ORIGINAL PAPER

Recovery of corals in Mu Ko Ang Thong, the Western Gulf of Thailand

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Abstract: Coral recovery after bleaching events is influenced by coral larval supply, available substrate, settlement, and survival rate of juvenile corals. Larval connectivity among coral populations is a crucial aspect of understanding the recovery potential of coral reefs following natural and anthropogenic disturbances. Reef connectivity depends on oceanographic conditions and the sources of coral larval supply. There are varying degrees of self-seeding on coral reefs. This study investigated the coral recruitment patterns and relationships with adult coral communities at six study sites in Mu Ko Ang Thong, Surat Thani Province, the Western Gulf of Thailand. Live coral covers were in a range of 35.4-40.5 %, while dead coral covers were in a range of 35.0-50.8 %. Live coral cover at Ko Hindap was significantly higher than that of other reef sites. The highest density of juvenile corals was found at Ko Sam Sao (N), while the lowest was recorded at Ko Hindap. The brooding coral *Pocillopora* spp. at all study sites showed self-seeding. Most broadcast spawning corals showed low degrees of coral self-seeding at the study sites. Juveniles of *Pseudosiderastrea tayamai* and *Fungia* sp. were observed without their adult corals. This study reveals the low diversity of juvenile corals at Mu Ko Ang Thong and requires proper management strategies to prevent the local extinction of certain coral species.

Keywords: juvenile coral, recovery, self-seeding, Gulf of Thailand

1. Introduction

Coral reefs ecosystem are important centers of marine biodiversity and productivity that provide a variety of ecosystem services of substantial cultural and economic value to humankind, yet coral reefs worldwide are under serious threats as a result of human disturbances (Hughes et al., 2010; Graham et al., 2014). Population connectivity, the exchange of individuals between distinct populations, is essential for marine populations' ecology, evolution, and conservation. Connectivity influences, such as the flow of energy and materials, metapopulation dynamics, resistance to threats, and evolutionary divergence (Boström et al., 2011; Tett et al., 2013; D'Aloia et al., 2015; Puckett & Eggleston, 2016). Patterns and spatial scales of coral larval dispersal drive biogeographic distributions, genetic connectivity, population, and community dynamics and might play a critical role in adapting metapopulations to climate change through genetic rescue (Cowen, 2007; Gaines et al., 2007; Dixon et al., 2015). The onset and duration of larval competence can dramatically affect predicted species connectivity in the sea (Cowen, 2007; Connoly and Baird, 2010; Wood et al., 2014). Future environmental changes will affect coral populations; therefore, it is essential to understand their metapopulation structure over large geographic ranges. For marine organisms, recruitment is essential for interchanging individuals to populations and maintaining successive life cycle stages within populations and genetic flow (Caley et al., 1996). Thus, knowledge of dispersal distances and pathways is useful for understanding the recovery potential in coral populations (van Oppen et al., 2008). Many marine species have limited to no movement when adults (Caley et al., 1996; van Oppen et al., 2008). Among broadcast spawning coral species, the pelagic larvae are responsible for most of the connectivity among populations. New recruitment from locally and externally sourced larval stages and regrowth of surviving coral colonies and colony fragments strongly contributes to the recovery of corals (van Oppen et al., 2008). This study quantified juvenile corals' abundance and taxonomic composition (≤ 5 cm in diameter) on natural reef substrates and their relationships with adult coral communities at four study sites in Mu Ko Ang Thong, Surat Thani Province, the Western Gulf of Thailand.

2. Materials and Methods

The study sites are located in Mu Ko Ang Thong National Park, Surat Thani Province, the Western Gulf of Thailand (Figure 1). The park is the second largest marine national park of Thailand and comprises 42 relatively small islands. It is approximately 750 km south of Bangkok and about 31 km away from Ko Samui, at the northeast, a popular tourist destination in Thailand. Field surveys were conducted in 2018, four study sites were examined, including Ko Hindap, Ko Thaiphlao, Ko Sam Sao (West), and Ko Sam Sao (North). Coral communities were found at approximately 1-7 m. in depth. At each study site, live coral cover was recorded in three permanent belt-transects of 30×1 m, and scleractinian corals (>5 cm diameter) were identified to genus level. The visible juvenile coral colonies (≤ 5 cm in diameter) quadrats (16x16 cm^2) were randomly placed on available substrates, and juvenile corals were counted and identified to genus level. Normal distribution of live coral cover data was analyzed using a one-way ANOVA and Tukey HSD test to detect the difference between the study sites.

