Status of Coral Reefs in East Asian Seas Region: 2018

Edited by KIMURA Tadashi, TUN Karenne and CHOU Loke Ming

GCRMN Global Coral Reef Monitoring Network

Ministry of the Environment Government of Japan

JWRC

Front Cover: Shallow coral reef in Sekisei Lagoon, Okinawa, Japan (© Tadashi Kimura, 2017)
Back Cover: Shallow coral reef in Sekisei Lagoon, Okinawa, Japan (© Tadashi Kimura, 2017)

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1-2-2 Kasumigaseki, Chiyoda, Tokyo 100-8975, Japan
Telephone: (+81) 3 3581 3351
www.env.go.jp

Japan Wildlife Research Center
3-3-7 Koto-bashi, Sumida, Tokyo 130-8606, Japan
Telephone (+81) 3 6659 6332
Facsimile (+81) 3 6659 5633
www.jwrc.or.jp

FOREWORD

This regional report is a direct response to the International Coral Reef Initiative (ICRI) strategy on research and monitoring determined in the 'Call to Action' developed in Dumaguete City, The Philippines in 1995 which promotes cooperation among national research programs and monitoring networks.

Responding to the 'Call to Action', the Ministry of the Environment of Japan and the Japan Wildlife Research Center, in association with the regional coordinators on coral monitoring for Northeast and Southeast Asia have worked with national coral reef monitoring coordinators to produce a regional status of coral reefs since 2004. This 2018 report contains special issues on the mass coral bleaching event that occurred from 2014 to 2017, which was the third of global coral bleaching events since 1998.

The GCRMN is specifically tasked with providing information on the status of coral reefs to assist in their effective conservation and management. The global reports can only provide a brief summary of data and information from individual countries; therefore it is essential to provide more comprehensive data and information for national governments and regional organisations to assist them in their efforts to conserve coral reefs for use by their people into the future.

PREFACE

The Global Coral Reef Monitoring Network (GCRMN) was launched in 1996 with the purpose of collecting information on the state of coral reefs and raising awareness about coral reef conservation. This was in response to the "Call to Action" by the International Coral Reef Initiative (ICRI) in 1995 at its Dumaguete meeting, which encouraged the 1) promotion of linkages between regional and global research and monitoring networks, and 2) use of regional networks to achieve better coordination and cooperation among national research programmes.

In response to the first point, a series of reports 'The Status of Coral Reefs of the World' edited by Clive Wilkinson was published in 1998, 2000, 2002, 2004, 2008 and they represented a massive global effort at documenting the condition of the world's reefs based on national monitoring initiatives. In response to the second point, Japan's Ministry of Environment and the Japan Wildlife Research Center took the lead for the East Asian Seas region and published the 'Status of Coral Reefs in East Asian Seas Region' in 2004, 2010, 2014 and this latest edition. The aim is to provide more detailed information on the coral reef condition in a region that has the world's richest coral reef biodiversity and also the highest threats.

One of the immediate future goals of the East Asian Seas regional network is to analyze reef status trends in response to threats and management over the long-term. Continued monitoring and reporting are necessary as they provide the basis for such an analysis and it is our hope that national coordinators, all operating on a voluntary basis will maintain their interest and passion for this significant regional cause.

Tadashi Kimura

GCRMN East and North Asia coordinator / Japan Wildlife Research Center

Karenne Tun

GCRMN Southeast Asia coordinator / National Parks Board, Singapore

Loke Ming Chou

Chairman, Asia Pacific Coral Reef Society

CONTENTS

1. Global Event on Coral Bleaching

1.1 Overview of the third Global Coral Bleaching Event (2014-2017)

Denise A. Devotta[1,2], Jacqueline L. De La Cour[1,3], Erick F. Geiger[1,3], Andrea M. Gomez[4], Scott F. Heron[1,5], Gang Liu[1,3], Benjamin L. Marsh[1,5], William J. Skirving[1,5], and C. Mark Eakin[1]

denisedevotta@gmail.com

[1]U.S. National Oceanic and Atmospheric Administration, Coral Reef Watch, 5830 University Research Court, College Park, Maryland 20740, USA
[2]Global Science and Technology, Inc., 7855 Walker Drive, Suite 200, Greenbelt, Maryland 20770, U.S.A.
[3]Earth System Science Interdisciplinary Center/Cooperative Institute for Climate and Satellites-Maryland, University of Maryland, STAR/NESDIS/NOAA Affiliate, 5825 University Research Court, College Park, MD 20740, U.S.A.
[4]City University of New York, Ecosystem Science Lab – NOAA CREST, New York City, NY 10031, U.S.A.
[5]ReefSense, P.O. Box 343, Aitkenvale BC, Aitkenvale, QLD 4814, Australia

INTRODUCTION

From June 2014 to May 2017, prolonged heat stress repeatedly cycled across tropical oceans, giving rise to an unprecedented, multi-year, global coral bleaching event (GCBE). The resulting damage to coral reefs was on a global scale unmatched by previously observed events. A GCBE is considered a mass coral bleaching event spanning hundreds of kilometers or more that continuously moves through all three tropical ocean basins – the Pacific, Atlantic, and Indian (Eakin et al. 2018a). Two prior GCBEs occurred in 1998 and 2010 (Heron et al. 2016a), and each lasted approximately one year (Eakin et al. 2018b). In contrast, the third GCBE spanned three years, becoming the longest, most widespread, and most damaging GCBE on record (Eakin et al. 2017; Eakin et al. 2018a). Globally, > 75% of coral reefs were exposed to bleaching-level heat stress, with approximately 30% of reefs experiencing mortality-level heat stress (Eakin et al. 2018a). Over half of the reefs that experienced bleaching-level heat stress were exposed twice or more to this stress. Also, thermal conditions during this GCBE caused mass bleaching in several locales with no previously documented bleaching history (Eakin et al. 2016).

Start of the third GCBE – 2014

In late 2013, anomalous conditions in atmospheric-ocean heat transfer caused an unusually warm patch of water (termed "The Blob") to form in the northeastern Pacific Ocean (Bond et al. 2015). By mid-2014, ocean warming had caused mass coral bleaching in waters around Guam and the Commonwealth of the Northern Mariana Islands (CNMI, Heron et al. 2016b), inducing the start of the third GCBE (Eakin et al. 2016; Fig. 1). At this time, NOAA predicted a weak to moderate El Niño (Eakin et al. 2014) that initiated, but never fully formed (Bluden and Armdt 2015). However, warm thermal anomalies remained across the oceans. In October, these anomalies propagated to the northeast, toward the Northwestern Hawaiian Islands, merging with the southwestward extension of "The Blob". Bleaching occurred in the Papahānaumokuākea Marine National Monument and parts of the Main Hawaiian Islands (Bahr et al. 2015; Eakin et al. 2016). In September, teleconnected warming also induced severe bleaching in southeastern Florida and the Florida Keys (Eakin et al. 2016; Eakin et al. 2018a) in the Atlantic Ocean. In November, significantly high ocean temperatures promoted the most damaging bleaching on record in the Republic of the Marshall Islands (Fellenius 2014).

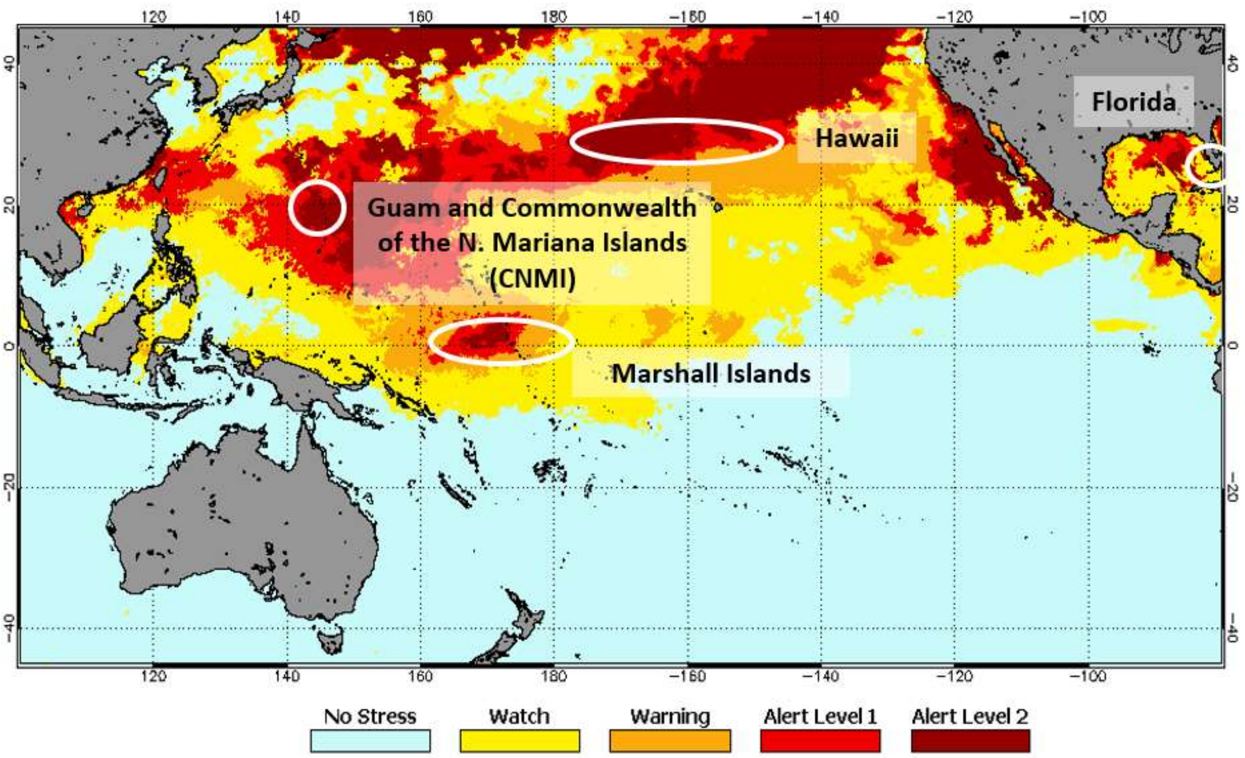

Fig. 1. NOAA Coral Reef Watch Maximum Bleaching Alert Area map for September 2014. Marked are four areas where severe coral bleaching was observed in the latter half of 2014. Alert Level 2 is associated with widespread coral bleaching and mortality. (Adapted from Figure 1 in Eakin et al. 2016)

Bleaching spreads – 2015

In early 2015, heat stress was documented in the South Pacific, causing bleaching in Papua New Guinea, the Solomon Islands, Fiji, and American Samoa (Eakin et al. 2016; Figure 2). Subsequent moderate levels of heat stress resulted in modest bleaching across a large expanse of the Indian Ocean (Eakin et al. 2016). The onset of the 2015-2016 El Niño in March brought bleaching conditions to the central and eastern tropical Pacific Ocean (Eakin et al. 2017). In the Main Hawaiian Islands, the worst documented bleaching on record and first instance of consecutive bleaching occurred. Severe bleaching also was reported in Panama and the Line Islands of Kiribati (Eakin et al. 2016). In June, severe localized bleaching was reported from Dongsha Atoll in East Asia (DeCarlo et al. 2017) and the southern Red Sea (Monroe et al. 2018). In the Atlantic Ocean, bleaching heat stress returned to Florida for a second consecutive year in September (FRRP 2015; FRRP 2016) and was similarly observed across the Caribbean in October. By this time, occurrences of widespread bleaching in the Indian, Pacific, and Atlantic Oceans prompted NOAA to declare that the third GCBE was underway (NOAA 2015). During 2015, > 40% of global reefs had been exposed to thermal conditions that likely caused bleaching (Degree Heating Week values ≥ 4°C-weeks), and most reefs had surpassed their average warm season temperatures (Fig. 2; Eakin et al. 2017).

