水研センター研報，第32号，11－17，平成22年
Bull. Fish. Res. Agen. No. 32, 11-17, 2010

Effects of recent ecological events on the distribution and growth of macroalgae in marine waters around Taiwan

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Abstract: Macroalgal resources are particularly abundant in the northeast coast and Hengchung Peninsula in the southern part of Taiwan as well as in several smaller islands around Taiwan. Classified as being in the tropical and subtropical areas, the diversity of macroalgal species and seasonal growth types are based on their geographical distributions in different coasts of Taiwan. During the past years, there were more than 600 species of macroalgae identified with certainty. Basically, tropical macroalgae are found in the eastern and southern parts of Taiwan, Shiao-Liou-Chou Island, Green Island, and Orchid Island. The subtropical macroalgae mainly occurred in the northeast coast of Taiwan. Mixed tropical and subtropical macroalgae can be found in the Pescadores, the three Northern Islands, and Kueishan Island. Besides geographical distribution, the Kuroshio and its branch currents also can affect the distribution of tropical macroalgal species. Some subtropical macroalgae, such as *Porphyra*, *Bangia*, and *Petalonia*, can only grow in cool areas washed by the cold current coming from the coast of Mainland China. Giant kelps, such as *Laminaria* and *Undaria,* cannot be found in Taiwan and offshore tropical islands, but some of them are cultured in Kinmen Islands and Matsu Islands off the coast of nearby Fujian province.

Recently, the macroalgal resources in Taiwan area have affected by global climate changes, coastal development, tourism, and environmental pollution. The species composition and cover of macroalgae in different coastal environments have changed as a result. For example, the mass proliferation of *Codium* species overgrows the hard corals in Nanwan Bay of Hengchung Peninsula. The diversity of corals decreased and the dominant benthos has phase-shifted from corals to macroalgae. In order to alleviate the situation, conservation organizations decided to increase the feeding pressure on the overgrowing macroalgae by prohibiting the harvest of herbivorous sea urchins from coral reefs. On the other hand, the coastal geomorphology of northeastern Taiwan was changed by several strong typhoons that struck during the past ten years. As a result, the harvest of some economic seaweeds such as *Porphyra*, *Gelidium*, *Eucheuma*, *Grateloupia* and so on declined dramatically. *Gelidium* harvest was also affected seriously by the release of herbivorous fish by some fishery groups. In February of 2008, a deep cold current was recorded in the Pescadores. The cold seawater caused more than ten thousand tons of fish to die. After this catastrophic event, studies have shown that macroalgae there grew more abundantly than ever before. It is obvious that recent ecological events have affected the normal distribution and growth of macroalgae around Taiwan and these phenomena should be further investigated

2010年７月１日受理（Received on July 1. 2010）
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Introduction

Benthic macroalgae are one of the most important biological resources in shallow marine ecosystems. They can support some of the most diverse and productive communities in the marine environment by performing the important role of primary producers. They also can provide the food and habitat for different generations of marine organisms. Recently, human activities, including agriculture, urbanization, and tourism have led to increased anthropogenic nutrient loading into shallow shores and caused these fragile ecosystems to shift to different phases. Nutrient enrichment was found to increase the biomass of macroalgae among these observed phase shifts, especially among some dominant and nuisance species (McClanahan *et al.,* 2007). Additionally, direct and indirect effects of overfishing activities may strongly affect biological interactions among coastal organisms, such as decreasing marine organism abundance, and changing population structures and distributions of certain species within the coral reef ecosystem (Hughes, 1994). Although macroalgal resources are particularly abundant in the northeast coast and Hengchung Peninsula in the southern part of Taiwan as well as in several smaller islands around Taiwan, the problems of overgrowing or degradation of macroalgal communities are rampant with serious consequences than conditions prevailing ten years ago (Dai, 1997; Tsia *et al.,* 2005).