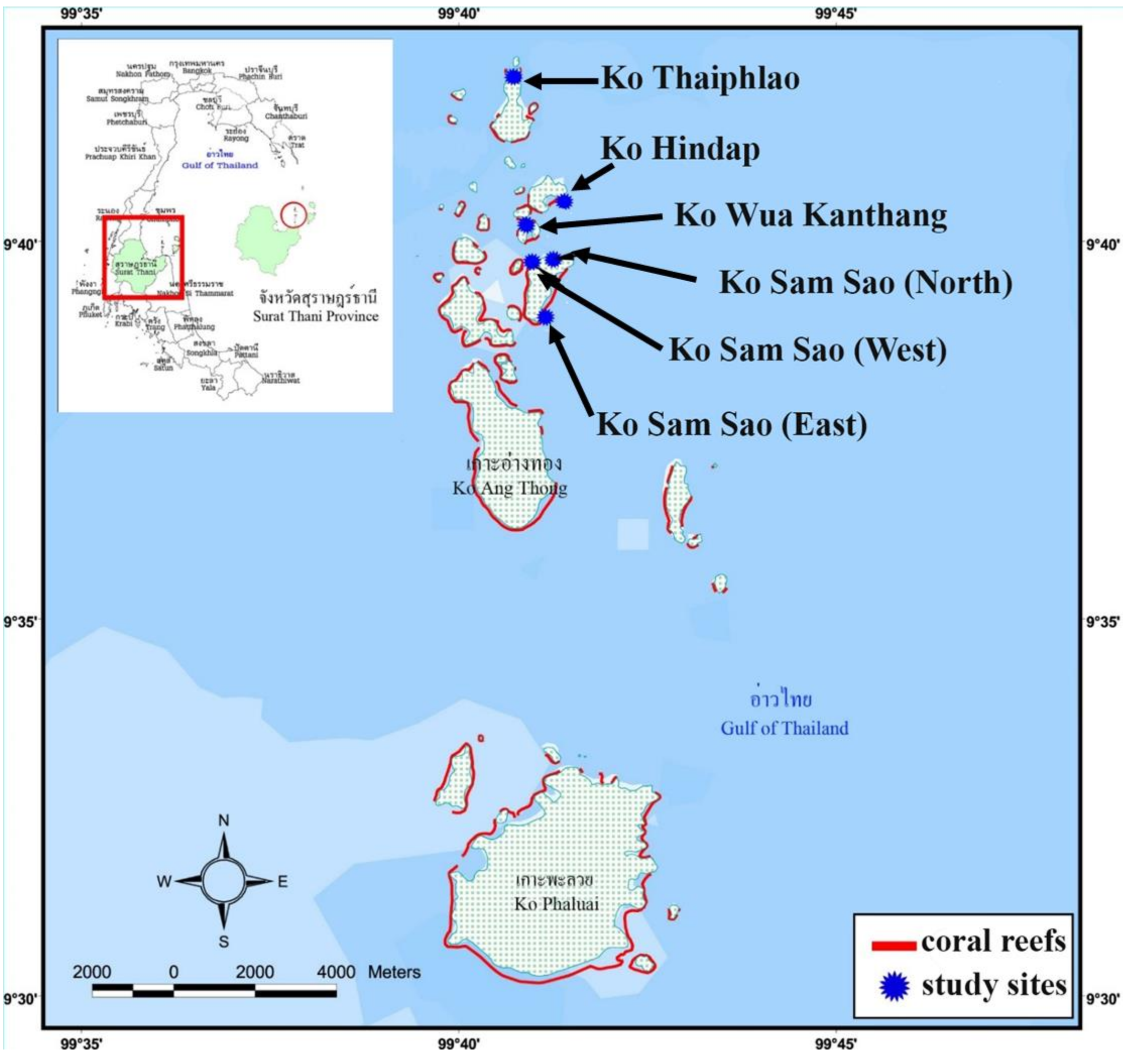


Figure 1. Map of study sites at Mu Ko Ang Thong

3. Results

The benthic components (including live corals and dead corals) are shown in Figures 2 and 3. Live coral covers varied between 35.4-40.5 %, while dead coral covers were in a range of 35.0-50.8 %. The live coral cover at Ko Hindap was significantly higher than that of other reef sites (one-way ANOVA; Tukey's HSD test; $p<0.05$) (Table 1). The highest density of juvenile corals in Mu Ko Angthong was found at Ko Sam Sao (N) (6.7±1.3 colonies/m^2), while the lowest density was recorded at Ko Hindap (2.1±0.4 colonies /m^2) (Figure 4).

