ORIGINAL ARTICLE

Coral recruitment and self-seeding potential in Mu Ko Samet, the Gulf of Thailand

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Abstract. Knowledge of coral recruitment is required for understanding and managing coral reef ecosystems. This study quantified the abundance and taxonomic composition of juvenile corals on natural reefs and their relationships with coral community structures in Mu Ko Samet, the Eastern Gulf of Thailand. The live coral covers at the study sites were in a range of 29.4-54.2 %. The density of juvenile corals recorded in this study were 7.8-23.8 recruits/m^2. The difference of coral self-seeding among the study sites in Mu Ko Samet was observed. The reef sites at Ao Kiew Na Nok and Ao Kiew Na Nai showed high degrees of coral self-seeding. Several coral taxa were observed at the study sites both adult and juvenile corals, including *Acropora* sp., *Favia* sp., *Favites* sp., *Fungia* sp., *Goniastrea* sp., *Pavona* sp., *Platygyra* sp. *Pocillopora* sp., *Porites* sp. and *Symphyllia* sp. whereas juveniles of *Leptastrea* sp. and *Turbinaria* sp. were found with the absent of adult colonies. A better understanding of coral recovery and coral recruitment pattern is necessary for planning and management of coral reefs in a changing climate.

Keywords: coral bleaching, coral recruit, self-seeding, connectivity, management

1. Introduction

Coral reefs in tropical seas are degrading due to the impacts from natural and anthropogenic disturbances (McClanahan et al. 2005; Hughes et al. 2010: Pandolfi et al. 2011; Darling et al. 2013; Palumbi et al. 2014; Manikandan et al. 2017). Increasing frequency of natural disturbances, especially bleaching, diseases and storms as well as anthropogenic disturbances including sedimentation, eutrophication, destructive fishing and overfishing have decreased the live coral cover in the reefs (Yeemin et al. 2009; Burke et al. 2011; Sutthacheep et al. 2013). These disturbances also affect the recovery and resilience of coral reefs (Sutthacheep et al. 2018). The important factors controlling coral recovery from large-scale disturbances, especially coral bleaching events are a major concern for coral reef research (Hughes et al. 2010; van Hooidonk et al. 2013; Yeemin, et al. 2013a; Bramanti and Edmunds, 2016; Tsounis and Edmunds, 2016; Yadav et al. 2016). Based on a review of recovery rates after disturbances at 48 reef sites, coral reefs in the western Pacific Ocean had the fastest recovery while those in the isolated eastern Pacific Ocean were the slowest recovery, indicating regional differences in coral composition, fish functional diversity and geographic isolation (Graham et al. 2011). Coral recovery rates depend on several factors, such as recruitment rates, structural complexity of reefs and the functional composition of coral reef fishes (Fox and Caldwell, 2006; Burkepile and Hay 2008; Adjeroud et al. 2009; Golbuu et al. 2012).

Reproductive biology of corals, particularly fecundity, fertilization rate, larval dispersal, and recruitment rate play a major role in controlling abundance and species composition of corals (Richmond 1997; van Woesik and Jordán-Garza 2011). Maintenance of coral populations needs higher recruitment rates compared to mortality rates. Coral recruitment depends on complex environmental factors, including reproductive output of adult population, fertilization, larval development, dispersal of planulae by hydrodynamic characteristics, available substrates for settlement, settlement, survival of juvenile corals and recruitment patterns (Feng et al. 2016; Shlesinger and Loya 2016; Thompson et al. 2018). Basic population parameters such as the abundance of corals and juvenile coral colonies are essential for understanding changes in population sizes of corals and potential coral recovery (Edmunds, 2000). After severe natural and anthropogenic stresses, coral recovery potential is mostly controlled by recruits derived from sexual reproduction originating from reefs internal and external to the affected reefs (Gilmour et al. 2009; Jones et al. 2009; Tsounis and Edmunds 2016). Connectivity of coral populations is a very important aspect for coral recovery and it has been studied and assessed to identify self-seeding reefs and level of connectivity among coral reefs (Sammarco and Andrews 1988; Selkoe and Toonen 2011; Feng et al. 2016). Coral reef connectivity and self-seeding vary among reef sites and are controlled by oceanographic conditions and larval supply sources (Kough and Paris 2015).

