THE 4TH INTERNATIONAL MARINE AND FISHERIES SYMPOSIUM 2017

Proceeding

“Towards Resilient and Sustainable
Maritime Economic in The Era of
Globalization and Climate Change”

PROCEEDING
THE 4th INTERNATIONAL MARINE AND FISHERIES SYMPOSIUM 2017

*Theme: Towards Resilient and Sustainable Maritime Economic in The Era of
Globalization and Climate Change*

Makassar, Mei 20, 2017

Keynote Speaker:

Prof. Dr. Mohammad Ikhwanuddin
(Institute of Tropical Aquaculture, University Malaysia Terengganu)

Prof. Kent Schoeder
(Australian National University)
Prof. Dr. Ir. Andi Akhmad Mustafa, MP.
(BRPBAP3 Maros)

Prof. Dr. Ir. Jamaluddin Jompa, M.Sc
(Hasanuddin University)

Marine Science and Fisheries Faculty
Hasanuddin University, Makassar
Makassar, 2 October 2017

Proceeding of The 4 International Marine and Fisheries Symposium 2017

Theme: Towards Resilient and Sustainable Maritime Economic in The Era of Globalization and Climate Change

Steering:

Dean of Marine Science and Fisheries Faculty, Unhas
Prof. Dr. Ir. Jamaluddin Jompa, M.Sc.

Person in charge:

Vice of Dean I of Marine Science and Fisheries Faculty, Unhas
Dr. Ir. St. Aisjah Farhum, M.Si.

Editor: Moh. Tauhid Umar, Siti Aslamyah, Yushinta Fujaya, Hilal Anshary,
Alfa Nelwan, Mukti Zainuddin, Khusnul Yaqin, Nursinah Amir, Irmawati,
Dwi Fajriati Inaku..

ISBN: 978-602-71759-4-5

Published by: Marine Science and Fisheries Faculty,
Hasanuddin University, Makassar, October 2, 2017
Kampus Tamalanrea Jalan Perintis Kemerdekaan Km. 10 Makassar
Telephone: +62411-586025
Email: fikpuh@indosat.net.id dan simnaskp.unhas@gmail.com
Website: <http://fikp.unhas.ac.id> dan <http://simnaskpunhas.com>

All rights reserved

No part or overall of this book may be reproduce without written permission of the Publisher.

PREFACE

Might thanks to Allah SWT who given a blessing to us, so the proceedings of 4th International Fisheries and Marine Symposium have been finished on time. This proceedings contents 18.articles that have been presented at the symposium with the theme of symposium was “Towards resilient and sustainable maritime economic in the era of globalization and climate change” that have been held at Harper Hotel Makassar on 20 May 2017.

All manuscript that published in this proceedings have been selected and reviewed by reputable reviewers. We noted that there was 102.articles were selected to be presented in the symposium, which are 86 articles have been presented as oral presentation and 16 articles have been presented as poster presentation. For increasing quality of articles, we have made an assessment and reviewed by pointed participant during a presentation. Questions and suggestions for improving their articles have been given back to the author. The revised article then sent back to OC to be reviewed by pointed internal reviewers. Minor correction was not substantial and could be revised by our editors, while major correction of article have to be revised by the author.

This proceedings could be finished by supporting and contributing many parties. For this reason, we would like to thanks to all parties who have been assisted since collecting, editing and publishing this proceedings. We also would like to apologize for our weakness in this proceedings, so we really appreciated for a positive feedback from readers for improving our symposium in the future.

Hopefully, our proceeding could be a significant contribution for global marine economic development.

Makassar, 1 September 2017

Coordinator of organizing committee

Prof. Dr. Ir. Yushinta Fujaya, M.Si

TABLE OF CONTENT

	Page
KATA PENGANTAR	
SAMBUTAN DEKAN FAKULTAS ILMU KELAUTAN DAN PERIKANAN	
Article	
The Analysis System of Profit Sharing for The Fishermen a Boat at Bontosunggu Village Bontoharu District of Selayar Archipelago	1
<i>Benny Audy Jaya Gosari, Sri Suro Adhawati, Abdul Wahid, Syamsiah</i>	
Evaluation of Giving Commercial Probiotic and Molasses to Seabass (<i>Lates calcarifer</i>) Growth	6
<i>Cut Yulvizar, Irma Dewiyanti, Rizki Ananda</i>	
Economic Valuation of Mangrove Forest Ecosystem in Untia Area For Sustainable Use and Management in Makassar	14
<i>Hamzah Tahang, Amiluddin, and Bachrianto Bachtiar</i>	
The Effect of Nitrobacteria on Plankton Abundance and Survival of Larvae Swimming Crab (<i>Portunus pelagicus</i>) Megalopa Stage	25
<i>Indra Cahyono, Hasnia and Fadlan Amir</i>	
Biodiversity of Marine Macroalgae in The Intertidal Zone of Lhok Bubon Beach, West Aceh, Aceh Province	31
<i>Mohamad Gazali and Muhammad Nurdin</i>	
The Sensory Hedonic Quality and Physical Characteristics Effect of <i>Kappahycus Alvarezii</i> Seaweed and Catfish Bone on Traditional Food Ilabulo Catfish (<i>Pangasius</i> sp.)	39
<i>Rita Marsuci Harmain, Faiza Dali, Nurjanah, Agoes Mardiono Jacob</i>	
Ecoedutourism as Marine Conservation Alternative: Case of Taka Bonerate National Park	49
<i>Riza Sativani Hayati and Andi Ida Pala</i>	
Extracts of Majapahit (<i>Crescentia cujete</i>) Fruit for Use Ineradicating <i>Vibrio Harveyi</i> Bacteria Caused Vibriosis in Vannamei Shrimps: An <i>Insilico</i> Method Approach	57
<i>Sri Rahmaningsih</i>	
Fingerprints of the Anthropocene: the 2016 Coral Bleaching Event in an Equatorial Archipelago	66
<i>Abigail Moore, Samliok Ndobe, and Jamaluddin Jompa</i>	
Rare Earth Element Potential in Sulawesi: A New Source for Clean Energy Technology	87
<i>Adi Maulana</i>	
The Application of the Different Prebiotic Level Added to the Diet on the Activity of <i>Lactobacillus</i> Bacteria in the Digestive Track of White Shrimp, <i>Litopenaeus vannamei</i>	97
<i>Alexander Rantetondok, Yenni Mustafa and Siti Aslamyah</i>	
On Board Survey of the Small Pelagic Purse Seine Fishing	103
<i>Aris Widagdo</i>	
Status of Coral Reef Ecosystem and Indication of Coral Bleaching Event in Morotai Islands Water, North Moluccas	105
<i>Ashma Karimah, Darmawan A Mukharror, Muhammad Ichsan, Niomi Pridina and Tiara Isnaini Baiti</i>	

Role of Cooperation to Increasing Economic in Coastal Communities <i>Abdul Wahid, Benny Audy Jaya Gosari</i>	113
Temporal Distribution of Mesozooplankton in Bidong Archipelago, Peninsular Malaysia <i>Khyril Syahrizan Husain and Zainudin Bachok</i>	118
Phytoplankton in Bidong Archipelago, Peninsular Malaysia <i>Khyril Syahrizan Husain and Zainudin Bachok</i>	129
Value Chain dan Pola Pengembangan Kelembagaan Komoditi Rumput Laut (<i>Kappaphycus Alvarezii</i>) di Desa Kolorai Kabupaten Pulau Morotai <i>Ruzkiah Asaf, Erna Ratnawati dan Tarunamulia</i>	140
Genetic Relationship of Flyingfish (<i>Hirundichthys oxycephalus</i>, Bleeker) Caught in Pare-Pare and Polman Waters (Makassar Strait) and Takalar and Bulukumba Waters (Flores Sea) Based on Morphometric Characters <i>Syamsu Alam Ali, Yusran Nur Indar, M Natsir Nessa, Dewi Januarita and Nita Rukminasari</i>	149
Performance of Marron (<i>Cherax cainii</i>) Origin Probiotic <i>Bacillus mycoides</i> in Earthen Commercial Marron Ponds. <i>Irfan Ambas, Ravi Fotedar and Nicky Buller</i>	155