Table 1. A result of one-way ANOVA testing for differences between study sites

Source of variation	SS	df	Mean Square	*F*	*P*
Between study sites	288.88	3	96.26	4.12	0.049
Within study sites	187.19	8	23.40		
Total	176.07	11			

*Significant difference $p<0.05$), *df*: degree of freedom

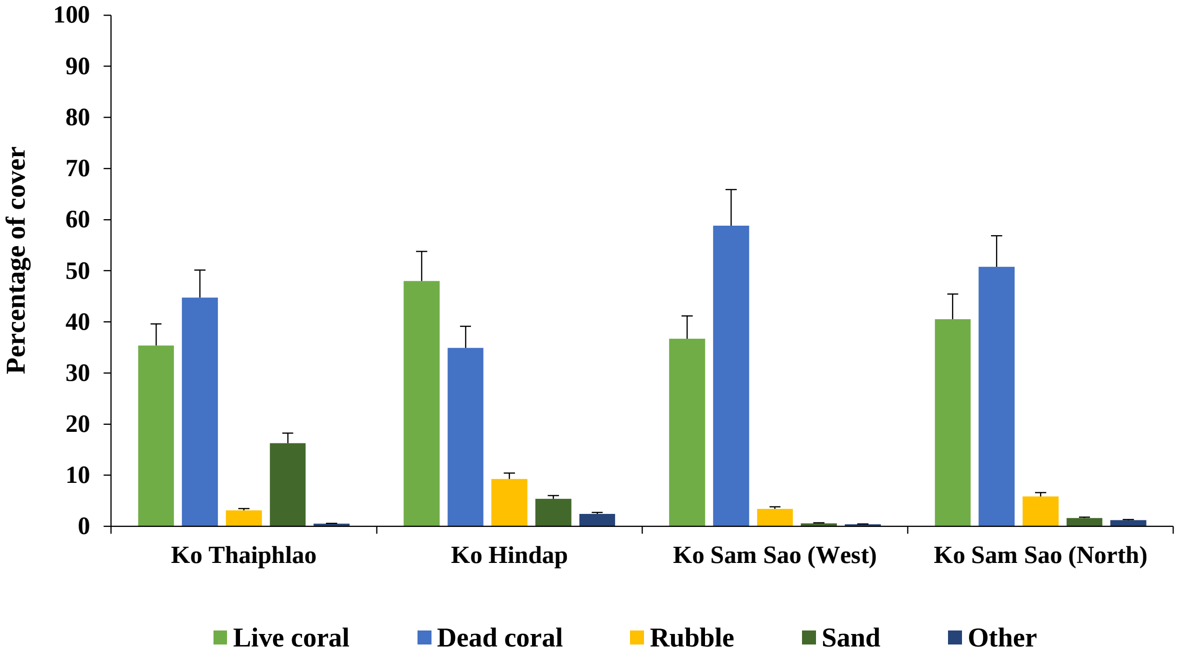


Figure 2. Benthic components at three study sites from Mu Ko Ang Thong (Mean ± SD)

Platygyra sinensis *Diploastrea heliopora* *Pocillopora acuta* *Porites lutea*

Figure 3 Underwater photographs of common corals at the study sites.