Mu Ko Samet consists of a group of islands on the coast of Rayong Province, the Eastern Gulf of Thailand. There are several well-known islands which have good conditions of sandy beaches and water quality. There are also several coral reefs which are hot spots for tourism activities, such as swimming, snorkeling and scuba diving. However, the severe coral bleaching event in 2010 led to high coral mortality in some reef sites (Yeemin et al. 2012a). Knowledge of coral recovery, particularly coral recruitment pattern is necessary for planning and management of coral reefs in the Gulf of Thailand. This study quantified the abundance and taxonomic composition of juvenile corals on natural reef substrates and their relationships with coral community structures in Mu Ko Samet, the Eastern Gulf of Thailand.

2. Methodology

The study was conducted in Mu Ko Samet, Rayong Province, the Eastern Gulf of Thailand in January 2017. Four study sites were examined, i.e. Ao Phrao, Ao Platom and Ao Kiew Na Nai on the west coast of Ko Samet and Ao Kiew Na Nok on the east coast of Ko Samet (Figure 1). The coral communities at the study sites were about 2-6 m in depth. At each study site, live coral cover and benthic components were recorded in three permanent belt-transects of 30×1 m^2. The live scleractinian corals (>5 cm diameter) were identified to genus level using the identification guides by Veron (2000). The average percent cover of live coral, dead coral, rubble, sand and other benthic components were calculated. The number of visible juvenile coral colonies (1-5 cm diameter) was also measured in these three-permanent belt-transects. All juvenile corals were identified to the genus level. The average density of juvenile corals was expressed as a number of juvenile corals per square meter. The data were checked for the assumptions of ANOVA. The live coral cover and juvenile coral density data were analyzed using one-way ANOVA and Tukey HSD test to detect the difference between the study sites.

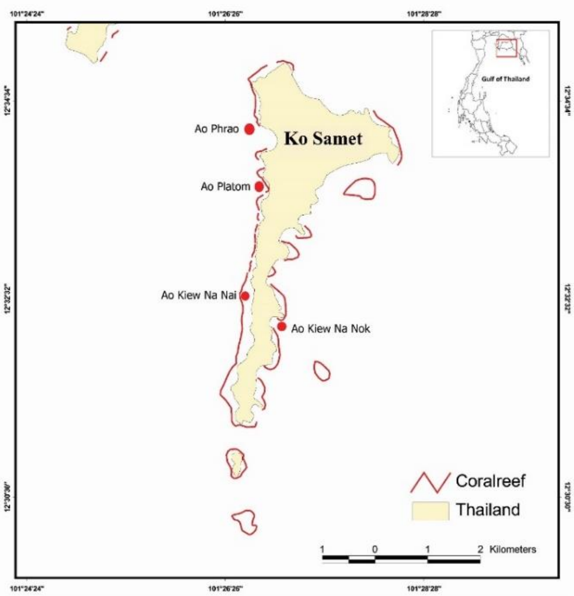

Figure 1. Map of Ko Samet, the Eastern Gulf of Thailand showing the locations of the study sites

3. Results

The benthic components, i.e. live corals, dead coral, rubble, sand and others are shown in Figure 2. Live coral covers were in a range of 29.4-54.2 % while dead coral covers were in a range of 24.7-44.7 %. The live coral cover at Ao Platom was significantly lower than that at other study sites (one-way ANOVA; Tukey's HSD test; $p<0.05$). The adult coral community at all study sites was dominated by *Porites* sp. and several dominant juvenile coral taxa were recorded (Figure 3).

