Introduction for This Book: General Aspects of the Coral Reefs of Japan

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Abstract

Japanese coral reef ecosystems are characterized by high biodiversity. Their inherent beauty attracts many tourists, and they provide various kinds of ecological services such as sustenance, educational opportunities, and coastal protection; however, they are easily impacted by human activities. Japanese reefs range from subtropical reefs at the southern tip of the Ryukyu Archipelago to temperate reefs at Tsushima Island in the far north which marks the limit of coral reef distribution in the Pacific Ocean. Reef development in the region is extensive and diverse, and productive fringing reefs, submerged platforms, and mesophotic reefs have accumulated. A long history research on the coral reef ecosystems in Japan has provided important knowledge on basic sciences and conservation including fundamental aspects of the biology of coral reef organisms but also has broadened our understanding of the functioning and survival of coral reef ecosystems and those occurring at environmental extremities. In this chapter, as an introduction for this book, we synthesize some of the latest multidisciplinary information that is available about the coral reef ecosystems of Japan.

Keywords

Japan • Kuroshio Current • Subtropical reef • Temperate reef • Fringing reef

1.1 Features of Coral Reefs of Japan

Coral reef ecosystems of Japan are located in the northern hemisphere at the periphery of coral reef growth in the Pacific Ocean. In the Ryukyu Archipelago, coral reefs are present from latitudes 24°N to 31°N and in the Ogasawara Islands from latitudes 26°N to 27°N. Okinotorishima Island (20°N) is a small table reef. The northern limits of coral reef development are found at Iki Island (33°48′N, 129°40′E) and Tsushima Island (34°25′N, 129°16′E) near the mainland of Japan (Yamano et al. 2001, 2012). Coral reefs are formed by calcium carbonate which calcifying organisms produce (such as scleractinian corals, coralline algae, molluscs, foraminifera, and calcareous algae). Zooxanthellate corals (Cnidaria, Anthozoa, Scleractinia) are key ecological engineers of the reef structure. Around coral reef ecosystems of Japan, over 400 coral species have been reported (Veron et al. 2009). This high diversity of coral species is maintained by the warm currents (Kuroshio Current and Tsushima Warm Current; Fig. 1.1) which enables coral species to distribute in higher latitude area and form coral reefs (around 34°N), while southern limits of coral reefs around Australia is located at Lord Howe Island (around 31°S).

The species composition of corals changes between Japan mainland and the Ryukyu Archipelago-Ogasawara Islands. Furthermore, the species composition of corals along the Ryukyu Archipelago also changes from north to south. The composition of present-day coral communities at Ryukyu

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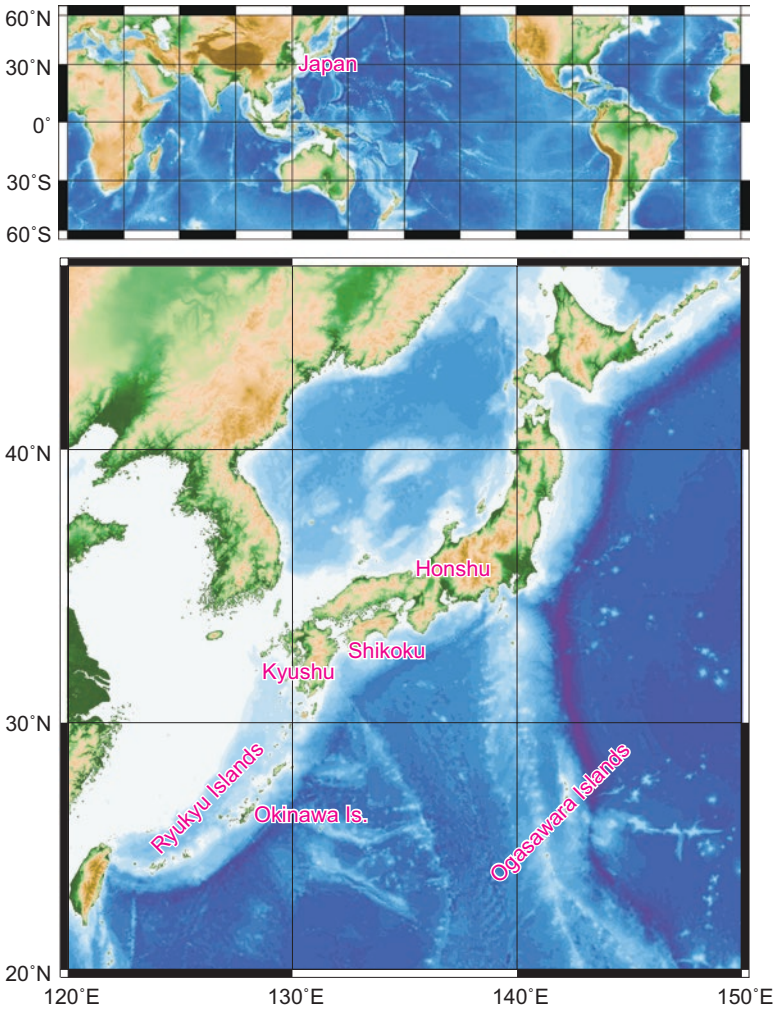

