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Coral Reef Restoration for Coastal Protection: Water Quality Monitoring in Indonesia Coral Reef Garden Nusa Dua, Bali

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Abstract - The Indonesia Coral Reef Garden (ICRG) is a coral reef restoration program with Nusa Dua as one of five sites in Bali. A plantation program has been done by 2020, but it is necessary to monitor the condition. A field survey in Nusa Dua was carried out on October 3-4, 2022 to measure and check ocean parameters that are suitable for coral life and diving in artificial coral reefs installed. In the survey, several points had been measured through CTD Valeport Midas+ prior to measuring ocean parameters in the same location as a preliminary survey done two years in advance. The sea condition of temperature, salinity, pH, turbidity, and DO is 24.89 - 28.69 °C, 33.75 - 34.22 psu, 8.0 - 8.1, 1.19 - 4.27 FTU, and 4.47 - 5.24 mg/L, respectively. Based on the conformity of water quality, the water condition is good for coral growth. A total of 15 locations are used to put artificial coral reefs in many forms or structures. The coral plantation program in Nusa Dua shows promising progress in qualitatively consisting of species of *Montipora* sp., *Acropora* sp., and *Alcyonacea* sp. A continuous measurement is demanded to monitor the condition of coral growth quantitatively.

Keywords: coral reef restoration, ocean parameter monitoring, Indonesia Coral Reef Garden, Nusa Dua

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Introduction

Background

Over more than a hundred Marine Protected Areas in Indonesia, several spots are located in Bali (Doherty *et al.*, 2013; Ruchimat *et al.*, 2013) with the topmost priority and long term in saving marine habitat (Wicaksana, 2020). The Indonesia Coral Reef Garden (ICRG) program's objectives is to have coral reef restoration at five locations in Bali, namely Pandawa, Serangan, Sanur, Buleleng, and Nusa Dua (Untung, 2021). This program is organized by the government and supported by numerous stakeholders such as private sector companies, academic institutions (*i.e.* universities), NGOs, and local communities (*i.e.* student groups, diving clubs, etc.) (Razak *et al.*, 2022). This program also supports the local economy by absorbing the local workforce primarily when covid-19 pandemic hit and affected marine tourism activities (Tosepu *et al.,* 2020; Paramita and Putra, 2020).

Nusa Dua is located in the southern part of Bali around 22 kilometers from Denpasar (capital city of Bali). This area has a high level of marine biodiversity as part of the Coral Triangle and Marine Biodiversity. Indeed, Nusa Dua is part of the coastal and marine area that has become one of the priority locations for conservation areas in Bali. With a shoreline of around ±16 km, Nusa Dua is filled with many coastal and marine ecosystems, such as mangroves, seagrass, coral reefs, and species such as turtles, dolphins, sharks, and dugongs. As a result, Nusa Dua has an economic value for the local residents, especially marine tourism based on coral reef ecosystems. In 2012, coral reefs in Nusa Dua were 37% live and 63% dead, meanwhile in 2016, 85% were alive and 15% were dead since Nusa Dua has a lot of activity related to preserve and protect the coral reefs (Susiloningtyas *et al.*, 2018). However, on a global scale, around 20% of coral reefs have been affected due to destructive fishing practices and overexploitation for food, aquarium and trinket trade, and medicinal purposes (Burke *et al.,* 2002; Wilkinson, 2004; Burke *et al.,* 2011). Coral reefs play also an important role in protecting beaches from erosion by attenuating wave energy (Braithwaite *et al.*, 2022).

In supporting the coral plantation in Nusa Dua, preliminary survey activities were done in 2020 consisting of seabed and ocean parameter measurements (water temperature, salinity, dissolved oxygen, pH, turbidity) in determining the potential of the coral plantation area (Badriana *et al.*, 2021). Linear with the ICRG mission, a continuous monitoring of water quality assessment is necessary. These activities mainly include measuring ocean parameters and sightseeing coral plantations in Nusa Dua, Bali. The collected information therefore can be used as an evaluation and to determine further strategies for coral implementation areas and ecosystems locally.