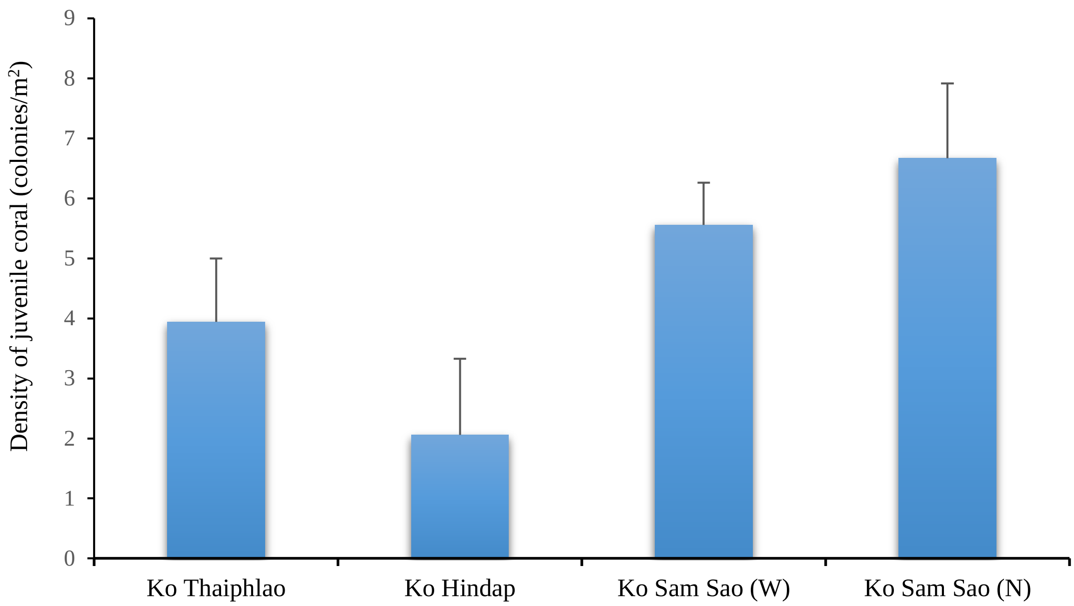


Figure 4 Densities of juvenile corals (mean ± SD) on available substrates at the study sites

Compositions of live corals and juvenile corals at Ko Thaiphlao are shown in Figure 5. Fourteen coral taxa were recorded as adult corals, while seven taxa composed juvenile corals. Four coral taxa were recorded as both adult and juveniles, i.e., *Pocillopora* sp., *Favia* sp., *Platygyra* sp., and *Goniopora* sp., while ten coral taxa, i.e., *Montipora* sp. *Echinophyllia* sp., *Hydnophora* sp., *Symphyllia* sp., *Favites* sp., *Goniastrea* sp., *Montastrea* sp., *Diploastrea* sp., *Leptastrea* sp., and *Porites* sp., had no their juvenile corals. Juveniles of *Pseudosiderastrea tayamai*, *Fungia* sp., and *Turbinaria* sp. were observed without their adult colonies.

Compositions of live corals and juvenile corals at Ko Hindap are shown in Figure 6. Eighteen coral taxa were recorded as adult corals, while four taxa composed juvenile corals. Four coral taxa were recorded as both adult and juveniles, i.e., *Pocillopora* sp., *Favites* sp., *Goniastrea* sp. and *Leptastrea* sp. while fourteen coral taxa, i.e., *Galaxea* sp., *Pavona* sp., *Fungia* sp., *Pectinia* sp., *Merulina* sp., *Turbinaria* sp., *Lobophyllia* sp., *Symphyllia* sp., *Favia* sp., *Goniastrea* sp., *Platygyra* sp., *Diploastrea* sp., *Cyphastrea* sp. and *Goniopora* sp., had no their juvenile corals.