Fig. 1.1 Map of Japan coastal area along which corals and coral reefs are distributed

Archipelago-Ogasawara Islands is dominated by species from genera *Acropora*, *Montipora*, *Pocillopora*, and *Porites* (The Japanese Coral Reef Society and Ministry of the Environment 2004). However on the temperate reefs of Iki and Tsushima Islands, the coral community is dominated by *Dipsastraea*, *Echinophyllia*, and *Caulastrea* (Sugihara et al. 2009). The occurrence of well-developed coral reefs in temperate areas which is facilitated by the warm Kuroshio and Tsushima Currents is one of the most intriguing features of the coral reefs in Japan.

As may be expected, the number of coral species is lower in the temperate areas than it is in the subtropical locations. In the subtropical locations, typical coral species dominant in the Western Pacific are frequently encountered; however, these species are not encountered in the temperate areas (Fig. 1.2). The converse pattern also occurs, for example, in the case of genus *Acropora* which is most diversified coral taxa and main reef-building corals; *A. solitaryensis* is frequently observed in temperate area (Suzuki and Fukami 2012) but not along the Ryukyu Archipelago. Hence, the seascape around subtropical area is quite different from that around temperate area (Fig. 1.3).

The main region where coral reefs are well developed is along the Ryukyu Archipelago formed by small and stepping stone islands. Fringing reefs are main type of coral reefs along the Ryukyu Archipelago. Thus, coral reef ecosystems along the Ryukyu Archipelago are easily influenced by human impacts compared to barrier reefs. In particular, Okinawajima has high human density, and the land use practices are also high. Thus, coral reef ecosystems around Okinawajima have been relatively devastated by human impacts. In addition, the Ryukyu Archipelago is a subtropical area located between temperate and tropical areas. Thus, seasonal variation of sea surface temperature is high, and the sea surface temperature in winter season is quite low for corals. Therefore, coral species living around the Ryukyu Archipelago are exposed by large environmental changes compared to those in tropical area (Fig. 1.4).

A plethora of knowledge exists about the formation of coral reefs in Japan. In the Ryukyu Archipelago, reef growth

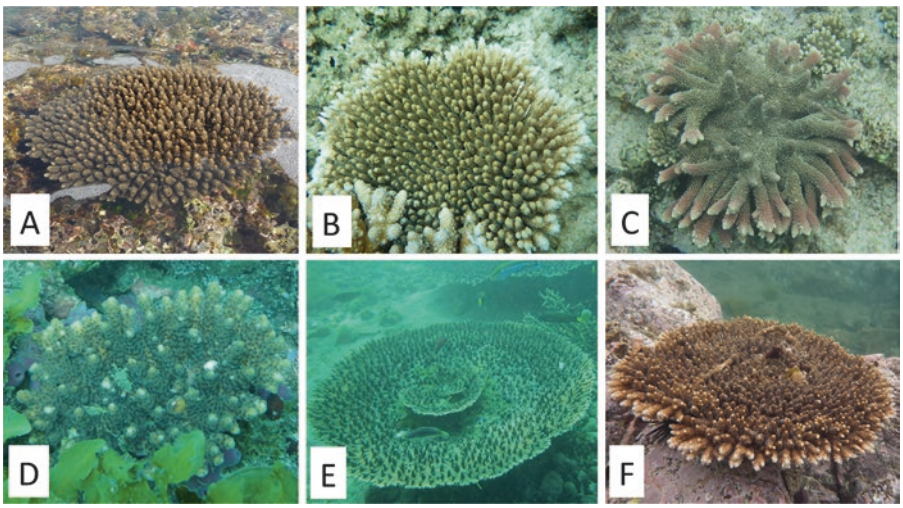

Fig. 1.2 Some typical *Acropora* species in each subtropical (**a**–**c**) and temperate area (**d**–**f**)

