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Coral recovery trends in Mu Ko Chang National Park, the Eastern Gulf of Thailand

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Abstract. The recovery potential of corals after the bleaching events is controlled by coral larval supply, proper substrate, settlement, and survival rates of juvenile corals. Larval connectivity among coral populations is an essential aspect of understanding the recovery potential of corals after severe disturbances. Reef connectivity depends on oceanographic conditions and sources of coral larval supply. This study investigated the coral recruitment patterns and their relationships with adult coral communities at seven study sites in Mu Ko Chang, Trat Province, the Eastern Gulf of Thailand. Live coral covers were in a range of 25.9-71.2 % while dead coral covers varied between 10.8 and 50.6 %. The live coral covers at Hin Gurk Maa and Ko Thong Lang were significantly higher than those of other reef sites. Low coral recruitment was found at Ko Wai, Ko Thong Lang, and Ko Yak Lek. The brooding coral *Pocillopora* spp. at Ko Thian and, Ko Yak Lek showed evidence of self-seeding. The broadcast spawning coral Poritidae exhibited indications of a high degree of self-seeding. Recruits of *Leptastrea*, *Lithophyllon*, and *Psammocora* were frequently found without their parent colonies. The inter reef connectivity and local coral recruitment are required for further studies to provide proper management strategies of coral reefs in the Gulf of Thailand.

Keywords: connectivity, coral recruitment, Gulf of Thailand, management, self-seeding

1. Introduction

Coral reefs are recognized as an important ecosystem that shelters thousands of species worldwide, providing food and livelihoods for millions of people who live in tropical countries besides serving as coastal protection from disturbances of climate variability as well (Mora et al. 2016). However, most coral reefs have been degraded by natural stressors such as temperature fluctuations, diseases, and heavy storms. In addition, coral reefs ecosystems were also threatened by anthropogenic disturbances, especially coastal development, chemical pollution, overfishing, sedimentation, and global warming. At the same time increasing interest in coral reefs tourism is leading to increased pressure on these ecosystems (Yeemin et al. 2012; Baker et al. 2008; Guillemot et al. 2010; Valentine and Heck 2005; Yeemin et al. 2013; Heery et al. 2018; Kleypas and Yates 2009).

Coral recovery after bleaching events is determined by the availability of coral larvae, proper substrate, settlement, and survival rates of juvenile corals (Edwards and Gomez 2007). Previous coral bleaching events already caused a reduction in fecundity and growth of surviving adult corals in addition to decreased reproductive outputs and recruitment rates (Anthony et al. 2015; Bramanti and Edmund 2016). Thereby, the coral recruitment rate is frequently used as a bioindicator of coral reef health, recovery, and resilience potential, since showing high numbers of recruits, indicates a high potential for quick coral recovery after severe disturbances. (Yeemin et al. 2012).

Coral recovery is determined by several factors such as grazing herbivores that limit algal growth, coral larval supply, recruitment rate, the survival rate of juvenile corals, and their tolerance to environmental stresses (Shlesinger and Loya 2016; Manikandan et al. 2017; Perez et al. 2014; Rotha et al. 2018). On the other hand, coral recruitment rates are influenced by several environmental factors such as water pollution, overfishing, and coastal development that can affect negatively the ability of coral competition, fecundity, successful fertilization, settlement, and survival of juvenile corals (Graham et al. 2011; Kuffner et al. 2006; Richmond 1997). Connectivity of coral populations is a very important aspect of understanding the recovery potential of corals after severe disturbances.

Mass coral bleaching events were reported worldwide in 1998, 2010, and 2016, including some sites in the Gulf of Thailand (Sutthacheep et al. 2013; Yeemin et al. 2012; Yeemin 2018). Studies following the last phenomenon indicated that the severity of coral bleaching varied significantly among reef sites (Sutthacheep et al. 2012), and coral mortality was higher than in 2010 because the seawater temperature was rapidly dropped by southwest monsoon started earlier (Yeemin 2018). Therefore, this study examined the coral recruitment patterns and their relationships with adult coral communities at seven study sites in Mu Ko Chang, Trat Province, the Eastern Gulf of Thailand.

2. Materials and Methods

2.1 study sites

Seven study sites in Mu Ko Chang, eastern Gulf of Thailand were investigated: Ko Wai (11°54′02″N 102°24′16″E), Ko Baidang (11°53′55″N 102°27′01″E), Ko Thian (11°48′58″N 102°23′43″E), Ko Tong Lang (11°49′07″N 102°24′06″E), Hin Gurk Maa (11°47′28″N 102°23′57″E), Ko Yak Yai (11°47′14″N 102°23′42″E) and Ko Yak Lek (11°47′03″N 102°23′37″E) (Figure 1.)