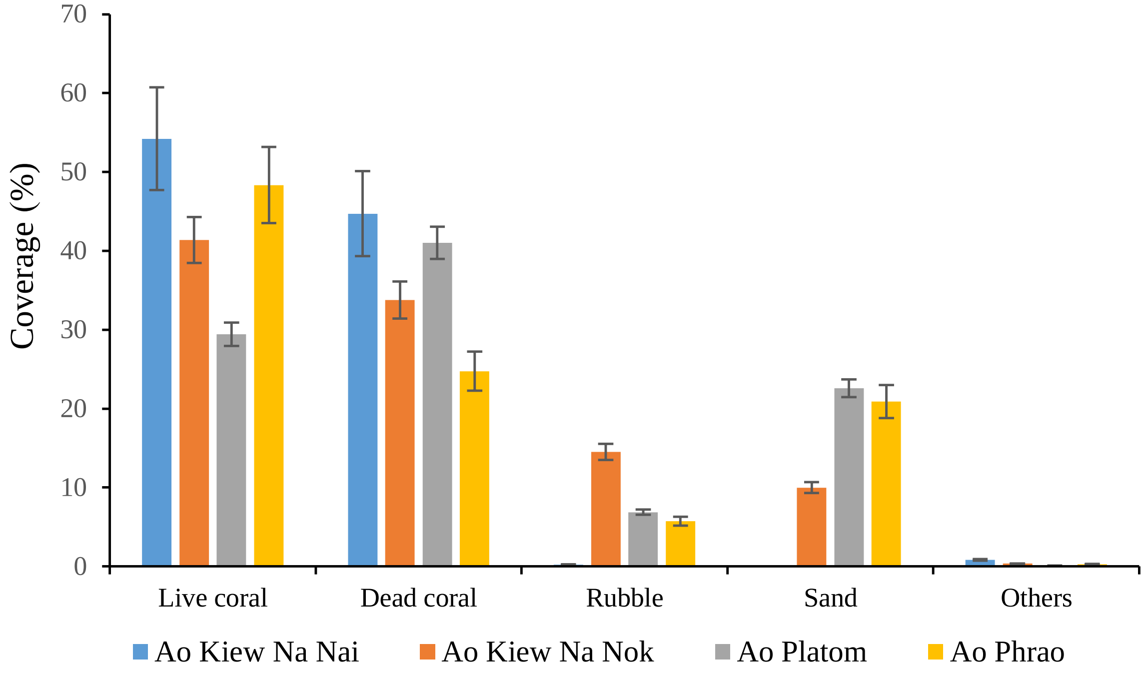

Figure 2. Average percent cover of benthic components at the study sites (Mean ± SE)