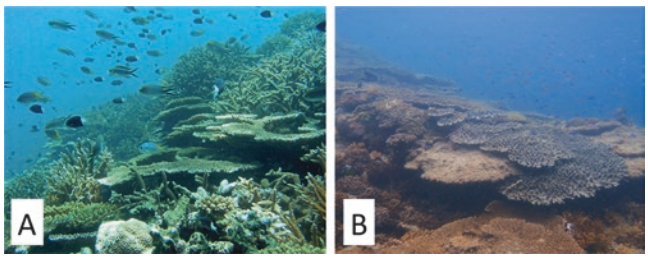

Fig. 1.3 Seascapes of subtropical and temperate areas. (**a**) Iriomote Island, Okinawa, Japan. (**b**) Goto Islands, Nagasaki, Japan

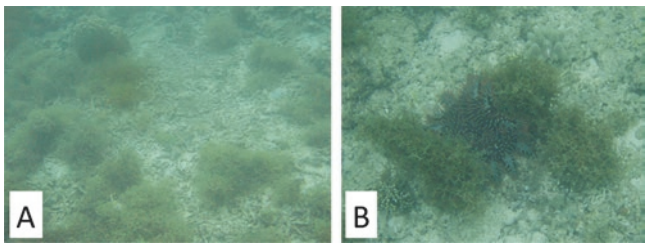

Fig. 1.4 Seascape of coral reef affected by nutrient enrichment. (**a**) Near Sesoko Island, Okinawa, Japan. (**b**) Crown-of-thorns starfish near Sesoko Island, Okinawa, Japan

started in earliest Quaternary time (1.45–1.65 Ma, 1 Ma=1 million years ago), and that extensive reef formation dates back to ~0.8 Ma (Yamamoto et al. 2006). Pleistocene reefs are exposed widely in the Ryukyu Archipelago (e.g., southern Okinawajima, Miyako Islands, and Yaeyama Islands). Holocene reefs are also widely distributed. The Holocene reefs began growing about 10,000 years ago at which time the sea surface temperature in the region had not reached the critical average temperature of 18 °C (Kayanne et al. 2004). From 10,000 to 6,000 years ago, the reefs mainly developed via the accumulation of corals and other calcareous organisms (e.g., calcareous algae) in response to a rapidly sea-level rise (Kan and Kawana 2006; Hongo and Kayanne 2009; Kan 2011). From 6000 to 4000 years ago, the upward reef growth stopped as sea level stabilized (Kan and Kawana 2006; Hongo and Kayanne 2009). After this time period, the reef expanded laterally to form flat shallow zones. Fragments of their skeletons were transported landward to shallow lagoons, and the shallow lagoons were gradually buried by sand and gravel.

The Ryukyu Archipelago is a tectonically active region. The Holocene uplifted reefs have been exposed around some islands such as Kikaijima, Kodakarajima, Okinawajima, and Kumejima Islands (Nakata et al. 1978; Koba et al. 1979, 1982; Takahashi et al. 1988; Webster et al. 1998; Sasaki et al. 1998; Sugihara et al. 2003). In Okinotorishima Island, the coral reef has been maintained throughout the past 7600 years, composed of *Pocillopora*, *Acropora*, *Porites*, *Montastraea*, and the other corals (Kayanne et al. 2012). At the northern limit of coral reefs (Iki and Tsushima Islands), the Holocene reefs consisted of *Cyphastrea*, *Dipsastraea*, *Hydnophora*, *Caulastrea*, *Echinophyllia*, and others (Yamano et al. 2001, 2012) which overlaps with the modern-day community. Hence, the coral reefs of Japan provide unique opportunities to understand geographic reef changes from the past to present and future.

1.2 Current and Future Coral Reef Studies of Japan

Coral reefs around Japan are characterized by unique geographical and geological features and have so far provided important knowledge on basic sciences and conservation studies regarding coral reef ecosystems. Coral reef studies are inherent multidisciplinary nature of various research fields. This book brings together all the different disciplines to encourage collaboration and lateral thinking.