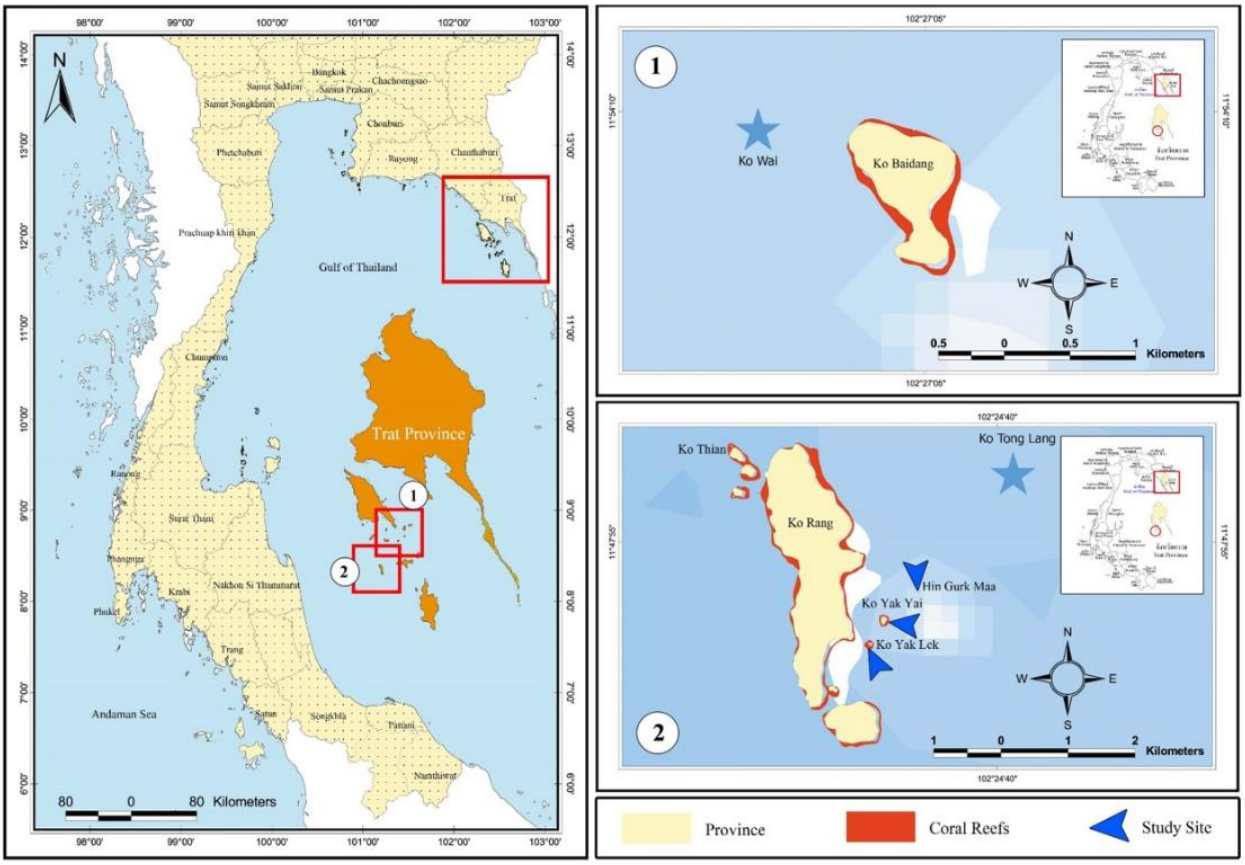

Figure 1. The location of seven study sites in Mu Ko Chang, Trat

2.2 Data collections

This study was conducted from January to October 2018. Coral communities of seven study sites extend at approximately 3-7 m in depth. At each study site, the substrate cover of live coral, dead coral, rubble, sand, and rock was assessed within 50cm to each side of a 30 m line (30x1m), comprising three replicates, in which all coral colonies above 5 cm in diameter were counted and identified to genus level, following Veron, 2000. The number of visible juvenile coral colonies, below 5 cm in diameter, was also measured as a colony/unit area, along these three-permanent belt-transects. All juvenile corals were also identified to genus level according to identification guides (Veron 2000; English et al. 1997; Babcock et al. 2003).

2.3 statistical analysis

R program for statistical analysis version 3.5.0 with package "vegan" was used to perform a One-way ANOVA analysis of live coral cover among reef sites. The Tukey HSD test was used to determine the difference between the study sites by using the R program.

3. Results

Live coral covers varied from 25.9 to71.2 %, while dead coral covers were in a range of 10.8-50.6 % (Figure 2.). Live coral cover at Hin Gurk Maa and Ko Thong Lang were significantly higher than those of other reef sites (Figure 3.). In addition, Ko Wai had significantly lower live coral cover.

The percent coverage of each coral species and the recruitment of juvenile corals are shown in Figures 4-10. The total densities of juvenile corals (<5 cm in diameter) at the study sites ranged around 0.35–0.71 colonies/m^2. The highest rate of coral recruitment was found at Ko Bai Dang (0.71 colonies/m^2) and Ko Yak Yai (0.70 colonies/m^2) whereas low coral recruitment was recorded at Ko Thong Lang, Ko Wai, and Ko Yak Lek (0.42, 0.35 and 0.35 colonies/m^2, respectively). Nine genera of juvenile coral were commonly found, namely,