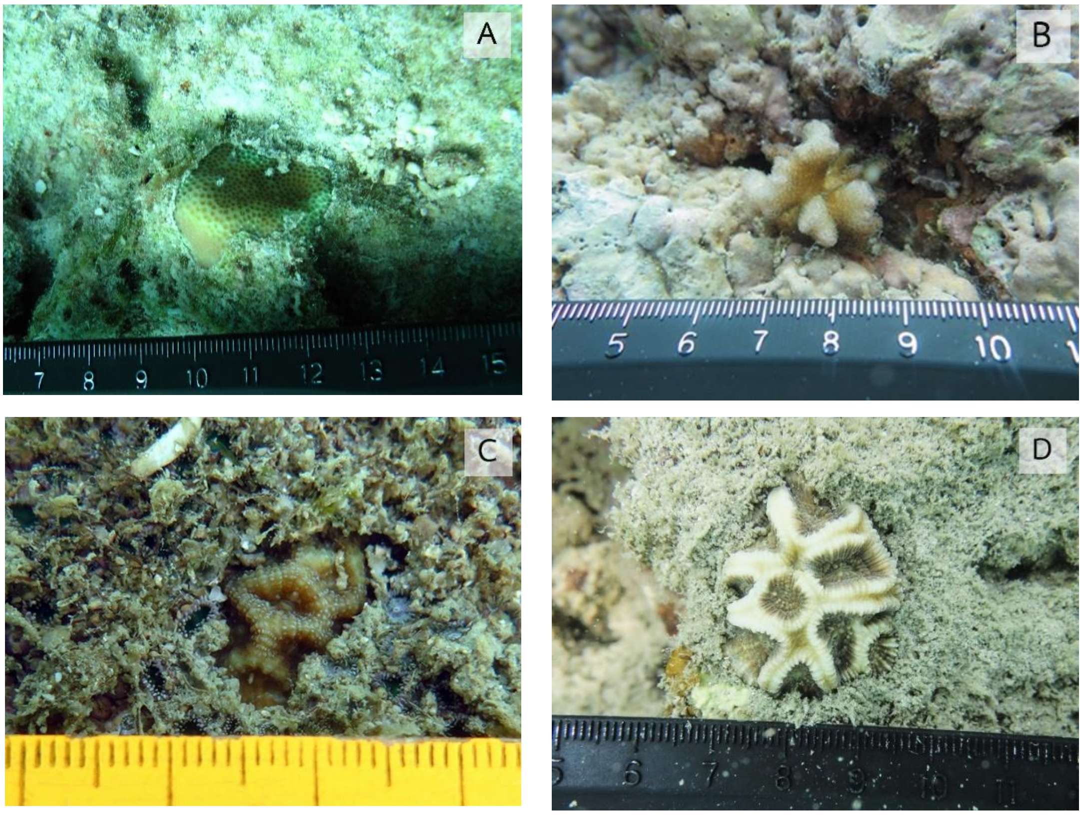

Figure 3. Some juvenile corals at the study sites in Mu Ko Samet; (A) *Porites* sp. (B) *Pocillopora* sp. (C) *Favites* sp. (D) *Favia* sp.