Fingerprints of the Anthropocene: the 2016 Coral Bleaching Event in an Equatorial Archipelago

Abigail Moore^{1*}, Samliok Ndobe^{2,4}, Jamaluddin Jompa³

¹ Doctoral Program in Fisheries Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, Indonesia

² Aquaculture Study Program, Faculty of Animal Husbandry and Fisheries, Tadulako University (UNTAD), Palu, Indonesia

³ Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, Indonesia

⁴ Central Sulawesi Sea Partnership, Palu, Indonesia

*Corresponding author - contact email: abigail2105@yahoo.com

ABSTRACT

Coral reef ecosystems worldwide are experiencing increasingly frequent episodes of temperature-related “coral bleaching”. The Banggai Archipelago in Central Sulawesi, Indonesia, has extensive coral reefs and is home to the endemic Banggai cardinalfish, *Pterapogon kauderni*, a species listed as Endangered in the IUCN red List. A rapid survey was undertaken at seven sites (1.2°S-2°S) in this archipelago, in response to the national call for action during the 2016 global bleaching event. The CoralWatch method (6 point colour scale: CW1-CW6) was used; colony life-form (Global Coral Reef Monitoring Network categories) and genus (Indo-Pacific Coral-finder) were recorded. Partial and full bleaching were observed at all sites; of 1166 colonies, 64.7% were fully bleached (CW1) or very pale (CW2); with 13.5% in CW4-CW6. Water temperatures were 1-3°C above recorded maxima from 2004-2012. Branching and encrusting life-forms had the highest full/severe bleaching rates. Common genera with above average bleaching rates included *Stylophora*, *Seriatopora*, *Pocillopora*, *Isopora*, *Merulina*, *Galaxea*, some forms of *Acropora* and *Porites*. Algal overgrowth was observed on both live (fully/partially) bleached and dead colonies. Densities of *Diadema* sp. urchins, a key symbiont of the Banggai cardinalfish, until recently the most abundant coral reef herbivore, were extremely low (orders of magnitude less than 2004 densities), with few adult individuals present at 5/7 sites. The Caribbean experience underlines the urgency of addressing the unregulated *Diadema* fishery which has developed in the Banggai Archipelago since around 2007. Rehabilitating populations of this key invertebrate herbivore would contribute to biodiversity conservation and reef resilience/recovery in this equatorial archipelago.

Keywords: Banggai Archipelago, Invertebrate herbivory, *Diadema* sp., *Pterapogon kauderni*, Coral resilience

Introduction

Our home planet, “a pale blue dot [...], a lonely speck in the great enveloping cosmic dark, ...” the only world known so far to harbor life” (Sagan, 1997) has gone through many eras since life first evolved around 3.7 billion years ago. Although some scientists still regard our present epoch as the Holocene, which began around 11,500 years ago at the end of the last ice age, there is a growing consensus that we are now in a new geological epoch, the “Anthropocene” (Zalasiewicz et al., 2011; Barnosky, 2014). Coined by Nobel Laureate Crutzen in 2000 (Crutzen & Stoermer, 2000; Crutzen, 2002), Anthropocene comes from two ancient Greek words; *Anthropos*, humans, and *kainos*, “new”. Thus we have entered the “new epoch of humans” or the “Age of Humanity”, an age where “humans are becoming the dominant force of change on earth” (Schwägerl, 2014).

There is ongoing debate regarding the start date of the Anthropocene, with cogent arguments for the beginnings of widespread agriculture (Ruddiman, 2003), the dawn of the industrial age, and in particular the invention of the steam engine (Crutzen and Stoermer, 2000; Crutzen, 2006; Steffen et al., 2011), or the mid-20th

Century (Steffen et al., 2015). However a growing body of scientific evidence demonstrates beyond all reasonable doubt that in this 21st Century humanity is radically altering the biosphere on which we all depend (Ellis, 2011; IPCC, 2014). Furthermore, we as a species are responsible for the 6th major extinction event (Pimm et al., 1995; Jackson, 2008; Dirzo et al., 2014).

One hallmark of the Anthropocene is an unprecedented rate of global climate change (GCC). One of the main drivers of GCC is the increase in emissions of carbon dioxide, (CO₂) and other greenhouse gases (GHG) with long residence times in the atmosphere (IPCC, 2014). Ocean temperature and chemistry are changing, as much of the additional CO₂ and heat energy have been absorbed by the oceans; observed phenomena include higher average seawater temperatures, lower seawater pH, and increasing instability in climate regimes leading to increased frequency and severity of extreme weather events (Hoegh-Guldberg et al., 2007; Jackson, 2008).

One particularly visible “footprint” of the Anthropocene is the increased prevalence of mass bleaching in scleractinian corals and related organisms (Hoegh-Guldberg et al., 2007; Bowen, 2015). At the global level, the fate of coral reefs in forthcoming decades and centuries is arguably dependent on a massive global shift in policies and actions (Hoegh-Guldberg, 2007; Gattuso et al., 2015), it is a well-established fact that local policies and activities can have a major influence on the severity of impacts, through affecting both the resistance and resilience/recovery potential of corals and coral reef ecosystems to GCC in general and temperature-related bleaching in particular (Westmacott et al., 2000; Grimsditch & Salm, 2006; Jackson, 2008; Hoegh-Guldberg et al., 2009; Aswani et al., 2015).

In this context it is vital to have data on coral reef ecosystem responses to the conditions which cause mass coral bleaching events at a variety of scales. The Indonesian Province of Central Sulawesi occupies a strategic position, with coasts and small islands in four seas: Sulu-Sulawesi Sea, Makassar Straits, Tomini Bay and Gulf of Tolo, including three major small island groups: the Togean, Menai and Banggai Archipelagos. The Banggai Archipelago is perhaps best known as the home of the Banggai cardinalfish, *Pterapogon kauderni* (Koumans, 1933), a small marine fish with no pelagic phase which is endemic to shallow (< 6m) sheltered waters in this Archipelago and a few nearby islands (Vagelli, 2011). Traded as an ornamental fish (Lunn & Moreau, 2004; Moore et al., 2011&2012; Vagelli, 2011; Ndobe et al., 2013a&b), the Banggai cardinalfish is listed as Endangered in the IUCN Red List (Allen & Donaldson, 2007) and has been proposed twice for CITES Appendix II listing¹. Coral diversity is high (Allen & McKenna, 2001) and the Banggai Archipelago is at or very close to the centroid of coral distribution for all

¹ Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES): CoP14 Proposal 19. Inclusion of the Banggai cardinalfish (*Pterapogon kauderni*, Koumans 1933) in Appendix II of CITES. Retrieved from <https://cites.org/sites/default/files/eng/cop/14/prop/E14-P1>; CoP17 Proposal 46. Inclusion of *Pterapogon kauderni* in Appendix II, in accordance with Article II, paragraph 2(a) of the Convention and satisfying Criteria A and B in Annex 2a of Resolution Conf. 9.24 (Rev. CoP16), <https://cites.org/sites/default/files/eng/cop/17/prop/060216/E-CoP17-Prop-46.pdf>

Indo-Pacific corals combined, and of the Genus *Acropora* in particular (Veron et al., 2015); thus this island group can truly be considered to be at the heart of the coral triangle.

Initial signs of bleaching in Central Sulawesi were noted in all four areas during a survey on priority conservation species in mid-2015. As the magnitude of the 4th global scale mass bleaching became apparent, the Indonesian Ministry of Marine Affairs and Fisheries (MMAF) issued a call to stakeholders (Letter 860/PRL.0/IV/2016) outlining a national survey program and requesting assistance in collecting additional data on the extent and severity of coral bleaching across the archipelagic nation. In Central Sulawesi, the core central government program was limited to one site, the Togean Islands in Tomini Bay. The Central Sulawesi Sea Partnership responded to this call for action and gap in coverage by planning and implementing a rapid survey of several key sites, in particular the Banggai Archipelago in the Gulf of Tolo.