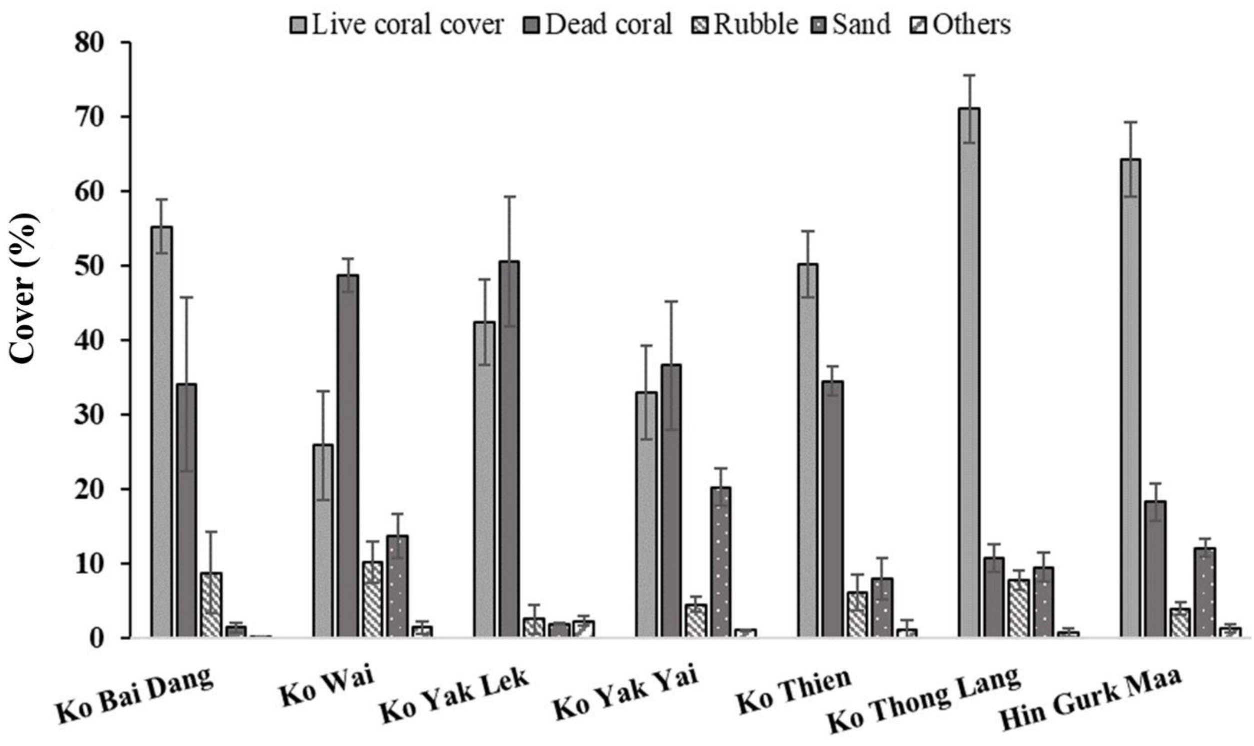

Figure 2. The percentage of live coral cover, dead coral, rubble, sand, and others at each study site.

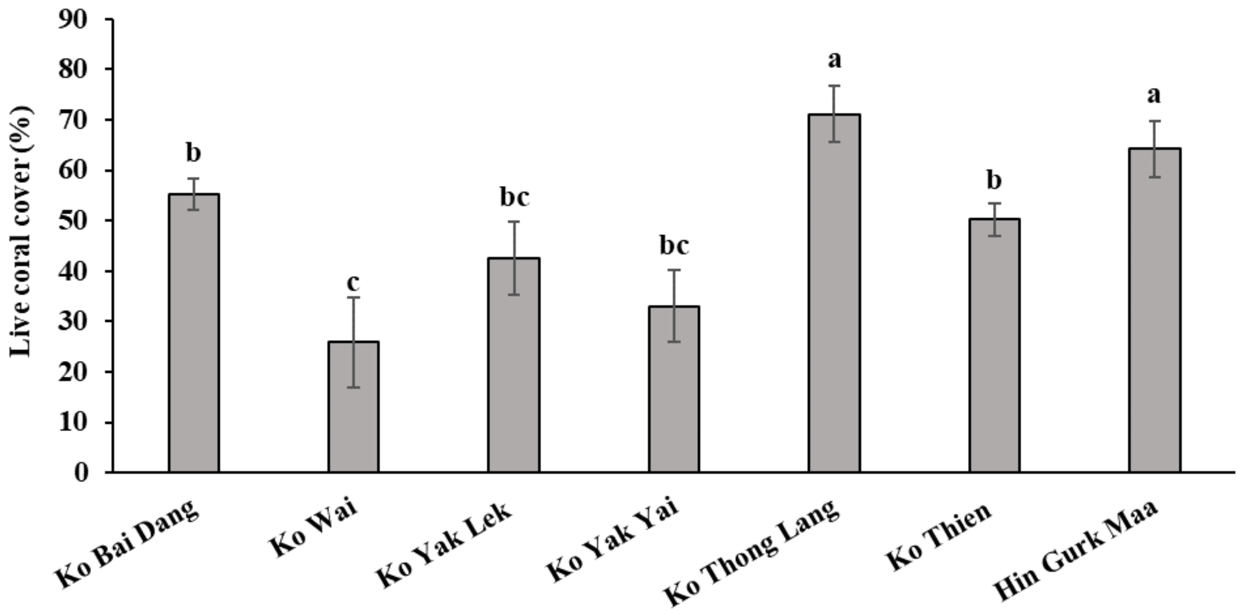

Figure 3. The percentage of live coral cover at each study site. The different letters above bars represent the significant difference ($p < 0.05$) by using Tukey's HSD test this experiment

Favia, *Favites*, *Fungia*, *Goniastrea*, *Lithophyllon*, *Pavona*, *Pocillopora*, *Porites*, and *Psammocora*. The brooding coral *Pocillopora* spp. at Ko Thien and, Ko Yak Lek showed evidence of self-seeding. On the other hand, the broadcast spawning coral *Porites* showed signs of significantly high degrees of coral self-seeding at Ko Bai Dang, Ko Thien, Ko Yak Yai, and Ko Wai. Recruits of *Leptastrea*, *Lithophyllon*, and *Psammocora* were frequently found without adult colonies.

