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Population and distribution patterns of juvenile scleractinian corals in Sempu Island Nature Reserve, East Java, Indonesia

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Abstract. *Isdianto A, Ishaq SY, Yamindago A, Iranawati F, Yanuar AT, Hidayah LN, Marsela K, Adhihapsari W, Lelono TD, Fathah AL, Atikawati D, Putri BM, Wardana NK, Supriyadi, Luthfi OM. 2024. Population and distribution patterns of juvenile scleractinian corals in Sempu Island Nature Reserve, East Java, Indonesia. Biodiversitas 25: 3480-3490.* Coral reefs, which play a vital role in tropical marine ecosystems, are threatened by anthropogenic and natural stressors, despite their important ecological and economic roles. This study examines the resilience of coral ecosystems through the lens of juvenile coral populations at Floating House Beach, which is part of the Sempu Island Nature Reserve, East Java, Indonesia. Using the Underwater Photo Transect (UPT) method along a 100-meter reference line with a 1 × 1-meter transect, our study found that coral cover was severely damaged, with live coral cover of only 18.67% and 17.61% at two observation stations, which was dominated by the life form CM (Coral Massive) at both stations. However, twelve juvenile coral genera were identified that showed potential for natural recovery, namely *Acropora, Favia, Favites, Galaxea, Leptoseris, Montipora, Mycedium, Platygyra, Pocillopora, Porites, Stylophora*, and *Turbinaria*. Juvenile coral densities were low, at 0.55 and 0.88 colonies/m², indicating a very low coral recruitment category with *Pocillopora* being the most common. Spatial distribution, analyzed using the Morisita Index, showed a predominantly clumped arrangement (Ip>0), indicating non-random aggregation of juveniles. The results of this study highlight the significant impact of environmental stressors on juvenile coral communities and underscore the urgent need for targeted conservation efforts to support coral resilience and recovery.

Keywords: Coral resilience, juvenile coral density, Morisita Index, oceanographic parameters, Underwater Photo Transect (UPT)

INTRODUCTION

Coral reefs are typical ecosystems of tropical waters, habitats for various marine life to grow and reproduce in a symbiotic life. Coral reef ecosystems have a major role for the environment in the fields of ecology and economics (Shah 2021). Ecologically, coral reefs play a role in maintaining coastal stability, protecting from waves and coastal erosion, as a life support for various marine organisms, namely spawning, enlargement and feeding areas economic benefits of coral are by supporting capture fisheries, tourism activities, and as a building material (Sukandar et al. 2022; Putri and Kamila 2023). The structural complexity of coral reefs provides essential habitats for a wide range of marine organisms, including commercially important fish species (Holbrook et al. 2015). This biodiversity not only enhances ecological stability but also supports significant economic activities, such as fisheries, tourism, and coastal protection (Shaver and Silliman 2017).

Coral reef ecosystems are widely utilized by communities, especially in coastal areas, because corals support fisheries and tourism activities. However, this utilization activity is not balanced with commensurate maintenance. Coastal communities in Sempu Strait are close to coral reef ecosystems that have the potential to exert pressure in the form of anthropogenic activities (Isdianto et al. 2023). These include household garbage and waste, the use of destructive fishing gear, oil spills from water transportation activities, and other activities that have direct or indirect impacts on coral reef ecosystems (Rafilu et al. 2020; Eddy et al. 2021). Coral reef ecosystems also suffer from natural pressures, such as global climate change which causes these ecosystems to be increasingly stressed (Shah 2021). Previous research in the waters of Sempu Strait indicates that coral reef cover conditions fall into the poor category, which ranges from 6-21% of the total substrate covered by live coral. This percentage represents the amount of the substrate that is covered by live coral in the surveyed area with Floating House beach is the research station that has the lowest coral cover (Isdianto et al. 2023). Low coral cover can be caused by anthropogenic activities, sedimentation, and competition from algae (Koester et al. 2021).

In the face of changes and pressures that have occurred, corals have their own ecosystem recovery efforts naturally, which can be seen in the appearance of young corals (juveniles) with a relatively small size as a sign that there has been the addition of new colonies in the coral community (Rafilu et al. 2020; Koester et al. 2021). A form of natural succession by corals to be able to restore their population is to carry out reproductive strategies and release larvae into water column. The settlement of larvae is crucial for the recovery and maintenance of coral populations, as it replenishes coral communities. This process helps maintain genetic diversity and supports the resilience of coral reefs, enabling them to recover from environmental disturbances (Lei et al. 2021). However, as is known, the Floating House Beach is the closest beach to the settlement. Settlements and their community activities certainly provide anthropogenic impacts that can affect coral reef recovery efforts at this location (Isdianto et al. 2023). Coral reefs are very vulnerable to changes in environmental conditions so that continuous monitoring is needed to be able to know their condition temporally (Luthfi et al. 2017).

This analysis studies the growth patterns of juvenile corals at Floating House Beach to gain insight into the process of sustainability of coral reef ecosystems. The research that will be conducted is expected to provide knowledge about the recovery of coral reef ecosystems and their vulnerability to disturbances, which can serve as a foundation for policymakers and conservationists to current restoration strategies and evaluate the effectiveness of ongoing coral reef conservation efforts, especially juvenile corals on Floating House Beach. It is intended that the sustainability of coral reefs in the Floating House and its surroundings can recover and be maintained.