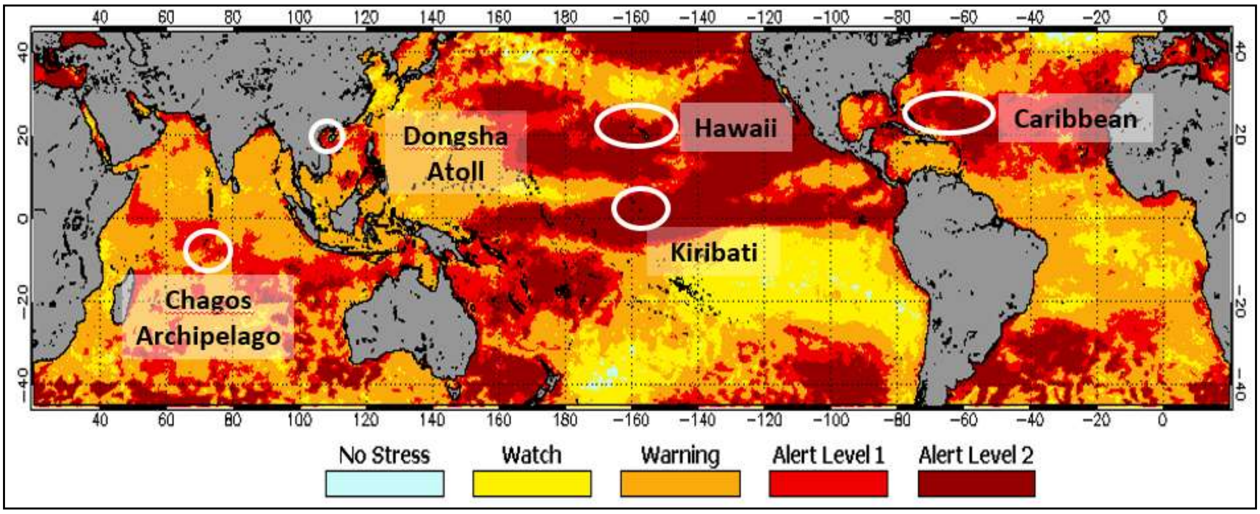

Fig. 2. NOAA Coral Reef Watch Maximum Bleaching Alert Area map for 2015. Marked are five areas where bleaching was documented in 2015. (Adapted from Figure 4 in Eakin et al. 2016)

Global bleaching continues – 2016

Continuation of the strong El Niño caused heat stress to return to the Southern Hemisphere in early 2016 (Fig. 3) and follow similar spatial progression through the tropical oceans as in 2015 (Eakin et al. 2018a). Compared to 2015, heat stress in 2016 was significantly more severe and widespread, with > 50% of global reefs exposed to bleaching-level conditions (Eakin et al. 2018a). In Fiji, severe heat stress caused widespread coral death in February, right before a cyclone cooled ocean temperatures (Eakin et al. 2017). The first documented mass bleaching event on the northern and far northern sectors of the Great Barrier Reef (GBR) peaked in March (Hughes et al. 2017), resulting in approximately 30% mortality (Hughes et al. 2018). Lagoon corals in New Caledonia also fluoresced in March in response to bleaching conditions. Continuous heat stress in the central Pacific Ocean from April to May caused the highest heat stress values Coral Reef Watch ever recorded (DHW > 25°C-weeks) in the Northern Line Islands (Eakin et al. 2017). By May, corals in Kiritimati and Jarvis Island had experienced 80% and 98% mortality respectively (Harvey 2016; Brainard et al. 2018). In the western Indian Ocean, heat stress reached maximum levels in May (CORDIO-EA 2016), causing bleaching of 69-99% and mortality of 50% of the coral cover in the Seychelles (SIF 2017). In southeast Asia, thermal conditions between March and October bleached and killed 16-24% of corals in the Gulf of Mannar (Patterson Edward et al. 2018), and prompted Thailand to close its reefs to recreational divers in May (Agence France-Presse 2016).

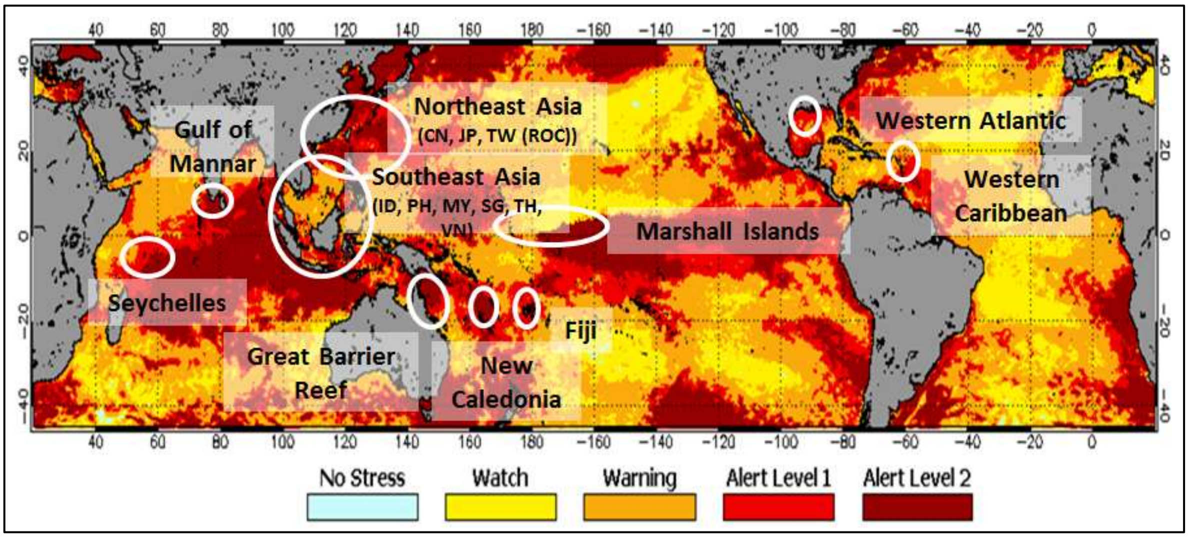

Fig. 3. NOAA Coral Reef Watch Maximum Bleaching Alert Area map for 2016. Marked are nine areas where bleaching was observed in 2016. (Adapted from Fig. 5 and 6 in Eakin et al. 2016)

In the latter half of the year, > 90% of coral cover bleached with approximately 70% mortality on the largest coral reef in the Ryukyu Islands, Japan (Fig. 3; Harvey 2017). From September through November, heat stress returned to the western Atlantic Ocean, Gulf of Mexico, and Caribbean (Eakin et al. 2017). The worst bleaching ever recorded at the Flower Garden Banks National Marine Sanctuary, off the coast of Texas, occurred in October (Johnston et al. 2017). Patchy bleaching also was documented in the eastern Caribbean, and moderate to severe heat stress conditions occurred in parts of the Mesoamerican Barrier Reef at this time. By November, bleaching had returned to the Republic of the Marshall Islands (Eakin et al. 2017).

The third GCBE ends – 2017

In early 2017, severe bleaching occurred in Niue, American Samoa, and Samoa (Eakin et al. 2017; Fig. 4). Mild bleaching began in Fiji but was halted by storm conditions. In March, the first consecutive bleaching event occurred on the GBR, killing a further 22% of corals, predominantly in the northern and central sectors (Hughes and Kerry 2017). In the Indian Ocean, limited heat stress caused moderate bleaching in southwestern Madagascar in April (CORDIO-EA 2016). Bleaching elsewhere in the Indian Ocean was minimal (Eakin et al. 2017). Although more coral bleaching occurred in certain locales in the second half of 2017, the absence of widespread coral bleaching in the Indian Ocean in June signaled the end of the third GCBE (NOAA 2017).

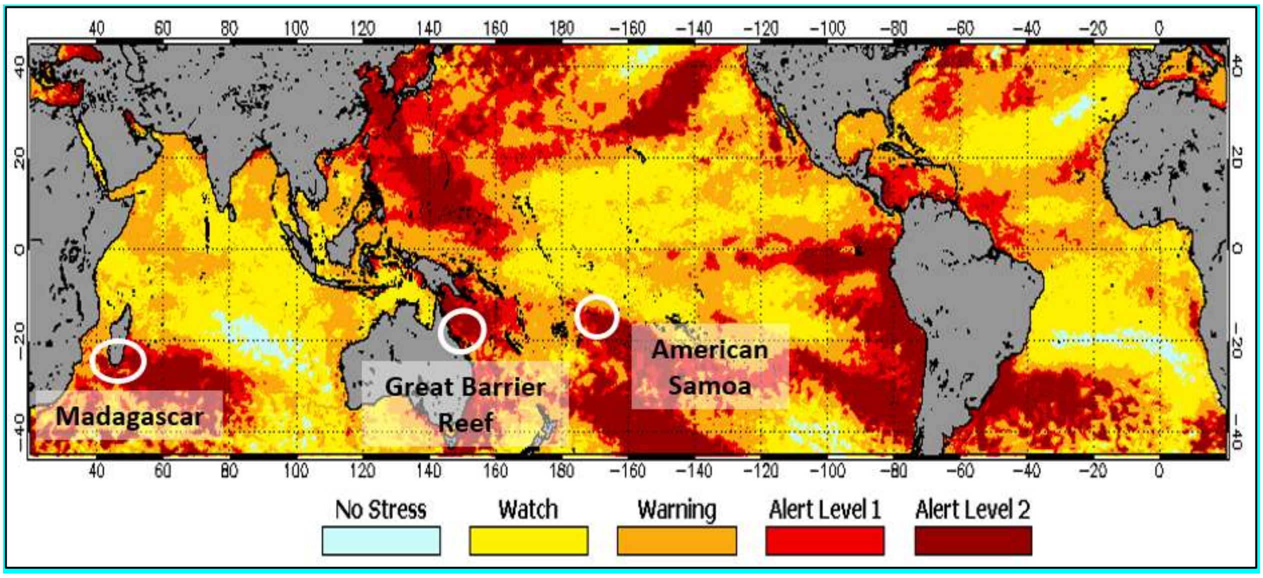

Fig. 4. NOAA Coral Reef Watch Maximum Bleaching Alert Area map for 2017. Marked are three areas where bleaching was documented in 2017.

Final Thoughts

With the unprecedented damage inflicted by the third GCBE, there is a greater imperative than ever for coral reef scientists, managers, decision makers, and the general public to work together to increase our collective knowledge and protect coral reefs. This includes implementing comprehensive management strategies and response plans on local and global scales as the climate continues to warm. While continuing and expanding efforts to reduce local stressors, we all must work to address the main cause of global warming through reducing atmospheric carbon dioxide concentrations and emissions.

Acknowledgements

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2. Coral Bleaching in East Asia

2.1. Summary of coral bleaching from 2015 to 2017 in Cambodia

Marianne Teoh[1] and Ouk Vibol[2]

marianne.teoh@fauna-flora.org

[1]Fauna and Flora International, Cambodia
[2]Ministry of Agriculture, Forestry and Fisheries, Cambodia

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

Coral reef surveys were conducted in the Koh Rong Archipelago in Cambodia using a modified ReefCheck methodology. Data exist for the years 2015 and 2016 at 17 out of 18 sites chosen as 'permanent monitoring sites' (Fig. 1A) for the Koh Rong Archipelago Marine Fisheries Management Area (Figure 1B). No data were collected in 2014 or 2017.

Coral distribution is known to be relatively uniform across the archipelago, with structural composition of these fringing reefs leaning heavily towards massive growth forms – *Porites* spp., *Favites* spp., *Favia* spp. and *Diploastra heliopora* as the most prevalent genera (Thorne et al, 2015). This trend of abundant massive corals, and relative lack of branching and foliose species, is thought to be due to high sedimentation rates in the region, which tend to cause much stress for the less tolerant species (Thorne et al, 2015; Yim, 2014; Rodgers, 1990).

It is important to note that a large-scale bleaching event was witnessed in the archipelago between May and October 2010 (van Bochove et al, 2011), though this incident appeared to be a single episode and bleaching at this scale has not been witnessed since. Coral recovery has been documented throughout this subsequent time period (Thorne et al, 2015; Longhurst & Clay, 2013).

To summarise the data collection methods relevant for this report, after conducting a fish survey, a 20-m point-intercept transect (PIT) was deployed in every survey site to record reef substrate. Substrate was recorded at 50 cm intervals along the PIT by an individual surveyor and classified for analysis: 'Hard coral' encompassed all living hard corals; 'rock' encompassed bedrock, 'dead coral', and 'recently killed coral' (these were not differentiated in this study). At the same time, another surveyor would move along transect line in an S-shaped roving search pattern 2.5 m either side of the transect to record all 'impacts', including incidences of bleaching. Basic bleaching data were recorded including percentage of colony bleached, number of bleached colonies, and estimated percentage of coral colonies bleached in transect area. Results of this bleaching are noted below for the years of 2015 and 2016. In addition to biophysical data collection, at every survey site distance from the nearest river mouth and river mouth width were estimated, as was distance from the nearest settlement and the settlement's size (human population size). Water temperatures were measured before each dive, both at the surface and at a depth of 3 m using personal dive computers. Identification of indicator taxa was confirmed using Allen et al. (2005) and Humann & Deloach (2010), when necessary. All of the methodology details can be sourced from Thorne et al, 2015.

Of note, data used in this study are being utilized by the Kingdom of Cambodia's Fisheries Administration to improve coral reef management and conservation efforts in the archipelago.

