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Observation of Scleractinian juveniles' composition, distribution, and density in shallow waters of Kondang Merak Beach, Southern Malang, East Java, Indonesia

ROSDIANTO[1,♥], OKTIYAS MUZAKY LUTHFI[2], ANWAN RAHMAT ARDIANSYAH[2], M. AZUREA BAHRI LUTHFI[2], ANDIK ISDIANTO[2], DESY SETYONINGRUM[2], ARIEF SETYANTO[3], LISA NUR HIDAYAH[3], AULIA LANUDIA FATHAH[4], BERLANIA MAHARDIKA PUTRI[5], NOVAR KURNIA WARDANA[6], SUPRIYADI[7]

[1]Department of Marine Science, Sekolah Tinggi Pertanian Kutai Timur. Jl. Soekarno Hatta, Kutai Timur 75683, East Kalimantan, Indonesia. Tel.: +62-549-2031985, ♥e-mail: rosdi_anto@yahoo.com
[2]Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran 1, Malang 65145, East Java, Indonesia
[3]Department of Fisheries, Faculty of Fisheries and Marine Science, Universitas Brawijaya. Jl. Veteran 1, Malang 65145, East Java, Indonesia
[4]Graduate Program of Environmental Resource Management and Development, Universitas Brawijaya. Jl. MT Haryono 169, Malang 65145, East Java, Indonesia
[5]Graduate Program of Environmental Sciences, Universitas Gadjah Mada. Jl. Teknika Utara, Sleman 55284, Yogyakarta, Indonesia
[6]Faculty of Vocational, Universitas Pertahanan. Kakuluk Mesak, Belu 85752, East Nusa Tenggara, Indonesia
[7]Doctoral Program of Ocean Resource and Environmental Changes. National Taiwan Ocean University. Keelung City 202, Taiwan (R.O.C)

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Abstract. *Rosdianto, Luthfi OM, Ardiansyah AR, Luthfi MAB, Isdianto A, Setyoningrum D, Setyanto A, Hidayah LN, Fathah AL, Putri BM, Wardana NK, Supriyadi. 2024. Observation of Scleractinian juveniles' composition, distribution, and density in shallow waters of Kondang Merak Beach, Southern Malang, East Java, Indonesia. Biodiversitas 25: 2663-2668.* Kondang Merak Waters, a habitat for various hard corals that grow in flat areas of intertidal reefs, serve as a crucial location for understanding the influence of juvenile corals on the dynamics of coral communities in shallow waters. The research was conducted in 2020 in Kondang Merak, which studied the composition and abundance of young corals on natural substrates on shallow reef flats and reef slopes. Quadrant transects measuring 1x1 m were deliberately placed to observe coral juveniles at two research stations. Quadrant transects are placed along a 100-meter line transect. Visible juvenile corals are counted and identified at the genus or species level. The six types of coral juveniles identified are *Favites flexuosa, Goniastrea favulus, Goniastrea aspera, Porites lobata, Montipora digitata* and *Montipora foliosa*. The overall density of juveniles is low, ranging from 0.01-0.08 colonies m^{-2}, with the highest density belonging to *F. flexuosa* and the lowest belonging to *M. foliosa*. The six species found showed a clustered distribution pattern, except for two species, namely *Goniastrea aspera* and *M. foliosa,* which showed a uniform distribution pattern. Coral juveniles have specific strategies depending on biology and environmental factors. This study revealed the distribution and composition of coral juveniles in intertidal areas as representative of dynamic ecosystems in coastal areas.

Keywords: Coral community in shallow waters, coral juvenile, coral reproduction, quadrats transect, reef resilience

INTRODUCTION

Coral juveniles are young corals that have settled on the reef after spending some time as larvae in the water column (Cruz and Harrison 2020). Typically, their diameter is smaller than 5 cm, and they have not yet reached the stage of reproductive maturity (Pedersen et al. 2019; Koester et al. 2021). Coral juveniles develop from coral larvae and recruits (<1 cm), which are produced by various reproductive mechanisms among coral species (Koester et al. 2021). Coral larvae must find a suitable substrate and respond to specific cues to settle on the reef. These cues can be chemical, biological, or physical and are often associated with coralline algae, which are calcareous red algae that grow on the reef (Luthfi and Asadi 2021; Asadi et al. 2022). Once coral larvae settle on the reef, they undergo metamorphosis, transitioning from free-swimming to sedentary life.