MATERIALS AND METHODS

Study area

This research activity is located at Floating House Beach which is located in the south of Malang District, precisely in Tambakrejo Village, Sumbermanjing Wetan Sub-district, Malang District, East Java Province, Indonesia (Figure 1). The research was conducted on May 15, 2024. This beach was named Rumah Apung Beach because previously there were Floating Houses on this beach that were built and used by residents for fish ponds. The waters of Floating House Beach are incorporated in the same area as the waters of Sempu Island, or commonly known as Sempu Strait. The data collection location consists of two stations. Each station has its own characteristics.

Based on observations in the field, Station 1 is close to residential areas, so there are still many human activities or activities carried out around the area. Apart from that, this station is closer to the shipyard area which is usually used to transport tourists, so there is the potential for pollution from oil waste and other inorganic waste. There are housing, plantations, and shipbuilding and repair sites near the research area. Station 2 is located in the western part of the Floating House Beach. The access road to Station 2 is in the form of coral rocks so it tends to be difficult to pass. The difficulty of access to this place causes few people or tourists to be found doing activities in the western part of this Floating House Beach. At this station there is also freshwater input because it is close to the river mouth.

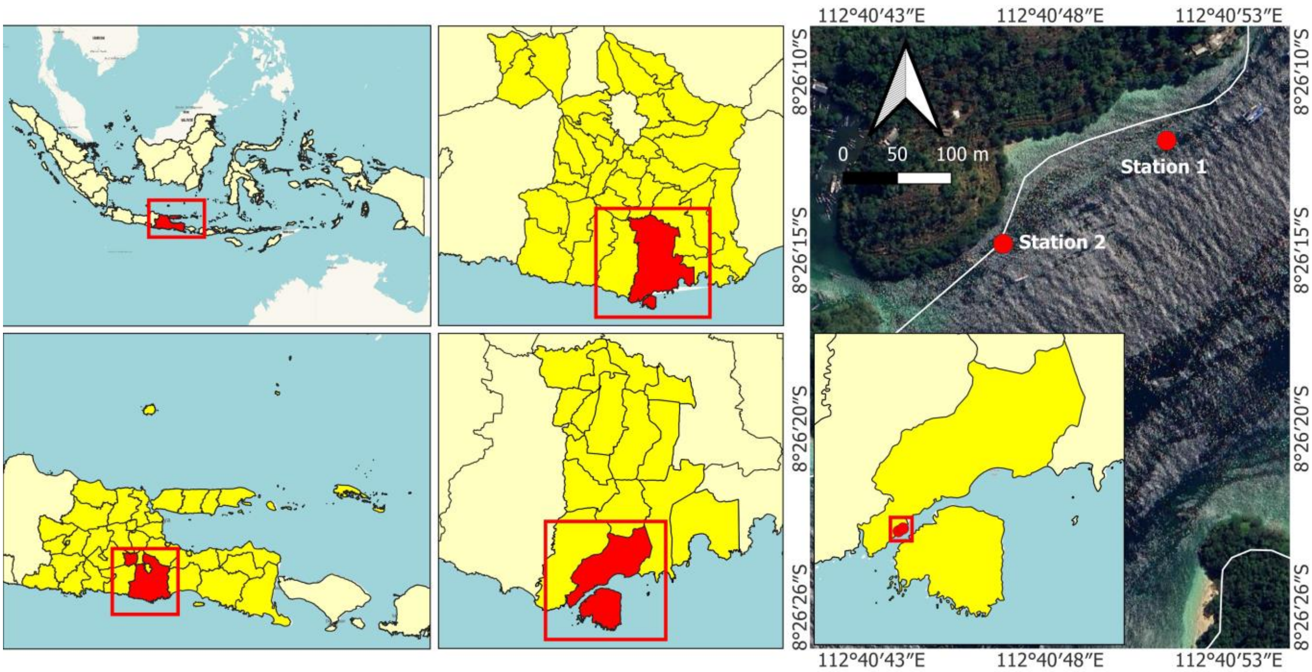

Figure 1. Map of research location at Floating House Beach, Malang District, East Java Province, Indonesia

Procedures

Coral data assessment

Data collection of coral cover and juvenile corals were taken in situ or data collection directly in the field. Data collection of coral cover and juvenile corals using the Underwater Photo Transect or (UPT) method which refers to Giyanto et al. (2014). This method is done by making a line transect or reference line along 100 meters parallel to the shoreline and start observing coral reef cover. Quadrant transects are used to see the composition of existing corals, using a quadrant transect measuring 1 × 1 meter. This aims to expand the observation area so that it is more representative of the condition of the research site. The placement of transect quadrants was placed with a consistent distance of 1 meter between quadrants, following a meandering pattern (Figure 2). The entire series of benthic data collection was collected by diving activities utilizing SCUBA equipment and underwater cameras.

Data collection of juvenile corals was also conducted using the Underwater Photo Transect method by taking pictures of each juvenile coral found in the transect. Naturally, there are three stages of larval settlement are pre larvae settlement, larvae settlement, and post larvae settlement. Observations of juvenile corals conducted for this study were at the post larvae settlement stage. In this study, the corals observed were all young coral colonies or juveniles that had fully attached to the natural substrate with a diameter of 1-5 cm. Each coral juvenile found was measured using a caliper and documented closely for more detail.