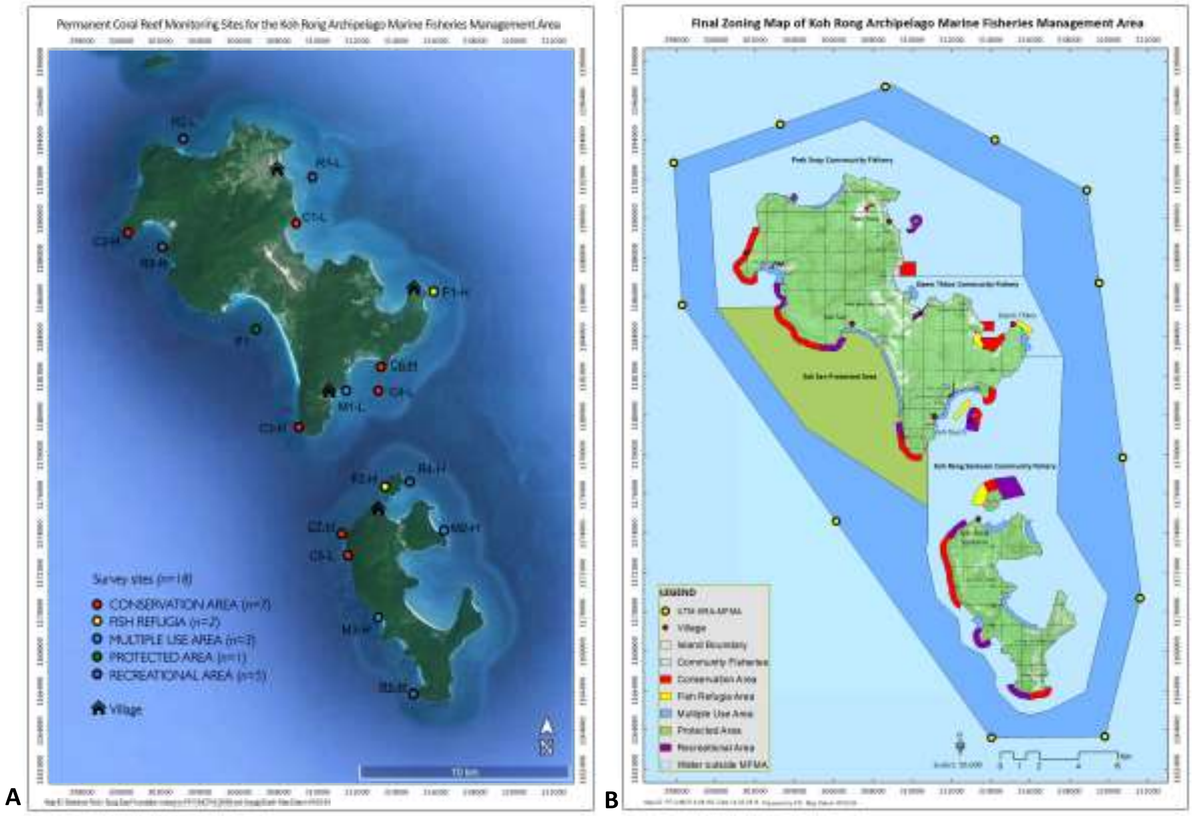

Fig. 1. (A) Map of permanent monitoring sites for the Koh Rong Archipelago Marine Fisheries Management Area (KRA MFMA), approved by the Technical Working Group for the KRA MFMA in 2015. (B) Zoning map for the KRA MFMA approved by the Ministry of Agriculture, Forestry and Fisheries in June 2016.

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

Please note that specific survey dates are included in the quantitative questionnaire. Data here are displayed as annual summaries for 2015 and 2016. There are no data available for 2014 and 2017.

2015

2015			
Total sites surveyed	Total sites Severely bleached*	Total sites Moderately bleached**	Total sites Minimally bleached***
9	0	0	6
%	0%	0%	67%

**Severe bleaching = >30% population level bleaching*
***Moderate bleaching = <30% (and >5%) population level bleaching*
****Minimal bleaching = At least one coral bleached colony observed*

2016

2016			
Total sites surveyed	Total sites Severely bleached*	Total sites Moderately bleached**	Total sites Minimally bleached***
17	4	8	4
%	24%	47%	24%

**Severe bleaching = >30% population level bleaching*
***Moderate bleaching = <30% (and >5%) population level bleaching*
****Minimal bleaching = At least one coral bleached colony observed*

Evidence suggests there was an increase in the detection of bleaching per site between 2015 (67% of sites, n=9) and 2016 (95% of sites, n=17). Also worthy of note, only minimal bleaching was detected in 2015, but both moderate and some small amount of severe bleaching was noted in 2016.

CONTRIBUTORS

Dan Steadman (Fauna & Flora International)

Ben Thorne (Song Saa Foundation)

Samuel Healy (Song Saa Foundation)

Numerous research volunteers (via Song Saa Foundation / Fauna & Flora International)

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2.2. Summary of coral bleaching from 2015 to 2017 in Indonesia

Muh. Firdaus Agung[1], Derta Prabuning[2], Permana Yudiarso[1], Hadi Yoga Dewanto[1], Sila Kartika Sari[2]

[1]firda_ku@yahoo.com, [2]derta@reefcheck.org

[1]Directorate General of Marine Spatial Management, Ministry of Marine Affairs and Fisheries
[2]Reef Check Foundation Indonesia

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

To monitor bleaching event and it's impact on the reef, timing is really important. However, tracking bleaching development in vast-scattered reef nations such as Indonesia is really challenging. Coral Bleaching Network Indonesia was created to cope with the 2009-2010 bleaching event. By 2016 the network has covered all main islands in Indonesia, and is led by the national government's Ministry of Marine Affairs and Fisheries.

How The System Works:

1. An alert, based on NOAA coral bleaching satellite data, is distributed regularly to the network during the hot season. This is followed by personal communication to certain members in bleaching alert areas.

2. The network provided an in situ coral bleaching early warning as well as rapid survey:

a) Time swim (diving or snorkeling) and from surface also (by boat/surfing board)

b) The main information: Location, Coral Bleaching YES/NO, % Bleaching Estimation

3. This information is then distributed to the scientist members and/or reef manager so that they can determine whether or not more thorough coral bleaching data are needed.

   The success of the rapid survey response as well as provision of coral bleaching early warning are facilitated by the structure of the network. Reef Check Network Indonesia (RCNI) started in 1997and supports the Coral Bleaching Network Indonesia. RCNI has grown rapidly comprising a full range of reef stakeholders from individual to institution, from fisherman to scientist.

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

2014

There was no bleached coral reported in this year.

2015

There was no bleached coral reported in this year.

2016

Based on Coral Bleaching Network's rapid survey, coral reef in 21 of 22 provinces surveyed were reported bleached, within the range of 25 to 75% in each province (Fig.1, Table 1).

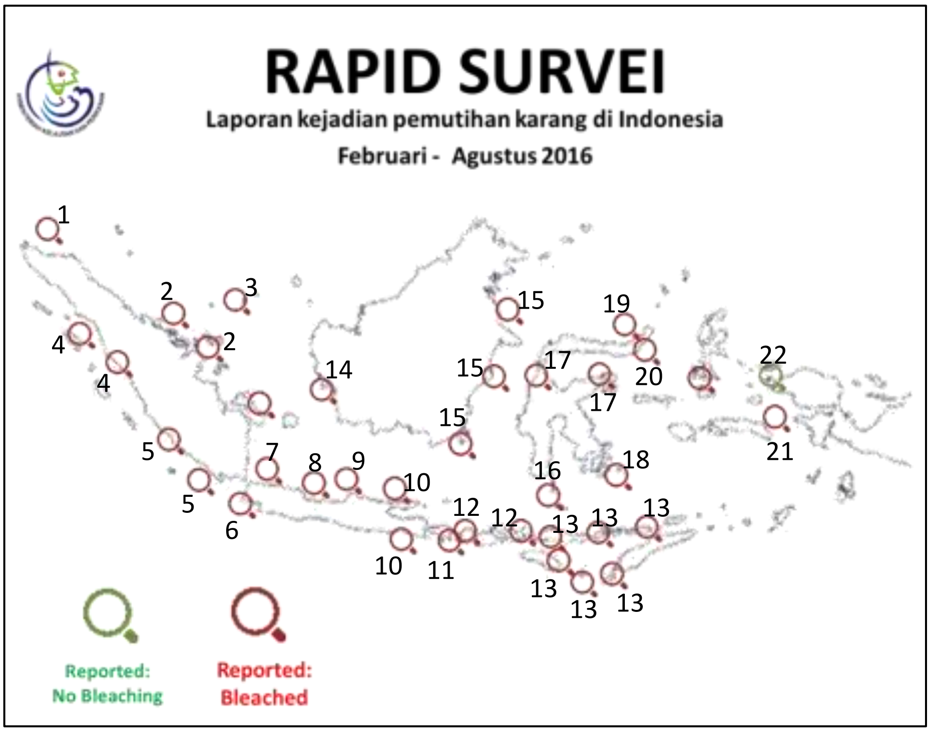

Fig. Results of Rapid Survey on Coral Bleaching in Indonesia 2016.

Of 145 data locations reported, West Papua is the one and only province with no reported bleaching. Bleaching mostly impacted branching corals. Less affected were massive, encrusting and foliose coral. Both reef flat and reef slope were similarly affected by coral bleaching. Data were all generated from the rapid surveys as well as citizen monitoring.

Table 1. Results of Rapid Survey on Coral Bleaching at 22 provinces in Indonesia 2016.

No	Province	% Range of Coral Bleaching	No	Province	% Range of Coral Bleaching
1	Aceh	<50%	12	West Nusa Tenggara	<25%
2	North Sumatera	<25%	13	East Nusa Tenggara	25-75%
3	Riau Archipelago	25-50%	14	West Kalimantan	25-50%
4	West Sumatera	50-75%	15	South Kalimantan	25-50%
5	Bengkulu	>75%	16	South Sulawesi	25-75%
6	Banten	50-75%	17	Central Sulawesi	50-75%
7	DKI Jakarta	25-50%	18	Southeast Sulawesi	25-75%
8	West Java	50-75%	19	North Sulawesi	<25%
9	Central Java	25-50%	20	Gorontalo	50-75%
10	East Java	50-75%	21	Maluku	25-50%
11	Bali	25-75%	22	West Papua	0%

2017

There were no data available.

CONTRIBUTORS

Coral Bleaching Network Indonesia: Ocean Diving Club – University of Syiah Kuala, Diving Proklamator University of Bung Hatta, Nikoi Island Resort – Riau Islands, Kelompok Mitra Konservasi Samudra – TWP Pieh, TAKA Foundation, Marine Diving Club – Diponegoro University, Bogor Agricultural Univesity, Acropora – Brawijaya University, Nusa Dua Reef Foundation, Coral Triangle Centre, Reef Check Indonesia, CORAL Reef Alliance, Organisasi Pemandu Selam Tulamben, DPL Bondalem, DPL Tejakula, DPL Penuktukan, Balai Pengelolaan Sumberdaya Pesisir dan Laut (BPSPL) Denpasar, Balai Pengelolaan Sumberdaya Pesisir dan Laut (BPSPL) Makasar, Marine Science Diving Club – Hasanuddin University, Indonesia Biodiversity Research Centre, FIN-DC Mulawarman University.

2.3. Summary of coral bleaching from 2014 to 2017 in Singapore

Tai Chong Toh[1, 2*], Danwei Huang[2, 3], Karenne Tun[4], Loke Ming Chou[2]

Taichong.toh@nus.edu.sg

[1] College of Alice and Peter Tan, National University of Singapore
[2]Tropical Marine Science Institute, National University of Singapore
[3]Department of Biological Sciences, National University of Singapore
[4]National Biodiversity Centre, National Parks Board

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

Coral reefs in Singapore are mainly found skirting the islands south of mainland Singapore and comprise fringing and patch reefs. To date, more than 200 species of hard corals have been recorded.

Bleaching data were contributed by different research groups in Singapore that maintain reef monitoring programmes. All data were standardized to Point Intercept Transect (PIT) at 10 cm intervals where possible, to facilitate analysis. Each colony on the transect was identified to the lowest taxonomic level and assigned to one of the two categories, pigmented or bleached. Data from secondary sources such as scientific publications, blogs, news and social media were also collated, and verified by research observations to ensure validity of the reports.

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

There was one reported episode of mild to moderate coral bleaching in 2014 (Taira et al. 2017) and another moderate to severe bleaching in 2016 (Toh et al. In prep). There were no reports of bleaching higher than the average level of bleaching in other years (Chou et al. 2016).

2014

In early May 2014, sea surface temperature (SST) exceeded the maximum monthly mean (MMM, 29.8°C) (NOAA, 2000) lasting two and a half months and peaked at 30.5°C in June. Singapore's subtidal reefs exhibited mild to moderate coral bleaching with bleaching prevalence ranging from 0% to 11.8% (Bleach Watch Singapore, 2016). Subsequent surveys at the most impacted site indicated bleaching prevalence between 6.2% and 9.7% (Bleach Watch Singapore, 2016)

2015

In early April 2015, the sea surface temperature (SST) exceeded the maximum monthly mean (MMM, 29.8°C) (NOAA, 2000) for three months and peaked at 30.7°C in June. While the duration of thermal stress was longer than in 2014, there were no reports of bleaching at the subtidal reefs.

2016

In early April 2016, the sea surface temperature (SST) exceeded the maximum monthly mean (MMM, 29.8°C) (NOAA, 2000) for three and a half months and peaked at 31.4°C in May. During this period, sea surface temperatures were higher than the bleaching threshold (30.8°C) on ten days. Consequently, Singapore's reefs showed moderate to severe bleaching (42% to 66%) across six subtidal sites and in all 24 intertidal sites surveyed (Toh et al. In prep). Preliminary assessments from one site indicated that the most susceptible genera were *Pocillopora* (89%), *Pachyseries* (86%) and *Fungia* (80%). None of the *Acropora* and *Galaxea* colonies bleached during this period. Analysis is underway to determine the impact of the 2016 coral bleaching event.