Geological and Stratigraphical Settings

Coral reef in Nusa Dua is part of the coral triangle where the biodiversity in marine ecosystems is at its highest level (Susiloningtyas *et al.*, 2018). The high diversity presents as a consequence of its location as a passageway connecting the Pacific Ocean and Java Sea to Indian Ocean (Hoeksema and Putra, 2000). The Indonesian Throughflow (ITF) which passing through Lombok Strait near Nusa Dua carrying cooler and less saline water (Gordon *et al.*, 2010). This inflow can lower local sea temperatures that can be beneficial for coral resilience. Bali's regional geological structure began with activities in the ocean during the Lower Miocene which produced pillow lava rock and breccia interbedded with limestone. In the southern part of Bali, limestone deposition occurs which then forms the Selatan Formation (Figure 1). The rocks are mostly hard limestone. The thickness is around 600 m, and the slope towards the south is between 7 - 10°. Land with a slope of 0 - 2% dominates the southern coastal area. Fossil content consisting of *Lepidocyclina emphalus*, *Cycloclypeus* sp, *Operculina* sp, indicates Miocene age. Apart from Nusa Dua or Bali southern peninsula, this formation also occupies Nusa Penida Island (Purbo-Hadiwidjojo *et al.*, 1998; Zulmi *et al.*, 2015).

Limestone and beach sands in Nusa Dua formed by a combination of coral growth, precipitation, crystallization, tidal, and wave reworking (Nugraheni *et al.*, 2021). This reef carbonate platform is accumulated by breakup and fragmentation of calcareous skeletons from marine organisms (corals, algae, mollusc, and more).

Methods and Materials

Methods

Ocean parameter survey was conducted in Nusa Dua, Bali utilizing CTD Valeport Midas+ to determine ocean parameters. Data collection was carried out on October 3-4, 2022. The depth is measured first using a portable depth sounder. The CTD instrument was pulled down until 0.8 (80%) of total depth or around 5-10 m above the

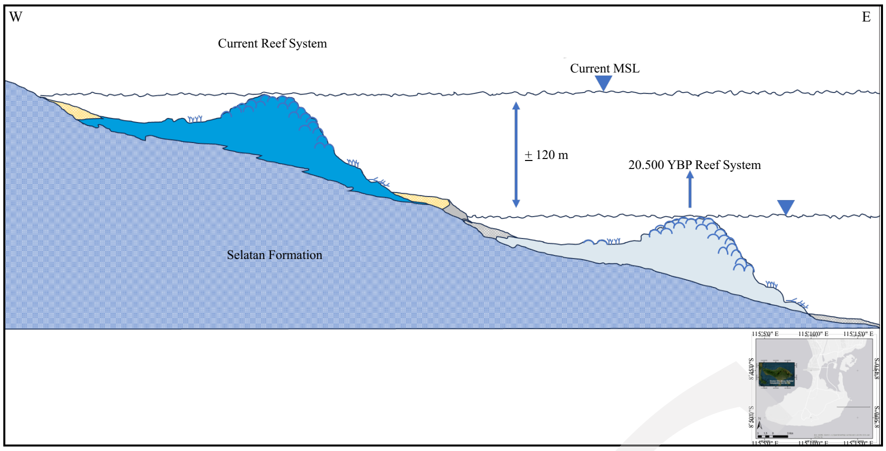


Figure 1. Illustration of reef carbonate development in Selatan Formation (redrawn from Nugraheni *et al.*, 2021).

seabed for the instrument's safety and was pulled up to the surface with the help of the boat's winch. Then the measurement result is compared with national standard quality to see its conformity for coral or marine biota. Moreover, the result is also compared with previous measurements taken in the same location and points in 2020 (Badriana *et al.*, 2021). Although the period is different, it is assumed to be in the same season (September-October-November).

In observing the progress of coral growth, two divers submerged in ICRG plantation points in Nusa Dua. A brief monitoring was done to see the artificial coral reef structure condition and check the coral attached to the structure.