Oceanographic parameter data collection

Measurement of these parameters is done to complete the ecological monitoring stage of direct changes for coral reefs. Measurement of water parameters including temperature, salinity, dissolved oxygen and turbidity utilized the AAQ Rinko 1183 device. Current speed was measured using a current meter by extending the device into the water and observing the value on the display unit. Measurements were taken while the vessel was at anchor. At the same time as the boat stopped, brightness measurements were also taken using a secchi disc. Observation of water pH using a digital pH meter ATC by immersing the sensor in the solution. Meanwhile sedimentation rate data collection using a sediment trap. The sediment trap is installed vertically and securely to collect data on sediment accumulation. The sedimentation rate is determined by measuring both the weight and volume of the sediment gathered in the trap over a set period, providing insights into sediment dynamics and environmental impacts.These tools were calibrated before measurement to maintain data accuracy. The results of these parameter measurements were analyzed in relation to the abundance of juvenile corals found.

Calculation of distribution pattern

The spatial distribution pattern of a species or population is calculated using the Morisita Dispersion Index calculation which refers to the formula (Pozebon et al. 2019) as follows:

$$Id = n\frac{(\sum x^2 - \sum x)}{(\sum x)^2 - \sum x} \quad \text{..........................(1)}$$

Where:
Id: Morisita's Degree of spread
n : Number of transects
x : Total individuals on the transect

Then calculate the two Morisita Dispersion Index criteria, namely the Uniform Index and the Clumped Index using the following equation:

$$M_u = n\frac{x^2{}_{0.975} - n + \sum x_i}{(\sum x_i - 1)} \quad \text{...................(2)}$$

$$M_c = n\frac{x^2{}_{0.025} - n + \sum x_i}{(\sum x_i - 1)} \quad \text{................... (3)}$$

Where:
$x^2{}_{0.975}$ = Table value *chi-square* with df (n-1) which has a value of 97.5%
$x^2{}_{0.025}$ = The value of the *chi-square* table with df (n-1) which has a value of 2.5%
$\sum x_i$ = Number of individuals in the transect
n = Number of transects

Based on the results of the Mu or Mc values obtained, it is then calculated based on one of the following conditions:

(i) If Id>1, and Id≥Mc, using the formula $Ip = 0.5 + 0.5(\frac{I_d - M_c}{n - M_c})$
(ii) If Id>1, and Id<Mc, use the formula $Ip = 0.5(\frac{I_d - 1}{M_c - 1})$
(iii) If Id<1, and Id>Mu, using the *formula* $Ip = -0.5(\frac{I_d - 1}{M_u - 1})$
(iv) If Id<1, and Id≤Mu, using the formula $Ip = -0.5 + 0.5(\frac{I_d - M_u}{M_u})$

Morisita Distribution Index value

The Morisita Distribution Index value as follows:
Ip = 0 Random spread
Ip > 0 Group/clustered distribution
Ip < 0 Uniform/regular distribution

Data analysis

Data processing and analysis was carried out in a quantitative descriptive manner using Microsoft Excel. This processing aims to describe and draw conclusions from a phenomenon using values and interpreted in graphs and tabulations. The data used is in the form of juvenile coral abundance identification data, and distribution pattern data. In addition, supporting data were presented including the percentage of live coral cover that analyzed using CPCe software and water quality parameters. Data analysis is supported by a literature review by reviewing various literature (journal articles, theses, literature reviews and books) related to the topic discussed, namely the abundance of hard coral juveniles based on environmental characteristics. Those literatures were searched through database such as Google Scholar, ScienceDirect, and related platform Secondary data from the literature is utilised as a comparison reference to analyse and validate primary data collected in the field, allowing for a more thorough comprehension and drawing of conclusions.

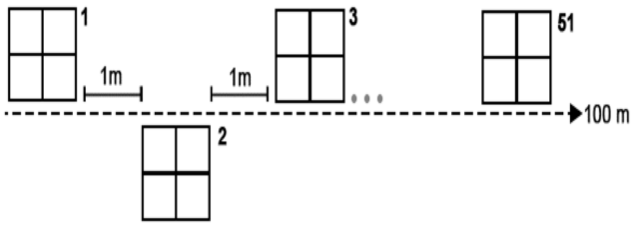

Figure 2. UPT data collection scheme

RESULTS AND DISCUSSION

Water quality parameters

Based on the results of data processing of benthic substrate conditions in the coastal waters of the Floating House. In this study, several factors were taken that are thought to affect the presence of juvenile corals. These factors include substrate type and water quality which includes temperature, salinity, pH, dissolved oxygen, brightness, turbidity, sedimentation, and current speed (Table 1). This assessment was carried out directly at the research location.

The temperature measurement at Station 1 was 24.65°C, while at Station 2 it was 24.50°C. The seawater quality standard for coral reef ecosystems according to Government of Indonesia (2021), the value range of 28°C-30°C, with a note that the natural conditions of the location can vary with time and season. Data collection took place during the 1st Transitional Season towards the Eastern Season which generally occurs upwelling so the temperature tends to be low (Atmadipoera et al. 2020). The optimal temperature for hard coral growth is around 23°C-29°C (NOAA 2024). Temperatures that are too low can cause the metabolic rate of corals to slow down or even completely stop (Sheppard et al. 2018).

Salinity at the two stations is not much different, namely at Station 1 worth 34.43 ppt and at Station 2 worth 34.45 ppt. The initial assumption at Station 2 which is close to the mouth of the river so that it causes lower salinity in this study was not proven. This is because data collection took place at high tide, so there was no brackish water input leading to Station 2 (Bakri et al. 2020; Revina et al. 2023). The salinity value at the study site is more than the optimal threshold. Salinity values that far exceed the threshold can disrupt the osmosis system in coral body tissues, causing loss of zooxanthellae and stunted coral growth (Ding et al. 2022).