Compositions of live corals and juvenile corals at Ko Sam Sao (North) are shown in Figure 7. Thirteen coral taxa were recorded as adult corals, while six taxa composed juvenile corals. Four coral taxa were recorded as both adult and juveniles, i.e., *Pocillopora* sp., *Turbinaria* sp., *Favia* sp., and *Goniopora* sp., while nine coral taxa, i.e., *Montipora* sp., *Galaxea* sp., *Pavona* sp., *Hydnophora* sp., *Lobophyllia* sp., *Symphyllia* sp., *Goniastrea* sp., *Platygyra* sp. and *Porites* sp., had no their juvenile corals. Juveniles of *Pseudosiderastrea tayamai* and *Favites* sp. were observed without their adult colonies.

Compositions of live corals and juvenile corals at Ko Sam Sao (West) are shown in Figure 8. Eleven coral taxa were recorded as adult corals, while five taxa composed juvenile corals. Four coral taxa were recorded as both adult and juveniles, i.e., *Pocillopora* sp., *Pavona* sp., *Favites* sp. and *Goniastrea* sp. while seven coral taxa, i.e., *Montipora* sp., *Physogyra* sp., *Lobophyllia* sp., *Symphyllia* sp., *Favia* sp., *Platygyra* sp. and *Porites* sp., had no their juvenile corals. There was only *Fungia* sp. having juvenile corals without their adult colonies.

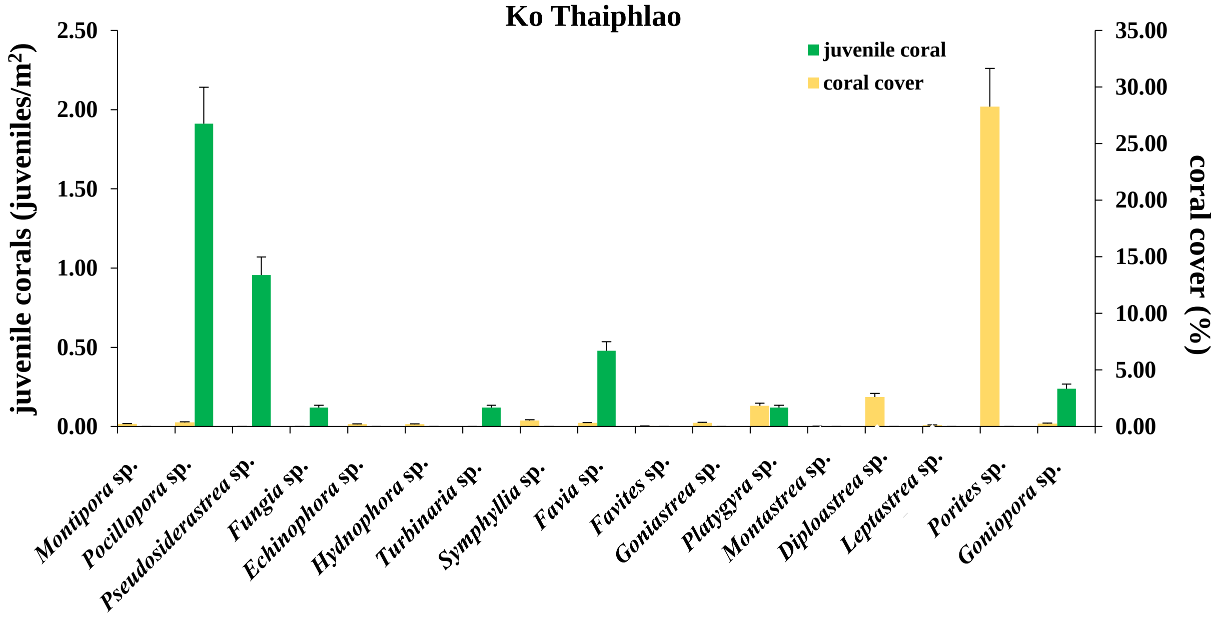


Figure 5 Compositions of live corals and juvenile corals at Ko Thaiphlao, Mu Ko Angthong (Mean ± SD)