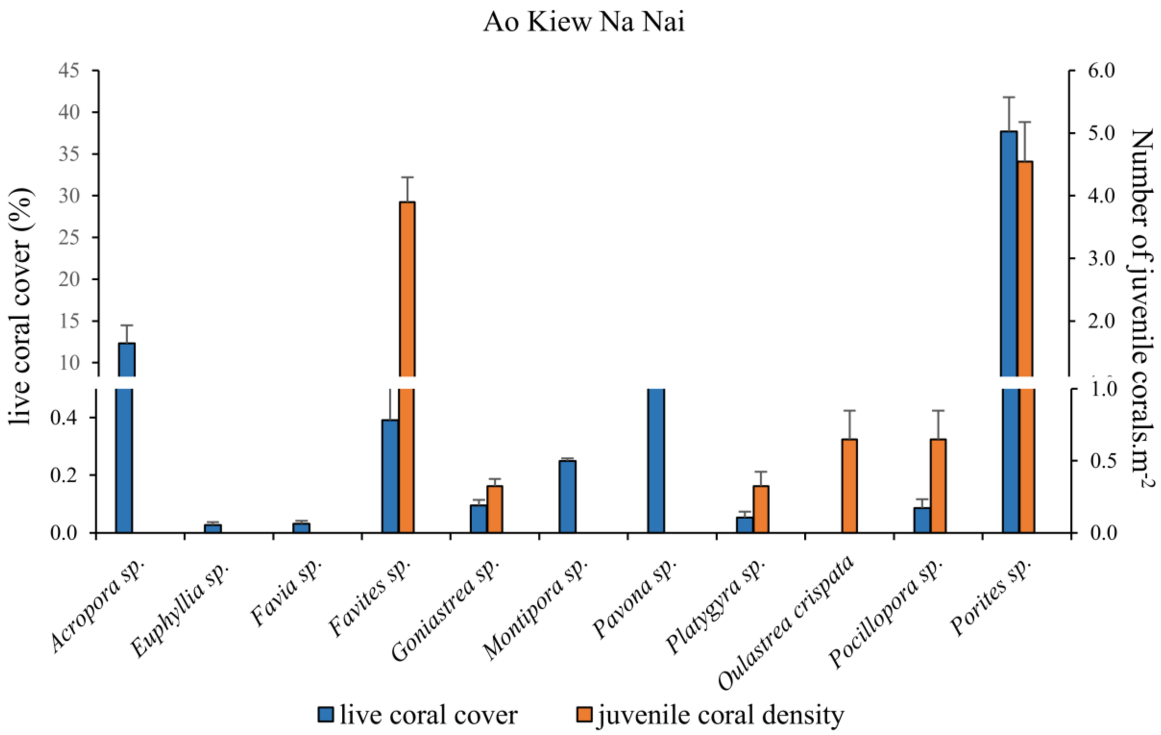

Figure 4. Compositions of live corals and juvenile corals at Ao Kiew Na Nai, Ko Samet (Mean ± SE)

Compositions of live corals and juvenile corals at Ao Kiew Na Nai are shown in Figure 4. The live coral cover was 54.2% and the density of juvenile corals was 23.8 recruits/m^2. Ten coral taxa were recorded as adult corals while six juvenile coral taxa were detected. Five coral taxa showed both adult corals and juvenile corals, i.e. *Favites* sp., *Goniastrea* sp., *Platygyra* sp. *Pocillopora* sp. and *Porites* sp. Five coral taxa, i.e. *Acropora* sp., *Euphyllia* sp., *Favia* sp., *Montipora* sp. and *Pavona* sp., had no their juvenile corals. There was only *Oulastrea crispata* having juvenile corals without their adult colonies

Compositions of live corals and juvenile corals at Ao Kiew Na Nok are shown in Figure 5. The live coral cover was 41.4 % and the density of juvenile corals was 11.5 recruits/m^2. Fifteen coral taxa were recorded as adult corals while nine juvenile coral taxa were detected. Eight coral taxa showed both adult corals and juvenile corals, i.e. *Acropora* sp., *Favia* sp., *Favites* sp., *Fungia* sp., *Goniastrea* sp., *Platygyra* sp., *Porites* sp., and *Symphyllia* sp. Seven coral taxa, i.e. *Coeloseris* sp., *Cyphastrea* sp., *Echinopora* sp., *Goniopora* sp., *Pavona* sp., *Podabacia* sp. and *Turbinaria* sp. had no juvenile corals. There was only *Leptastrea* sp. having juvenile corals without their adult colonies.

Compositions of live corals and juvenile corals at Ao Platom are shown in Figure 6. The live coral cover was 29.4 % and the density of juvenile corals was 17.2 recruits/m^2. Eleven coral taxa were recorded as adult corals while six juvenile corals taxa were detected. Four coral taxa showed both adult corals and coral recruits, i.e. *Favites* sp., *Pavona* sp., *Porite*s sp., and *Symphyllia* sp. Seven coral taxa, i.e. *Acropora* sp., *Astreopora* sp., *Cyphastrea* sp., *Goniopora* sp., *Platygyra* sp., *Plerogyra* sp. and *Podabacia* sp. had no juvenile corals. There were two juvenile corals taxa without their adult colonies, i.e. *Favia* sp. and *Fungia* sp