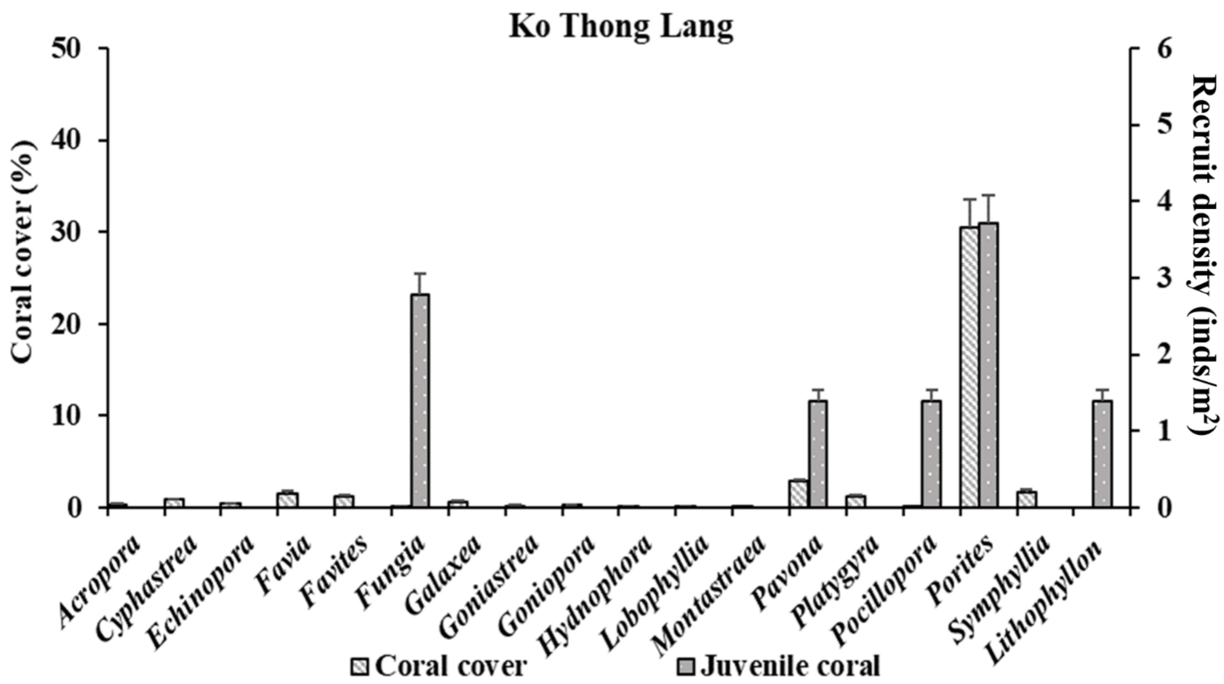

Figure 4. Percentage of coral cover and abundance of juvenile coral at Ko Thong Lang

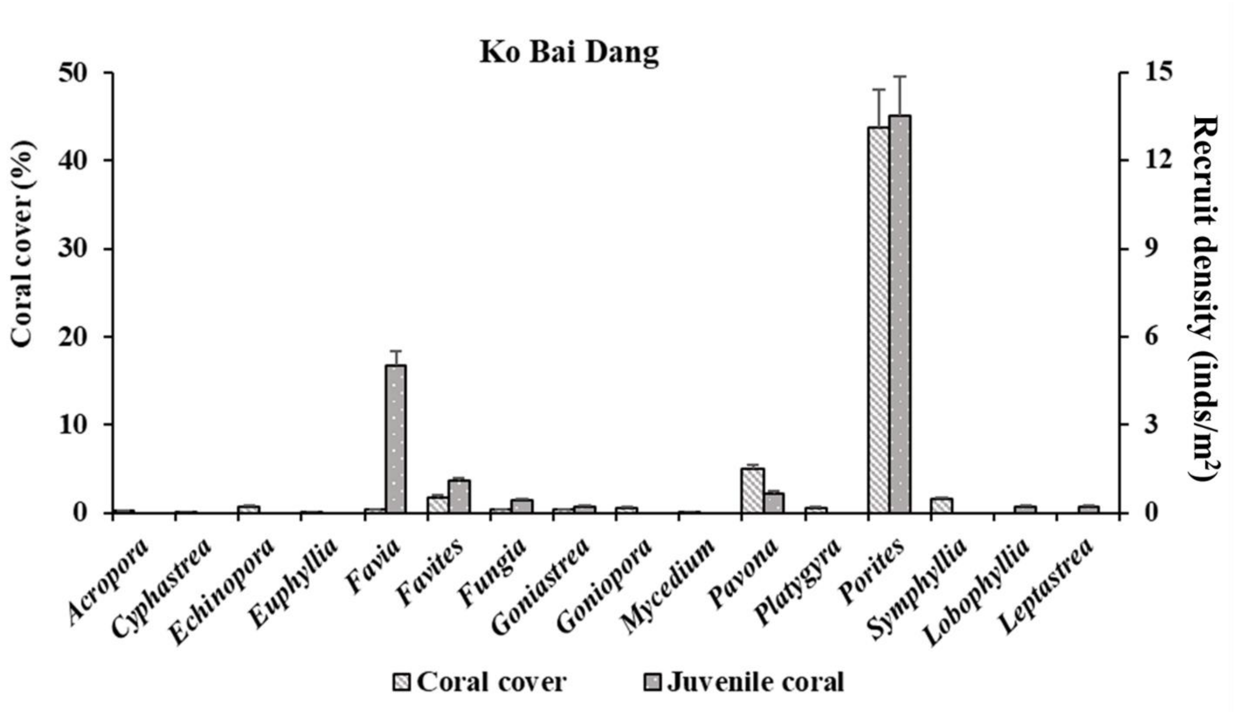

Figure 5. Percentage of coral cover and abundance of juvenile coral at Ko Bai Dang