The pH value in the waters of Floating House Beach is in the range of optimal values. Based on Government of Indonesia (2021), the quality standard set for pH ranges from 7-8.5. The pH levels outside the normal threshold affect the coral calcification process, especially in recruit corals or juvenile corals. In these conditions corals tend to have difficulty building $CaCO_3$ skeletons so that the resulting structure becomes smaller and more fragile (Foster et al. 2016).

Measurement of DO levels in the waters of Floating House Beach shows an optimal value of 6.8 mg/L. The quality standard value of oxygen levels in waters is more than 5 mg/L. Brightness at Station 1 is worth 7.21 meters while at Station 2 it is worth 7.2 meters. In this case the level of brightness in the Floating House Beach Waters is also in an optimal condition based on PP No. 22 of 2021, the value of good brightness is more than 5 meters.

Turbidity at Station 1 was 25.26 NTU and at Station 2 was 31.92 NTU. The high turbidity value of the waters at the research site is due to the time of the study taking place during high tide conditions which can transport sediment and cause particle stirring. The high turbidity value can also be caused by waves that are strong enough to cause the substrate to be lifted and become cloudy (Mi et al. 2020). Turbidity affects the level of sunlight penetration into the water. High turbidity values have a negative impact on the photosynthesis process of *zooxanthellae* and inhibit coral (Bessell-Browne et al. 2017). High turbidity values also reduce coral fertilization rates, despite the successful release of gametes (Lin et al. 2022).

Measurement of current velocity at Station 1 is 0.4 m/s and at Station 2 is 0.8 m/s. The condition of Sempu Waters is directly facing the Indian Ocean, which makes the current pattern and the movement of water masses influenced by the *South Java Current* phenomenon (Luthfi et al. 2014). Currents in the South Malang Waters tend to be strong in both the 1st and 2nd Transitional Season (Minarrohman and Pratomo 2017). Current enhances mass transfer that improved oxygen flux and inorganic carbon delivery, which are crucial for coral respiration and photosynthesis (Comeau et al. 2014), also removing sediments from their bodies. Currents that are too strong tend to compress the direction of coral growth while slower currents open up opportunities for corals to grow blooming or branching (Chindapol et al. 2013). The optimal current speed for corals is in the range of 0.1 m/s-0.4 m/s (Kesuma et al. 2024).

Coral morphology also play a crucial role in manages sediment, for instance, coral colonies with convex-shaped polyps are more effective in reducing the demand for active sediment clearing. This lessens the energy consumed in ciliary action to clear sediments and mucus production (Junjie et al. 2014). Meanwhile, corals with a branching form to remove sediment more efficiently by shedding sediment particles effectively (Fisher et al. 2018). Studies under different flow conditions have demonstrated that branching species can efficiently clear sediments than either large or plate-like forms (Browne et al. 2015; Duckworth et al. 2017).

The sedimentation rate at Station 1 was 87.85 mg/cm^2/day, while at Station 2 it was 64.36 mg/cm^2/day. Sedimentation rate has an inversely proportional relationship with the value of coral reef cover. Based on Pastorok and Bilyard (1985), sedimentation rates are divided into 3 categories: sedimentation values of 1-10 mg/cm^2/day (mild to moderate), 10-50 mg/cm^2/day (moderate to severe), and >50 mg/cm^2/day (very severe). High sedimentation rates can be lethal to corals especially in flat and creeping encrusting growth forms because sediment will tend to saturate their surfaces.

Table 1. Floating house water quality parameters

Parameters	Station		Optimal value
	1	2	
Temperature (°C)	24.65	24.5	28-30[a]
Salinity (‰)	34.43	34.45	33-34[a]
pH	7.8	8.1	7-8.5a
DO (mg/L)	6.8	6.8	> 5[a]
Brightness (m)	7.21	7.2	>5[a]
Turbidity (NTU)	25.26	31.92	<5[a]
Sedimentation Rate (mg/cm^2/day)	87.85	64.36	>50 mg/cm^2/day (very severe)[b]
Current (m/s)	0.4	0.8	0.1-0.4[c]

Source: a. Government of Indonesia (2021) on the Implementation of Environmental Protection and Management; b. Pastorok and Bilyard (1985); c. Kesuma et al. (2024)

Basic substrate condition

Rubble can dominate waters due to organism predation, coral disease, bioerosion, and extreme and unstable water conditions (Luthfi et al. 2019). Rubble or coral fragments are dynamic, easily moved and shifted by waves and currents. Rubble can impede recruitment by killing coral recruits and interfering with the binding mechanisms required to create a stable substrate (Kenyon et al. 2023). Substrate stability is an important factor for coral settlement and the early phase of coral life (juveniles) and rubble substrates cannot guarantee coral survival at this phase (Ceccarelli et al. 2020). Furthermore, addition of inorganic additives into the NHL-based substrates that contain the combination of strontium and magnesium carbonates enhanced the larval settlement process (Yus et al. 2024).

Dead Coral with Algae (DCA) is a major competitor for live corals. While dead coral skeletons provide a stable substrate that is ideal for young corals to attach to, the presence of algae on these skeletons creates significant competition for space and resources, hindering coral recruitment and growth. Algal overgrowth can block coral larvae from settling by covering available surfaces and competing for light and nutrients. Environmental factors, such as nutrient enrichment, can exacerbate algal growth, further limiting coral recovery (Nava et al. 2021; Najmi et al. 2023). Additionally, Fork et al. (2020) showed that dissolved organic matter influences nutrient limitation and the growth of benthic algae, indicating that ocean currents can indirectly impact algal productivity by altering nutrient and light availability. The introduction of organic waste into water bodies can also trigger large-scale algal blooms (Wear and Thurber 2015).