Materials and Methods

Coral bleaching data were collected during 12-20 May 2016. These comprised from 7 sites in the Banggai Archipelago (Banggai Laut and Banggai Kepulauan Districts), Central Sulawesi Province, Indonesia (Fig. 1). A GPS unit was not available, but for most sites approximate coordinates were known from previous research by the observer in this area; for the remaining sites approximate coordinates were determined using Google Earth. The latitudinal range was from approximately 1.2° South in Bakalan Island (Banggai Kepulauan District), close to the northern extremity of the Archipelago, to approximately 2° South at the southernmost tip of Bokan Island (Banggai Laut District), close to the southern limit of the Archipelago, and thus entirely within the Equatorial zone.

At the southernmost site (Mbuang-Mbuang) the survey was completed using SCUBA diving equipment, while at the other 6 sites snorkelling equipment was used. Each survey lasted about one and a half hours (90 minutes). Visual records were made using a Hero 4 digital underwater camera. At the SCUBA diving site, the observer descended to around 15m, then swam along the reef and back twice, at depths of 11-15m and 7-10m, then 3-6m and 1-3m. At the snorkelling sites, the observer swam out along or close to the reef crest (depending on depth) and back over the reef flat, thus avoiding any risk of counting the same colony more than once. Number of colonies recorded varied depending on coral condition/density and ease of identification (affected by depth as well as taxon).

Coral bleaching data were collected using the CoralWatch method (CoralWatch, 2011), modified to include collection of data on coral colony life-form using the Global Coral Reef Monitoring Network (GCRMN) categories (English et al., 1997). Coral colonies observed (N = 1366) were identified to Genus level using the Indo-Pacific Coralfinder (Kelley, 2011), to which a thermometer (1°C intervals) was affixed. The genus, life-form and CoralWatch code(s) of each coral colony were recorded on the Coralfinder slate using a 2B pencil. Sea water

temperature was recorded (at 1-2m depth) at the beginning of each survey when snorkelling, then each 30 minutes or whenever there was an observed change in temperature thereafter, and monitored at each depth range when SCUBA diving.

Figure 1. Map of Central Sulawesi Province showing survey sites. Approximate coordinates: Bone Baru: S1°32', E123°29'; Tolokibit: S1°43', E123°31'; Pompon: S1°44', E123°33'; Kapela: S1°42', E123°34'; Mbuang-Mbuang: S2°05', E123°52'; Bakalan: S1° 12', E123° 16'; Liang: S1° 33', E123° 14'.

Additional data collected varied at each site, but included weather parameters (Beaufort scale and Octa, English et al., 1997), time of day, a visual record of the surrounding environment and notes on coral reef condition. Wherever present, data were collected on the endemic Banggai cardinalfish abundance and size classes present, based on standard length (SL): recruit, $\leq 18\text{mm SL}$; juvenile, $18 < \text{SL} \leq 30\text{mm SL}$; sub-adult, $30 < \text{SL} \leq 42\text{mm SL}$; adult, $> 42\text{mm SL}$, based on Ndobe (2013). Sea urchins of the Genus *Diadema* (*D. setosum* and/or *D. savigny*, hereafter referred to as *Diadema* sp. or *Diadema* urchins) are an important symbiont of the Banggai cardinalfish (Vagelli, 2004; Ndobe et al., 2008&2013a&b; Moore et al., 2011 & 2012). Data were collected on the abundance and size of *Diadema* urchins. Further supporting data and information were collected through the key informant interview (KII) participatory rural appraisal (PRA) method (DFID-SEA, 2002). Respondents included stakeholders at village and district level: fishermen and other village community members, local leaders and government officers.

The CoralWatch data were tabulated and analysed descriptively by site, life-forms and genera as well as in comparison with data from other studies. Environmental data and data on the Banggai cardinalfish and *Diadema* sp. populations were tabulated and compared with observations made (published and unpublished) over the period 2004-2014 at the same or nearby sites. Finally, all data

were considered in the context of small island resilience and the conservation outlook for the endangered Banggai cardinalfish.

Results

Environmental conditions

Data on environmental parameters and conditions as well as Banggai cardinalfish and *Diadema* sp. populations are summarized in Table 1. Weather parameters were in the range of Beaufort 1-2 and cloud cover of 1-3 Octa, except at Pompon where the weather was Beaufort 2-3 with 5-6 Octa of cloud cover, and Tolokibit where cloud cover reached 7-8 octa, but in flat calm conditions. The survey at Bone Baru was undertaken in clear sunny weather but shortly after heavy, cold rain. It is likely that this influenced (reduced) the temperature on the extensive shallow reef flat in and around the village community MPA (marine protected area) where the survey took place, an area where the authors have carried survey and other research activities almost every year since 2004. Warmer currents above ambient temperature recorded could be felt, and it is considered likely that in the absence of rain the temperature would have reached a maximum of 33°C, similar to the three other relatively sheltered sites around Banggai Island. Sediment deposits on corals were minimal except close inshore at Tolokibit. Pollution other than domestic waste (garbage) was not observed, though sewage could be inferred from sanitary arrangements. Some pollution from motorised boats using the harbours was observed in Bakalan and Liang.

Subjectively, the warmer than usual temperatures were very noticeable. Whenever temperatures reached 33-34°C for more than a few minutes the observer was uncomfortably warm and experienced in-water sweating, a sensation only experienced prior to this survey during the 2010 global bleaching event in Tomini Bay, at a site where over 90% of corals were fully bleached or very pale and fluorescent. Invisible “stingers” (most likely propagules of Cnidaria such as hydroids or jellyfish) were also more abundant than usual, except at the more exposed Pompon and Mbuang-Mbuang survey sites, necessitating the use of protective clothing, including a full-body suit, hood and gloves, despite the warmth of the water. The increase in “*gatal-gatal*” (itchy skin after fishing or other waterborne activities) was also mentioned by KII respondents.

Coral bleaching

CoralWatch data are summarised in Fig.2, providing a snapshot of the extent and severity of bleaching across all taxa by site and for the survey area as a whole, while Fig. 3 contains examples of bleached coral colonies demonstrating some widespread trends. Table 2 contains a summary of CoralWatch data aggregated by life-form (all 7 sites). A summary of CoralWatch data aggregated by coral genus is given in Table 3; the coral genera recorded are also ranked according to the percentage of colonies in CW1 and CW2, as an indication of observed coral vulnerability. The number of colonies observed for each genus and the number of

sites at which the genus occurred are also shown, providing an indication of relative abundance within and across sites.

The majority of colonies observed were partially bleached but otherwise “normal” coloured, however some colonies exhibited abnormal “fluorescent” colouration. Unfortunately the fluorescent colours were not clearly visible in the visual record and thus not shown in Fig. 3. This phenomenon occurred predominantly in normally blue or bluish corals (fluorescing pale blue) as well as some reddish corals (fluorescing pink) and brownish corals (fluorescing yellow or yellowish-green), both representing several genera.

Figure 2. Summary of CoralWatch data by site and for all sites/coral colonies combined

Table 1. Summary of Environmental Data

No.	Site	Seawater	Horizontal	Environmental conditions	Condition and changes since 2004*	
	Name	temperature (°C)	visibility (m)		Banggai cardinalfish population	
1	Bone Baru	31-32	> 15	Average 32°C. Algal overgrowth increased Recent mechanical damage to corals in/near village MPA	Reduced from several thousand readily visible, all age/sizes, often in groups of hundreds, to a few dozen found after extensive search, mostly adults in small groups of 1-10 associated with the few remaining <i>Diadema</i> urchins and sea anemones	Red larg mos
2	Tolokibit	33	3-15	Increase in coral cover Turbidity limited to intertidal area and reef flat close to shore, otherwise clear waters Algal overgrowth increased		Red larg grou imm
3	Kapela	31-33	7-10	Tidal temperature variation Increase in coral cover	Increased population since 2011	Sim 201
4	Pompon	31-32	> 10	Exposed site (waves/currents)	New sites, though both close to previous survey sites; none observed (suspect too exposed)	One sites
5	Mbuang-Mbuang	33 31-32	> 15	Depth: 1-7 m (thermocline) Depth: 8-15m (mostly 32°C)		Very prot
6	Liang	32-33	> 15	Average 32°C, with hot currents at 33°C Algal overgrowth increased.	Reduced from many thousands in 2004 to a few dozen in remaining <i>Diadema</i> urchins and sea anemones	Red a few juve
7	Bakalan	32-34	2-10	Average 33°C, with hot currents at 34°C, similar to temperature measured in Luwuk to the North (0.97°S) on the Sulawesi mainland	Suspect this is an introduced population Site with second highest abundance (after Kapela) in this survey	Red to 2 juve thou

A. *Stylophora*. At some sites 100% of colonies were bleached and at all sites > 50% were in CW1 - fully bleached, often with polyps visibly feeding in daytime (left); some (live) CW1 colonies were being covered by filamentous algae (centre); example of very pale CW2 colony (right)

B. *Seriatopora*. This genus generally has relatively fine sharply pointed branches. The majority of colonies at all sites were fully bleached (CW1), very pale (CW2), or mixed (left). Where polyps have died, this genus seems especially vulnerable to rapid algal overgrowth, sometimes spreading over live tissue (right), and there was often some skeletal pigmentation in CW1 colony skeletons, so that even fully bleached colonies were rarely pure white.