Taiwan (21° 53' – 25° 18' N, 120° 1' –122° 0' E) is an island located in the western Pacific off East Asia with tropical and subtropical climates, because of being bisected by the Tropic of Cancer. There are some smaller islands around Taiwan, including the Pescadores Islands, Orchid Island, Green Island, and Shiao-Liou-Chou Island. The entire coastline stretches for 1,566.3 km around Taiwan. Oceanographic conditions around the islands vary with topography, water temperature, and current patterns. Macroalgae mainly occur on rocky shores in the northeastern and southern coasts as well as in other smaller islands. During the past years, there were more than 600 species of macroalgae identified with certainty in these areas (Chiang and Wang, 1987; Lewis and Norris 1987; Huang, 1990). Basically, tropical macroalgae are found in the eastern and southern parts of Taiwan, Shiao-Liou-Chou Island, Green Island, and Orchid Island. Subtropical species mainly occur along the northeast coast of Taiwan. Mixed tropical and subtropical macroalgae can be found in the Pescadores, the three Northern Islands, and Kueishan Island. Besides geological and topographical variations, water temperature and currents have also caused differences in macroalgal composition between the northern and southern parts of the Pescadores and Taiwan. The two main two currents affecting the coastal areas of Taiwan are the Kuroshio Current and the Mainland Coastal Current. The Kuroshio Current brings water of higher temperature and salinity up from the Philippines and the equatorial regions toward southern Taiwan where it branches into two. The stable, main branch with higher than 20 ℃ water temperature runs past the east coast of Taiwan where some tropical species are found. A smaller branch, subjected to seasonal variability, veers northwestward through the Taiwan Strait to the southern parts of the Pescadores. Flowing south along the Chinese mainland coastal region, the Mainland Coastal Current carries colder water from the East China Sea to the northern parts of Taiwan Strait, and is particularly strong in summer and less so in winter. Typhoons also occur disturbing the coastal areas every year and have caused considerable damages to marine ecosystems.

Some subtropical macroalgae, such as *Porphyra, Bangia*, and *Petalonia*, can grow in cooler areas washed by the cold current coming from the coast of Mainland China. On the other hand, tropical species such as *Halimeda* spp. can be found in the areas washed by the Kuroshio Current. Most of the macroalgae found in Taiwan exhibit obvious seasonal growth because of their annual characteristics. Macroalgae are most abundant from the end of winter to spring (about November to next May), and the plants disappear in the summer season. Giant kelps, such as *Laminaria* and *Undaria,* cannot be found in Taiwan and offshore tropical islands, but some of them are cultured in the Kinmen Islands and the Matsu Islands off the coast of nearby Fujian province across the Taiwan Strait. In Taiwan, the primary source of economic seaweeds has been natural populations collected by coastal fishermen throughout the natural growing seasons. Therefore, the biomass and community structure of macroalgae are highly variable and impacted due to such activities (Wang and Chaing, 1994).

Recently, there were some serious ecological events that occurred in the coastal areas around Taiwan. The first major ecological event took place when the coral reef ecosystem in southern Taiwan exhibited a phase shift to macroalgae-dominated reef systems as a result of the combined effects of nutrient enrichment and herbivory reduction in Nanwan Bay, Kenting National Park. The second one happened in February, 2008 off the coasts of the Pescadores which were affected by a devastating deep cold current. Lots of herbivores and marine organisms died after this catastrophic event and the economic green seaweed *Monostroma latissimum* grew more abundantly than ever before due to the absence of its natural predators. Another case of interaction between macroalgae and herbivores was also observed in the northern coast of Taiwan. *Gelidium* harvest was affected seriously by the large-scale release of herbivorous fish (rabbit fish) by some fishery groups. This paper will cite these cases of macroalgae blooms and the close interactions between herbivores and seaweeds around Taiwan.