During metamorphosis, coral larvae build a skeleton composed of calcium carbonate, which functions in firmly attaching them to the substrate. After metamorphosis, coral juveniles encounter many challenges that hinder their survival and development. Coral larvae must compete with other organisms, such as macroalgae, to maintain space, light, and nutrients (Isdianto et al. 2023). Adapt to many environmental stressors, including temperature, salinity, pH levels, Dissolved Oxygen (DO) concentrations, nitrate and phosphate levels, turbidity, water clarity, substrate composition, current velocity, wave height, total suspended solids, and pollution (Andika et al. 2020; Moira et al. 2020; Fikri et al. 2021). They must also protect themselves against predators like fish, snails, worms, and starfish (Rahimi et al. 2021). Coral juveniles must also be able to withstand viruses and parasites that could infect them. To overcome these challenges, they use various methods, including rapid growth, colony formation, morphological or color changes, and chemical production.

Many scientists concluded that coral juveniles are essential for reef recovery, as they can increase coral cover and diversity after disturbances such as bleaching or storms (Carlot et al. 2021). Some reef restoration projects in the northern Philippines have successfully contributed to enhancing coral recovery in those areas (Cruz and Harrison 2020; Ligson et al. 2020). Coral juveniles can also provide insights into the connectivity and resilience of coral populations as they reflect the reproductive output and dispersal patterns of adult corals. Moreover, coral juveniles contribute to the structure and function of coral reefs by adding new corals to the reef (Pisapia et al. 2019), creating new habitats and niches for other species (Brambilla et al. 2021), and enhancing the genetic diversity and connectivity of coral populations (Eckert et al. 2019). Coral juveniles also indicate climate change since they respond to environmental changes and stressors differently than adult corals (Evans et al. 2020).

Coral distribution in Kondang Merak has been reported by previous work with critical importance, such as the coral live percentage is low, under 25%, and was dominated by massive, foliose, and branching coral (Luthfi et al. 2023). Some micro atolls were found in the reef flat area, mostly from Poritids and *Goniastrea* coral (Asadi et al. 2022). Thus, scleractinians in Kondang Merak are treated by natural events such as increasing sea temperature that affects coral bleaching, disease, heavy metal contamination, bioeroder, and tourism activities (Luthfi et al. 2019; Asadi et al. 2022). This study aimed to extend knowledge of coral dynamics in the early life phase by monitoring the composition, distribution, and density of coral juveniles. We also explained how environmental and anthropogenic factors affect coral juvenile success in the most dynamic shallow water areas.

MATERIALS AND METHODS

Study site and juvenile identification

The research was conducted from July 2020 to November 2020 in Kondang Merak (8° 23'48.64"S-112° 31'1.56"E), Malang District, East Java, Indonesia (Figure 1). The coral juvenile in this research is defined as a young coral that has settled onto a substrate and begun to grow, with the longest diameter ≤10 cm. A quadrant transect from PVC 1x1 m (1 m^2) was placed following a 1 x 100 m line transect in two stations, resulting in 200 m^2 of Kondang Merak reef flat area (Figure 2).