2017

In early April 2017, the sea surface temperature (SST) exceeded the maximum monthly mean (MMM, 29.8°C) (NOAA, 2000) for two months and peaked at 30.7°C in May. There were no reports of bleaching on the subtidal reefs.

CONTRIBUTORS

Tai Chong Toh (College of Alice and Peter Tan / Tropical Marine Science Institute, National University of Singapore)

Danwei Huang (Tropical Marine Science Institute / Department of Biological Sciences, National University of Singapore)

Karenne Tun (National Biodiversity Centre, National Parks Board)

Loke Ming Chou (Tropical Marine Science Institute, National University of Singapore)

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2.4. Summary of coral bleaching from 2015 to 2017 in Thailand

Thamasak Yeemin

thamasakyeemin@hotmail.com

Marine Biodiversity Research Group, Faculty of Science, Ramkhamhaeng University

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

The coastal areas of Thailand have suitable environmental conditions for coral reef growth and development. There are approximately 240 km2 of coral reef areas and over 300 relatively small islands along over 3,000 km of Thailand's coastline. There are three reef types in Thai waters, i.e. coral communities with no true reef structure, developing fringing reefs and early formation of fringing reefs. These coral reefs are generally classified into four geographical areas with different oceanographic conditions:

- the Inner Gulf of Thailand: Chonburi Province
- the Eastern Gulf of Thailand: Rayong, Chanthaburi and Trat Provinces
- the Western Gulf of Thailand: Prachuab Kirikhan, Chumporn, Suratthani, Nakhon Si Thammarat, Songkhla, Pattani and Narathiwat Provinces
- the Andaman Sea: Ranong, Phuket, Phang-Nga, Krabi, Trang and Satun Provinces

Coral reef monitoring programs in Thailand have been implemented for over three decades. The coral bleaching data were compiled from the major coral reef monitoring programs which were mostly carried out by the Department of Marine and Coastal Resources, the Department of National Parks, Wildlife and Plant Conservation, the Marine Biodiversity Research Group of Ramkhamhaeng University and the networks of Thai coral reefs. Most coral reef survey methods were belt-transects, 0.5 x 30 m, 3 replicates, in the shallow and deep zones of over 100 reef sites in the Gulf of Thailand and the Andaman Sea.

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

2014

Coral bleaching was reported in the year 2014 both in the Gulf of Thailand and the Andaman Sea. The coral reef surveys conducted in early March, 2014 revealed that two types of symptoms were obvious at four study sites in Trat Province, the Eastern Gulf of Thailand, i.e. pale colonies and partially bleached colonies. There were significant differences in the severity of bleaching among study sites and coral taxa. Most bleached coral colonies were massive *Porites* spp. Some colonies of *Porites* spp. showed the highest severity of bleaching at Ko Bai Dang and the lowest at Ko Phrao Nok. Bleaching of several colonies of faviid corals was also recorded. Most bleached coral colonies recovered within a few months (Ruangthong et al., 2014).

In the Andaman Sea, the extent of coral bleaching in 2014 at certain reef sites in Krabi Province was recorded. The coral *Fungia fungites* was the only bleached coral while the partially bleached corals included *Acropora divaricata*, *A. hyacinthus*, *A. miliopora*, *A. muricata*, *A. palifera*, *F. fungites*, *Goniastrea edwardsi*, *Platygyra pini*, *Pocillopora damicornis* and *Porites lutea*. Coral bleaching at Ko Mai Phai was more severe than Ko Phiphi Le. The 2014 coral bleaching event was relatively mild compared with the severe bleaching event in 2010 (Yeemin et al., 2014).

2015

There were no reports on coral bleaching in Thai waters.

2016

A mass coral bleaching event in the Gulf of Thailand and the Andaman Sea was reported during the end of April – May, 2016. There were significant differences in the severity of bleaching among reef sites. The coral bleaching surveys were conducted at 102 stations in 14 provinces, 62 stations in the Gulf of Thailand and 40 stations in the Andaman Sea. Severe coral bleaching (bleached corals were over 50% of live coral cover) was observed at 37 stations (36.27%). Severe coral bleaching was recorded at 20 stations in the Andaman Sea (50%) and 17 stations in the Gulf of Thailand (27.42%). Mortality following the bleaching in 2016 was much lower than the 2010 coral bleaching event because the southwest monsoon started from the end of April 2016 and the seawater temperature dropped rapidly (DMCR, 2016).

The intensive study of coral bleaching in the year 2016 was conducted at 11 study sites in Prachuap Khiri Khan, Chumphon and Surat Thani Provinces, the Western Gulf of Thailand. The levels of coral bleaching varied significantly among the study sites. The highest severity level of coral bleaching was observed at Ko Ngam Noi, Chumphon

Province while the lowest was recorded at Ko Sang, Prachuap Khiri Khan Province. The levels of bleaching susceptibility varied greatly among coral taxa. *Acropora florida*, *Fungia fungites*, *Montipora tuberculosa*, *Plerogyra sinuosa*, *Pocillopora* spp. and *Porites rus* showed high bleaching susceptibility while the high resistant species were *Favites abdita*, *Galaxea fascicularis*, *Goniopora planulata*, *Pavona cactus*, *P. decussata* and *P. frondifera* (Sutthacheep et al, 2016).

The 2016 coral bleaching event was a good opportunity to conduct the first field experiment concerning impacts of shading on bleaching recovery and survival of corals in Thai waters. The field shading experiments were carried out on coral communities of Ko Ngam Noi, Chumphon Province , the Western Gulf of Thailand during the coral bleaching event. The experimental corals were shaded under mid-water floating shading nets. The light intensity levels and sedimentation rates under the shaded areas were lower than those in the unshaded areas. The bleaching recovery rates of some corals, such as *A. muricata*, *Fungia fungites*, *Lobophyllia hemprichii*, *P. decussata*, *Pocillopora* spp. and *P. lutea*, under the shading areas were higher. Mortality rates of *A. muricata* under shaded areas after the bleaching event were also lower (Yeemin et al, 2016).

2017

There were no reports on coral bleaching in Thai waters.

CONTRIBUTORS

These coral bleaching data were provided by the Department of Marine and Coastal Resources (Pinsak Suraswadi, Niphon Phongsuwan, Nalinee Thongtham, Lalita Putchim), the Department of National Parks, Wildlife and Plant Conservation (Songtham Suksawang, Prarop Plangngan, Chainarong Ruangthong), the Marine Biodiversity Research Group, Ramkhamhaeng University (Thamasak Yeemin, Makamas Sutthacheep, Sittiporn Pengsakun, Wanlaya Klinthong, Watchara Samsuvan, Wichin Suebpala, Juthamart Putthayakool, Charernmee Chamchoy) and Prince of Songkla University (Sakanan Plathong).

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2.5. Summary of coral bleaching from 2015 to 2017 in Viet Nam

Vo Si Tuan[1], Nguyen Van Long[1] and Phan Kim Hoang[2]

vosituan@gmail.com, longhdh@gmail.com

[1]Institute of Oceanography,
[2]Vietnam Academy of Science and Technology

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

Assessments of coral bleaching were carried out at 268 transects on the reef flats and reef slopes of 122 sites at 10 major areas in the coastal waters of Vietnam including Hai Van – Son Cha (Thua Thien Hue province), Cu Lao Cham MPA (Quang Nam province), Quy Nhon bay (Binh Dinh province), Van Phong bay, Nha Trang bay and Cam Ranh bay (Khanh Hoa province), Ninh Hai coast (Ninh Thuan province), Hon Cau MPA (Binh Thuan province), Con Dao MPA (Ba Ria-Vung Tau province) and Phu Quoc MPA (Kien Giang province) during the summer (April – July) from 2015 – 2017. The numbers of transects monitored at each area in each year are presented in Table 1.

Table 1: Numbers of transects in each year of monitoring.

No.	Name of area	2015	2016	2017	Total
1	Hai Van-Son Cha			6	6
2	Cu Lao Cham MPA		18	23	41
3	Quy Nhon bay			40	40
4	Van Phong bay	12	4	2	18
5	Nha Trang bay MPA	35	8	23	66
6	Cam Ranh bay	2	4		6
7	Ninh Hai coast		6	21	27
8	Hon Cau MPA			5	5
9	Con Dao MPA		9	19	28
10	Phu Quoc PMA		11	20	31
Total		49	60	159	268

Parameters monitored included benthic cover of hard coral (HC), soft coral (SC), recently killed corals (RKC), dead coral with algae (DCA), turf algae (TA), coralline algae (CA), macro-algae (SW), NIA (nutrient indicator algae), sponges (SP), rock (RC), rubble (RB), sand (SD), silts/clay (SI), others (OT) and bleaching corals (BL); other benthos such as Reefcheck counts of macro-invertebrates; all species of fish and target families fish; and ambient variables such as physical parameters of impacts.

Reefcheck method has been used as the key technique for assessment and monitoring of coral reefs during the bleaching event between 2015 and 2017.

The main sources of funding for ongoing monitoring activities were supplied by USAID, Khanh Hoa Department of Science and Technology, Management Board of the Cu Lao Cham - Hoi An World Biosphere Reserve and Phu Quoc MPA Authority.

The institute of Oceanography (IO) is the main institution coordinating monitoring programs in collaboration with some MPA authorities (Cu Lao Cham, Nui Chua, Con Dao and Phu Quoc).

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

Bleaching events occurred during May – July in 2015 and 2016 with different levels of impacts to the coral reefs in the coastal waters in Vietnam.

2015

In 2015, the bleaching was found in the shallow waters (2 – 7m deep) at some areas with an extreme low mean cover and ratio of slight bleached corals recorded in Van Phong bay (1.8 ± 7.1% and 3.7 ± 11.3% respectively), Nha Trang bay (0.2 ± 1.0% and 1.0 ± 4.9%) and Cam Ranh bay (0.6 ± 1.2% and 2.5 ± 4.6%).

2016

In 2016, bleaching caused more serious impact to coral reefs in Phu Quoc to the depth of 10m, with mean cover and ratio of bleached corals at 20.2 ± 16.6% and 28.2 ± 12.2% respectively. This was much higher than other areas located in south-central Vietnam including Van Phong bay and Nha Trang bay (no bleaching), Ninh Hai coast (4.8 ± 12.5% and 5.6 ± 12.6%) and in the south-west (Con Dao: 3.8 ± 5.4% and 6.9 ± 8.1%).

2017

There were no bleaching recorded at the 7 major locations monitored above in 2017 with an exception of slight mean cover and ratio of slightly bleached corals of 0.1 ± 0.4% and 0.2 ± 1.2% respectively in Phu Quoc.

CONTRIBUTORS

Thai Minh Quang, Mai Xuan Dat

2.6. Summary of coral bleaching from 2014 to 2017 in Taiwan

Chao-yang Kuo[1], Ming-Jay Ho1, Yei-Chia Chen[1], Sung-Yin Yang[1], Ya-Yi Huang[1], Hernyi Justin Hsieh[2], Ming-Shiou Jeng, Chaoluan Allen Chen[1]

cykuo.tw@gmail.com, acropora.chen@gmail.com

[1] Biodiversity Research Center, Academia Sinica, Taipei, Taiwan
[2] Penghu Marine Biology Research Center, Fisheries Research Institute, Council of Agriculture, Penghu 880, Taiwan

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

Corals can be found in the jurisdictional waters of Taiwan, including the main Island of Taiwan, several offshore islands, such as Pengchiayu, Mienhuayu and Huapingyu, Turtle Island (Gueishan Island) and Keelung Islet in the north, the Penghu Archipelago and Hsiaoliuchiu in the Taiwan Strait, Ludao (Green Island) and Lanyu (Orchid Island) in the east, and Dongsha Atoll (Pratas Islands, N 20.702410 ^{o}, E116.724205 ^{o}) and Taiping Island (Itu Aba Island, N 10.377053 ^{o}, E114.365460^{o}) of the Spratlys in the South China Sea (Dai 2011a, b). The marine environment condition and coral species distribution of Taiwan are mainly influenced by climate and currents, including the Kuroshio Current flowing year-round from the Philippines towards southern Japan, and the South China Sea Surface Current (SCSSC) mainly driven by the southwest monsoon in summer into the Taiwan Strait. The Kuroshio current splits into two branches in Luzon Strait with the main branch flowing through the East of Taiwan consistently and the other flowing into the Taiwan Strait with seasonal variations driven by the southwestern or northeastern monsoon. In summer, southwestern monsoon drives SCSSC through the Taiwan Strait towards northern main Island of Taiwan. In winter, the warm water of the Kuroshio Current is pushed south by cold, fresh China Coastal Water (CCW) driven by northeastern monsoon and strapped around southern Penghu in southern part of the Taiwan Strait (Wang and Chen 1988, 1992; reviewed in Chen and Keshavmurthy 2009). Unlike the main Island of Taiwan, which is influenced by continuous north-flowing Kuroshio Current, the marine environment of the Dongsha Atoll and Taiping Island are affected by the SCSSC (Hellerman and Rosenstein 1983, Chen et al. 2004). In general, the currents move southwards pushed by the northeast monsoon and generate a large anticlockwise gyre in winter. By contrast in summer, a weak anticlockwise gyre remains in the northern South China Sea (NSCS), above 12^{o}N, while a clockwise gyre occupies the southern South China Sea (SSCS), below 12^{o}N, (Wyrtki 1961, Morimoto et al. 2000, Su 2004).