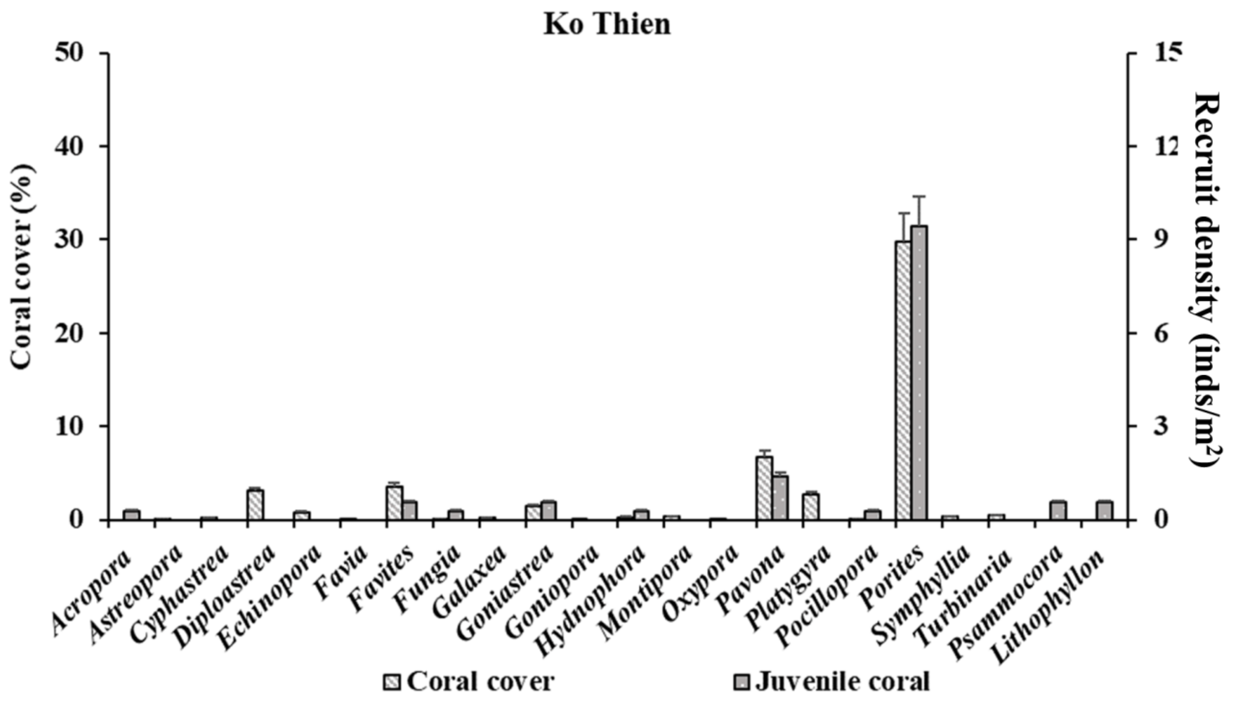

Figure 6. Percentage of coral cover and abundance of juvenile coral at Ko Thien

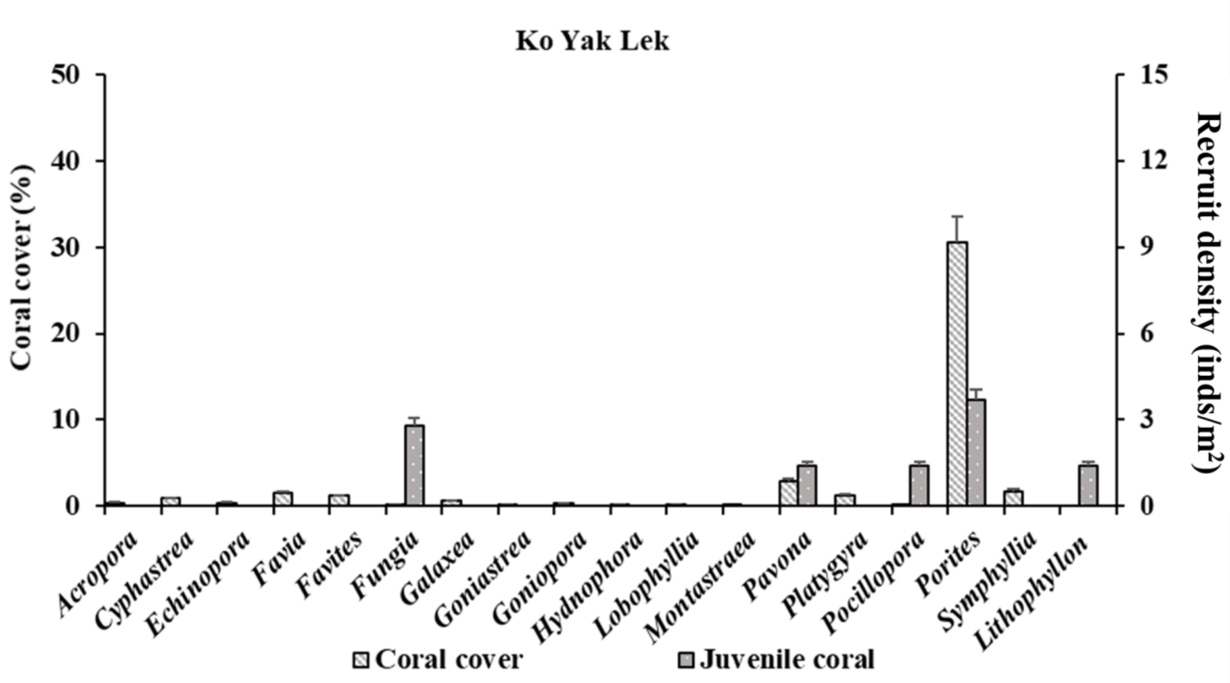

Figure 7. Percentage of coral cover and abundance of juvenile coral at Ko Yak Lek