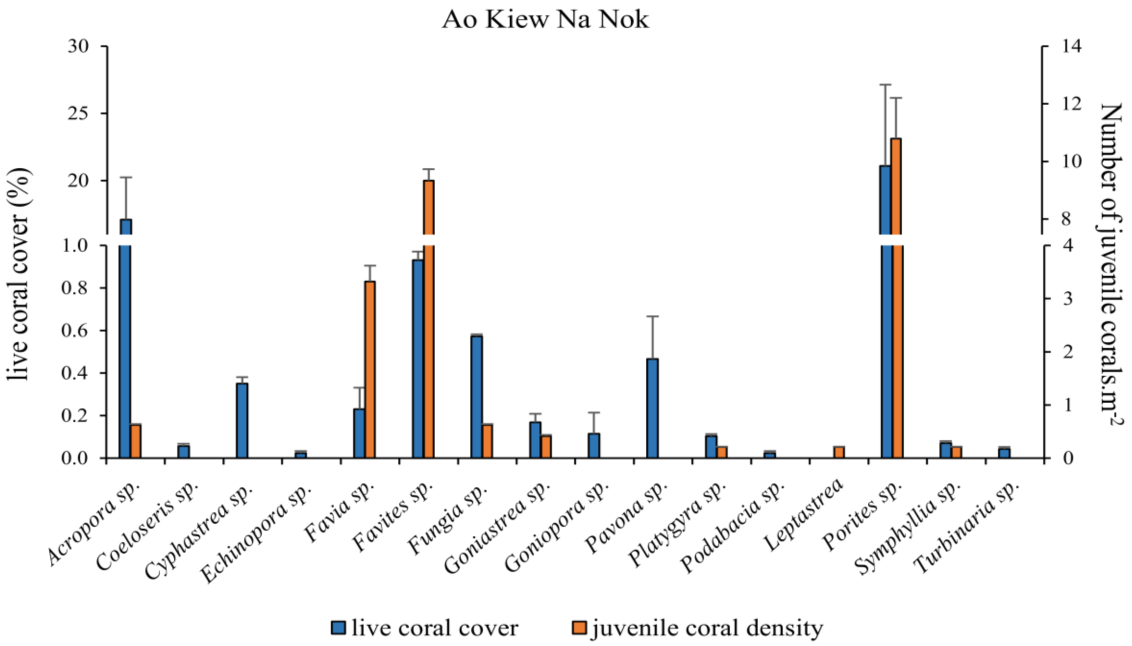

Figure 5. Compositions of live corals and juvenile corals at Ao Kiew Na Nok, Ko Samet (Mean ± SE)

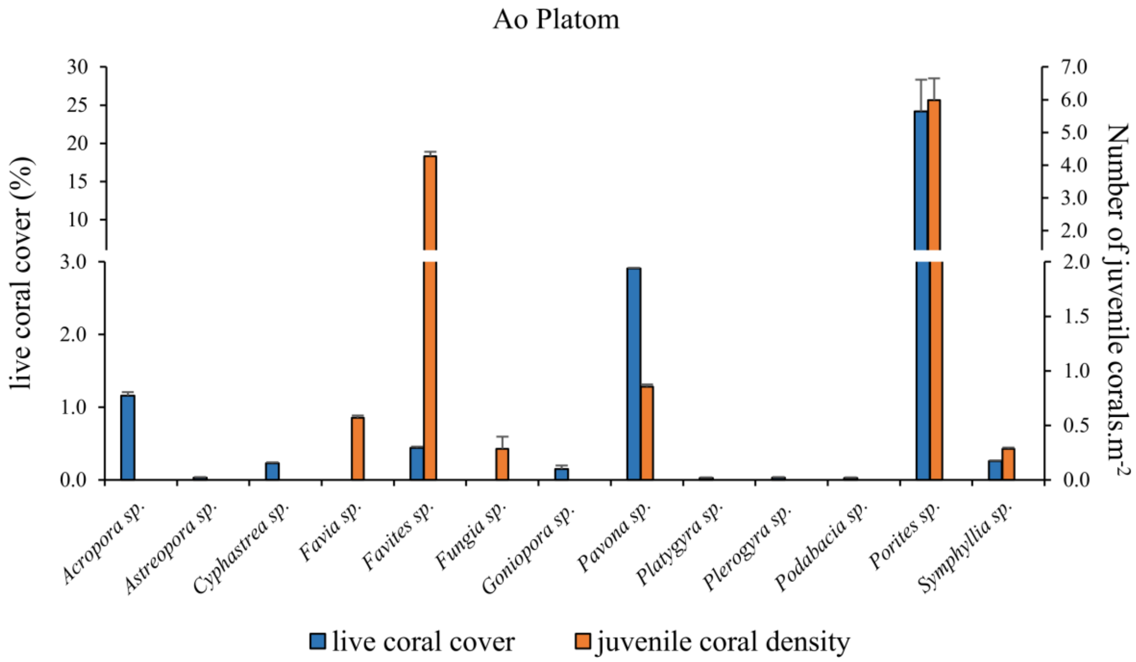

Figure 6. Compositions of live corals and juvenile corals at Ao Platom, Ko Samet (Mean ± SE)