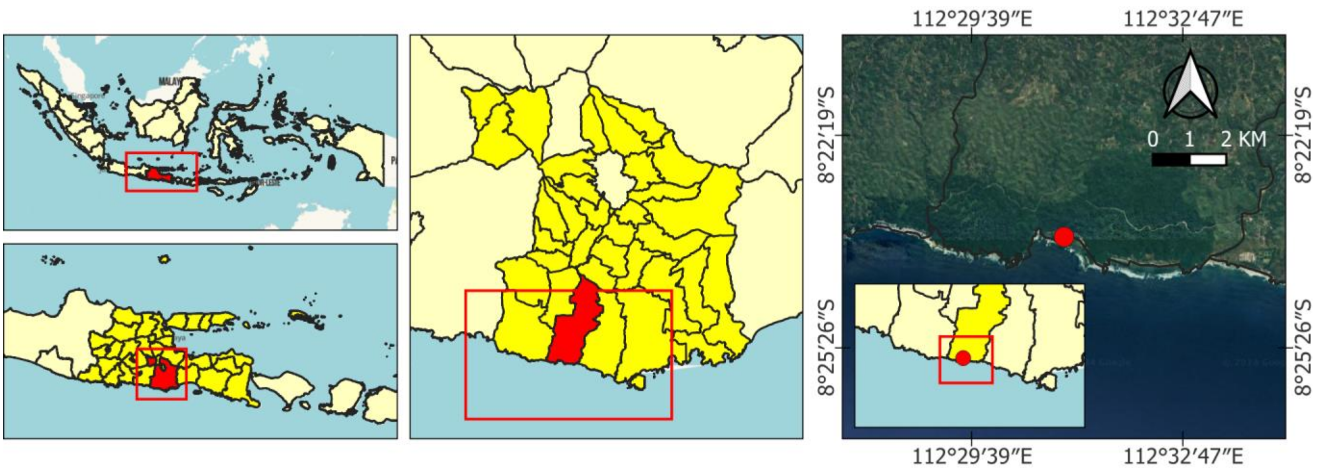

Figure 1. The area of study location in the Kondang Merak beach (8°23'48.64"S - 112°31'1.56" E), Bantur, Malang, East Java, Indonesia

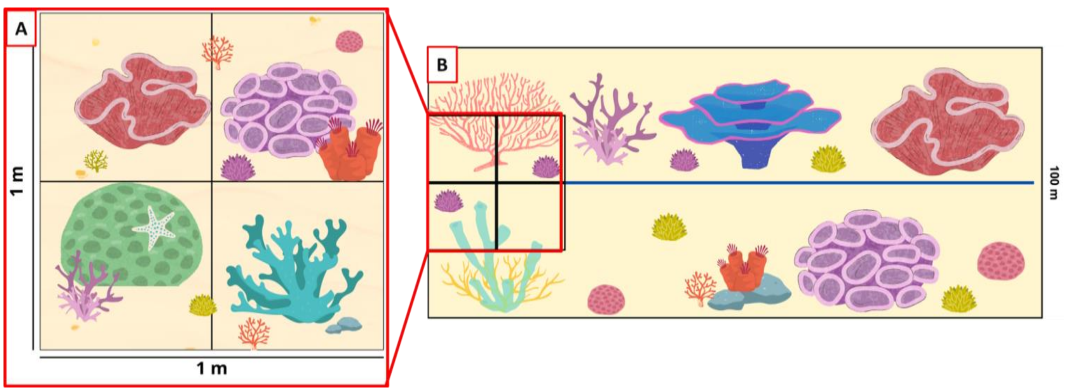

Figure 2. A. Quadrant Transect; B. Observation area

Each quadrant transect is divided into four sections, each 50 x 50 cm, and photographed at least five times (1 for the whole frame and 4 for each section) using an underwater camera, Olympus Tough TG-5 (Japan). Image-J software was used to measure the coral juvenile, summarized in an MS Excel file.

Data analysis

Coral juvenile density

In general, density has been defined as the number of species population present in an established area. At the same time, this study was determined by collecting several coral juveniles in one quadrant transect. This definition can then be written into the following formula:

$$D = \frac{P}{A}$$

Where: D: Coral juvenile density (colony.m^{-2}); P: Coral juvenile population number (colonies); A: Area (m^2)