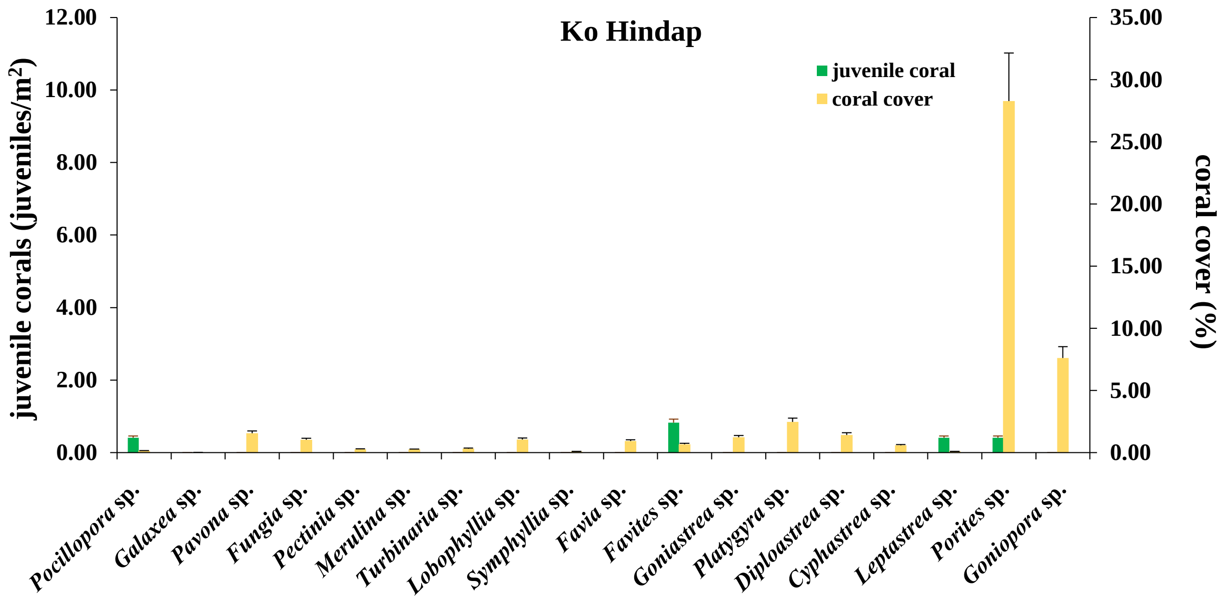


Figure 6 Compositions of live corals and juvenile corals at Ko Hindap, Mu Ko Angthong (Mean ± SD)