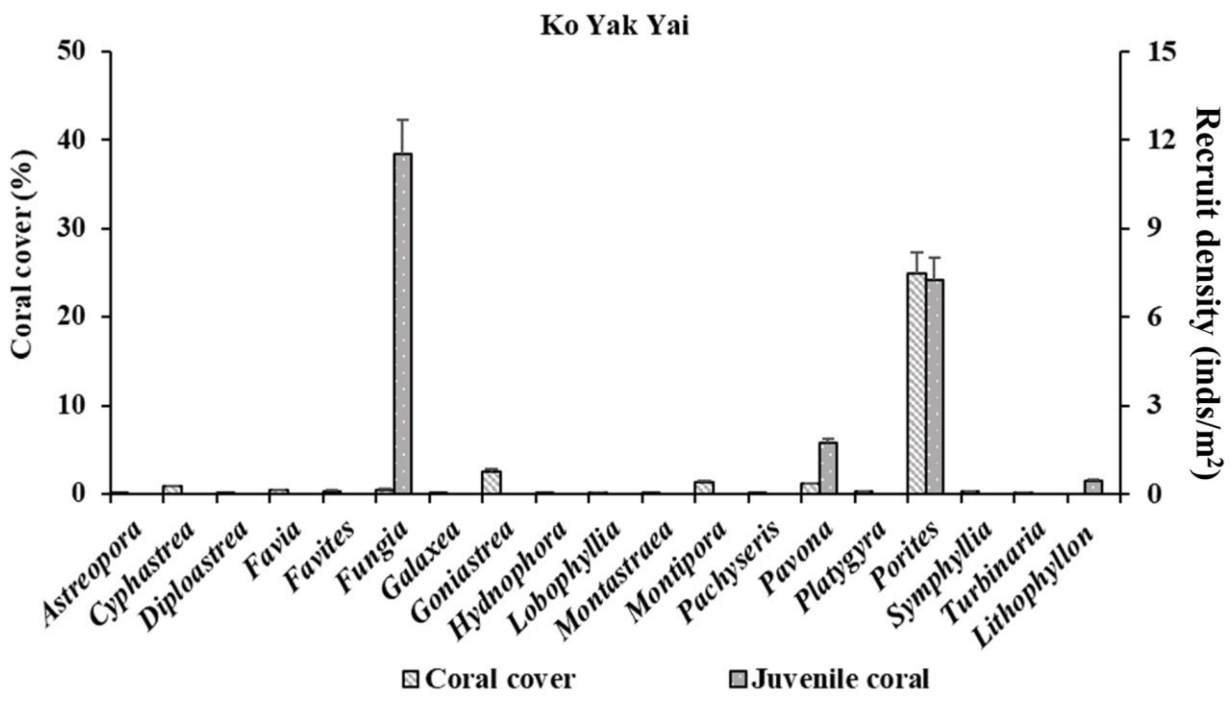

Figure 8. Percentage of coral cover and abundance of juvenile coral at Ko Yak Yai