Coral cover

Based on the collected data, the hard coral cover at both stations in Floating House Beach falls into the "damaged" category, as outlined by KepMen LH No. 4/2001, which defines damaged coral reefs as having a cover percentage between 0% and 24.9%. At Station 1, the coral cover was recorded at 18.67%, while Station 2 showed a slightly lower percentage at 17.61%. These figures suggest considerable degradation of the coral reef ecosystem, likely caused by environmental stressors such as pollution or human activities. As previously mentioned, a coral reef ecosystem with a high percentage of rubble cover indicates significant physical damage, particularly affecting branching coral species. Furthermore, the high presence of dead coral overgrown with algae at this site suggests that many corals have been dead for an extended period, either due to losing competition with algae or suffering from health issues that ultimately led to their death.

Based on the form of growth, hard corals found in Floating House Beach include Acropora Branching (ACB), Acropora Digitate (ACD), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Massive (CM), and Coral Mushroom (CMR). The results of data processing show that coral cover at stations 1 and 2 has a hard coral composition dominated by life-form CM (Coral Massive) with a percentage of 8.42% at Station 1 and 8.36% at Station 2.

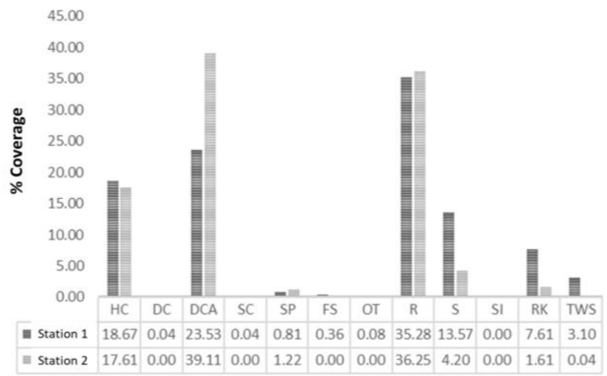

Figure 3. Benthic Substrate Cover. HC: Hard Coral; DC: Dead Coral; DCA: Dead Coral with Algae; SC: Soft Coral; SP: Sponge; FS: Fleshy Seaweed; OT: Other; R: Rubble; S: Sand; SI: Silt; RK: Rock; TWS: Tape With Shadow

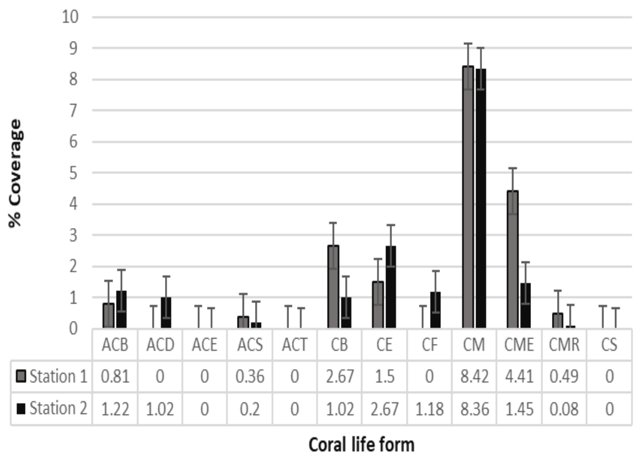

Figure 4. Hard coral cover. ACB: Acropora Branching; ACD: Acropora Digitate; ACE: Acropora Encrusting; ACS: Acropora Submassive; CB: Coral Branching; CE: Coral Encrusting; CF: Coral Foliose; CM: Coral Massive; CME: Coral Millepora; CMR: Coral Mushroom; CS: Coral Submassive

Massive corals tend to have a higher chance of survival compared to branching corals, particularly under stressful conditions. For instance, a study observed that large and encrusting coral transplants had survival rates between 50% and 100%, whereas branching corals showed much lower survival rates, ranging from 16.6% to 83.3% (Frias-torres et al. 2023). This is further supported by Ryan et al. (2019), which found significant differences in survival rates on reef platforms, with massive corals demonstrating greater resilience while branching corals faced high mortality. Physically, due to their larger tissue structures, massive coral often exhibit greater thermal resistance compared to the more fragile branching corals, which are more susceptible to disturbances such as cyclones (Barshis et al. 2018).

Juvenile coral identification

Based on the observation of juvenile corals in the coastal waters of the Floating House, 73 colonies of juvenile corals were found. These juvenile corals are scattered in Station 2 as many as 45 colonies and in Station 1 as many as 28 colonies. The results of this observation found 12 genus of hard corals which include *Acropora*, *Favia*, *Favites*, *Galaxea*, *Leptoseris*, *Montipora*, *Mycedium*, *Platygyra*, *Pocillopora*, *Porites*, *Stylophora* and *Turbinaria* (Table 2).