The composition of coral juveniles was shown for each coral juvenile to a total number of coral juveniles. The distribution pattern of coral juvenile species in the Kondang Merak has been used Morisita Index to measure the dispersion of individuals in a population and used to compare overlap among samples. The index ranges from -1 (no similarity) to 1 (complete similarity). The Ip value can conclude the dispersion pattern, in which Ip = 0 indicates a random pattern, Ip>0 indicates a clumped pattern, and Ip<0 indicates a uniform pattern (Krebs 1989). The index is calculated as follows:

$$I_d = n\left[\frac{\sum x^2 - \sum x}{(\sum x)^2 - \sum x}\right]$$

Where: I_d: Morisita Index, n: Number of sampling quadrants, x: The number of individuals found in each plot

RESULTS AND DISCUSSION

Composition coral juvenile

The composition of coral juveniles is shown in Figures 3 and 4. The result showed that the highest composition at the Kondang Merak station was obtained by *F. flexuosa* (30.61%), followed by two other massive corals, *Goniastrea* and *Porites*. The adult colony form of this juvenile is massive (CM), which has a spawner reproduction type that can spread coral larvae far from their parent colony. Coral juveniles have specific morphological characteristics, which are cardioid to almost the placoid shape of the corallum. This coral also has thick walls with more distinct septal spine (Isomura et al. 2014). This type of coral is widespread in tropical and non-tropical areas with a spawner reproductive type. The research on coral reproduction by Gilmour et al. (2016) showed that only *F. flexuosa*, possibly *Favites pentagona* and *Montipora undata*, are thought to spawn in spring or early summer among non-*Acropora* species. In contrast, the proportion of colonies in *Acropora* species known to spawn during spring is generally low. The consistency of this coral spawning regularly, the physical and chemical oceanographic factors that support it, and the lack of predators make juvenile coral *F. flexuosa* dominate in the waters of Kondang Merak.

The lowest species composition was *M. foliosa* (2.04%) where the number of *M. foliosa* colonies was known to be small in the Kondang Merak area. Colonization of *Porites microatoll* coral in Kondang Merak was carried out by six different coral species, namely: *Porites lobata*, *Porites cylindrica*, *Pocillopora damicornis*, *Montipora capricornis*, *M. foliosa* and *Goniastrea* sp. which a total number about 200 colonies. *M. foliosa* was only found in 20 colonies of all the colonies that had been reported (Luthfi et al. 2017).

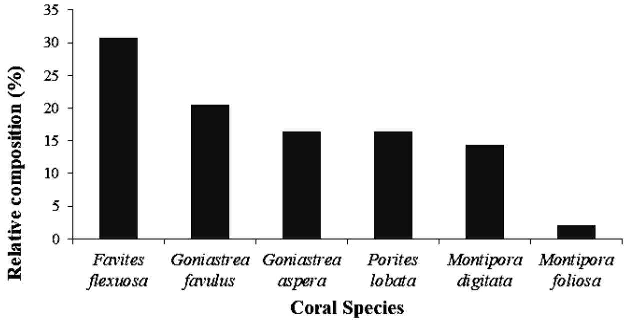

Figure 3. Composition of juvenile coral species in the Kondang Merak beach, Malang, Indonesia