Distribution of coral species and species composition in Taiwan can be broadly divided into two main categories; non-reefal coral community and tropical coral reefs (Chen 1999), due to seasonal variation of sea surface temperature (SST) and currents (Dai 1989;

Chen 1999). Non-reefal coral communities include rocky shore in northern Penghu and northern Taiwan, where corals grow on top of volcanic rocks without forming aragonite reef structure due to SST of below 18^{0}C (Veron 1995). The tropical coral reefs can be found in southeastern Taiwan, and offshore islands including southern Penghu, Ludao, Lanyu, Hsiaoliuchiu, Dongsha Atoll, and Taiping Island (Chen 1999; Chen and Keshvmurthy 2009; Chen 2014).

Most recent census reports that 317 scleractinian coral species (Dai and Horng 2009; Hsieh et al. 2016) and 50 species of soft corals (Dai et al. 2004) were recorded in Taiwan. However, coral species richness decreases sharply from around 300 species in southern Taiwan Island to around 150 species at areas near the Tropic of Cancer, including the Penghu Archipelago and offshore islands at the east coast of Taiwan Island, to around 100 in the north (Dai 1989; Chen 1999; Dai and Horng 2009). In the South China Sea, 277 and 229 scleractinian coral species have been recorded from Taiping Island (Jeng et al. 2017) and Dongsha Atoll (Jeng et al. 2008), respectively.

Nevertheless, multiple natural and anthropogenic disturbances have shaped the status of coral reefs in Taiwan. Based on live coral cover (LCC) from 50 sites surveyed using different monitoring methods between 2010 and 2013 in Taiwan and offshore islands, coral assemblages in "poor" condition (<25% of LCC) can be found in most regions in Taiwan except Green Island (Chen 2014, Ribas-Deulofeu et al. 2016). If only 25 sites surveyed using the same method with coral identification to species level in 2010 and 2011 are considered, coral communities in Taiwan are dominated by turf algae (49%). More importantly, local disturbances and habitat degradation have reduced the latitudinal gradient of diversity in some taxa identified previously (Ribas-Deulofeu et al. 2016). Sites in Taiwan Island and nearby offshore islands are being monitored regularly, due to their easy accessibility. In contrast, Dongsha Atoll and Taiping Island lack regular monitoring surveys due to their remoteness. The most recent survey conducted at Dongsha Atoll in 2017 showed that the coral assemblages in eight out of the 15 reef flats and four out of the 12 reef slopes surveyed were in "poor" condition, with only one reef flat coral assemblage was in "healthy" condition (50-75% of LCC) (Chen et al. 2017). By contrast, the coral assemblages in Taiping Island were in good state where 5 of the 6 sites surveyed were in "healthy" (50-75% of LCC) or "very healthy" condition (>75% of LCC) (Jeng et al. 2017).

Several monitoring programs with different survey methods have been applied to coral reef monitoring in Taiwan. The details of the survey method of each program are listed below.

Scholars of the Taiwan Coral Reef Society (TCRS) had been leading postgraduate students and volunteers from local diving shops to monitor the status of coral reefs using Reef Check monitoring protocol (Hodgson et al. 2006), at several sites in Taiwan from 1998 until 2009 (Dai 2010). In 2009, Reef Check in Taiwan shifted from a scholar-based to a citizen scientist-based event. Since 2009, Taiwan Environmental Information Association (TEIA) collaborating with well-trained citizen scientists as volunteers conducts Reef Check surveys using the same protocol at several monitoring sites in different regions of Taiwan. Two depths, 5m and 10m, at each site are surveyed. Within each of the four 20m x 5m belt transects at each depth, volunteers swim in an S-shaped search pattern along the belt transect and visually estimate the proportion of bleached coral colonies within each transect and the portion of bleached tissue of each coral colony. In addition, local diving operators or instructors who know the monitoring sites well are involved in order to reduce the survey bias and re-monitor the same site annually, even though permanent markers are not applied in situ at each site. However, due to the logistic support of gathering volunteers from different cities in Taiwan and the weather, not all the sites monitored by TEIA have been conducted annually and the survey result, in particular, bleaching events, is highly dependent on the season when surveys are conducted. For example, the bleaching events that happened in summer are not captured in the report of the surveys conducted before summer (June to September).

DeCarlo et al. (2017) conducted coral bleaching survey at the 1-3m deep reef crest on the eastern side of the rim of Dongsha Atoll between 29^{th} May and 7^{th} June 2015 as the pre-bleaching survey, and between 27^{th} July and 2^{nd} August as the post-bleaching survey. All the nine stations monitored were located along a W-E line crossing the 2000m-width rim. Benthic community composition was monitored using 0.5m X 0.5m photo quadrats with one-meter interval along five 50m transects laid in a N-S (along-shore) orientation at each station. Benthic community and bleaching severity was determined by Coral Point Count with Excel (CPCe) (Kohler and Gill 2006) software.

Tan and Fan (unpublished data) conducted coral bleaching survey at Hejie, located at the west coast of the Hengchun Peninsula, the outlet of the third Nuclear Power Plant and Houbihu, located at the west coast of Nanwan Bay, Kenting National Park. Benthic community composition was monitored using photo quadrats along three 10m permanent transects laid at 3-5m in depth at each site in July 2016 and September 2017, the middle and the end of summer season in Taiwan. Coral cover was determined by Coral Point Count with Excel (CPCe) (Kohler and Gill 2006) software.

The methods used for the bleaching surveys conducted in Dongsha Atoll in 2016 (Chen et al. 2017) and in Kenting National Park in 2017 were the same as the one used by the Australia National Coral Bleaching Taskforce in 2016 (following Hughes et al. 2017, 2018). Multiple 10m x 1m belt transects were used to estimate the bleaching severity. Four transects were placed on both reef crest and reef slope of the 15 reefs surveyed in Dongsha Atoll in July 2016, and three transects were placed around 5m depth at three sites, including Howan, Wanlitung, and Hongchai, on the west coast of Hengchun Peninsula in Kenting National Park in December 2017. Every coral colony along the transect was identified to genus and morphology and a categorical bleaching score was assigned following Gleason (1996): Bleaching Category 1: no bleaching, Category 2: pale, Category 3: 1-50% of colony bleached, Category 4: 51-99% of colony bleached, Category 5: 100% of colony bleached, and Category 6: recently dead colony.

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

There was no Taiwan-wide coral bleaching between 2014 and 2017. Instead, several local scale minor bleaching events occurred due to abnormal high sea water temperature. The details of each bleaching event are summarised below.

2014

With more than 8 Degree Heating Week (DHW), corals in shallow reefs in Kenting National Park showed mild level of bleaching severity in 2014. In the most severe bleached site at the outlet of the Third Nuclear Power Plant (N 21.931811, E 120.744977), 60% of the corals on reefs shallower than 5 m were bleached but only 20% were bleached at 10 m depth. An average of 30% of corals bleached at the remaining sites in Kenting National Park. However, no quantitative survey was conducted.

2015

A bleaching event causeing a loss of 40% of the coral colonies surveyed within an area of 300m X 2000m on the reef flat was reported in Dongsha Atoll in June 2015 as a result of the extremely unusual high SST that exceeded 6^{o}C above normal summertime levels (DeCarlo et al. 2017). This was because the water exchange between heated sea water on the reef crest, which is 1-3m deep, and the open ocean was reduced due the reduced wind speed and surface wave height by an anomalous high-pressure system during neap tide. However, there is doubt whether this result can be used to represent the status of the coral community in Dongsha Atoll given the fact that the study was conducted only and partially on the reef crest of the coral rim encircling the Dongsha lagoon, while there are many patch reefs scattered in the lagoon. In addition, all the *in situ* sea water temperature and the status of coral assemblages were monitored within a limited range on the eastern reef crest of the 2km width and 25km in diameter rim of the atoll.

2016

Several small-scale bleaching events were observed in Ludao, Lanyu, Kenting National Park, Penghu Archipelago, and Dongsha Atoll (TEIA 2016, Chen et al. 2016). Bleaching affected 35% of coral population (around 10% bleaching in individual colonies) at 5m depth in Beauty Rock, Lanyu (TEIA 2016). Among rest of the sites surveyed by TEIA in 2016, only minor bleaching events were recorded from two sites in Lanyu in April, three sites in Ludao in June, and three sites in Dongyuping Islet, Penghu Archipelago in August (TEIA 2016). More precisely, partially bleached coral colonies were only observed on reefs with less than 1m in depth on only two, Dongji Islet and Xiji Islet, out of the 15 islands/islets visited crossing the Penghu Archipelago between July and September in 2016. However, while there was no follow-up observation of the bleaching severity in Lanyu, corals in Dabaisha, mild bleaching was recorded two months after the Reef Check survey conducted in Ludao in June. Sixty percent of the corals in shallow water were bleached, mainly Acroporidae, Pocilloporidae, and soft corals, and the bleaching event expanded to around 16m in depth. Meanwhile, a severe bleaching event happened in Kenting National Park but restricted to the western side of Nanwan Bay where around 80% of the corals bleached. More precisely, Tan and Fan recorded 61.2% and 61.3% of bleached coral colonies between 3-5m depth at the outlet of the third Nuclear Power Plant and Houbihu, in July 2016, separately (Tan and Fan, unpublished data).

Minor to mild levels of bleaching also occurred in Dongsha Atoll (25km in diameter) in 2016 (Chen et al. 2017). Around 70% of the 560 colonies on 15 patch reefs surveyed in July 2016 belonged to Bleaching Category 1 (No bleaching) and Category 2 (Pale) and 20% belonged to Category 3 (1-50% bleached) and Category 4 (51-99% bleached). Furthermore, there was no spatial pattern of bleaching severity among the patch reefs surveyed in Dongsha Atoll (Chen et al. 2017).

2017

The corals in Kenting National Park and Hsiaoliuchiu were affected by a bleaching event in 2017. Thirty percent of corals at 5m and 10m depth in Hsiaoliuchiu were in Bleaching Category 3 (1-50% bleached) in November 2017 (TEIA 2017).

Table 1. Bleaching severity in three sites, Howam, Wanlitung, and Hongchai, along the west coast of Hengchun Peninsula, Taiwan, in early December 2017. Data are the percent of colonies in each of six bleaching categories (Category 1: no bleaching, Category 2: pale, Category 3: 1-50% of colony bleached, Category 4: 51-99% of colony bleached, Category 5: 100% of colony bleached, and Category 6: recently dead colony) for all the colonies recorded on survey transects. The number in the bracket after each site name indicates the colony numbers recorded in each site.

Bleaching Category	Howan (350)	Wanlitung (281)	Hongchai (161)
Category 1	88.86	93.24	94.41
Category 2	0.29	1.07	3.11
Category 3	4.00	0.71	1.86
Category 4	0.57	2.14	0.00
Category 5	4.57	1.07	0.00
Category 6	1.71	1.78	0.62

In Houbihu and the outlet of the third Nuclear Power Plant, the west side of Nanwan Bay, Kenting National Park, 54.7% and 30.8% of the coral colonies surveyed were bleached in September. In addition, bleaching event also occurred on the west coast of Hengchun Peninsula, which is unusual and 61.3% of the corals surveyed in Hejie bleached in September (Tan and Fan unpublished data). Another bleaching survey conducted at 5m depth at three sites along the west coast of Hengchun Peninsula in early December 2017 showed 92.5% of the 792 coral colonies in Bleaching Category 1 (no bleaching) and Category 2 (pale) with a gradient in bleaching severity increasing from the south toward the north (Table 1).

The relative abundance of corals in Bleaching Category 1 and Category 2 decreased from 97.5% in Hongchai, the southernmost surveyed site, to 94.3% in Wanlitung, the site in the middle, to 89% in Howan, the northernmost site (Table 1). Meanwhile, the relative abundance of corals in Bleaching Category 5 (100% bleached) and Category 6 (Recently dead) increased from 0.62% in Hongchai to 2.85% in Wanlitung and 6.28% in Howan (Table 1). Historical sea water temperature at each site recorded using *in situ* hobo data log confirmed that this gradient in bleaching severity was due to small-scale sea water temperature variation which was not shown in large-scale prediction dataset using remote sensing technique, such as NOAA Coral Reef Watch.

CONTRIBUTORS

MJH, YCC, SYY, YYH, and CAC conducted the quantitative bleaching survey in Dongsha Atoll in 2016. CAC contributed the summary of the severity of bleaching in Kenting National Park in 2014 and 2016. HJH and MSJ contributed the summary of the severity of bleaching in Penghu Archipelago in 2016. CYK conducted the quantitative survey on the west coast of Hengchun Peninsula in 2017 and wrote the first draft of this report. All authors contributed to the writing of subsequent drafts.