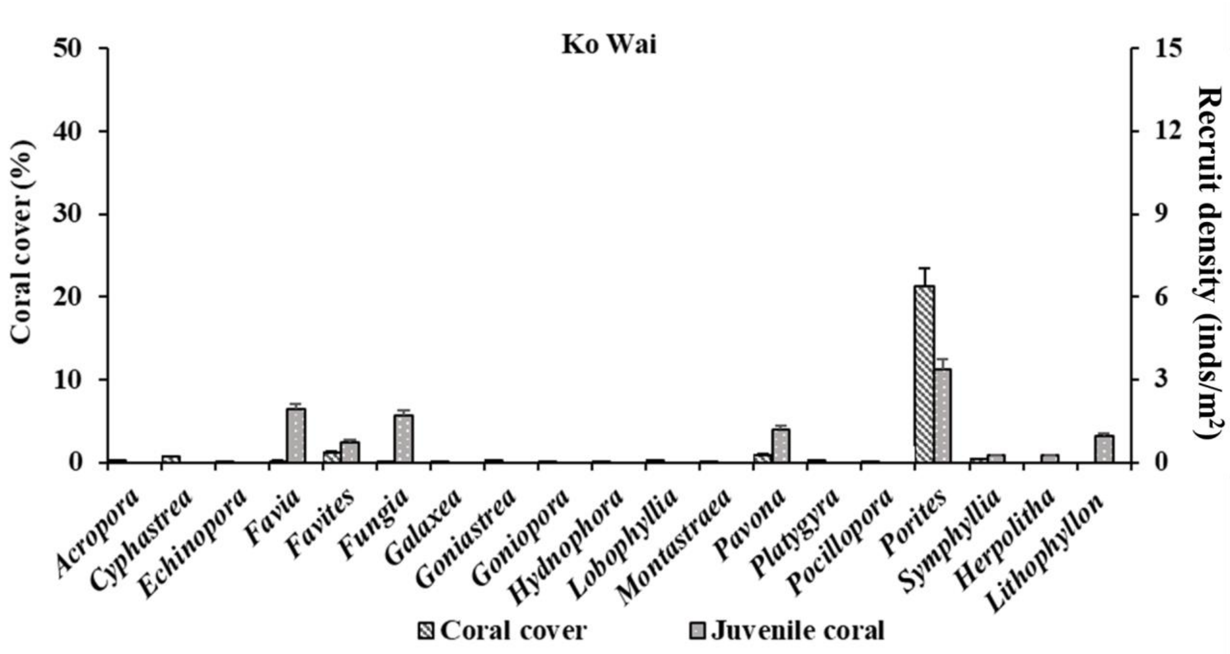

Figure 9. Percentage of coral cover and abundance of juvenile coral at Ko Wai

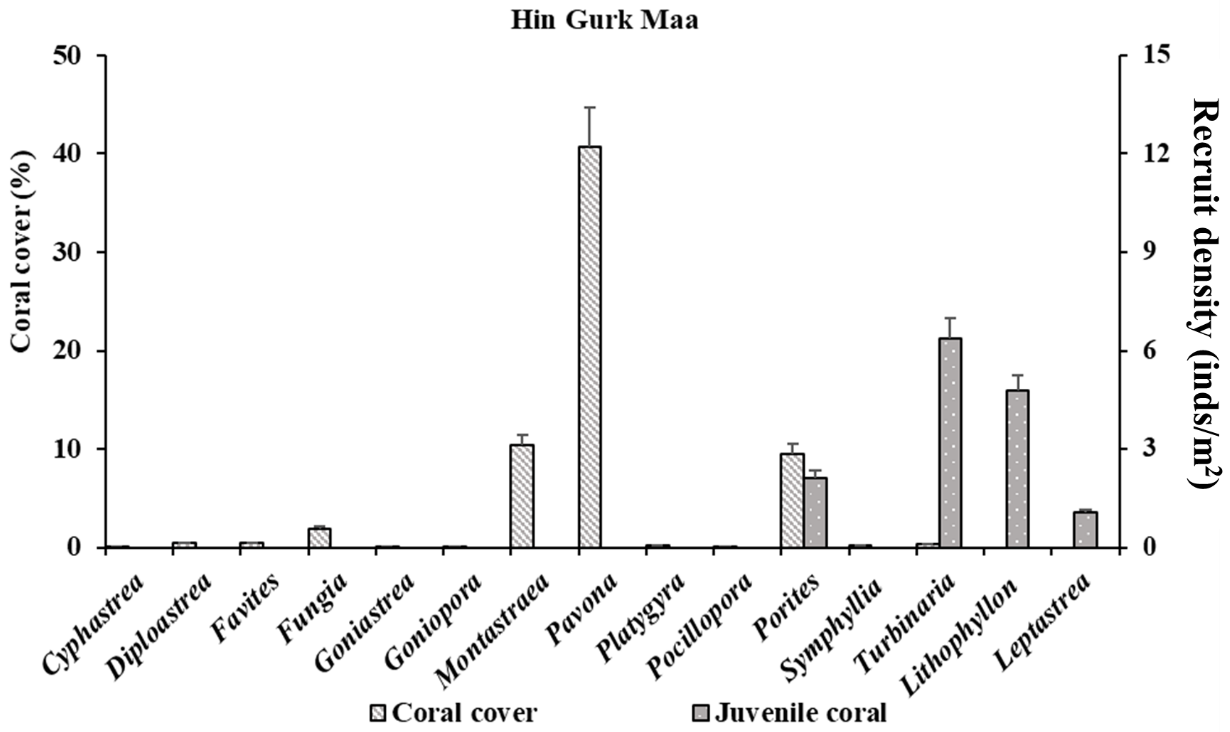

Figure 10. Percentage of coral cover and abundance of juvenile coral at Hin Gurk Maa

4. Discussion

The coral reefs in the Gulf of Thailand have experienced severe coral bleaching events during the last two decades. Moreover, the coral reefs have been degraded by the impacts of coastal development, sedimentation, destructive fishing, and the expansion of tourism on coral reefs. (Sutthacheep et al. 2013; Yeemin et al. 2013). The coral cover of coral communities at Mu Ko Chang was higher than those in Ko Samui due to that over two decades, the coastal development of Ko Samui for hotels and resorts to accommodate intensive tourism (Yeemin et al. 2009). Moreover, the coral cover of tolerant coral species, *Porites* are significantly high in Mu Ko Chang even they have been through the severity of coral bleaching events in the years 1998 and 2010 (Yeemin et al. 2009; Sutthacheep et al. 2012; Sutthacheep et al. 2013; Printrakoon et al. 2016).

The densities of juvenile corals in the Gulf of Thailand are usually low when compared with the other reef sites in the Indo-Pacific region, in which the juvenile coral density at some reef sites was over 50 colonies/m2 (Sheppard et al. 2008; Roth and Knowlton 2009; Yeemin et al. 2009). Therefore, the coral community structures in the Gulf of Thailand could be maintained by the survival of resistant and/or tolerant coral species. The results of this study suggest that highly resistant and tolerant coral species at Ko Bai Dang, Ko Thong Lang, Ko Thien, and Hin Gurk Maa play a major role in the high resilience potential of coral communities after coral bleaching events. The *Porites* communities among study sites at Mu Ko Chang National Park are extremely important to the high resilience potential of nearshore reef sites (Fitt et al. 2009; Buerger et al. 2015). These coral communities may contribute larval supply to nearshore reefs along the Eastern Gulf of Thailand through the connecting sea surface current in the Gulf of Thailand (Sojisuporn et al. 2010). Connectivity among reef sites and local coral recruitment are important factors for consideration when aiming to provide appropriate management strategies, especially for the designation of marine protected areas and establishing coral reef restoration projects in the Gulf of Thailand.

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References

Anthony KR, Marshall PA, Abdulla A, Beeden R, Bergh C, Black RE, CM, Game ET, Gooch M, Graham NA (2015) Operationalizing resilience for adaptive coral reef management under global environmental change. Global Change Biology 21:48–61

Babcock RC, Baird AH, Piromvaragorn S, Thomson DP, Willis BL (2003) Identification of Scleractinian Coral Recruits from Indo-Pacific Reefs. Zoological Studies 42(1): 211–226

Baker AC, Glynn PW, Riegl B (2008) Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. Estuarine, Coastal and Shelf Science 80: 435–471

Bramanti L, Edmund PJ (2016) Density-associated recruitment mediates coral population dynamics on a coral reef. Coral Reefs 35: 543–553

Buerger P, Schmidt GM, Wall M, Held C, Richter C (2015) Temperature tolerance of the coral Porites lutea exposed to simulated large amplitude internal waves (LAIW). Journal of Experimental Marine Biology and Ecology 471: 232–239

Edwards AJ, Gomez ED (2007) Reef Restoration Concepts and Guidelines: making sensible management choices in the face of uncertainty. Coral Reef Targeted Research & Capacity Building for Management Programme, St Lucia

English S, Wilkinson C, Baker V (1997) Survey Manual for Tropical Marine Resouces. Australian Institute of Marine Science, Queensland

Fitt WK, Gates RD, Hoegh-Guldberg O, Bythell JC, Jatkar A, Grottoli AG, Gomez M, Fisher P, Lajuenesse TC, Pantos O, Iglesias-Prieto R, Franklin DJ, Rodrigues LJ, Torregiani JM, van Woesik R, Lesser MP (2009) Response of two species of Indo-Pacific corals, Porites cylindrica and Stylophora pistillata, to short-term thermal stress: The host does matter in determining the tolerance of corals to bleaching. Journal of Experimental Marine Biology and Ecology 373: 102–110