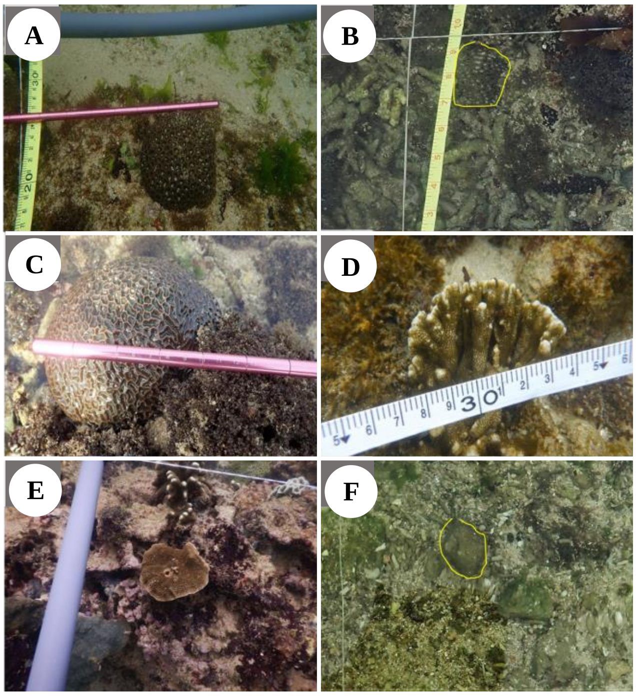

Figure 4. Coral species found in the study area of the Kondang Merak beach, Malang, Indonesia. A. *Goniastrea aspera*; B. *Favites flexuosa*; C. *Goniastrea favulus*; D. *Montipora digitata*; E. *Montipora foliosa*; F. *Porites lobata*

The coral reef zone of Kondang Merak Waters, a reef flat zone strongly influenced by hydro-ocean conditions, is a unique and intriguing ecosystem. The form of coral growth in the reef flat zone or intertidal area is influenced by subaerial exposure, where at the lowest low tide, the coral will emerge to the surface and be exposed to direct air exposure. The temperature in the Kondang Merak Waters is the highest temperature of all research locations, namely with a value of 26.70±0.58° C; this is because data collection was carried out at the lowest low tide so that the subaerial exposure factor greatly influences the Kondang Merak Waters. The coral juveniles at the Kondang Merak station are dominated by corals with massive growth and encrusted forms, namely *Favites*, *Goniastrea*, and *Porites*. With their unique massive and encrusted forms, these corals resist extreme conditions. Tides are one of the factors that influence the form of coral growth that grows in waters that are influenced by tides, namely coral types resistant to direct exposure to sunlight and air, such as massive and encrusted corals (Halid et al. 2016).

Distribution coral juvenile

The clustered distribution pattern at the Kondang Merak was obtained by the species *F. flexuosa*, *G. favulus*, *P. lobata*, and *M. digitata* with the criteria of Ip>0 (Table 1). If two or more species with clumped distribution patterns were found in each quadrant transect, they were considered as having a clumped distribution based on Morisita Index. The species *G. aspera* and *M. foliosa* showed a uniform distribution pattern based on the criteria of Ip<0. Species that exhibit a uniform distribution pattern are characterized by only one colony in each quadrant transect, for example, species *M. foliosa*. Eight colonies of *G. aspera* were observed, each located on a separate transect. Therefore, the species was considered to exhibit a uniform distribution pattern.

Grouping using the Morisita Index is used to see the distribution of juvenile corals on a substrate; for sessile marine organisms like coral, spatial dispersal patterns are related to the life histories of coral that involve different reproductive methods. Spawner types usually tend to have characteristics with more dispersive juveniles, such as *G. aspera*, which has more dispersed and not clustered juveniles. At the same time, the brooder type will usually produce planulae that sink quickly and immediately attach to the substrate (Dornelas and Connolly 2008). The relationship between larval density and initial settlement in juvenile corals also greatly influences coral grouping. Brooding species produce competent planulae, allowing settlement within a few meters of an adult colony (Pedersen et al. 2019). In addition, the number of larvae produced by the dispersion and density of coral juveniles are also influenced by the adult colony. Coral settlement experiments conducted in the field showed that the number of larvae affected the distribution pattern of juvenile corals on a substrate; if the number of larvae <1,000 or 2,000 to 5,000 were dispersed, it would result in coral recruits being more dispersal and tending not to cluster (Cameron and Harrison 2020). Limited ability to disperse at a local spatial scale can lead to a positive correlation between the number of settlers and reproductive adults (Vermeij and Sandin 2008).

Density of coral juvenile

The highest density at the Kondang Merak station was *F. flexuosa*, with a value of 0.08 colonies/m^2. The lowest density results at the Kondang Merak station were obtained by the species *M. foliosa* with a value of 0.01 colonies/m^2 (Figure 5). The total density of juvenile coral species at the Kondang Merak was 0.25 colonies/m^2.