Considering the base of high biodiversity in coral reef ecosystems, the study on cycles of matter is essential for understanding the ecological aspects of coral reefs. In Chap. 2, Drs. Yasuaki Tanaka (Universiti Brunei Darussalam) and Ryota Nakajima (Scripps Institution of Oceanography) provide this related topic based on their research experiences. They have so far been involved in the studies on dissolved organic matter (DOM) in coral reefs of Japan. They focus on cycles of matter in coral reefs especially for DOM production removal processes. They also introduce some candidates involved in the DOM production removal processes such as corals, benthic algae, phytoplankton, and bacteria and their roles in the processes. In particular, their main field, Shiraho Reef, Ishigaki Island, Okinawa, Japan, is a fringing reef which is common reef type in Okinawa Islands. Thus, the case study in Shiraho reef would be applicable to other reefs in tropical and subtropical islands which are widely distributed around the Coral Triangle with highest biodiversity in coral reef ecosystems.

After ecological studies above, the studies on the relationship between corals and their responses to changing environments have been introduced. Corals are main important reef builders in coral reef ecosystems and well known to be very sensitive to various environmental chances such as high seawater temperature which has been often dealt in the context of global warming. Dr. Tomihiko Higuchi (University of Tokyo) has so far carried out the studies on stress responses of corals from physiological and chemical aspects. He has published several papers on this topic by focusing on not only high seawater temperature but also other stresses (e.g., addition of H_2O_2). In Chap. 3, he introduces the summary of local stressors on corals around Japan. Then, he also introduces studies on stress responses of corals performed in Japan mainly focusing on laboratory experiments. He also reports studies on coral bleaching in Japan which is related not only to high seawater temperature but also to low one assumed at high latitude area in Japan and discusses the physiological aspect of bleaching mechanism.

One of the threats on corals is coral disease of which the number is reported to be increasing. Coral diseases are also known in corals around Japan coastal area, and some researchers are also tackling this issue. Dr. Naohisa Wada (University of Miyazaki), Aki Ohdera (Penn State University), and Dr. Nobuhiro Mano (Nihon University) are now conducting comprehensive approaches targeting coral diseases in Japan. In Chap. 4, they introduce historical perspective of coral diseases (mainly black band disease (BBD), White syndrome (WS), and growth anomalies (GAs)) and current situation on the related studies in Japan. They also provide the information about how coral diseases can be examined both in epidemiological and pathological approaches by including their studies. Based on the information, they provide the future direction of coral disease research in Japan.

Another threat on corals is ocean acidification which has been caused by increasing CO_2 from human activities since the industrial revolution. The number of studies on the effects of ocean acidification on corals is rapidly increasing. Some Japanese researchers are also reporting this topic not only from laboratory approaches but also field-based surveys. In Chap. 5, Dr. Shoji Yamamoto who is an expert in conduction ocean acidification provides an introduction to ocean acidification research in Japan. He explains basic concept of ocean acidification from the aspect of carbon chemistry and the impacts on calcifiers and marine ecosystems by citing important studies performed in Japan. He also discusses future direction of ocean acidification research in Japan and proposes what is needed for facilitating this research field.

When we consider the coral responses to environmental changes, we also need to focus on how corals have responded to past environmental changes. In this aspect, earth science approaches are very informative in coral reef studies. In fact, many studies have been carried out to understand past environmental conditions in coral reefs using coral skeletal cores. In Chap. 6, Drs. Sowa Kohki and Tanaka Kentaro provide the content related to coral paleoenvironmental studies. In their part, at first, they introduce the merit of coral skeleton for retrospective archive (coral skeletal growth as a parameter for coral physiological condition, chemical composition of coral skeleton as proxies of past seawater conditions such as sea surface temperature, sea surface salinity, etc.). After explaining the basic logic and the merit of the approach, they introduce previous coral paleoenvironmental studies. They also introduce the case studies around Japan by focusing on the merit for reconstructing past environmental conditions at both global and local scales in this area. Finally, they discuss future direction for coral paleoenvironmental studies in Japan.