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2.7. Summary of coral bleaching from 2014 to 2017 in Japan

Tadashi KIMURA, Naoko DEWA, Shinichi DEWA, Minaho FUKAGAWA, Isao HIRABAYASHI, Kenji IWAO, Kenji KAJIWARA, Masato KIYOMOTO, Hisashi MATSUMOTO, Takeshi MATSUMOTO, Takuma MEZAKI, Tomofumi NAGATA, Satoshi NOJIMA, Keiichi NOMURA, Katsuki OKI, Tetsurou SASAKI, Goh SHIMADA, Tomoki SUNOBE, Hikaru TOMINAGA, Mitsuhiro UENO and Minoru YOSHIDA

tkimura@jwrc.or.jp

Japan Coral Reef Monitoring Network (JCRMN)

INTRODUCTION

The Ministry of the Environment started a national coral reef monitoring program in 2003 with a preliminaly survey to develop a methodology and select monitoring sites to assess the status of coral reefs around Japan. The official monitoring began in 2004 at 24 sites with a spot check (timed swim) method.

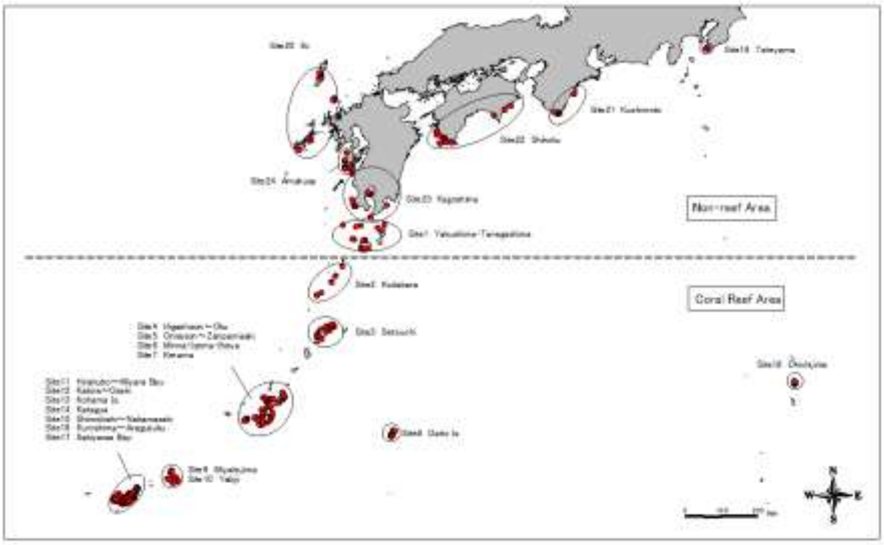


Fig.1. Location of the monitoring sites of the national coral monitoring program by the Ministry of the Environment (red circles).

Coral percent cover as a primary indicator of coral health is estimated by observers through 15 minutes of snorkeling who also recorded indicators of disturbances such as numbers of *Acanthaster planci*, (Crown-of-thorns (COTs) starfish) percent cover of bleached corals, and *Drupella* infestations etc. Seven non-reef area sites from Yaku and Tanegashima Islands northward and 17 coral reef area sites from the Tokara Islands southward were selected (Fig. 1).

Monitoring survey was conducted every 5 years at 2 remote sites in the Tokara Islands and Daito Islands, while the other 22 regular sites were surveyed annually.

The surveys are conducted by coral reef scientists, research agencies, local consultants and dive operators (Table 1) with collaboration of volunteers from NGO/NPOs in some sites. A total 70 stakeholders were involved in the monitoring program in 2012.

Table 1. Members of Japan Coral Reef Monitoring Network and monitoring sites of national monitoring program

<table>
<tr><th colspan="2">Monitoring Area (prefecture)
Site no.: site name</th><th>member</th><th colspan="2">Monitoring Area (prefecture)
Site no.: site name</th><th>Member</th></tr>
<tr><td rowspan="11">Non Reef Area</td><td rowspan="3">Tateyama (Chiba)
Site 19: Tateyama</td><td rowspan="2">Masahito KIYOMOTO</td><td rowspan="11">Coral Reef Area</td><td>Tokara Islands (Kagoshima)
Site 2: Kodakara</td><td>Tadashi KIMURA</td></tr>
<tr><td>Amami Is (Kagosima)
Site 3: Setouchi</td><td>Katsuki OKI</td></tr>
<tr><td>Tomoki SUNOBE</td><td>Okinawa Is (Okinawa)</td><td>Tomohumi NAGATA</td></tr>
<tr><td>Kushimoto (Wakayama)
Site 21: Kushimoto</td><td>Keiichi NOMURA</td><td>Kerama Is (Okinawa)</td><td>Kenji IWAO</td></tr>
<tr><td rowspan="2">Ootuki Chou (Kochi)
Site 22: Shikoku</td><td>Humihito IWASE</td><td rowspan="2">Miyako Is (Okinawa)</td><td>Kenji KAJIWARA</td></tr>
<tr><td>Takuma MEZAKI</td><td>Hisashi MATSUMOTO</td></tr>
<tr><td>Southern Kagoshima
Site 23: Kagoshima</td><td>Shinichi DEWA</td><td>Ishigaki Is (Okinawa)</td><td>Minoru YOSHIDA</td></tr>
<tr><td>Amakusa (Kumamoto)
Site 24: Amakusa</td><td>Satoshi NOJIMA</td><td rowspan="2">Sekisei Lagoon
(Okinawa)</td><td>Tadashi KIMURA</td></tr>
<tr><td>Suou Chou (Yamaguchi)
(no national monitoring)</td><td>Masaaki HUJIMOTO</td><td>Mitsuhiro UENO</td></tr>
<tr><td>Yakushima (Kagoshima)
Site 1: Yakushima-Tanegashima</td><td>Takeshi MATSUMOTO</td><td rowspan="2">Ogasawara (Tokyo)</td><td rowspan="2">Tetsuro SASAKI</td></tr>
<tr><td>Iki & Tsushima (Nagasaki)
Site 20: Iki</td><td>Kaoru SUGIHARA</td></tr>
</table>

CORAL BLEACHING EVENT FROM 2004 TO 2017

Overview of Coral Reef Area

Average coral cover of all coral reef area sites (table 2 and Fig. 2) increased gradually from 32.4% in 2004 to 35.8% in 2006 and suddenly dropping to 26.3 in 2007 because of coral bleaching by high water temperature during the summer. From 2008 to 2012 coral cover gradually recovered from 26.3 to 27.1% before decreasing to 21.8% in 2013. Although coral cover again recovered up to 30.5% in 2015, it dropped to 23.1 in 2016 and 22.1 in 2017 due to the severe coral bleaching in 2016.

COTs predation was a major disturbance in coral reef areas since 2000 when the outbreak started in Amami Islands (site 3: Setouchi), continued and ended in 2007 causing large scale of destruction of corals. The outbreak also started in the Yaeyama Islands (consisting of Ishigaki (site 11-12), Iriomote (site 17) Islands and Sekisei Lagoon (site 13-16)) in 2001 and the number of individuals increased rapidly from 2009 with large aggregations around Ishigaki, Iriomote Islands and Sekisei Lagoon until 2012. COTs aggregations were also found around Miyako Island (site 9) and Yabiji reefs (site 10) in 2002 with the outbreak continuing until 2012. An outbreak also appeared in Kerama (site 7) Islands in 2004 and ended in 2007.

Table 2. Changes of average coral cover, coral bleaching and mortality in the Coral Reef Area from 2004 to 2017.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
average coral cover (%)	32.4	35.4	35.8	26.3	26.3	28.7	28.7	26.4	27.1	21.8	28.8	30.5	23.1	22.1
average coral bleaching (%)	0.4	13.3	6.4	29.3	18.5	17.7	15.5	11.6	7.5	14.5	22.5	21.6	54.9	40.7
average mortality (%)	0.4	0.5	0.7	19.4	2.7	0.2	0.5	0.0	0.03	3.6	3.2	1.0	24.9	4.3

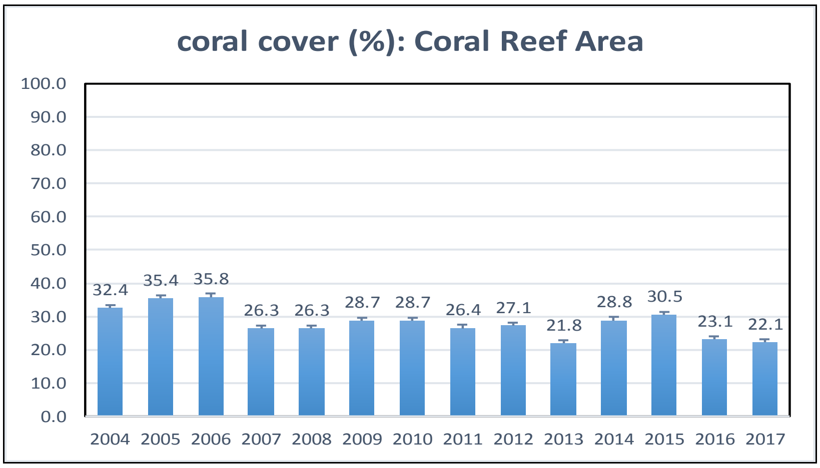
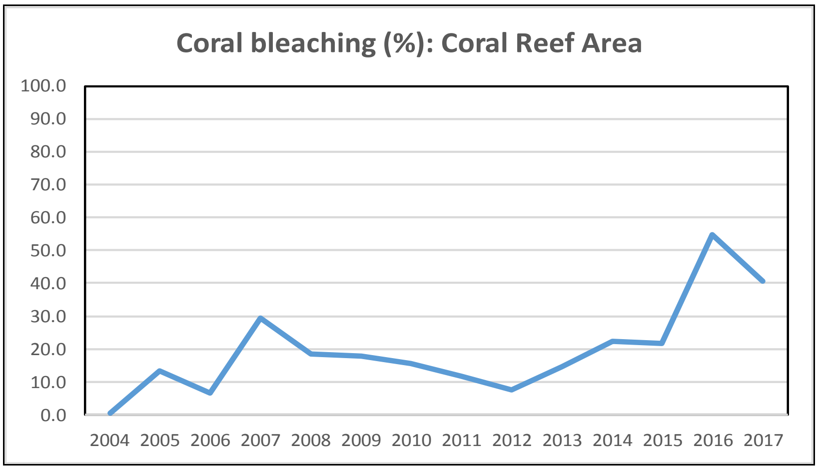


Fig. 2. Mean live coral cover (%) in coral reef area from 2004 to 2017. Error bar on each column indicates standard error of the mean coral cover.

Coral bleaching by high water temperature was another major disturbance (table 2 and Fig. 3). Mass bleaching was observed in Yaeyama Islands in 2007 with 30 to 60% of corals affected by the high water temperature. Corals were also damaged by typhoon that hit this area right after the bleaching event leading to degradation of coral cover in 2007. Bleaching caused by low water temperature was also observed around Yabiji reefs in 2008 and 2009.

Average coral cover showed a slight recovery after the decline from bleaching in 2007 until 2010. However, COTs predation was still a major problem in Miyako (site 9), Ishigaki (site 11-12), Iriomote (site 17) Islands and Sekisei Lagoon (site 13-16) and typhoons were another regular disturbance adding further damage to corals. Coral cover decline in 2011 was caused by COTs predation in Miyako Island and Yabiji reefs, and typhoon damage around Okinawa Island (site 4-5).



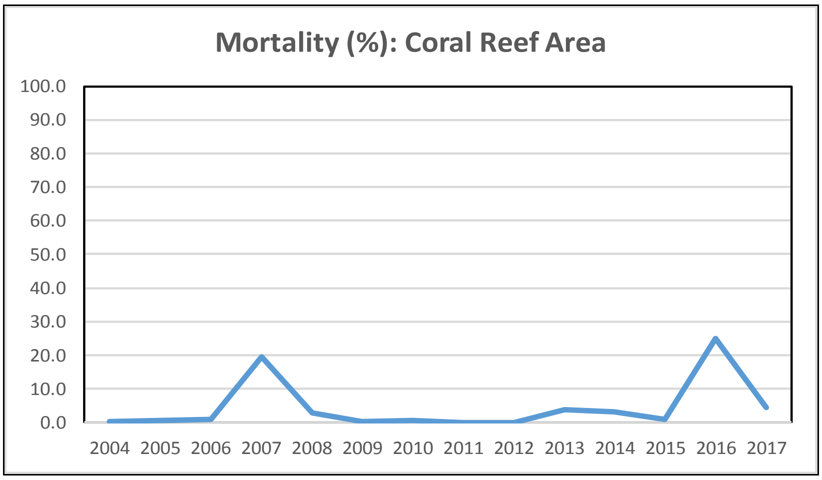


Fig. 3: Mean coral bleaching (%) in coral reef area from 2004 to 2017 (above) and mean coral mortality (%) from 2004 to 2017 (below).

Average of coral bleaching rate was the highest in 2016 with 54.9% and the second highest in 2007 with 29.3%. The average mortality was 24.9% in 2016 and 19.4% in 2007. Coral bleaching in 2016 was the severest during this coral monitoring program from 2004 to 2017.