Graham NAJ, Nash KL, Kool JT (2011) Coral reef recovery dynamics in a changing world. Coral Reefs 30: 283–294

Guillemot N, Chabanet P, Pape OL (2010) Cyclone effects on coral reef habitats in New Caledonia (South Pacific). Coral Reefs 29: 445–453

Kleypas JA, Yates KK (2009) Coral Reefs and Ocean Acidification. Oceanography 22(4): 108–117

Kuffner IB, Walters LJ, Becerro MA, Paul VJ, Ritson-Williams R, Beach KS (2006) Inhibition of coral recruitment by macroalgae and cyanobacteria. Marine Ecology Progress Series 323:107–117

Heery EC, Hoeksema BW, Browne NK, Reimere JD, Ang PO, Huanga D, Friessi DA, Chou LM, Loke LHL, Saksena-Taylor P, Alsagoff N, Yeemin T, Sutthacheep M, Vo ST, Bos AR, Gumanao GS, Hussein MAS, Waheed Z, Lane DJW, Johan O, Kunzmann A, Jompa J, Suharsono, Taira D, Bauman AG, Todd PA (2018) Urban coral reefs: Degradation and resilience of hard coral assemblages in coastal cities of East and Southeast Asia. Marine Pollution Bulletin 135: 654–681

Manikandan B, Ravindran J, Vidya PJ, Shrinivasu S, Manimurali R, Paramasivam K (2017) Resilience potential of an Indian Ocean reef: An assessment through coral recruitment pattern and survivability of juvenile corals to recurrent stress events. Environmental Science and Pollution Research 24: 13614–13625

Mora C, Graham NAJ, Nyström M (2016) Ecological limitations to the resilience of coral reefs. Coral Reefs 35: 1271–1280

Perez K, Rodgers KS, Jokiel, PL, Lager CV, Lager DJ (2014) Effects of terrigenous sediments on settlement and survival of the reef coral. Pocillopora damicornis. PeerJ 2, e387

Printrakoon C, Yeemin T, Valentich-Scott P (2016) Ecology of Endolithic Bivalve Mollusks from Ko Chang, Thailand. Zoological Studies. doi:10.6620/ZS.2016.55-50

Richmond RH (1997) Reproduction and recruitment in corals: Critical links in the persistence of reefs. In Life and Death of Coral Reefs; Birkeland, C., Ed.; Chapman & Hall: New York, NY, USA, pp. 175–197

Roth MS, Knowlton N (2009) Distribution, abundance and microhabitat characterization of small juvenile corals at Palymra Atoll. Marine Ecology Progress Series 376: 133–142

Rotha F, Saalmann F, Thomson T, Coker DJ, Villalobos R, Jones BH, Wild C, Carvalho S (2018) Coral reef degradation affects the potential for reef recovery after disturbance. Marine Environmental Research 142: 48–58

Sheppard CCR, Harris A, Sheppard ALS (2008) Archipelago-wide coral recovery patterns since 1998 in the Chagos Archipelago, Central Indian Ocean. Marine Ecology Progress Series 362: 109–117

Shlesinger T, Loya Y (2016) Recruitment, mortality, and resilience potential of scleractinian corals at Eilat, Red Sea. Coral Reefs 35: 1357–1368

Sojisuporn P, Morimoto A, Yanagi T (2010) Seasonal variation of sea surface current in the Gulf of Thailand. Coastal Marine Science 34: 1–12

Sutthacheep M, Pengsakun S, Yucharoen M, Klinthong W, Sangmanee K, Yeemin T (2013) Impacts of the mass coral bleaching events in 1998 and 2010 on the western Gulf of Thailand. Deep-Sea Research II 96: 25–31

Sutthacheep M, Yucharoen M, Klinthong W, Pengsakun S, Sangmanee K, Yeemin T (2012) Coral mortality following the 2010 mass bleaching event at Kut Island, Thailand. Phuket Marine Biological Center Research Bulletin 71: 83–92Valentine JF, Heck Jr KL (2005) Perspective review of the impacts of overfishing on coral reef food web linkages. Coral Reefs 24:209–213

Veron JEN (2000) Corals of the World. Australian Institute of Marine Science: Townsville, Australia, Volume 1–3

Yeemin T (2018) Summary of coral bleaching from 2015 to 2017 in Thailand. In Status of Coral Reefs in East Asian Seas Region; Kimura T, Tun K, Chou LM, Eds.; Ministry of the Environment of Japan and Japan Wildlife Research Center: Tokyo, pp. 25–28

Yeemin T, Mantachitra V, Plathong S, Nuclear P, Klinthong W, Sutthacheep M (2012) Impacts of coral bleaching, recovery and management in Thailand. In Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9–13 July p. 5

Yeemin T, Pengsakun S, Yucharoen M, Klinthong W, Sangmanee K, Sutthacheep M (2013) Long-term changes in coral communities under stress from sediment. Deep-Sea Research II 96: 32–40

Yeemin T, Saenghaisuk C, Yucharoen M, Klinthong W, Sutthacheep M (2012) Impact of the 2010 coral bleaching event on survival of juvenile coral colonies in the Similan Islands, on the Andaman Sea coast of Thailand. Phuket Marine Biological Center Research Bulletin 71: 93–102

Yeemin T, Saenghaisuk C, Sutthacheep M, Pengsakun S, Klinthong W, Saengmanee K (2009) Conditions of coral communities in the Gulf of Thailand: A decade after the 1998 bleaching event. Galaxea, Journal of Coral Reef Studies. 11: 207–217