The mass proliferation of *Codium* in southern Taiwan

Coastal areas along Hengchun Peninsula in the southern part of Taiwan, which are among the most well developed coral reef ecosystems in Taiwan, have been subjected to increasing anthropogenic pressures resulting from expanded urban development and increasing tourism activities. Most nearshore reefs in Hengchun Peninsula, especially in Nanwan Bay (21° 57' N, 120° 44' E), are characterized by high abundance of fleshy macroalgae and low abundance in herbivorous fishes (Dai, 1997). These algal blooms in Nanwan Bay are often dominated by opportunistic algae in the genera *Ulva*, *Codium*, *Laurencia,* and *Sargassum*. Decreases in species numbers, colony numbers, reef coverage, and species diversity of corals were observed in Nanwan Bay from 1987 to 1997 (Dai *et al.*, 1998). It is well known

Fig. 1. The mass proliferation of *Codium edule* in southern Taiwan

that the shift of coral reefs to algae-dominated reefs generally causes a dramatic decline in fish stocks and biodiversity in coral reef ecosystems (NRC, 2000). Thus, an understanding of macroalgal abundance on southern Taiwan coral reefs is an important aspect of the ecological, environmental, aesthetic and socio-economic value of the reefs.

Codium edule (Fig. 1) is the most abundant species among nuisance macroalgae in Nanwan Bay of southern Taiwan (Chiang and Wang, 1987; Dai, 1997). A specialized organ that acts as a proliferative propagule is often issued from the side of utricles at the end of the growth season. Juvenile filaments were sprouted out from these propagules and formed new utricles after laboratory culture of 10-14 days. The new utricle and filament were divided by a septum and propagules showed the ability to eventually develop into a new thallus. We suggested that the propagule buds are possibly transformed gametangia showing incomplete meiosis as shown by nucleus staining experiments. The propagule buds may serve as a persistent stage when the macrothalli disintegrate at the end of the growing season, and act as a "seed bank" for vegetative reproduction for *C. edule* into the next season (Chang, *et al.,* 2004). A new pathway within the *C. edule* life cycle has been proposed by Chang (2002, see Fig. 2).

Besides the opportunistic asexual stage of *Codium edule* as one of the main reasons for its mass proliferation in Nanwan Bay, the decline of herbivores brought about by overfishing has been identified as another important factor causing the shift of coral reefs to algal dominated systems causing a dramatic decline in the biodiversity and altering ecological dynamics in the reef ecosystem (Liu *et al.,* 2009). In order to alleviate the situation, conservation organizations decided to increase the feeding pressure on the overgrowing macroalgae by prohibiting the harvest of herbivorous sea urchins (such as *Tripneustes gratilla*) from coral reefs. At present, the number of sea urchins has slowly increased from about 8 to 13 / m^2 while the species number of coral fish has also increased from 31 to 110. Thus, a thorough understanding of the macroalgal population dynamics can be considered