Overview of Non-reef Area (high latitude coral community area)

Average coral cover of all the non-reef area sites (Fig. 4) was 24.9% in 2004 and 22.5% in 2005. The difference of the coral cover between these initial two years was due to the number of the monitoring stations, which were increased in 2005 with higher coral cover. The mean coral cover increased gradually to 33.0% from 2005 to 2010 and dropped to 20.4% in 2013. The coral cover again recovered up to 29.2% in 2016 and decreased to 27.5% in 2017. These differentiation of coral cover reflected responses/effect/recovery of corals from the disturbances that occurred each year. Two events, COTs predation and typhoon damage affected coral cover, which dropped in 2007 and 2011 before the minimum coral cover of 20.4% was recorded in 2013.

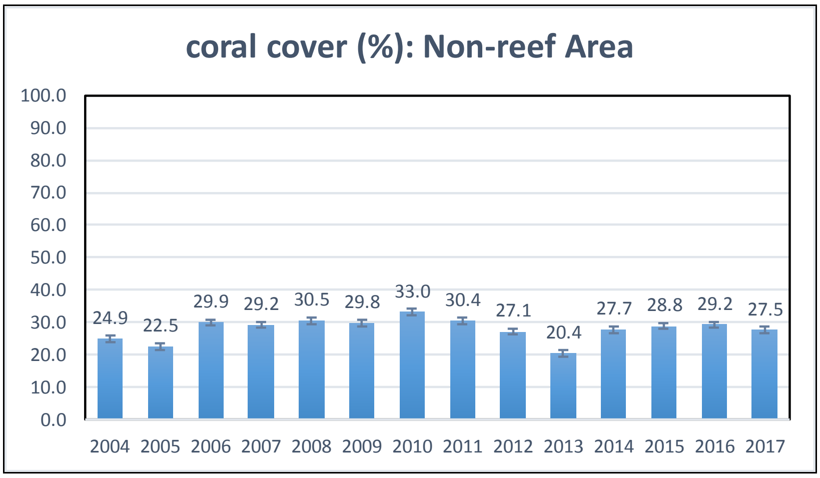
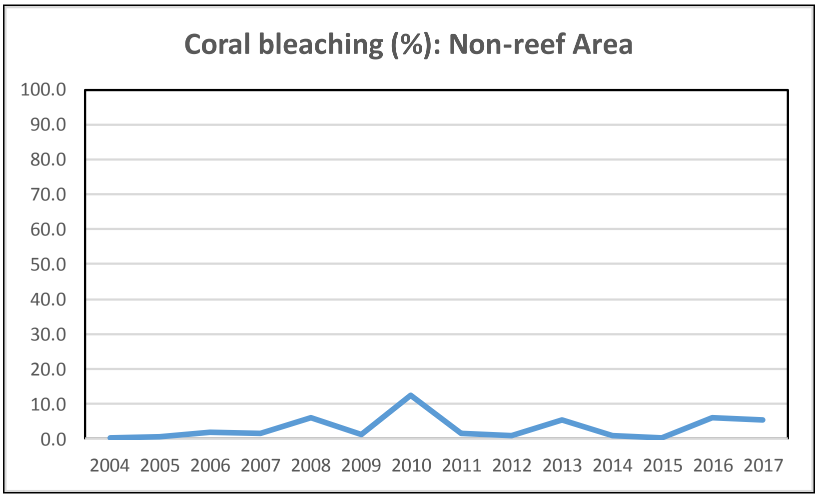


Fig. 4. Mean live coral cover (%) in non reef area from 2004 to 2017. Error bar on each column indicates standard error of mean coral cover.

Predation by COTs was also one of the major disturbances on coral communities in the non-reef area and the degradation of coral cover in 2005. Large numbers of COTs were observed around Kushimoto (site 21) in early 2000 and the first aggregation in 2004. The maximum number of individuals and degradation of coral cover was recorded in 2005. COT numbers also started increasing along the Shikoku (site 22) southern west coast in 2004. Coral cover at this site had been affected by COTs predation since 2008 and the maximum number of individuals was observed in 2010. Although the peak in the number has passed, some of the stations within the Shikoku site showed high aggregations. Along the Kagoshima (site 23) southern coast, significant numbers of COTs were recorded in 2007 and predation expanded into the site and remained until 2011. The numbers declined in 2012, but aggregations are still present. In Amakusa site (site 24), many aggregations of COTs appeared since 2002 before the monitoring program started. The number of individuals observed was low until 2007 when it increased rapidly from 2008 to reach a maximum in 2009 before decreasing.

Typhoon damage was observed in 2012 in Iki & Tsushima site (site 20: Iki) resulting in reduction of coral cover. Kushimoto (site 21) and Shikoku (site 22) are located on the major route of typhoons passing through mainland Japan from Okinawan waters, which often cause coral damage. Serious damage from typhoons was recorded in Kushimoto site in 2004, 2005 and 2009 with minor damage in 2006, 2007, 2011 and 2012. At Shikoku southern west coast site, coral cover was affected by typhoon damage in 2007 and 2011.



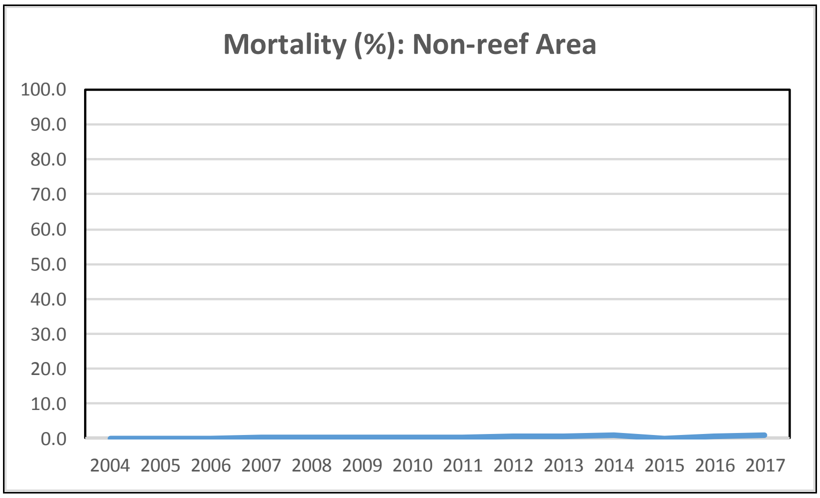


Fig. 5. Mean coral bleaching rate in non reef area (above) and mean mortality (below) from 2004 to 2017.

Kagoshima (site 23) southern coast was also affected by typhoon in 2012. In Amakusa site (site 24), typhoons hit in 2006 and 2012, but the average coral cover did not show much effect. Coral disease was one of the major disturbances together with typhoon and COTs damage coral communities in Kushimoto site (ste 21). Bleaching by lower water temperature in winter was observed around Kushimoto (site 21), Shikoku (site 22) southern west coast and Amakusa sites (site 24). It killed 20% of the coral community, especially most of the *Acropora* species in Kushimoto site (site 21) in 2012.

Major coral bleaching event occurred in 2010 among the coral communities in the Non-reef Area (fig. 5 and table 4). However, damage on coral cover was not significant with 0.3% of mortality.

Table 3. Changes of average coral cover, coral bleaching and mortality in the Coral Reef Area from 2004 to 2017.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
average coral cover (%)	24.9	22.5	29.9	29.2	30.5	29.8	33.0	30.4	27.1	20.4	27.7	28.8	29.2	27.5
average coral bleaching (%)	0.1	0.6	1.7	1.6	6.1	1.0	12.5	1.6	0.7	5.3	0.9	0.3	5.8	5.3
average mortality (%)	0.0	0.0	0.1	0.4	0.2	0.2	0.3	0.3	0.5	0.6	0.8	0.0	0.7	0.8

CONCLUSION

Coral bleaching in 2016 was the severest disturbance on coral communities in the Coral Reef Area, especially southern most area including Miyako Island, Ishigaki Island, Iriomote Island and Sekisei Lagoon.

Table 4. Overall results of coral bleaching from 2015 to 2017 at all the sites of the national monitoring program by the Ministry of the Environment.

Area	no.	site name	average coral cover (%)			average coral bleaching (%)			average mortality (%)		
			2015	2016	2017	2015	2016	2017	2015	2016	2017
Coral Reef Area	3	Amami Islands	34.2	38.3	33.9	0	8.5	1.8	0	2.1	0
	4	Okinawa Island, East coast	31.2	34.5	35.5	0.7	21	31.5	0	0.7	0.7
	5	Okinawa Island, West coast	26.8	29.1	36.2	0.03	13.1	31.3	0	4.3	5.2
	6	Okinawa Outer Islands	26.2	58	54.3	0.01	48.4	4.2	0	13.5	1.8
	7	Kerama Islands	17.4	15.8	22.5	0	7.3	0	0	5.4	0
	9	Miyako Island	25.5	18	17	0	68.8	0.5	0	31	0.5
	10	Miyako Outer Reefs	32.5	8.8	6.3	12.5	70.1	0	0	67.5	0
	11	Ishigaki Island, East coast	27.4	27.5	19.6	0	47.9	0.3	0	8.8	0.3
	12	Ishigaki Island, West coast	13.8	13.9	12.1	0	63.2	0.4	0	14.8	0.4
	13	Sekisei Lagoon, North	37	23	20.1	52.6	91.5	85	2.8	46.9	6.7
	14	Sekisei Lagoon, East	31	9.3	5.2	62.3	99.5	94.6	2.5	67.9	11.3
	15	Sekisei Lagoon, Center	34.3	18.8	17.2	65.4	94.9	92	3.1	49.7	8.5
	16	Sekisei Lagoon, South	31.2	17.9	13.2	66.3	98.2	94.1	2.5	50	10.2
	17	Iriomote Islands	48.9	32.4	27.3	39.5	94.3	84.7	1.6	34.8	6.7
	18	Ogasawara Islands	45	41.7	45	<1	2.9	1.3	0	1.9	0.2
Non-ree Area	19	Tateyama	2.9	2.9	2.9	0	0	0	0	0	0
	20	Iki and Tsushima Islands	47	37.3	32	1.9	2.1	0.4	0.3	1.1	0.3
	21	Kushimoto (Wakayama Pref.)	32.3	33.1	27.7	0	0.8	13.3	0	0.1	0.5
	22	Shikoku Southwestern coast	25.8	30.9	25.4	0	3	7.1	0	0.5	1.3
	23	Kagoshima Southern Coast	19	18.4	16.4	0	20.7	0	0	0	0
	24	Amakusa (Kumamoto Pref.)	26.6	27.6	31.1	0	0.2	0.5	0	0	0
	1	Tanegashima & Yakushima	34.2	38.3	33.9	0	8.5	1.8		2.1	0

The highest mortality was 67.9% recorded at Sekisei Lagoon and the second highest mortality was

67.5% at the outer reef of Miyako Island (table 4). On the other hand, coral bleaching in Non-reef Area was not significant in 2016 and 2017. The major disturbance on the coral communities in the Non-reef area was the predation of Crown-of-Thorns starfish and typhoon damage.

2.8. Summary of coral bleaching from 2015 to 2017 in South Korea

Heung-Sik PARK

hspark@kiost.ac.kr

Korea Institute of Ocean Science and Technology

OVERVIEW OF CORAL DISTRIBUTION AND DATA COLLECTION

Coral distribution is no longer limited to tropical and subtropical areas. Corals are now being distributed also in temperate areas, although they do not normally from coral reefs. In regions affected by poleward warm currents such as Korea and Japan, corals are distributed at higher latitudes than in other regions. Remarkable declines in coral diversity have been observed along a latitudinal gradient around Korean waters. *Alveopora japonica* has recruited massively on Northern coasts of Jeju Island and is out-competing kelp and sea weed and dominating the hard bottom. As a consequence, coral migration might result in 'Phase Shift' from algal-dominant to coral-dominant community. This alteration will subsequently modify the composition of associated marine organisms, such as fish and macro invertebrates from temperate to tropical species.

CORALS AROUND KOREAN WATERS

Korean waters do not have any typical reefs by reef building stony corals (MOE, 2009). To date, a total of 134 species of corals are found in Korean waters including 25 species of zooxanthellate coral, and about 90 species of Octocorallia. Although soft corals and Octocorallia have been studied widely in Korea, information on zooxanthellate corals is scarce. At Jeju Island, zooxanthellate corals have been commonly found only around Seogwipo on the southern coast. Song(1991) reported three zooxanthellate coral species (*Montipora trabeculata*, *Alveopora japonica*, and *Psammocora profundacella*. Park and Choi(2001) also reported three zooxanthellate coral species (*Alveopora japonica*, *Alvepora sp*., *Montastrea* sp., *Oulastrea* sp., and two *Acropora* sp., although the organism recorded in this study as *Montastrea* sp. may in fact have been *Zoanthus* sp. Unfortunately, there are less specialists to identify zooxanthellate corals in Korea. Recently zooxanthellate scleractinian coral studies have been carried out by Jeju University scientists joining with Japanese taxonomist. They re-identified the common zooxanthellate corals of Jeju Island, and reported 7 species, *Montipora millepora*, *Alveopora japonica*, *Psammocora albopicta*, *Psammocora profundacella*, *Oulastrea crispata*, *Acanthastrea lordhowensis*, *Favites* sp.