C. *Porites* – branching Life-form (CB). A substantial number of colonies were fully bleached (CW1), with many more pale or very pale (CW3 - CW2). At the Bakalan site, close to 100% of one branching *Porites* type were in CW; some polyps were actively daytime feeding, while others were being overgrown by algae (left). Nearby colonies of different colours (presumably different species and/or strains of symbiotic zooxanthellae, *Symbiodinium* sp.) sometimes exhibited very different conditions (right). Anemones hosting clownfishes (*Amphiprion* sp.) and Banggai cardinalfish (*Pterapogon kauderni*) were also partially bleached (left), though rarely fully bleached

D. *Porites* – massive and semi-massive life-forms (CM and CS). At most sites few massive corals were fully bleached (CW1, above), though many, often the vast majority, were unusually pale (CW2 or CW3), and some (mainly colonies with a bluish colouration) exhibited abnormal fluorescent colouring. At the Luwuk site, 100% of large-polyped *Porites* shown above were bleached, and most were actively daytime feeding

E. *Acropora*. Proportionately more branching colonies (ACB) were fully bleached (CW1, left) compared to tabulate (ACT, right) or digitate (ACD) colonies. The majority were unusually pale (CW2 or CW3), while a substantial number of partially or totally recently dead colonies were observed. Some colonies in CW1 to CW3 were being overgrown with algae, especially branching life-forms (left, right hand side of frame).

Figure 3. Some examples of bleached coral colonies by Genus.

This phenomenon was also observed during coral bleaching in Tomini Bay in 2010, 2015 and 2016, and in Palu Bay in 2016 (Moore, unpublished data). The blue fluorescent colonies were predominantly massive corals in the Genus *Porites*, with the highest frequency at Bakalan, also the site with the highest seawater temperature. Pink and yellowish fluorescence occurred in isolated colonies of several genera spread across sites; these were highly visible even at the limits of visibility.

Table 2. CoralWatch data aggregated by Life-Form

Life-form		Percentage of Colonies by CoralWatch Colour Code						No of colonies
Code	Description	CW1	CW2	CW3	CW4	CW5	CW6	
Genus Acropora								
ACB	Branching	28.3%	43.5%	15.2%	9.4%	2.2%	1.4%	138
ACD	Digitate	6.7%	33.3%	33.3%	26.7%	0.00%	0.00%	15
ACT	Tabulate	23.9%	39.1%	19.6%	8.7%	8.7%	0.00%	46
Other coral genera (non-Acropora)								
CB	Branching	37.1%	35.1%	17.2%	8.6%	1.7%	0.3%	302
CS	Semi-massive	8.9%	56.6%	19.4%	13.3%	1.8%	0.00%	113
CM	Massive	11.8%	49.3%	27.4%	10.2%	1.3%	0.00%	373
CF	Foliose	17.0%	39.3%	23.2%	12.5%	8.0%	0.00%	112
CE	Encrusting	48.3%	20.7%	17.2%	13.8%	0.00%	0.00%	29
CMR	Mushroom	10.6%	34.2%	34.2%	18.4%	2.6%	0.00%	38
Total	All colonies	21.8%	42.9%	21.9%	10.7%	2.2%	0.5%	1166
Level of observed impact on coral colonies		Severe		Mild		No impact		
		64.7%		32.6%		2.7%		
Increased risk of mortality from 2016 bleaching event		Yes		No				
		86.5%		13.5%				

Table 3. Coral watch codes by genus, ranked by observed coral vulnerability

Rank (CW1+2)	Coral Genus	CoralWatch colour intensity (bleaching) code						No. of sites colonies	
		CW1	CW2	CW3	CW4	CW5	CW6		
1	Paraclavarina	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	1	4
2	Stylophora	54.8%	32.1%	10.7%	2.4%	0.0%	0.0%	6	84
3	Merulina	42.9%	42.9%	14.3%	0.0%	0.0%	0.0%	2	14
4	Pectinia	23.1%	61.5%	15.4%	0.0%	0.0%	0.0%	3	13
5	Gardineroseris	16.7%	66.7%	16.7%	0.0%	0.0%	0.0%	2	6
6	Euphyllia	11.1%	66.7%	22.2%	0.0%	0.0%	0.0%	2	9
7	Cyphastrea	14.3%	57.1%	28.6%	0.0%	0.0%	0.0%	4	14
8	Seriatopora	34.2%	37.0%	21.9%	6.8%	0.0%	0.0%	7	73
9	Astreopora	11.8%	58.8%	29.4%	0.0%	0.0%	0.0%	4	17
10	Galaxea	29.6%	40.7%	20.4%	9.3%	0.0%	0.0%	5	54
11	Symphyllia	2.8%	66.7%	22.2%	8.3%	0.0%	0.0%	5	36
12	Goniastrea	15.4%	53.8%	15.4%	11.5%	3.8%	0.0%	4	26
13	Favites	13.5%	54.1%	27.0%	2.7%	0.0%	2.7%	6	37
14	Acropora	25.6%	41.7%	17.6%	10.6%	3.5%	1.0%	7	199
15	Pocillopora	31.0%	35.7%	26.2%	7.1%	0.0%	0.0%	4	42
16	Echinopora	33.3%	33.3%	33.3%	0.0%	0.0%	0.0%	1	6
17	Porites	25.0%	40.8%	16.3%	13.6%	3.3%	1.1%	7	184
18	Isopora	10.0%	55.0%	17.5%	15.0%	2.5%	0.0%	5	40
19	Favia	0.0%	61.3%	38.7%	0.0%	0.0%	0.0%	4	31
20	Platygyra	20.0%	40.0%	40.0%	0.0%	0.0%	0.0%	1	5
21	Mycedium	20.0%	40.0%	40.0%	0.0%	0.0%	0.0%	2	5
22	Pavona	13.3%	46.7%	40.0%	0.0%	0.0%	0.0%	3	15
23	Montastrea	6.7%	53.3%	20.0%	20.0%	0.0%	0.0%	4	15
24	Hydnophora	10.0%	50.0%	20.0%	10.0%	10.0%	0.0%	3	10

Table 3. Coral watch codes by genus, ranked by observed coral vulnerability (Continued)

Rank (CW1+2)	Coral Genus	CoralWatch colour intensity (bleaching) code						sites	No. of colonies
		CW1	CW2	CW3	CW4	CW5	CW6		
25	Diploastrea	6.7%	53.3%	20.0%	20.0%	0.0%	0.0%	3	15
26	Pachyseris	0.0%	54.5%	9.1%	9.1%	27.3%	0.0%	3	11
27	Turbinaria	22.9%	28.6%	28.6%	11.4%	8.6%	0.0%	4	35
28	Psammocora	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%	1	4
29	Polyphyllia	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%	1	2
30	Lobophyllia	0.0%	50.0%	30.0%	20.0%	0.0%	0.0%	2	10
31	Fungia	18.2%	31.8%	31.8%	18.2%	0.0%	0.0%	1	22
32	Caulastrea	0.0%	50.0%	37.5%	12.5%	0.0%	0.0%	2	8
33	Goniopora	0.0%	44.0%	28.0%	24.0%	4.0%	0.0%	4	25
34	Heliofungia	0.0%	40.0%	40.0%	20.0%	0.0%	0.0%	1	5
35	Montipora	9.2%	26.3%	31.6%	28.9%	3.9%	0.0%	6	76
36	Herpolitha	0.0%	33.3%	33.3%	22.2%	11.1%	0.0%	2	9
37	Oulophyllia	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	1	1
38	Leptastrea	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	1	2
39	Coscinaraea	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%	1	2

Fishery-related threats to coral reef ecosystems

Many invertebrate taxa were noticeably less abundant than when observed by Ndobe et al. (2005) in 2004, including edible sea urchins (genus *Tripneustes* and *Diadema*) and sea cucumbers; sea anemones (all large species used by clownfishes of genus *Amphiprion* and *Premnas* and by the Banggai cardinalfish); and molluscs (bivalves and gastropods). Information obtained from KII respondents in the Banggai Archipelago confirmed a continued rising trend in the unregulated and unreported invertebrate fisheries first observed in 2008 (Ndobe et al., 2008). All benthic animals with any economic or subsistence value were being collected, both as targets and opportunistically, including several protected species (all clam species in the Family Tridacnidae, the helmet shell *Cassus cornuta*, and the now extremely rare *Charonia tritonis*).