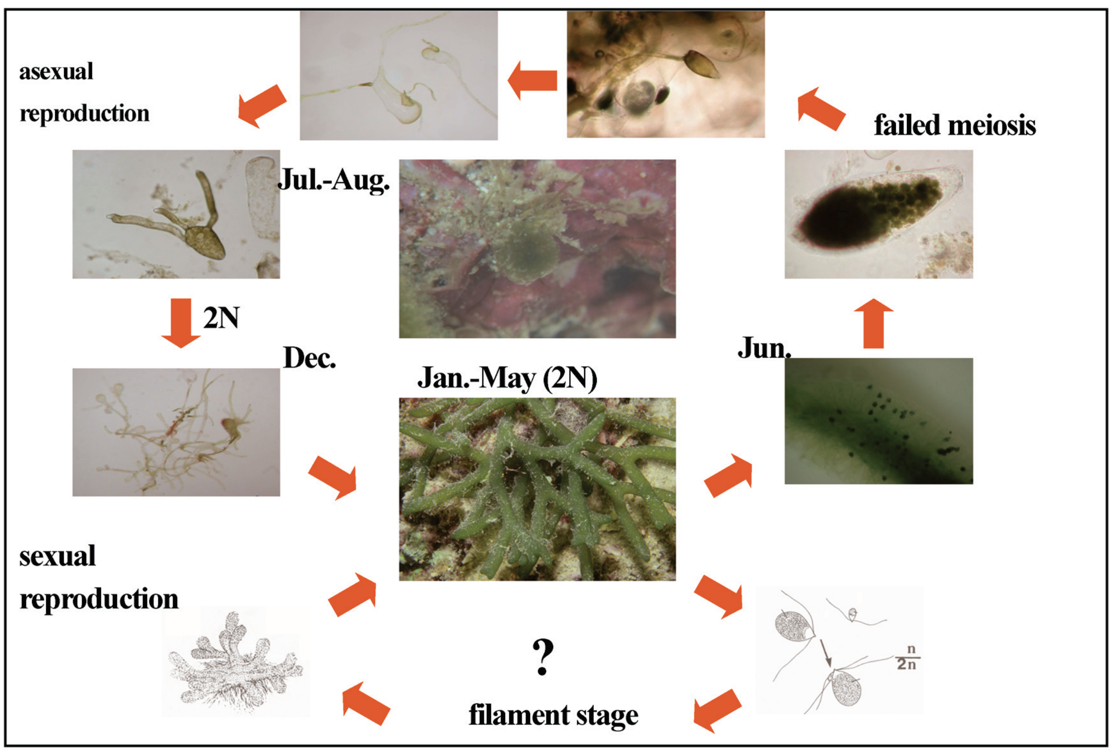

Fig. 2. The stage of asexual reproduction by propagation buds transforming from immature gametangia in the life cycle of *Codium eduleof* southern Taiwan.

to be an important aspect of the ecological, environmental, aesthetic and socio-economic value of reefs.

The interactions between macroalgae and herbivores as affected by environmental change

The coastal geomorphology of northeastern Taiwan has been changed by several strong typhoons that struck during the past ten years. As a result, the harvest of some economic red macroalgae such as *Porphyra*, *Gelidium*, *Eucheuma*, *Grateloupia* and so on declined significantly. However, the impact of herbivores on macroalgal populations can be as devastating as the effects of typhoons. Besides sea urchins, rabbit fish is another well known herbivorous organism in the tropical Pacific waters. It is captured and sometimes cultured for its economic value as a food fish. It was chosen as one of the introduced species to supplement the existing coastal fishery resources by fishery groups in Taiwan and subsequently released into the wild (Fig. 3). During the past three years, *Gelidium* harvest was not only affected seriously by destructive typhoons, but also adversely affected by the intentional release of herbivorous fish by some fishery groups. This unfortunate intervention to release introduced fish for a good purpose should have been carefully evaluated prior to its implementation taking into account the close interaction between macroalgae and herbivores and some long term effects on the marine ecosystem as a whole. Species introductions generally have far reaching ecological consequences whose impacts do not surface until several years thereafter.

In February of 2008, a deep cold current was recorded in the Pescadores. The cold seawater caused more than ten thousand tons of fish to die. After this catastrophic event, studies have shown that macroalgae grew more abundantly than before, especially the economic species, *Monostroma latissimum* (Fig. 4). It was supposed that lots of herbivores died after the cold current occurred, causing a major shift in the natural herbivore-macroalgal equilibrium. Although the value and harvest of this edible alga in 2009 was the

Fig. 3. The mature rabbit fish being the dominant species and feeding on the macroalgae (especially on *Gelidium*) in northeast coast of Taiwan. (Photo by Dr. LiSu Chen)

highest seen during the past 15 years, the impact of the cold current on the other coastal fishery resources are only starting to be felt. Hopefully the slow recovery of affected marine resources stock should be on the horizon, with coastal fishery managers learning from this experience to devise new and relevant marine coastal resource management strategies.