We also provide biological studies on corals in Japan. One of the important life histories is reproduction which is essential for the maintenance of organisms. In Chap. 7, Drs. Naoko Isomura and Hironobu Fukami introduce the studies on coral reproductive studies in Japan. One of the famous phenomena of coral reproduction is the synchrony of coral spawning (mainly *Acropora* species). Although *Acropora* species show high synchrony of spawning, it is also reported that there are variations in the spawning patterns of *Acropora* species around high latitude area. In addition, some other coral species also show several geographic variations of spawning patterns around Japan. Based on the past coral reproductive studies including Japanese literatures, they discuss comprehensive patterns of coral spawning events around Japan, which is very informative to understand the evolutionary processes of coral reproduction. They also report the studies on fertilization and hybridization of corals in Japan and their significances. Based on previous and their studies, they provide future perspectives for Japanese coral reproduction studies.

Understanding how coral populations are maintained is one of the important topics to understand future responses of coral reef ecosystems. Thus, the information on how coral populations are connected to each other is essential for understanding the resilience of coral reef ecosystems, and many approaches have been tested in order to establish marine protected areas (MPAs). In the approaches, population genetic analyses using DNA markers have provided important information on the maintenance of coral populations. In Chap. 8, Dr. Yuichi Nakajima, who has been involved in studies on coral population genetics, at first, introduces the merit and the history of DNA markers for population genetic analyses of corals. He also explains some research examples regarding the relationship between reproductive modes of corals and the patterns of gene flow of coral populations. When we use DNA markers, we can obtain the information regarding not only connective patterns among populations but also genetic diversity of each population. The information on genetic diversity is also useful for evaluating recovery potential of coral populations, which has been discussed by citing some examples of coral species including the Japanese corals. Based on the information above, future direction for population genetics of corals in Japan is discussed from some aspects including methodological approaches such as seascape genetics and development of novel molecular markers.

Several threats on corals have been known as described above, and one of them is predation by crown-of-thorns starfish (COTS). In Japan, predation of corals by COTS has been known in most of the coral reef areas, and many trials to remove COTS for protecting corals have been historically performed. In Chap. 9, Dr. Nina Yasuda, who has been involved in COTS studies (mainly population genetic approaches), provides a review of historical COTS distribution and outbreaks in Japan. At first, presumed five species in genus *Acanthaster* and their characteristics are introduced. Then, the studies on reproduction and early life ecology of COTS are described. She also introduces population genetic analysis of COTS in Japan based on her studies including unpublished data and discusses patterns of COTS outbreak. Regarding the outbreak of COTS in Japan, the information for the past outbreak patterns (including the sources in Japanese) and the works by local people and governments to cope with COTS problems are also introduced in detail. In addition, she also proposes the possibility of poleward range expansion of COTS possibly due to the progress of global warming.

There have been already many studies on corals around shallow waters. In recent years, some researchers are focusing on corals around deeper waters (called as mesophotic coral ecosystems (MCEs)). In Chap. 10, Drs. Frederic Sinniger and Saki Harii (the University of the Ryukyus) are conducting comprehensive surveys of mesophotic coral ecosystems around Japan. In the chapter, they introduce a concept of MCEs and the environmental conditions (e.g., light, temperature) including their original measurements. They also explain current situation of studies on mesophotic coral reef ecosystems from some areas along the Ryukyu Archipelago. Not only coral composition but also other fauna in MCEs from these areas are presented in detail. In addition, they provide detailed information on some typical coral species in MCEs and their biological features (e.g., reproduction), which would be intriguing topics in comparison with corals in shallower waters. They also discuss the importance of mesophotic corals for recovery of coral communities and threats on mesophotic coral ecosystems in Japan. They also provide future perspectives for mesophotic research in Japan and the future conservation efforts.

One of important ecological services provided by coral reef ecosystems is the role of natural breakwater of coral reefs, affected by tropical cyclones. In Chap. 11, Dr. Chuki Hongo (the University of the Ryukyus) describes impacts of tropical cyclones to mechanical destruction of corals and change in reef topography. Many researches of the impact of tropical cyclones to coral reefs focus on related wind speeds. However, corals and coral reefs are directly influenced by hydrodynamic impacts. In Japan, an observation network of wave height and wave period has been maintained since 1970s because Japan is especially prone to tropical cyclones in the world. The increase of intensity of tropical cyclone and human impacts will likely cause severe impact of coral reefs at the near future. Based on these aspects, Dr. Hongo proposes future perspective of hydrodynamic impacts of tropical cyclones to coral reefs under the attacking of intensified tropical cyclones and the human impacts for the future. Additionally, Dr. Hongo prospects the strategies of keeping and/or recovery for natural breakwater for the near future.

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