment and biota. As stated above, urchin barren, particularly when maintained solely by sea urchin, has been demonstrated to turn to seaweed beds by removal of sea urchins in many coasts of the country from Kyushu to Hokkaido (Fujita *et al.,* 2008). On the contrary, when isoyake is maintained by plural herbivores (particularly escapable fish, high density of snails etc.), restoration of seaweed beds is quite difficult. Furthermore, where the coastlines and rivers are drastically changed irreversibly by civil engineering such as land reclamation and dam construction, restoration efforts scarcely result in the recovery of original states before isoyake. Recently, natural disaster type of isoyake is decreasing, while anthropogenic and complex types are increasing; the author call these types 'structural barren', which is similar to the structural depression in economics (Fujita 2009).

As the local fishing villages are suffered from sluggish economy, depopulation, aging of fishermen and increase of part-time fishery as a combined

provocation, now is the timing to reestablish new systems and rules to manage seaweed beds as well as coasts and resources living there. Under the present circumstances, the most important is not to continue 'barren' discussions on the desk, but to start any actions including trial and error (to be directed in adaptive management) for the dissolution of isoyake problems. In addition, oceanographic literacy (PADI 2000, Tokyo University of Marine Science and Technology 2010) should be strengthened in education of national people. More practically, development and popularization of knowledge and technology for monitoring and managing seaweed beds will be the base on the activity (Fig. 5). The final target should be the establishment of moderate fishery and balanced utilization of coasts and resources. As stated in the introduction, seaweed beds are important communities in various aspects; the values of component seaweeds are elevating day by day because of promised contribution to the human health. Therefore, many people should take part in the monitoring and maintenance of seaweed beds. For example, local residents, amateur divers and anglers can be volunteers, seaweed industries and electric and construction companies can participate in these activities through CSR (Corporate Social Responsibility) projects. All of them can support fishermen to monitor and restore the seaweed beds. Marine high schools and universities of fisheries, although both of them are losing field works and departing from fisheries, should rear key persons who can be core of the activities. Fates (e.g. coastal changes) and restoration of seaweed beds should not be discussed secretly between the local offices and fisheries cooperation but should be open to local society to find the best ways by introducing a variety of knowledge and techniques.

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