The dominant or most juvenile coral found in this study is the genus *Pocillopora* (Figure 5). The distribution of these corals can be found in almost all Indonesian and Western Pacific waters. *Pocillopora* corals have a good ability to recover and colonise, particularly in disturbance-prone areas. Their opportunistic behaviour is especially obvious in these areas, where *Pocillopora* and Porites corals are more dominant than sensitive species like Acropora (Adjeroud et al. 2018; Romero-Torres et al. 2020). *Pocillopora's* diverse symbiotic associations, notably with various kinds of dinoflagellates, allow them to adapt to changing environmental conditions, contributing to their widespread dispersion throughout the Indo-Pacific (Turnham et al. 2023). *Pocillopora* corals can still reproduce well and produce planula larvae even in conditions of warming sea water temperatures and ocean acidification (Bahr et al. 2020). The high density of juvenile *Pocillopora* corals is greatly supported by their reproductive mechanisms, particularly brooding, which allows for the development of well-adapted larvae (Goffredo and Dubinsky 2016). This reproductive method, together with the corals' capacity to thrive in a variety of settings, accounts for their success in coral reef ecosystems.

At Station 1, juvenile coral colonies of *Mycedium* species were found (Figure 6), however no corals of this type were found at Station 2. The distribution of *Mycedium* genus corals is common in Indo-Pacific Waters and Micronesian Islands. *Mycedium* corals live in environments that are protected from strong waves. This type of coral is generally found at depths of more than 5m or in waters where the light is not too bright (Blakeway et al. 2013; Law and Huang 2023). *Mycedium* corals belong to the *Merulinidae* family with a *spawning* mode of reproduction. This coral has a laminar or *Encrusting* shape. The shape of the corallite can be seen clearly, protruding and facing the direction of growth. The distance and size between the corallites are irregular (Bradley et al. 2022).

At Station 2, a number of *Acropora* and *Montipora* corals were found (Figure 7), while at Station 1 not a single juvenile of this type was found. This is assumed to be due to a greater concentration of adult coral with Acropora and Encrusting growth types than at Station 1 (Figure 4). Spawning is a reproductive method used by both Acropora and Montipora corals, and it has a substantial impact on juvenile density and recruitment success. Acropora species, with their biannual spawning patterns, exhibit a strong link between gametogenesis and juvenile density, with appropriate larval density increasing recruitment success (Gilmour et al. 2016; Doropoulos et al. 2017; Cameron and Harrison 2020). Similarly, Montipora corals, such as *Montipora capitata*, demonstrate spawning in response to lunar cycles and environmental conditions, influencing larval availability and juvenile density (Padilla-Gamiño and Gates 2012). In both species, reproductive success and juvenile survival are closely linked to spawning events and environmental conditions, highlighting the need of optimising these aspects to improve juvenile density and coral population dynamics (Henley et al. 2022; Rahnke et al. 2022).

Table 2. Identification table of juvenile corals found in the waters of Floating House Beach, Malang District, East Java, Indonesia

Genus	Reproduction mode	Station		Total
		1	2	
Acropora	*Spawning*	0	7	7
Favia	*Brooding*	4	4	8
Favites	*Brooding*	8	5	13
Galaxea	*Spawning*	5	4	9
Leptoseris	*Spawning*	0	1	1
Montipora	*Spawning*	0	5	5
Mycedium	*Spawning*	1	0	1
Platygyra	*Spawning*	0	1	1
Pocillopora	*Brooding*	10	12	22
Porites	*Spawning*	0	2	2
Stylophora	*Brooding*	0	2	2
Turbinaria	*Spawning*	0	2	2
Total		28	45	73

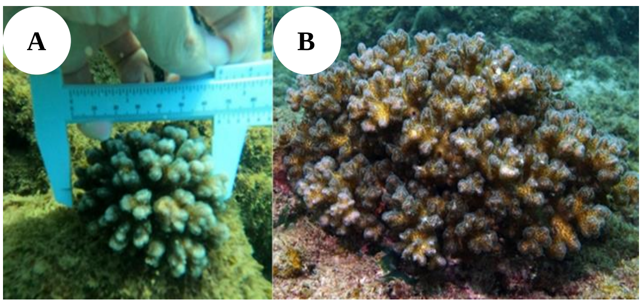

Figure 5. Corals of *Pocillopora* species; A. Juvenile *Pocillopora* corals found in the study area; B. Adult phase of *Pocillopora damicornis*

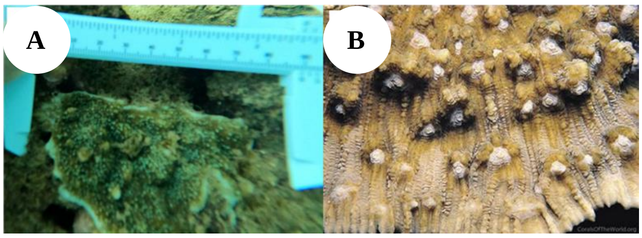

Figure 6. Corals of *Mycedium* species; A. Juvenile *Mycedium* corals found in the study area; B. Adult form of *Mycedium elephantotus*

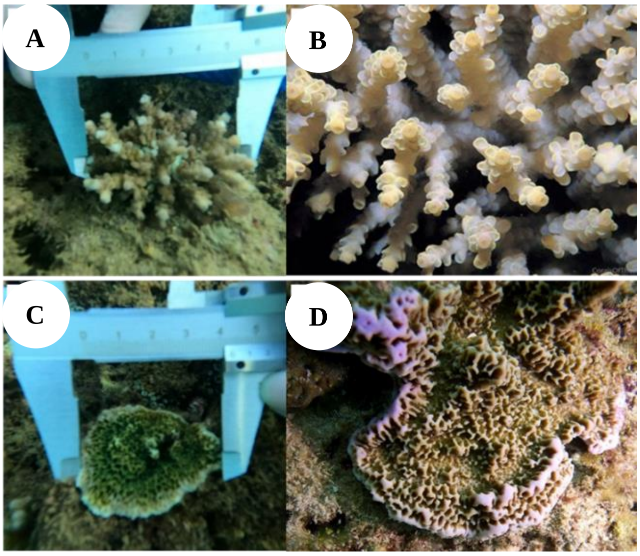

Figure 7. *Acropora* and *Montipora* corals; A. Juvenile *Acropora* corals found in the study area; B. *Acropora tennuis*; C. Juvenile Montipora corals found in the study area; D. *Montipora confusa*