Diadema urchins were increasingly sought after for three main purposes: as a source of protein for coastal community members, many of whom are finding it increasingly difficult to catch fish nearby; as an aphrodisiac; and as feed for the grow-out of carnivorous reef fish. Despite growing awareness of their decline in abundance, these urchins would be collected as soon as they were considered likely to be sufficiently large to have mature gonads, as it is the gonads which are consumed. Seaweed farming, generally considered environmentally benign, was implicated in this process. *Diadema* sp., and indeed all edible shallow water fish and invertebrates, were increasingly targeted by seaweed farmers who no longer have the time or energy to go fishing further away from their farms, mostly over shallow seagrass, reef flat or coral reef habitat.

Degradation of the coral reef ecosystem within the Bone Baru community-based marine protected area (MPA) was especially noticeable. In addition to the

widespread decline in Banggai cardinalfish and *Diadema* sp. populations, a significant decrease in live coral cover and increase in rubble and dead coral were observed in the Bone Baru community-based marine protected area (MPA), where few fish were visible and very few non sessile invertebrates were visible. This MPA was informally established in 2006, and despite not having any official status, by 2014 the once degraded reef within the MPA was vibrant and colourful; most available hard substrate was covered with corals of all life-forms and at least 44 genera (Ndobe & Moore, 2015), providing habitat for relatively abundant and diverse populations of reef-associated fishes and invertebrates. Physical damage observed in the MPA was consonant with the use of blunt objects and brute force to break apart the corals, a practice common in the highly destructive abalone fishery. According to KII respondents, crowbars were still the main gear used to overturn coral colonies and collect the high-value abalone (*Haliotis asinina*, locally called *mata tujuh*) hidden below, just as they were in 2004 (Ndobe, 2005). However the fishing grounds had shifted in what appears to be a serial depletion process such as those described by Berkes et al. (2015), albeit at a much smaller scale.

The village conservation group, Kelompok Kalli, and indeed all villagers, felt powerless to prevent incursions by outsiders collecting fish and/or invertebrates, as the MPA does not have legal status. It was also reported that the raiders generally came at night, when the villagers are generally sleeping, and giving chase would be very difficult if not impossible. There were indications that some villagers participated in the extractive activities, on the grounds that if their MPA was going to be trashed anyway they might as well get a share of the (short-term) benefits.

Respondents from the various government agencies involved in fisheries and marine resource management revealed that they felt equally powerless. They were unanimously of the opinion that the otherwise legal collection of non-protected/unregulated species would become illegal if it caused damage to the coral reefs, and that action should be taken with respect to destructive fishing, even when not involving explosives or poisons. However each was also of the opinion that another service should be the one approached and responsible for responding, if by any chance any member of the public should wish to report an infraction in progress. It was pointed out that the number of enforcement personnel was very low and that they were already overloaded with other tasks. In particular the current emphasis from the Ministry for Marine Affairs and Fisheries (MMAF) on proper administrative procedures for fishing vessels, e.g. sailing and fishing permits, was placing a great strain on human resources; in addition, there was an acute lack of logistical support for any “field” work, even as close as Bone Baru, just a few kilometres up the coast from Banggai Town, the district administrative centre. None of the officers (or any other respondents) had any knowledge of there being any kind of helpline or reporting mechanism other than coming directly to the offices of a relevant agency – by which time, as pointed out by many respondents, the offenders would be long gone. Should they catch

an offender, even red-handed, they were very pessimistic about the chances of making a successful case and obtaining a conviction.

Discussion

Seawater temperature and bleaching patterns

Based on the data in Table 1, observed seawater temperatures can be considered unusually high for this area. Ndobe et al (2013a) compiled data on sea temperature in the shallow coastal waters of the Banggai Archipelago (0.5-6m depth) in order to estimate the parameter M (natural mortality) of the Banggai cardinalfish. They concluded that sea temperatures ranged from 26-31°C with an average of around 28°C, though there were indications that in some years or at some sites it might be closer to 29°C. Thus, the average (32-33°C) seawater temperatures during this survey were about 4°C above the estimated average for the area. Furthermore, the maximum observed temperatures (32-34°C) were 1-3°C higher than the highest values previously recorded for the same or nearby sites in the Banggai Archipelago (Ndobe et al., 2005, 2008, 2013a; Ndobe, 2013; unpublished data²).

It is a well established fact that Seawater temperature elevation above “normal” regional or seasonal ranges by 1-2°C over several weeks or by 3-4°C over a few days substantially increases the likelihood of bleaching in scleractinian corals (Jokiel and Coles, 1990; Goreau & Hayes, 1994; Loya et al., 2001; Coles & Brown, 2003; Pendleton et al., 2016). The synergistic combination of time and temperature is reflected in the NOAA global coral reef watch methodology (NOAA, 2011), where bleaching risk is measured in degree heating weeks (DHW). The spatial resolution of the NOAA data products are too coarse to provide more than a very general indication for the areas surveyed; however the NOAA reef watch predictions in the national call for action showed bleaching alerts (level 1 and Level 2) for the general area of the Banggai Archipelago in May and June 2016.

With actual seawater temperatures in the range measured during this survey, widespread bleaching would not be unexpected. Comparing the temperature data (Table 1) and bleaching prevalence (Fig. 2), it can be seen that empirically the percentage of coral colonies sampled which were fully bleached (CW1) correlated with sites with higher maximum seawater temperatures. Although the number of samples and the survey method do not support the use of inferential statistics, these observations indicate a positive correlation between seawater temperature and bleaching impact.

² Data collected by a team from the STPL-Palu lead by the authors when carrying out Ecosystems Approach to Fisheries Management (EAFM) evaluation activities in 2013 and 2014 under a contract with the Worldwide Fund for Nature Indonesia (WWF-Indonesia)

Bleaching and coral diversity

The data on coral bleaching severity and prevalence in Tables 2 and 3 and Figure 3 show that the vast majority of corals in both study areas were negatively impacted by the 2016 global bleaching phenomenon. As in other regions/previous bleaching events (e.g. Baird and Marshall, 2002), bleaching was not uniform within or among taxa. There were a few notable differences in susceptibility in this study compared to other published studies, for example Marshall and Baird (2000) found the Genus *Galaxea* particularly resistant to bleaching; however in this study not only were over 90% of colonies recorded fully or partially bleached, but an unusually high (compared to other genera) number of recently dead colonies were observed; it is highly likely that most (possibly all) were bleaching casualties. This indicates that responses may vary between sites, regions or possibly species within genera, and points to a need for more fine-scale bleaching data with the highest possible taxonomic resolution (minimal to Genus level).

Foden et al. (2013) conducted an in-depth review of the vulnerability of coral species to climate change. All species were considered to have high sensitivity, but overall vulnerability was modified by adaptability and exposure. While temperature-related bleaching was not the only factor considered, it is interesting to compare their evaluations with the results of this survey. The temperature data show that all species were exposed, however Table 4 shows the percentage of species in high and low un-adaptability categories for each of the genera recorded in this survey, alongside the rank based on percentage of colonies in CW1 and CW2 categories. It is clear that severity of observed bleaching in this study and predicted ability (or lack of ability) to adapt based on Foden (2013) do not correlate well. Genera with relatively low observed bleaching and low un-adaptability (e.g. *Caulastrea*, *Pachyseris*, *Turbinaria*) could be expected to fare better than those with high bleaching and high un-adaptability (e.g. *Astreopora*, *Cyphastrea*, *Favia*, *Favites*, *Gardinoseris*, *Goniastrea*, *Porites*, *Stylophora*, *Symphyllia*). The second group is not only more diverse but contains genera which are more abundant in the Banggai Archipelago.