GLOBAL WARMING AFFECTS ON KOREAN WATERS

Environmental information such as water temperature can provide a baseline not only for understanding coral community structure at the latitudinal limits of distribution, but also for examining ecosystem modification resulting from global warming. Takatsu et al. (2007) reported that sea surface temperatures (SST) have risen by 1.2-1.3℃ during the past 100 years around Korea and Japan. Poleward range expansions of corals have been documented by a series of field surveys, at speeds up to 14km/year during the past 80 years on temperate Japanese coasts (Yamano et al. 2011). KIOST reviewed SST based on long-term data around East China Sea and established that a schematic contourline representing 20℃ minimum surface water temperature has moved 50-100 km in 30 years from 1980 to 2010 (KIOST. 2012) (Fig. 1).

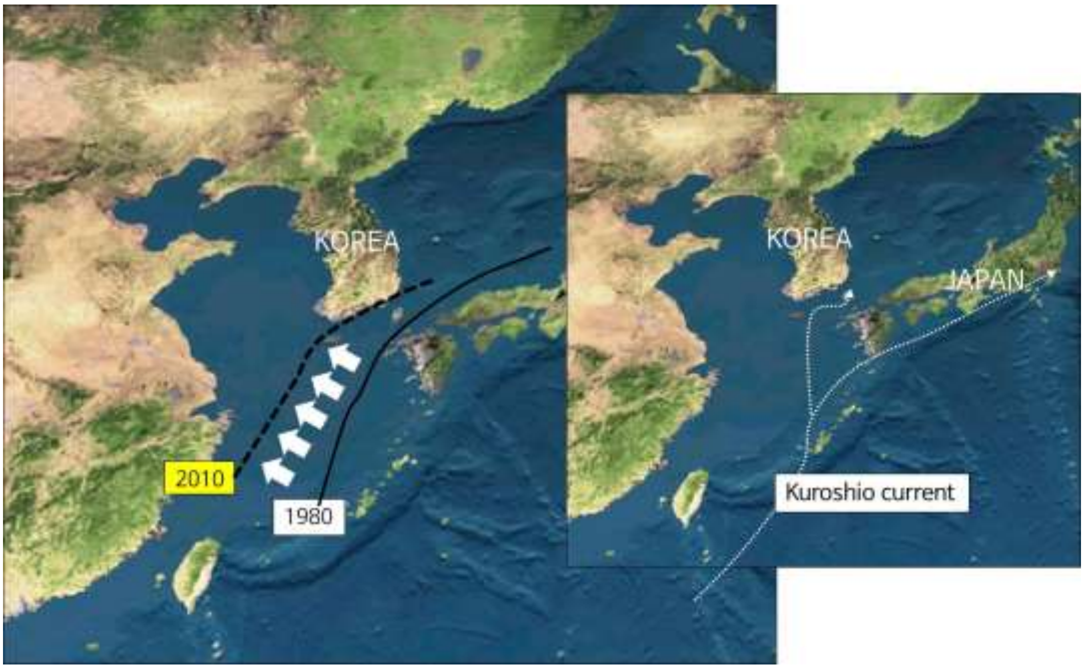


Fig. 1. A shift of minimum surface water temperature (20 ℃) line for 30 years from 1980 to 2010

The line, which explained the limitation of zooxanthellate corals in Korea has moved to the southern coast of Jeju Island making it a potential eco-region for coral reef development. Actually, the southern coast of Jeju island, which located in south sea of

Korean peninsula have been influenced by the Yellow Sea Warm Current (YSWC). The current system however, is complex, and two origins have been proposed. The first is that the YSWC is a branch of the Tsushima Warm Current, and the second is that the YSWC is a branch of a current from Taiwan. SST on the southern coast of Jeju Island ranged from 19^{0}C in February to 27℃ in August.

ZOOXANTHELLATE CORALS ARE MOVING NORTHWARD IN EAST CHINA SEA

Seven of common zooxanthellate corals identified in Jeju Island have migrated from East-South sea based on bio-geographical data suggesting the influence by the warm Kuroshio current (Fig 2). Global warming effects in East Asia caused by warm current expansion with the water mass moving up from the tropic ocean can facilitate migration of coral juveniles into southern parts of Korean peninsula. The cover of *A. japonica* beds is increasing at the northwest of Jeju Island and coral communities are developing over a wide range of the shallow hard bottom. Organisms associated with corals have also shown range expansions following the coral expansions.

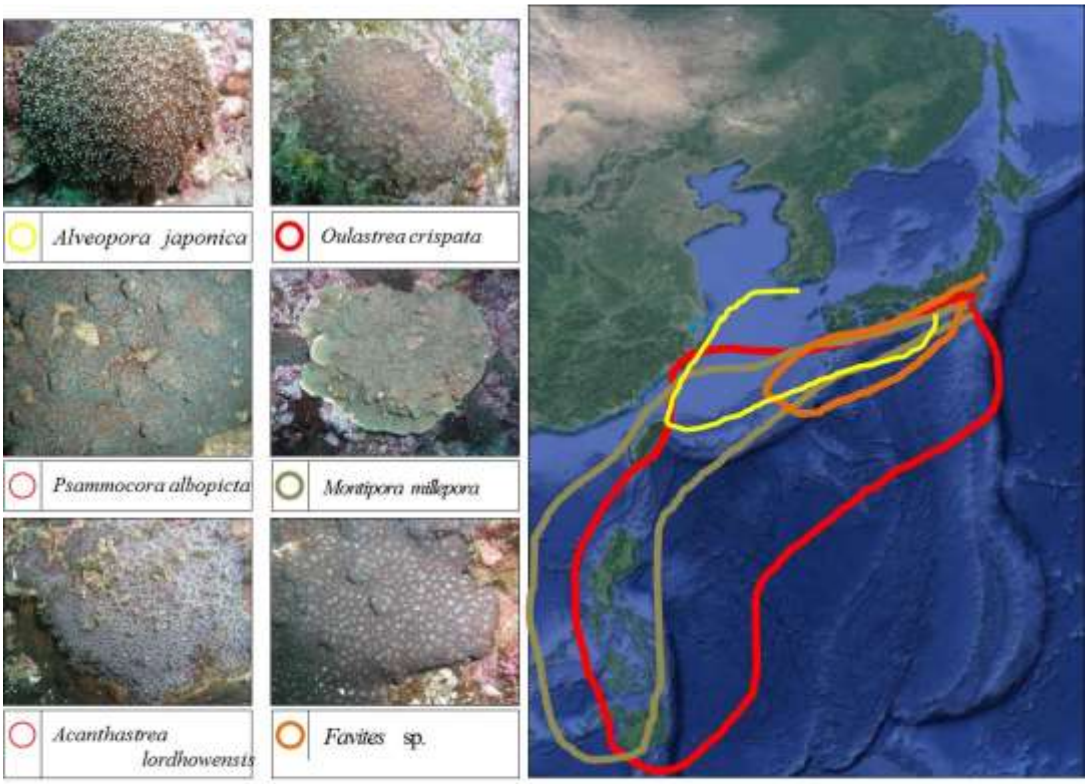


Fig. 2. Boundary of zooxanthellate corals found in Korean waters based on bio-geographical data.

Accordingly, corals on the Korean coasts may also have experienced range extensions. With the transportation by warming sea surface currents, tropical corals might be able to establish a sizeable community in temperature region and out-compete with the original community builders such as kelp or seaweed (Fig. 3 & 4). Expansion to the high latitude areas due to global warming may be one of the response mechanisms of corals from becoming locally extinct in the tropics (GCRMN, 2014)

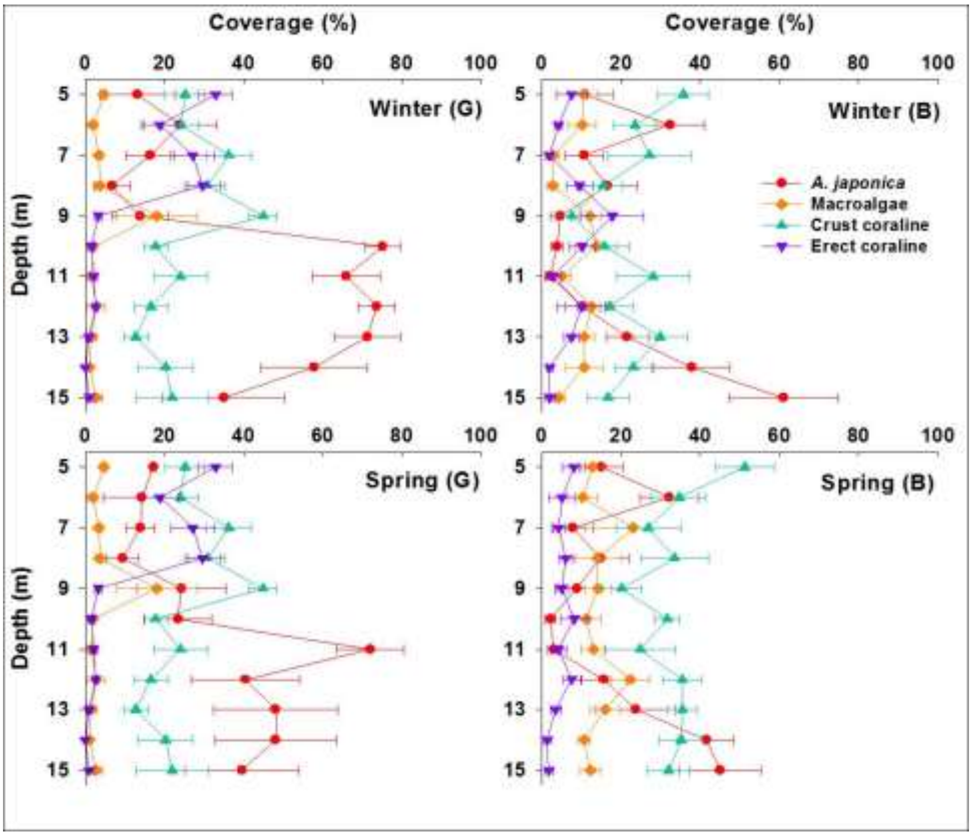


Fig. 3. Seasonal competition between coral and kelps on the northern (G) and southern (B) coasts of Jeju Island

Fig. 4. A phase-shift of benthic community in the same area over 20 years in southern coasts of Jeju Island.

CORAL BLEACHING DURING THE GLOBAL EVENT OF HIGH WATER TEMPERATURE

No coral bleaching was detected in Korean waters from 2014 to 2017.

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3. Conclusion of Coral Bleaching in East Asia

3. Conclusion of coral bleaching from 2015 to 2017 in East Asia

Loke Ming Chou

tmsclm@nus.edu.sg

National University of Singapore

Past global coral bleaching events that occurred in 1998 and 2010 were confined to those specific years. The most recent global coral bleaching event however spanned three years from mid-2014 to mid-2017 and is assessed to be the most widespread and most damaging with many reefs subjected to multiple thermal stress as the oceans warmed repeatedly. The following summary of the response of East Asia's coral reefs is based on submitted reports from Cambodia, Indonesia, Japan, South Korea, Singapore, Taiwan, Thailand and Vietnam.

The impact on East Asia's reefs was widespread with the greatest bleaching severity reported in 2016. In Indonesia, bleaching occurred in 21 of the 22 monitoring sites covering all the major islands. No bleaching was seen in West Papua. In Thailand, the 2016 bleaching resulted in mortality that was much lower than the 2010 bleaching due to the start of the southwest monsoon. In Japan, the highest mortalities at coral reefs sites were recorded at Sekisei Lagoon (67.9%) and the outer reef of Miyako Island (67.5%). Bleaching was not significant in Japan's non-reef areas (coral communities) in 2016 and 2017 where the major disturbances of these coral communities remain Crown-of-Thorns starfish predation and typhoon damage. There is no Taiwan-wide coral bleaching between 2014 and 2017 as bleaching was restricted to specific locations at different times. Throughout the region, mild to moderate bleaching was observed in some countries/states in 2014 and 2015 and no bleaching occurred in 2017 except in Taiwan's Kenting National

Park and Hsiaoliuchiu. No bleaching was observed in South Korea, where a few species of zooxanthellate corals have extended their range to facilitate by the warmer sea temperature.

A common pattern is the obvious difference in bleaching severity among reef sites. The levels of bleaching susceptibility also varied greatly among coral taxa. Experiments with shading on bleaching recovery and survival of corals in Thailand indicated higher bleaching recovery rates of some coral species that were shaded. Mortality rate of *A. muricata* in shaded areas after the bleaching event was also lower.

Monitoring capacity varies among countries/states. There are logistic and funding constraints especially for those with a large expanse making it challenging to access some of the more remote reefs. This is commonly being addressed by involving local NGOs and dive clubs. It is also necessary to step up monitoring when bleaching alerts are given so that data can be generated from which information on community and species response to first-time or repeated bleaching can be analyzed. A scheduled reef monitoring programme based on seasons or fixed times of the year should be supplemented with additional surveys before, during and after the onset of a bleaching event.