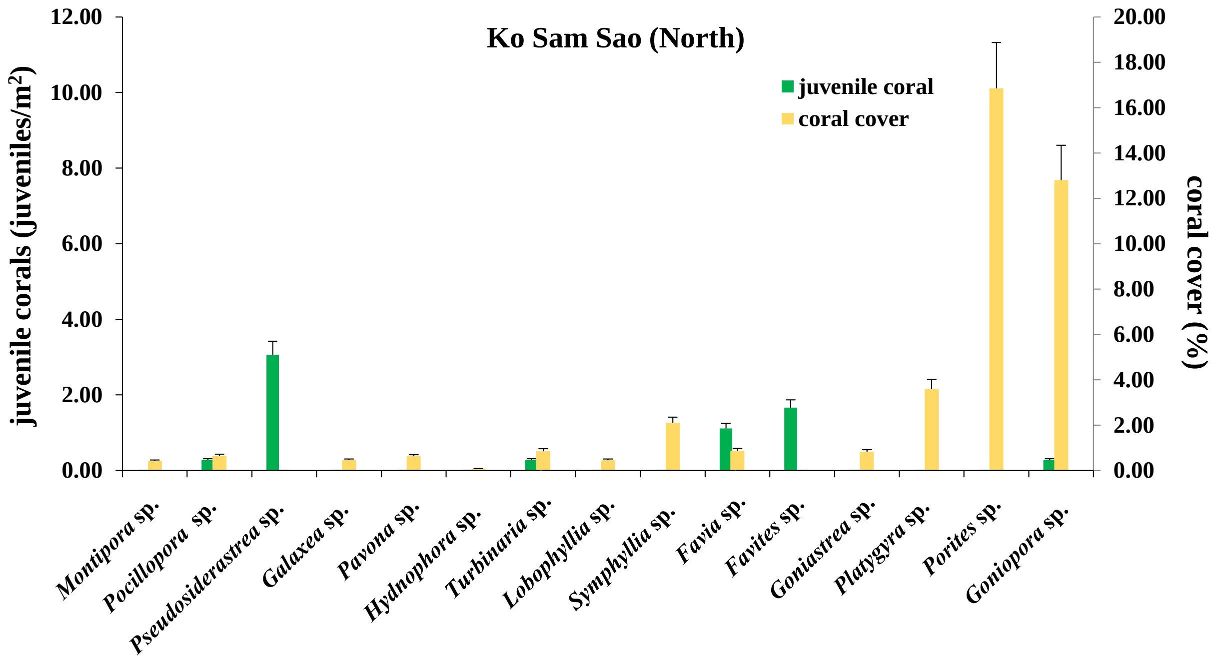


Figure 7 Compositions of live corals and juvenile corals at Ko Sam Sao (North), Mu Ko Angthong (Mean ± SD)

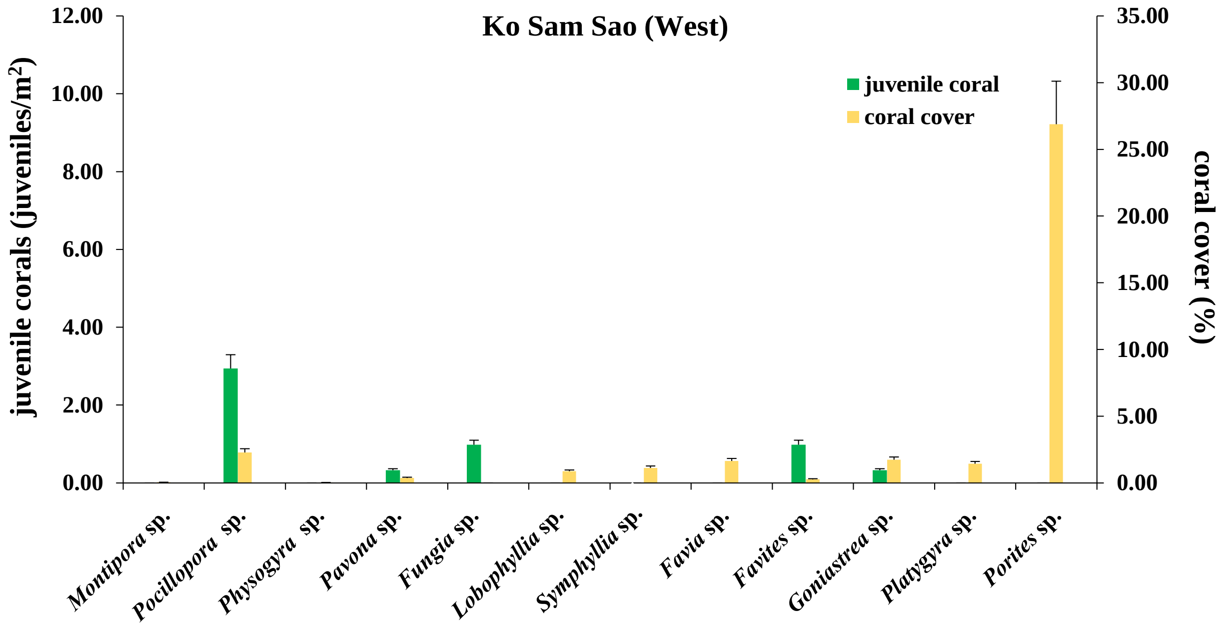


Figure 8 Compositions of live corals and juvenile corals at Ko Sam Sao (West), Mu Ko Angthong (Mean ± SD)