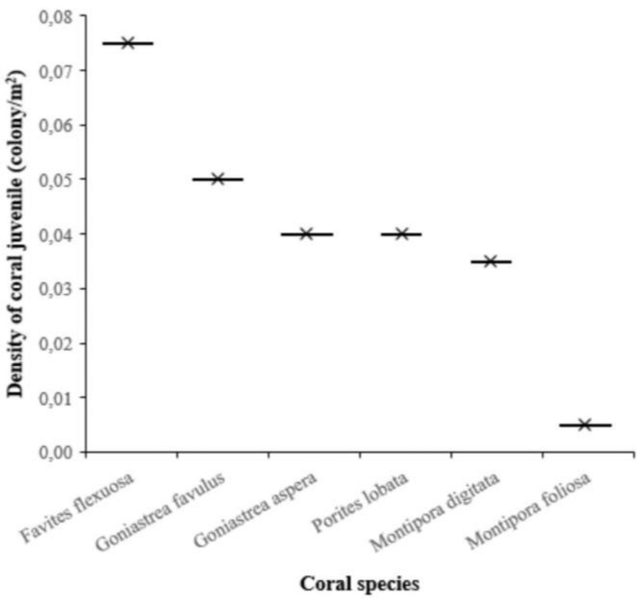

Figure 5. The density of juvenile coral species in the Kondang Merak beach, Malang, Indonesia

Table 1. Morisita distribution index of juvenile corals in the Kondang Merak beach, Malang, Indonesia

Species	I_d	M_u	M_c	I_p	Criteria	Dispersion
Favites flexuosa	3.81	4.122	9.331	0.45	Ip>0	Clumped
Goniastrea favulus	5.56	6.870	15.551	0.388	Ip>0	Clumped
Porites lobata	28.57	7.728	17.495	0.53	Ip>0	Clumped
Montipora digitata	9.52	8.832	19.994	0.544	Ip>0	Clumped
Goniastrea aspera	0	7.728	17.495	-0.074	Ip<0	Uniform
Montipora foliosa	0	61.826	139.960	-0.008	Ip<0	Uniform

Note: I_d: Morisita Index; M_u: Uniformity Index; M_c: Clustering Index; I_p: Standardized Morisita Index

The density of juvenile coral species in Kondang Merak is directly proportional to the species composition of the coral colonies. *F. flexuosa* has the highest density (0.08 colonies/m^2) compared to corals with other massive growth forms, *G. aspera* and *G. favulus,* and two types of coral with branching growth forms (*M. digitata*) and foliosa (*M. foliosa*). The first life form is a type of coral with slow growth, and the second is a category of coral with fast growth. The dominance of *F. flexuosa* was influenced by many factors, for instance, the biology of coral (availability of adult coral, regular reproductive system, parent colony has strong defense system) and oceanographic physics (support of reef flat shape, oxygen sufficiency, and micro-atoll). These factors are especially important in reef-building coral communities during the earliest stages of life, when reproduction provides mobility among stationary organisms and populations experience the most significant mortality bottlenecks before and immediately after settlement.

Naturally, the number of mature coral colonies in Kondang Merak is dominated by the genera *Porites*, *Favites*, *Pocillopora*, *Goniastrea*, and *Montipora* (Luthfi et al. 2016). Studies carried out in Palmyra Atoll showed positive correlations between the density of juveniles and the percentage of cover and density of adults (Pedersen et al. 2019). It is possible that the juvenile coral *F. flexuosa* found was the result of both asexual and sexual reproduction. Asexually, corals will perform fragmentation and fission by producing multiple daughter colonies (Pedersen et al. 2019). There are two forms of sexual reproduction: fertilization and brooding of the larvae within the polyp and external fertilization and development (Adjeroud et al. 2016). Since *F. flexuosa* is a spawner coral, this coral produces simultaneous eggs and sperms to the body of water to fertilize and then move to the next phase into recruits and coral juveniles (Isomura et al. 2014; Adjeroud et al. 2016). During this post-settlement phase, competition among reef biota and predator predation also threatened the coral juvenile. Still, some studies said these events did not affect coral juvenile distribution. The availability of parent colonies and the combination of asexual and sexual is a solid basis for why juvenile coral *F. flexuosa* dominates these waters.