Comparing the relative severity of bleaching with the “winners and losers” identified by Loya et al (2001) after the 1998 mass coral bleaching event at Okinawa in Japan reveals several similarities with this study. In particular, bleaching was more prevalent and severe in branching *Porites* than in massive forms of this genus, although large-polyped massive species were also severely affected in the Banggai Archipelago (as well as in nearby Luwuk on the Sulawesi mainland coast, see Fig. 3). Other short-term “losers” reported by Loya et al. (2001) which were also severely affected in this study include *Seriatopora*, *Stylophora*, *Pocillopora* and some species of *Acropora*. A review of the recovery process in Okinawa a decade later by van Woesik et al (2010), substantially the same team as Loya et al. (2001), showed that coral cover and diversity had rebounded; however a marked shift in coral community composition had taken place. The once common Pocilloporids had all but disappeared, indeed *Stylophora* and *Seriatopora* seem to have been extirpated (along with most branching and one

encrusting *Porites*), and *Pocillopora* recovery was minimal. This precedent bodes ill for the *Stylophora* and *Seriatopora* populations in the Banggai Archipelago, especially *Stylophora*, the common coral genus most severely affected by the 2016 bleaching event. In contrast, Loya et al (2010) report that all but one species of *Acropora* had recovered by 2010, and longer-term “winners” included some other branching species such as branching forms of *Montipora*.

Although relatively few corals in the reefs of the Banggai Archipelago were totally bleached (around 5-20%), and signs of recent mortality likely to be due to bleaching were limited, it is highly likely that coral mortality during and after the 2016 bleaching event was and will be significantly above background levels. The long term effects are as yet unknown, but it is likely that coral growth and reproduction will be affected, not only during but for some months after the event (Baird and Marshall, 2002). Furthermore, under the conditions predicted by global climate change scenarios, widespread bleaching events are likely to occur with increasing frequency worldwide (Hoegh-Guldberg et al., 2007; IPCC, 2014), and in the Coral Triangle in particular (Hoegh-Guldberg et al., 2009; Burke et al., 2012). Although there is no record of widespread bleaching in the Banggai Archipelago prior to 2015/2016, it is almost certain that the reefs around these islands will repeatedly experience bleaching again in the coming decades. The severity of bleaching in certain genera, particularly *Stylophora*, indicates the possibility of local extinctions (extirpation) of some species, thus reducing biodiversity and changing the community composition of corals and associated species. As noted by Chapin III et al. (2000), such changes in themselves could have negative consequences for coral reef productivity and resilience.

Diadema decline – causes and possible consequences

Environmental changes noted at several sites surveyed previously (Table 1) included a marked increase in algal overgrowth of dead (and sometimes even live) corals, and a sharp (drastic) decline (estimated 90-99%) in once abundant herbivorous *Diadema* sp. sea urchin populations in the Banggai Archipelago. Herbivory is considered to be a key factor in coral reef resilience, in particular coral recruitment and the coral-algal balance (Obura and Grimsditch, 2009; Jompa and McCook, 2002; Hughes et al., 2007); in this context, *Diadema* urchins in particular can play key role (Carpenter and Edmunds, 2006; Mumby et al., 2006 & 2007).

Very few other herbivores were observed during this or previous surveys in the Banggai Archipelago. High *Diadema* urchin abundances coupled with extremely low algal growth and high coral recruitment on dead coral as recently as 2004 (Ndobe et al., 2005) indicate that Diadematid urchins are likely to be a keystone species in this Archipelago, as they were in the Caribbean. Comparing temperature and *Diadema* urchin population data (Table 1) with bleaching prevalence (Fig. 2) it can be seen that, at equal maximum temperatures, the sites with the lowest proportion of bleached colonies were those with higher (less depleted) *Diadema* sp. populations. The number of samples and the survey

method do not support the use of inferential statistics; nonetheless, these observations indicate a negative correlation between herbivore populations (in this case *Diadema* sp.) and bleaching impacts, indicating the possibility of a mitigating effect from urchin herbivory at equal maximum temperatures, the sites with the lowest proportion of bleaching were those with higher (less depleted) *Diadema* sp. populations.

In the Caribbean, a decline of over 90% in *Diadema antillarum* abundance is widely viewed as a major causal factor in the widespread phase shift from coral to algal dominated coastal ecosystems across the region (Hughes et al., 1987; Mumby et al., 2006). Viewed from a restoration and climate change mitigation perspective, Aronson and Precht (2006) considered conserving and enhancing populations of *Diadema antillarum* as a key component of “the most direct route to coral recovery”, and considered these urchins to be “more effective than fish at reducing macroalgae and enhancing coral recruitment”. However the slow and uneven recovery to date (Rogers and Lorenzen, 2016) indicates that once depleted beyond a certain point, *Diadema* populations may not easily return to their former abundance and distribution.

Unlike the Caribbean case, *Diadema* sp. decline in the Banggai Archipelago is not due to disease, but to an unreported and unregulated fishery. Gleaning and the collection of shallow-water benthic organisms has been an integral part of local livelihoods and food security in the Banggai Archipelago since time immemorial, and all invertebrates of value for sale or as food were already exploited to some extent in 2004 (Ndobe et al., 2005). As reported by Ndobe et al. (2008, 2013b) and Moore et al. (2011, 2012) and confirmed by data collected during this survey, *Diadema* exploitation has been increasing since around 2007, mainly for human consumption but also as feed for the grow-out of carnivorous fish. The reasons are complex and the sea urchin fishery is not actually illegal; however it is part of the pervasive unregulated and unreported exploitation of shallow-water invertebrates causing extensive defaunation of small island coral reef and seagrass ecosystems, and the decline in this key symbiont due to overharvesting can be considered a major threat to endemic populations of the endangered Banggai cardinalfish, *Pterapogon kauderni* (Moore et al., 2011 & 2012; Ndobe et al., 2013a&b; this study).

conclusion

Equatorial coral reefs in the Banggai Archipelago, Central Sulawesi were significantly impacted by the 2016 global bleaching event. Despite signs of potential resilience at certain sites and in certain species, it is clear that these reefs are at risk from GCC in the Anthropocene. The 12th International Coral Reef Symposium (ICRS) Consensus Statement concluded with the words: “*A concerted effort to preserve reefs for the future demands action at global levels, but also will benefit hugely from continued local protection*”³. The observations made during

³ http://www.icrs2012.com/Consensus_Statement.htm

this study reinforce the view that outcomes will depend not only on the success of world-wide GCC mitigation measures, but also on local actions. The level of observed coral mortality due to mechanical damage as well as likely subsequent mortality from the effects of full or partial bleaching in the Banggai Archipelago, underscore the vital importance of promoting resilience and enabling recovery. This means addressing not only the well-recognised direct human impacts on corals and water quality, but also maintaining ecological processes such as herbivory.

While further research and ongoing monitoring are vitally important, existing data and knowledge are sufficient to implement concrete and urgent actions to minimise coral mortality (maximise resistance) and maximise recovery potential (resilience). In particular, the oft-repeated but still elusive effective implementation of existing legislation and regulations is essential to prevent stressors such as coral mining, destructive fishing, pollution, sedimentation from upland degradation, and all the other "normative" threats addressed in publications such as Westmacott et al. (2000) and Hoegh-Guldberg et al. (2009).

Equally important and often overlooked are local measures to maintain ecological balance, in particular the guild of herbivores, both fish and invertebrates. In the Banggai Archipelago, and possibly other areas where *Diadema* sp. urchins are experiencing sharp declines, the Caribbean example should be a warning. There is an urgent need to regulate this unreported and unregulated fishery, not only to save the charismatic Banggai cardinalfish, but also to maintain the ecosystem services of a keystone herbivore whose silent demise is likely to substantially reduce the resilience of small island socio-ecological systems. Thus, effective measures to conserve an iconic endangered endemic fish could also promote coral reef resilience and human welfare in the Anthropocene.