Acropora corals are characterized by axial corallites at branch tips are cylindrical and can grow several centimeters, while smaller radial corallites along the branches are only a few millimeters in size. This structural variation isimportant to the growth and diverse colony shapes of Acropora, including arborescent, corymbose, and digitate forms (Humblet et al. 2015; Zhao et al. 2021). Montipora is a genus of corals recognized for its small, porous corallite structures, which are key for identification. This genus displays diverse growth forms, including sub-massive, foliose, encrusting, and branching morphologies, which are thought to be adaptive responses to different environmental conditions, enabling *Montipora* corals to thrive in various reef habitats (Han et al. 2023). *Montipora* grows optimally in waters with temperatures of 25°C-29°C and salinities in the range of 35‰ (Ko et al. 2019).

Abundance of juvenile corals

Based on the results of data processing, the abundance of hard coral juveniles in the coastal waters of the Floating House is calculated based on the number of occurrences divided by the area of the study area.

The results of data processing juvenile coral abundance at Station 1 is 0.55 colonies/m^2, based on the category of abundance value is included in the Very low category. The abundance of juvenile corals at Station 2 was found to be 0.88 colonies/m^2, which is included in the Very low category. Some factors that are thought to affect the low abundance of juvenile corals in the study site are sedimentation rates and high turbidity levels. The relatively small size of juvenile corals and recruit corals are very vulnerable to the impact of sedimentation. Corals affected by sedimentation will expend more energy to move particles from the surface of their body, for example by extending tentacle body tissue, mucus production, and movement of cilia/tentacles. If this continues to happen, corals will be at high risk of stress and even death, because each type of coral has a different ability to adapt to sediments.

The number of colonies at Station 1 is lower when compared to the number of colonies at Station 2. This is likely influenced by the conditions around the location of Station 1 which is closer to coastal settlements compared to Station 2. An increase in human or population density in coastal areas can cause a decrease in the number of juvenile corals or young corals (Couch et al. 2023). The existence of port waste, ship activities, ship waste and household waste are factors that greatly affect the sustainability of corals in Sempu Strait (Wibawa and Luthfi 2017).

The location of Station 1 is close to a ship repair yard that has the potential to cause oil and oil spills. This is certainly very dangerous because direct contact or dissolved oil if exposed to corals will cause coral stress and even death. Stress caused by oil contamination includes death to coral tissue, causing reduced fertilization rates and gamete formation, reduced larval production and attachment, and an increased risk of juvenile coral mortality (Fernandes et al. 2022).

Distribution pattern of juvenile corals

Morisita dispersion index is used to see the distribution pattern of juvenile corals in the coastal waters of the Floating House. The calculation results show varying values.

At Station 1, the distribution pattern of *Favia, Favites*, and *Pocillopora* corals shows an index value of more than zero (Ip>0), which means it is included in the clustering category. These three types of corals have a *brooding* reproductive mode. *Brooding* reproductive mode allows corals to produce planula larvae that are ready to attach to the substrate. *Pocillopora* coral larvae have the ability to attach to the substrate quickly and tend to settle on reefs close to their origin, but they require natural cues from biofilm bacteria to select a suitable substrate for settlement, and their settlement can be influenced by environmental factors such as sedimentation, which can block these recruitment cues (Perez et al. 2014). This causes coral distribution patterns to tend to cluster.

Table 3. Abundance of juvenile corals

Station	Abundance of juvenile corals	Category
Station 1	0.55 Colonies/m^2	Very low
Station 2	0.88 Colonies/m^2	Very low

Table 4. Distribution pattern of juvenile corals in the Floating House Beach waters

Genus	Station	
	1	2
Acropora	-	Clustering
Favia	Clustering	Clustering
Favites	Clustering	Clustering
Galaxea	Uniform	Clustering
Leptoseris	-	Random
Montipora	-	Clustering
Mycedium	Random	-
Platygyra	-	Random
Pocillopora	Clustering	Clustering
Porites	-	Clustering
Stylophora	-	Uniform
Turbinaria	-	Uniform

Note : (-) The genus was not found at that station

At Station 1, only *Galaxea* corals have a *spawning* reproduction model and the distribution pattern is included in the uniform distribution category, but at Station 2 the distribution is clustered. This coral is known to be relatively resistant to *bleaching,* but the specific threats to this type of coral are not yet known in depth. The ability of these corals to cope with changing climate and water conditions has not been well studied (Amir and Tallant 2022).

Mycedium corals have an index value of 0, which is classified into the random category. This is because only one colony was found from this *Mycedium* genus. The original habitat of *Mycedium* corals is located at a depth of 5-10 m and areas where the lighting is not too bright (Blakeway et al. 2013; Law and Huang 2023). It is possible that corals are carried by currents from other areas during larval dispersal. Larval dispersal is influenced by currents, although larvae can swim, their movement is minimal (Afandy et al. 2017). The same thing was found at Station 2, namely *Leptoseris* and *Platygyra* corals. In conclusion, an index value of 0 in coral distribution indicates a random pattern, which is typically due to the presence of only a single colony, making it difficult to establish a clear distribution pattern. Coral spatial dynamics are complex and shaped by many factors which require data from multiple colonies to accurately describe distribution pattern.