Reef flat area in Kondang Merak is the broadest area in this reef, with coral and rubble dominated. At the highest tide, the depth of the reef flat area can reach 2-3 m and will change like land during the lowest tide, but many lagoons were still found that were inundated with seawater during the lowest tide, and so many types of coral live there. Most corals living in the reef flat area of Kondang Merak are encrusting, massive, branching, and laminar. Many juvenile corals are found living on other dead corals in the lagoon. Juvenile corals *F. flexuosa*, *G. aspera*, and *P. damicornis* lived side by side in the lagoon at Kondang Merak. Another advantage of living in a reef-flat area for corals is sufficient oxygen. Normal DO at sea corresponds to 3.4-13.6 mg/L^{-1} at 27°C. The reef flat area is a dynamic area where mass water transport occurs when currents and tides increase the gas exchange between water and sea, significantly affecting oxygen concentration (Nelson and Altieri 2019). Shallow reef environments, such as reef flats, tend to experience more significant daily fluctuations in oxygen levels compared to deeper reef environments, for coral oxygen plays a crucial role in the physiological processes of corals, both directly and indirectly, including respiration, photosynthesis, and calcification (Wijgerde et al. 2014; Linsmayer et al. 2020; Moskovich et al. 2023; Pezner et al. 2023).

The existence of a micro-atoll in Kondang Merak is like a tidal garden in a reef flat area because it has a large average size of 2.35-2.41 m^2, which can protect other biota from strong currents, waves, and drought at the lowest tide. The micro-atoll in Kondang Merak is formed from 3 hard coral genera, namely *Porites, Goniastrea,* and *Favites* (Luthfi et al. 2016). Furthermore, the micro-atoll also acts as a micro-habitat for various biota, including coral juveniles, found mostly in the dead parts of the micro-atolls and outside the micro-atolls. According to Luthfi et al. (2016), on 23 micro-atoll corals in the Kondang Merak area, a micro-atoll will host 52 other hard coral colonies, not including various microalgae and other bioeroders.

The lowest density at the Kondang Merak was the *M. foliosa* species, with a density of 0.01 colonies/m^2 because only one colony was found in the observation area. This result is the same as in the previous stations, which had the lowest density of *M. foliosa* corals, related to the reproduction pattern of the *M. foliosa* corals. Like *Acropora*, *Montipora* species are known to participate in annual mass spawning events in the GBR, and multiple simultaneous spawning has also been recorded in Hawaii, Japan, and Indonesia. The products of the sexual reproduction of coral are used for dispersal and recruitment to distant areas, which is crucial for genetic connectivity among coral populations and for maintaining healthy and resilient coral ecosystems (Grupstra et al. 2020; Doropoulos and Roff 2022).

The coral reef zone in Kondang Merak waters is a reef flat zone strongly influenced by hydro-oceanic conditions. Corals in the reef flat zone or intertidal areas growth form is influenced by subaerial exposure, where when the lowest ebb occurs, the coral will come to the surface and be exposed to direct air exposure (Castrillón-Cifuentes et al. 2017). The temperature in the waters of Kondang Merak is 26.70±0.58° C, which will be higher during the low tide event. Juvenile corals found at the Kondang Merak are dominated by corals' massive and encrusting life forms because they have resistance to extreme conditions. Tides are a factor that affects the shape of coral growth to adapt to environmental factors and also limit the population rate (Ferns 2016). These types of coral can withstand direct exposure to sunlight and air, such as massive and encrusting corals (Lyu et al. 2022).

The highlight of our essential finding in this research has shown the majority of coral juveniles in Kondang Merak were clumped, which indicates that most coral colony parents have brooder sexual methods. Further research on coral reproduction should be done to determine the type of coral reproduction. From 49 coral juveniles, the massive coral *F. flexuosa* was the most dominant in distribution, density, and composition. Many factors can support this successfully, mainly from the biological and environmental conditions of reef flats at Kondang Merak.

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