Acknowledgments

The authors acknowledge financial and logistical support from the Central Sulawesi Marine and Fisheries Service, through the Central Sulawesi Sea Partnership, for the survey in the Banggai Archipelago, which formed part of a rapid response bleaching survey. We express our gratitude to all the many individuals and organisations who supported the field study and the preparation of this manuscript, in particular the Central Sulawesi Sea Partnership Consortium; the Sekolah Tinggi Perikanan dan Kelautan (STPL-Palu); Banggai Laut and Banggai Kepulauan District Governments, in particular the Banggai Laut District Marine and Fisheries Service; the Luwuk-Banggai Fish Health and Quarantine Service in Banggai; the Liang Marine Secondary School; the Bone Baru Kalli Conservation Group; Pak Kasmat, Pak Takbir, Rusdin Sinaling; and the Faculty of Marine Science and Fisheries, Hasanuddin University (UNHAS). The authors also wish to thank all who provided encouragement and constructive criticism to improve this manuscript, in particular the editors and anonymous reviewers.

References

- Allen, G.R., Donaldson, T.J. (2007). *Pterapogon kauderni*. The IUCN Red List of Threatened Species 2007: e.T63572A12692964. <http://dx.doi.org/10.2305/IUCN.UK.2007.RLTS.T63572A12692964.en>
- Allen, G.R., McKenna, S.A. (Eds) (2001). A Marine Rapid Assessment of the Togeang and Banggai Islands, Sulawesi, Indonesia. RAP Bulletin of Biological Assessment 20. Conservation International, Washington DC, USA. 145 pages.
- Aronson, R.B., Precht, W.F. (2006). Conservation, precaution, and Caribbean reefs. *Coral Reefs*, 25(3): 441-450. doi: 10.1007/s00338-006-0122-9
- Aswani, S., Mumby, P., Baker, A.C., Christie, P., McCook, L. J., Steneck, R.S., Richmond, R. H. (2015). Scientific frontiers in the management of coral reefs. *Frontiers in Marine Science*, 2(50): 1-13. doi: 10.3389/fmars.2015.00050
- Baird, A. H., Marshall, P. A. (2002). Mortality, growth and reproduction in scleractinian corals following bleaching on the Great Barrier Reef. *Marine Ecology Progress Series*, 237: 133-141. doi: 10.3354/meps237133
- Barnosky, A.D. (2014). Palaeontological evidence for defining the Anthropocene. *In*: Waters, C. N., Zalasiewicz, J.A., Williams, M., Ellis, M.A., Snelling, A.M. (Eds) 2014. A Stratigraphical Basis for the Anthropocene. Geological Society, London, Special Publications, 395: 149–165. <http://dx.doi.org/10.1144/SP395.6>
- Bowen, J. (2015). The Coral Reef Era: From Discovery to Decline - A history of scientific investigation from 1600 to the Anthropocene Epoch. Springer Science+Business Media, Dordrecht. 194 pages.
- Burke L., Reynter K., Spalding M., Perry A. (2012). Reefs at risk revisited in the Coral Triangle. World Resources Institute, Washington, USA. 86 pages Retrieved from: <http://www.wri.org/publication/reefs-risk-revisited-coral-triangle>
- Carpenter, R.C., Edmunds, P.J. (2006). Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. *Ecology Letters*, 9(3): 268-277. doi: 10.1111/j.1461-0248.2005.00866.x
- Chapin III, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C., Díaz, S. (2000). Consequences of changing biodiversity. *Nature*, 405: 234-242. doi: 10.1038/35012241
- Coles, S.L., Brown, B.E. (2003). Coral bleaching - Capacity for acclimatization and adaptation. *Advances in Marine Biology*, 46: 183-223. doi: 10.1016/S0065-2881(03)46004-5
- CoralWatch. (2011). Do It Yourself Kit: Information leaflet, Coral Health Chart and CoralWatch Datasheet. CoralWatch, The University of Queensland, Brisbane, Australia. 5 pages. Available at: <http://www.coralwatch.org/web/guest/monitoring-products>
- Crutzen P.J. and Stoermer E.F. (2000) The ‘Anthropocene’. *IGBP Newsletter* 41, 17–18
- Crutzen P.J. (2002). Geology of Mankind: The Anthropocene. *Nature* 415: 23. doi: 10.1038/415023a
- DFID-SEA (2002). Handbook for Livelihoods Analysis (LHA) and Participatory Rural Appraisal (PRA). Research Institute for Aquaculture No.1, Ministry of Fisheries and DFID-SEA Aquatic Resources Management Programme.
- Dirzo, R., Young, H.S., Galetti, M., Ceballos, G., Isaac, N.J.B., Collen, B. (2014). Defaunation in the Anthropocene. *Science*, 345: 401-406. doi: 10.1126/science.1251817
- Ellis, E.C. (2011). Anthropogenic transformation of the terrestrial biosphere. *Philosophical Transactions of the Royal Society of London Series A*, 369: 1010-1035. doi: 10.1098/rsta.2010.0331

- English, S., Wilkinson, C., Baker, V. (1997). Survey Manual for Tropical Marine Resources. 2nd Edition, Australian Institute of Marine Sciences, Townsville, Australia. 390 pages
- Foden, W.B., Butchart, S.H.M., Stuart, S.N., Vié, J.C., Akçakaya, H.R., Angulo, A., ... Mace, G.M. (2013). Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. PLoS ONE, 8(6): e65427. doi: 10.1371/journal.pone.0065427
- Gattuso, J.P., Magnan, A., Billé, R., Cheung, W.W.L., Howes, E. L., Joos, F., ... Turley, C. (2015). Contrasting futures for ocean and society from different anthropogenic CO₂ emissions scenarios. Science, 349(6243): aac4722 1-10. doi: 10.1126/science.aac4722
- Goreau, T.J., Hayes, R.L. (1994). Coral Bleaching and Ocean "Hot Spots". Ambio, 23:176-180. doi: 10.2307/4314195
- Grimsditch, G.D., Salm, R.V. (2006). Coral Reef Resilience and Resistance to Bleaching. IUCN, Gland, Switzerland. 52 pages.
- Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S. Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., Hatzioiols, M.E. (2007). Coral Reefs Under Rapid Climate Change and Ocean Acidification. Science, 318: 1737- 1742. doi: 10.1126/science.1152509
- Hoegh-Guldberg, O., Hoegh-Guldberg, H., Veron, J.E.N., Green, A., Gomez, E.D., Lough, J., King, M., Ambariyanto, H.L., Cinner, J., Dews, G., Russ, G., Schuttenberg, H.Z., Penaflor, E.L., Eakin, C.M., Christensen, T.R.L., Abbey, M., Areki, F., Kosaka, R.A., Tewfik, A., Oliver, J. (2009). The Coral Triangle and Climate Change: Ecosystems, People and Societies at Risk. WWF Australia, Brisbane, 276 pages
- Hughes, T.P., Reed, D.C., Boyle, M.J. (1987). Herbivory on coral reefs: community structure following mass mortalities of sea urchins. Journal of Experimental Marine Biology and Ecology, 113(1): 39-59. doi: 10.1016/0022-0981(87)90081-5
- Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., Moltschanowskyj, N., Pratchett, M.S., Steneck, R.S., Willis, B. (2007). Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change. Current Biology, 17(4): 360-365. doi: 10.1016/j.cub.2006.12.049
- IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pages.
- Jackson, J.B.C. (2008). Ecological extinction and evolution in the brave new ocean. Proceedings of the National Academy of Sciences, 105(suppl. 1): 11458–11465. doi: 10.1073/pnas.0802812105
- Jokiel S.P., Coles, S.L. (1990). Response of Hawaiian and other Indo-Pacific reef corals to elevated temperature. Coral Reefs, 8: 155-162. doi: 10.1007/BF00265006
- Jompa, J., McCook, L.J. (2002). Effects of competition and herbivory on interactions between a hard coral and a brown alga. Journal of Experimental Marine Biology and Ecology, 47(2): 527-534. doi: 10.1016/S0022-0981(02)00040-0
- Kelley, R. (2011). Indo-Pacific Coral Finder 2.0. The Australian Coral reef Society. EYO Guides, Australia. [Accessible at <http://www.coralhub>].34 pages
- Koumans, F.P. (1933). On a new genus and species of Apogonidae. Zoologische Mededeelingen (Leiden), 16 (1-2): 78, Pl. 11933
- Loya, Y., Sakai, K., Yamazato, K., Nakano, Y., Sambali, H., Van Woesik, R. (2001). Coral bleaching: the winners and the losers. Ecology letters, 4(2): 122-131.