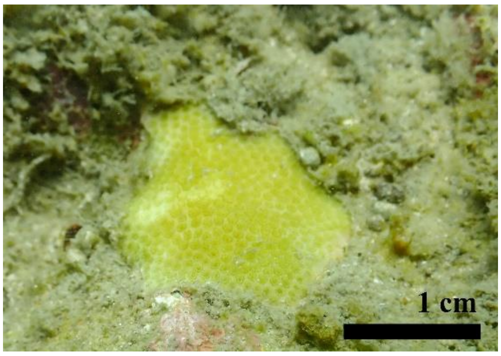
4. Discussion

Coral reef ecosystems in Mu Ko Ang Thong have high values of economic, cultural, and scientific benefits. The Mu Ko Ang Thong National Park was designated as a Ramsar site by the Ramsar Convention in 2002. The number of tourists visiting Mu Ko Ang Thong National Park has remarkably increased during the last decade. The densities of juvenile corals at the study sites in Mu Ko Ang Thong observed in this study are lower than those of other studies, such as Red Sea (Glassom and Chadwick, 2006), Chagos Archipelago (Sheppard et al., 2008), Palmyra Atoll (Roth and Knowlton, 2009), Indian Ocean Reefs (Manikandan et al., 2017), and Mu Ko Samet, the Eastern Gulf of Thailand (Sutthacheep et al., 2018). The densities of juvenile corals varied among reef sites in Mu Ko Ang Thong. They may be controlled by several factors, especially reproductive outputs of corals from connected reefs, dispersal, settlement and post-settlement mortality of planulae, grazing, predation, and sedimentation impacts (Edmunds, 2000; Yeemin et al., 2012; Yeemin et al., 2013, Bramanti and Edmunds, 2016; Feng et al., 2016; Shlesinger and Loya, 2016; Manikandan et al., 2017).

The coral reefs in Mu Ko Ang Thong are in shallow and turbid waters. The Tapi River has greatly influenced coral community structures at the study sites. High concentrations of suspended sediments can reduce gamete fertilization success and settlement of planulae (Yeemin et al., 2013a; Jones et al., 2015; Ricardo et al., 2015; Humanes et al., 2017). Sedimentation in inshore coral reefs influenced by river runoff can also intensify the already detrimental impacts of suspended sediments on corals, further reducing planula settlement success, survival, and growth rates of adult corals (Sudara et al., 1991; Fabricius, 2005; Weber et al., 2006, Brodie et al., 2012; Yeemin et al., 2013a; Humanes et al., 2017)

Adult and juvenile corals' diversities in this study indicate low degrees of self-seeding in Mu Ko Ang Thong. Although the brooding coral *Pocillopora* spp. At all study sites revealed self-seeding, many coral taxa had no their juvenile corals. Therefore, some corals in Mu Ko Ang Thong may have a high risk of local extinction following severe disturbances that caused mass mortality of corals, particularly coral bleaching events (Yeemin et al., 2013b). Coral self-seeding may be of great importance to sustaining coral reef populations and may affect connectivity among reef sites (Kendall and Poti, 2014).

Our results show that some broadcasting coral taxa were found at both adult and juvenile corals at the study sites, such as *Favia* sp., *Favites* sp., *Goniastrea* sp., and *Goniopora* sp. Juveniles of *Pseudosiderastrea tayamai* and *Fungia* sp. were observed without their adult corals. These data imply the connectivity of some coral populations in Mu Ko Ang Thong. However, molecular genetic studies should be conducted to assess the coral genetic connectivity and self-seeding (van Oppen et al., 2008).



Porites sp.

Favia sp.

Pocillopora sp.

Favites sp.

Figure 9 Underwater photographs of juvenile corals at the study sites.

The connectivity among coral reefs and spatial variation of coral recruitment are important factors for consideration to establish proper management strategies, particularly enhancing coral reef resilience and effective coral restoration projects in Mu Ko Ang Thong National Park and other marine protected areas in the Gulf of Thailand. The present study provides knowledge on coral recruitment patterns and their relationships with coral community structures and highlights the low diversity of juvenile corals at certain reef sites in Mu Ko Ang Thong National Park, the Western Gulf of Thailand. The proper management activities are needed to prevent the local extinction of certain coral species

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