Compositions of live corals and juvenile corals at Ao Phrao are shown in Figure 7. The live coral cover was 48.3 % and the density of juvenile corals was 7.8 recruits/m^2. Nine coral taxa were recorded as adult corals while seven juvenile corals taxa were detected. Four coral taxa showed both adult corals and juvenile corals, i.e. *Acropora* sp., *Favites* sp., *Pavona* sp. and *Porite*s sp. Five coral taxa, i.e. *Pocillopora* sp, *Diploastrea heliopora*, *Mycidium* sp., *Podabacia* sp. and *Symphyllia* sp. had no their juvenile corals. There were three juvenile corals taxa without their adult colonies, i.e. *Fungia* sp., *Oulastrea crispata, and Turbinaria* sp.

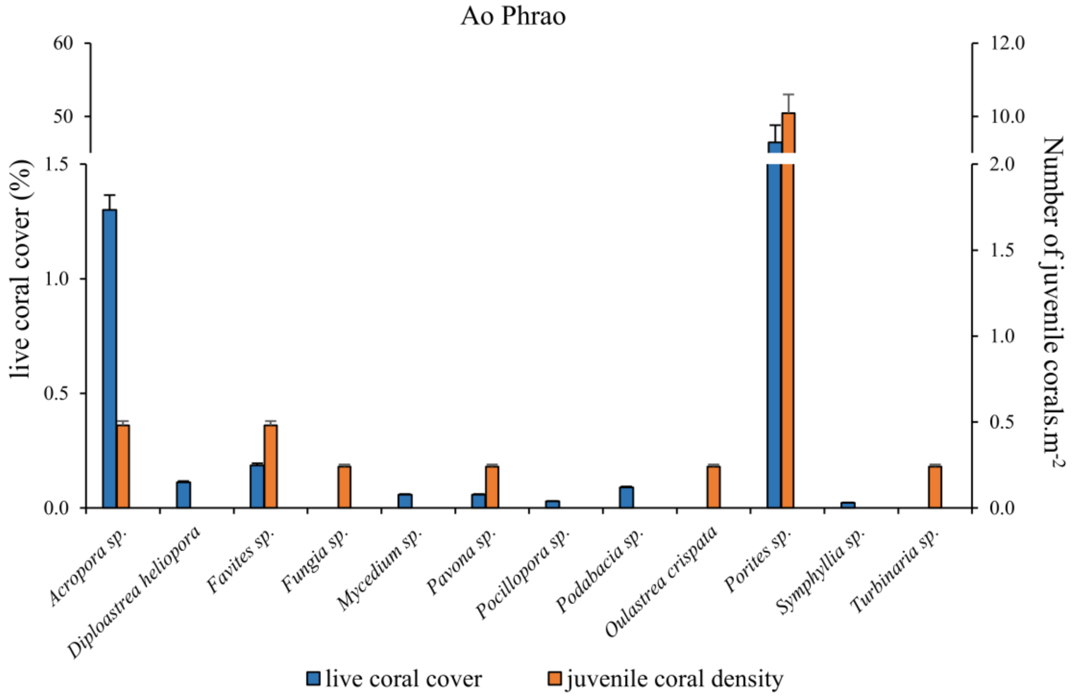

Figure 7. Compositions of live corals and juvenile corals at Ao Phrao, Ko Samet (Mean ± SE)