At Station 2, *Acropora*, *Favia*, *Favites*, *Galaxea*, *Montipora*, *Pocillopora*, and *Porites* coral species were found to be included in the clustering category. *Favia*, *Favites*, *Pocillopora* and *Porites* corals have a *brooding* reproductive mode so it is possible for these types of corals to spread in groups. *Acropora* and *Montipora* corals are corals that have a *spawning* mode of reproduction, but are found clustered at Station 2. This is likely due to the high turbidity and sedimentation conditions at Station 1 (Barus et al. 2018; Herawati et al. 2023).

Stylophora and *Turbinaria* corals are included in the uniform distribution category. Both of these corals have a reproductive mode that is *spawning*. The sedimentation rate at Station 2 supports these corals to grow well because *Stylophora* requires an environment with a low sedimentation rate (Widiastuti et al. 2023). *Turbinaria* corals are also known to be susceptible to exposure to pollutants such as ammonia. This is one of the possible reasons, why this coral was not found close to settlements that act as a source of pollution or at Station 1 (Spanton and Saputra 2017; Udomsap et al. 2018).

Contributions of juvenile corals to reef stability and recovery

This study conducted at Floating House Beach, located in the waters of Sempu Island Nature Reserve, has shown a direct correlation between juvenile coral density and overall coral reef ecosystem health. This indicates the important role of juvenile corals in supporting the recovery and stability of degraded coral reef ecosystems, as they represent the next generation of reef-building corals that can repopulate and restore damaged areas (Ussi et al. 2023). Although the area is categorized as “degraded” due to human activities and natural stressors, there are many diverse genera of juvenile corals indicating ongoing but slow ecosystem recovery. The low coral cover, with hard coral percentages of 18.67% and 17.61% respectively at the two study stations, coupled with the results of the environmental assessment, underscores the urgent need to improve conservation strategies in this area. Our findings show that juvenile corals with twelve genera were identified including *Pocillopora*, *Acropora*, *Montipora*, *Favia*, and *Porites*, with *Pocillopora* dominating the juvenile population. This is an important indicator of the potential resilience of coral reefs in this area and indicates ongoing recovery, albeit at a slow pace.

The clumped distribution pattern of juvenile corals further supports the need for local management practices that can encourage coral recruitment and subsequent ecosystem recovery. Juvenile corals often exhibit clumped distributions due to various ecological factors, including the availability of suitable substrates and the presence of adult corals that can enhance recruitment success. The strong coupling between juvenile corals and coral recruits, emphasizing that the density of juvenile corals is influenced by previous recruitment events, which can be affected by local environmental conditions and management practices (Edmunds 2021). Spatial patterns of juvenile corals are shaped by the surrounding habitat and the presence of adult corals, which can provide both physical structure and biological cues for recruitment (Pedersen et al. 2019). Successful coral recruitment is critical for establishing resilient reef communities, particularly in the face of environmental stressors (Giyanto et al. 2023). This study highlights the delicate balance between degradation and recovery, offering invaluable insights into the dynamics of coral ecosystems facing multiple stressors.

Juvenile corals are important indicators of ecosystem resilience, as they represent new growth and the potential for coral populations to expand and restore reef structure. The importance of juvenile corals in maintaining the balance of reef ecosystems, as they contribute to the structural complexity and biodiversity of coral habitats

(Richardson et al. 2018). The clustered distribution of juveniles, as seen in the Morisita Index results (Ip>0), indicates a strong potential for these juveniles to recruit in suitable habitats. This spatial distribution reflects a non-random pattern, which may be influenced by environmental conditions such as sedimentation, water quality, and human activities. For example, higher sedimentation at Station 1 likely explains the lower coral cover compared to Station 2, where better conditions were observed.

Implications for conservation and management

The presence of diverse juvenile coral species is a crucial indicator of the ongoing natural recovery processes within coral reef ecosystems, which is essential for their long-term sustainability. Juvenile corals represent new growth and potential for population expansion, and their diversity can enhance the resilience of coral reefs against environmental stressors. Although current coral cover may be low, the recruitment of juvenile corals can lead to increased coral cover over time, provided that local environmental conditions remain stable. Enhanced larval supply and recruitment can significantly replenish coral populations on degraded reefs, reinforcing the notion that local management practices aimed at improving environmental conditions can facilitate coral recovery (Cruz and Harrison 2020). This reinforces the need for conservation strategies aimed at reducing anthropogenic stressors, such as pollution and sedimentation, to provide a more conducive environment for juvenile coral growth and further ecosystem recovery.

In conclusion, the presence of diverse juvenile corals, even in such a short observation period, indicates ongoing recruitment and the resilience of the coral ecosystem in this area. Although long-term monitoring would provide more comprehensive insights, this initial assessment highlights key areas for future research and immediate conservation action. We recommend further studies to confirm these findings over extended periods, but the data collected during this assessment offer valuable initial insights into the condition of coral recruitment and recovery at Floating House Beach. Therefore, local management strategies that focus on mitigating stressors and improving habitat conditions are essential to ensure the long-term sustainability and resilience of the coral reef ecosystem in this area.

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