- Lunn, K.E., Moreau, A.M. (2004). Unmonitored trade in Marine Ornamental Fishes: the Case of Indonesia's Banggai Cardinalfish (*Pterapogon kauderni*). *Coral Reefs*, 23: 344-341. doi: 10.1007/s00338-004-0393-y
- Marshall, P. A., Baird, A. H. (2000). Bleaching of corals on the Great Barrier Reef: Differential susceptibilities among taxa. *Coral Reefs*, 19: 155-163. doi: 10.1007/s003380000086
- Moore, A., Ndobe, S., Zamrud, M. (2011). Monitoring the Banggai Cardinalfish, an Endangered Restricted Range Endemic Species. *Journal of Indonesian Coral Reefs (JiCor)*, 1(2): 99-113
- Moore, A., Ndobe, S., Salanggon, A.I., Ederyan, Rahman, A. (2012). Banggai Cardinalfish Ornamental Fishery: The Importance of Microhabitat. *Proceedings of the 12th International Coral Reef Symposium*, Cairns, Australia, 9-13 July 2012, 13C_1. 5 pages
- Mumby, P.J., Hedley, J.D., Zychaluk, K., Harborne, A.R., Blackwell, P.G. (2006). Revisiting the catastrophic die-off of the urchin *Diadema antillarum* on Caribbean coral reefs: Fresh insights on resilience from a simulation model. *Ecological Modelling*, 196: 131-149. doi: 10.1016/j.ecolmodel.2005.11.035
- Mumby, P.J., Hastings, A., Edwards, H.J. (2007). Thresholds and the resilience of Caribbean coral reefs. *Nature*, 450: 98-101
- NOAA. (2011). NOAA Coral Reef Watch Methodology, Product Description, and Data Availability of NOAA Coral Reef Watch (CRW) Operational and Experimental Satellite Coral Bleaching Monitoring Products. <http://coralreefwatch.noaa.gov/satellite/methodology/methodology.php>. [Accessed: 1 December 2016]
- Ndobe, S. (2013). Biologi dan Ekologi Banggai Cardinalfish, *Pterapogon kauderni* (Suatu Kajian Dalam Upaya Pengelolaan Perikanan Berbasis Konservasi. Doctoral Dissertation. Postgraduate Program, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, Indonesia. 397+xxviii pages
- Ndobe, S., Moore, A. (2015). Coral Biodiversity in the Banggai Archipelago using the Indo-Pacific Coral Finder. *Proceedings of the Simposium Nasional Kelautan dan Perikanan II*, Makassar, 9 May 2015, pp. 95-103
- Ndobe, S., Moore, A., Supu, A. (2005). Sulawesi Case Study - Banggai Kepulauan. Pages 5-143 & 165-229 *In* The Indonesian Ornamental Fish Trade: Case Studies and Options for Improving Livelihoods while Promoting Sustainability in Banggai and Banyuwangi. The International Seafood Trade: Supporting Sustainable Livelihoods Among Poor Aquatic Resource Users in Asia (EC Prep Project EP/RO3/R14). Poseidon and Network of Aquaculture Centres in Asia (NACA) STREAM. 286 pages.
- Ndobe, S., Madinawati, Moore, A. (2008) Pengkajian Ontogenetic Shift pada Ikan Endemik *Pterapogon kauderni*. *Jurnal Mitra Bahari*, 2(2):32-55
- Ndobe, S., Setyohadi, D., Herawati, E.Y., Soemarno, Moore, A., Palomares M.D., Pauly, D. (2013a). Life History of Banggai Cardinalfish (*Pterapogon kauderni*; Pisces, Apogonidae) in Banggai Islands and Palu Bay, Sulawesi, Indonesia. *Acta Ichthyologica Et Piscatoria (AIEP)*, 43 (3): 237-250. doi: 10.3750/AIP2013.43.3.08
- Ndobe, S.; Moore, A., Salanggon, A.I.M., Muslihudin, Setyohadi, D., Herawati, E.Y., Soemarno. (2013b). Banggai cardinalfish (*Pterapogon kauderni*) Management - an Ecosystem-Based Approach. *Marine Fisheries*, 2013(2):115-126
- NOAA. (2011). NOAA Coral Reef Watch Methodology, Product Description, and Data Availability of NOAA Coral Reef Watch (CRW) Operational and Experimental Satellite Coral Bleaching Monitoring Products. <http://coralreefwatch.noaa.gov/satellite/methodology/methodology.php>. [Accessed: 1 December 2016]

- Obura, D., Grimsditch, G. (2009). Resilience Assessment of Coral Reefs. IUCN, Gland, Switzerland. 70 pages
- Pendleton, L., Comte, A., Langdon, C., Ekstrom, J. A., Cooley, S. R., Suatoni, L., Ritter, J. (2016). Coral Reefs and People in a High-CO₂ World: Where Can Science Make a Difference to People? *Plos One*, 11(11): e0164699. doi: 10.1371/journal.pone.0164699
- Pimm, S.L., Russell, G.J., Gittleman, J.L., Brooks, T.M. (1995). The future of biodiversity. *Science* 269, 347–350. doi:
- Rogers, A., Lorenzen, K. (2016). Does Slow and Variable Recovery of *Diadema antillarum* on Caribbean Fore-Reefs Reflect Density-Dependent Habitat Selection? *Frontiers in Marine Science*, 3(63): 1-10
- Ruddiman, W.F. (2003). The anthropogenic greenhouse era began thousands of years ago. *Climate Change* 61: 261–293. doi: 10.1023/B:CLIM.0000004577.17928.f8
- Sagan, C. (1997). *Pale Blue Dot: A Vision of the Human Future in Space*. Ballantine books, New York. 193 pages
- Schwägerl, C. (2014). *The Anthropocene: the human era and how it shapes our planet*. Synergetic Press, London. 249 pages
- Steffen, W., Grinevald, J., Crutzen, P., McNeill, J. (2011). The Anthropocene: conceptual and historical perspectives. *Philosophical Transactions of the Royal Society Series A*, 369: 842-867. doi: 10.1098/rsta.2010.0327
- Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., Ludwig, C. (2015). The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review*, 1–18. doi: 0.1177/2053019614564785
- Ruddiman, W.F. (2003). The anthropogenic greenhouse era began thousands of years ago. *Climate Change* 61: 261–293. doi: 10.1023/B:CLIM.0000004577.17928.f8
- Vagelli A.A. (2004). Ontogenetic Shift in Habitat Preference by *Pterapogon kauderni*, a Shallow Water Coral reef Apogonid with Direct Development. *Copeia* 2004(2): 364-369
- Vagelli, A.A. (2011). *The Banggai Cardinalfish: Natural History, Conservation, and Culture of Pterapogon kauderni*. John Wiley & Sons, Ltd., Chichester, UK. doi: 10.1002/9781119950387
- van Woesik, R., Sakai, K., Ganase, A., Loya, Y. (2010). Revisiting the winners and the losers a decade after coral bleaching. *Marine Ecology Progress Series*, 434: 67-76. doi: 10.3354/meps09203
- Veron, J., Stafford-Smith, M., DeVantier, L., Turak, E. (2015). Overview of distribution patterns of zooxanthellate Scleractinia. *Frontiers in Marine Science*, 1(81): 1-19. doi: 10.3389/fmars.2014.00081
- Westmacott, S., Teleki, K. Wells, S., West, J.M. (2000). *Management of Bleached and Severely Damaged Coral Reefs*. IUCN Publications Services Unit, Cambridge, UK. 36 pages
- Zalasiewicz, J., Williams, M., Haywood, A., Ellis, M. (2011). The Anthropocene: a new epoch of geological time? *Philosophical transactions of the Royal Society Series A*, 369: 835-841. doi: 10.1098/rsta.2010.0339