4. Discussion

The coral reefs in Mu Ko Samet had low impacts from fishing activities due to the regulation of the Khao Laem Ya–Mu Ko Samet National Park. Tourism activities at the study sites were also relatively low and have no direct impacts to the reproduction and recruitment of corals. The oil spill incident in the Eastern Gulf of Thailand in July 2013 had low impacts on corals in Mu Ko Samet (Chamchoy et al. 2014). Coral conditions at all study sites except Ao Platom were categorized as good condition. The density of juvenile corals recorded in this study (7.8-23.8 recruits/m^2) was comparable to those values reported from Mesoamerican barrier reef (Ruiz-Zarate and Arias Gonzalez 2004), Biscayne National park (Miller et al. 2000), Gulf of Thailand (Yeemin et al. 2009) and Indian Ocean Reefs (Manikandan et al. 2017) but lower than those from undisturbed coral reefs in the Chagos Archipelago and Palmyra Atoll (Sheppard et al. 2008; Roth and Knowlton 2009). Variations of juvenile coral density among reef sites are controlled by several factors, particularly sexual reproduction outputs in the parent coral reefs, larval mortality, dispersal of planulae and connectivity, settlement and post-settlement mortality of planulae, grazing pressure and sedimentation (Edmunds, 2000; Edmunds and Carpenter 2001; Yeemin et al. 2012b; Yeemin et al. 2013b, Bramanti and Edmunds 2016; Feng et al. 2016; Thompson et al. 2018). The live coral cover at Ao Phrao was much higher than that at Ao Platom while the density of juvenile corals at Ao Phrao was much lower compared to Ao Platom. This study supports the previous finding that the density of the juvenile corals was not dependent on the abundance of adult corals (Edmunds 2000).

Comparison of the diversity of adult corals with the diversity of juvenile corals showed that Ao Kiew Na Nok and Ao Kiew Na Nai are high degrees of self-seeding whereas Ao Phrao and Ao Platom are a low degree of self-seeding. Several coral taxa were observed at the study sites both adult and juvenile corals, i.e. *Acropora* sp., *Favia* sp., *Favites* sp., *Fungia* sp., *Goniastrea* sp., *Pavona* sp., *Platygyra* sp. *Pocillopora* sp., *Porites* sp. and *Symphyllia* sp. whereas juveniles of *Leptastrea* sp. and *Turbinaria* sp. were found with the absent of adult colonies. Our results also imply the connectivity potential of *Favia* sp. and *Fungia* sp. in Mu Ko Samet. Assessing retention and connectivity among coral populations over ecological time scales are essential for understanding coral self-seeding at particular reef sites. The brooding coral *Pocillopora* spp. were observed at Ao Kiew Na Nai and Ao Phrao. However, their juveniles were found only at Ao Kiew Na Nai. Although local retention and extremely short dispersal may be common in brooding species (Jones et al. 2009) post-settlement mortality plays a major role in controlling coral recruitment (Pengsakun et al. 2012).

Broadcast spawning is a major reproductive mode of corals and has evolved in many ecologically dominant corals, such as the *Acropora* spp. in the Indo-Pacific (Harrison et al. 1984). In this study, self-seeding was not observed in ten coral taxa, i.e., *Astreopora* sp., *Diploastrea heliopora*, *Euphyllia* sp., *Goniopora* sp., *Montipora* sp., *Mycedium* sp., *Plerogyra* sp., *Podabacia* sp., *Coeloseris* sp. and *Cyphastrea* sp., therefore, they may have low recovery rates after a severe disturbance. A long-term coral reef monitoring program should examine the maintenance mechanisms of low self-seeding corals in the Eastern Gulf of Thailand. The potential for inter-reef connectivity and successful recruitment in down-current populations is needed for proper management strategies and planning for coral reef restoration in the Gulf of Thailand.

In conclusion, this study provides knowledge on coral recruitment patterns and their relationships with coral community structures at Ao Kiew Na Nai, Ao Kiew Na Nok, Ao Platom and Ao Phrao, Mu Ko Samet, Rayong Province, the Eastern Gulf of Thailand. The self-seeding of corals was significantly different among reef sites. Ao Kiew Na Nai showed a high degree of coral self-seeding. Further studies should be focused on coral reef connectivity in the Gulf of Thailand through studies on climate and oceanographic variability and molecular genetic applications.

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