Conclusion

The Isoyake phenomenon in Japan is one example that showcases the effects of changing environmental conditions on macroalgal communities. Similar phenomena around the world, particularly in the western Pacific Ocean have been documented. In Taiwan as well as in neighboring countries, drastic decrease or increase of macroalgal populations have been attributed to some environmental factors, such as global climatic change, seawater warming, or increase in dissolved nutrients discharges among other factors. The change in herbivore population is also emerging as an important factor that tends to upset the balance of trophodynamics in benthic ecosystems and drastically altering the structure of complex marine food webs. The documented cases in Taiwan are only beginning to be understood and much further research is necessary. We hope some key points of the dynamics of macroalgal blooms or their population decline in coastal ecosystems can be explained and eventually some effective strategies for coastal management can be proposed in a timely fashion while the marine environments continue to change in the future.

Acknowledgment

We acknowledge the financial support provided by the Tokyo University of Marine Science and Technology and gratefully thank Dr. Daisuke Fujita and his colleagues for their valuable help during our stay in Tokyo. We also appreciate the various help provided by Dr. Ming-Show Tseng (Biodiversity Research Center, Academia Sinica, Taipei) and Dr. Li-Su Chen (National Museum of Marine Science and Technology, Keelung) who shared the pictures used for presentation. Finally, we thank Dr. Lawrence M. Liao (Graduate School of Biosphere Science, Hiroshima University) for help and suggestions in the revision of the manuscript.

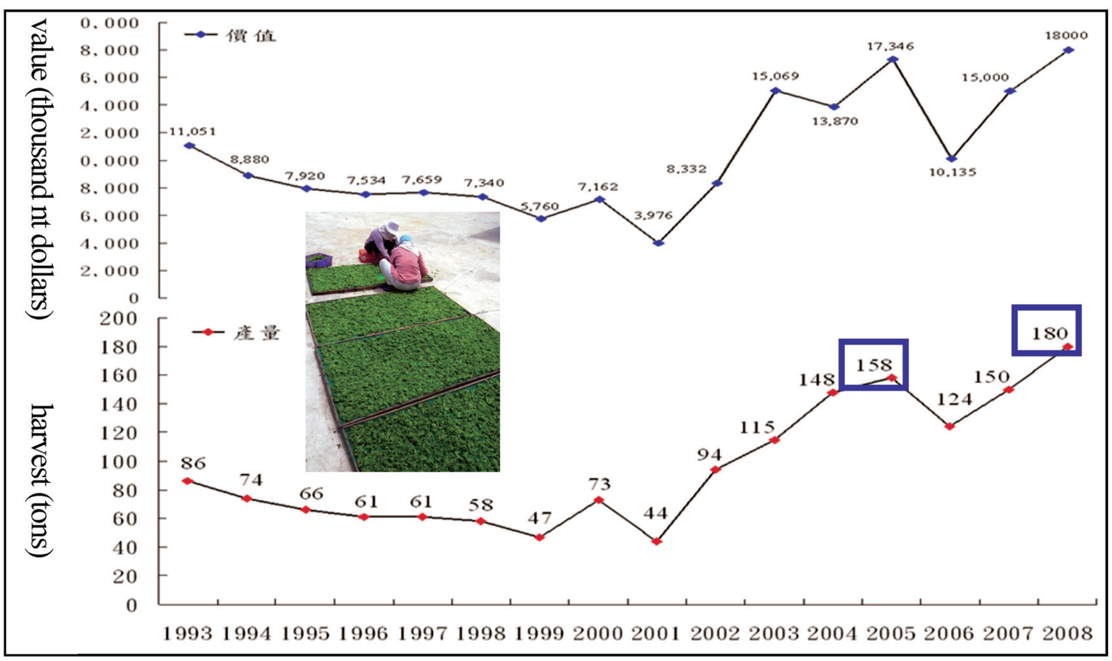

Fig. 4. The harvest and value of *Monostroma latissimum* from 1993 to 2008, especially while a abnormal lower seawater temperature made lots of herbivores died in Fabruary, 2008. (data from Fishery Annual Report, 2008)

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