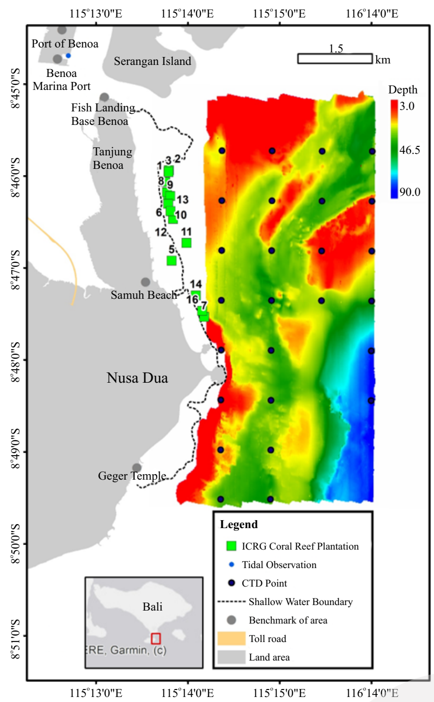
Materials

Ocean parameter was measured at 26 points as shown in Figure 2. Data consist of ocean parameters such as temperature, salinity, pH, turbidity, dissolved oxygen (DO), and chlorophyll. Each data recorded into raw ASCII file format with value and unit of each parameter. On the other hand, actual progress on ICRG is shown through photographs captured around artificial coral reef plantations.

Result and Analysis

A total of 26 points had been measured in the Nusa Dua area. Fewer points were collected compared to the earlier measurement due to high waves on the first day and winch problems on the second day. The bathymetry measurement had been reported in ICRG 2020 activities using a multi-beam echosounder (Badriana *et al.*, 2021) and the result became the reference for ICRG 2022 survey. The bathymetry in the Nusa Dua survey area varies from 3 m to 85 m with mean sea level (MSL) as a datum reference. The bathymetry measurement had been corrected by primary data which had been collected during survey activities. There is no issue in primary data since the pattern and value is fit with BIG data as reference (RMSE 10 cm) after both tidal data is normalized to MSL (Badriana *et al.*, 2021). The waters that are perpendicular with Tanjung Benoa are generally used for marine tourism and ship routes for entering the inner area of Tanjung Benoa or the port of Benoa. The coral plantation is put closer to the coast but still outside the low tidal area. Nusa Dua coastal areas were difficult to be surveyed due to the presence of wave breaking zone, rendering it unsafe for boat navigation.

The temperature has a range of 24.89° - 28.69°C. The average temperature in the bottom is likely the same with the surface area due to the mixing layer, however, the deeper point has a lower temperature. The temperature decreases linearly with increasing depth. Turbidity in the bottom is still less than 4.5 FTU (1.19 - 4.27 FTU). This value is still good since this turbidity is within water quality standards for tourism



point	number
Block 1	4,000 tables
Block 2	1,600 tables
Block 3	2,300 tables
Block 4	500 fish apartment 1,830 roti buaya structure
Block 5	Coral seedling
Block 6	2,500 hexagonal structure
Block 7	2,500 hexagonal
Block 8	500 fish apartment 1,830 roti buaya structure
Block 9	3,000 pipes
Block 10	500 fish apartment 1,830 roti buaya structure
Block 11	100 biorocks
Block 12	140 garuda Nusantara Statue
Block 13	450 fish apartment 1,830 roti buaya structure
Block 14	1,500 tables
Block 15	450 fish apartment 1,830 roti buaya structure
Block 16	250 brick houses

Figure 2. Bathymetry at Nusa Dua, Bali from ICRG 2020 survey (adapted from Badriana *et al.*, 2021), with number of artificial coral reef structure at each ICRG point plantation.

activities. The low turbidity shows the clear condition of seawater which is less influenced by any sediment. In actual condition, when the CTD was pulled down, the staff still saw the instrument until a certain depth (~>10 m). Higher turbidity is found in deeper areas that have a depth of more than 50 m (points 25-5 and 25-6). The pH parameter is stable with the least variance spatially and has values around 8.0 - 8.1. Salinity in Nusa Dua over the main survey area is within 33.75 - 34.22 psu which is a normal range for ocean salinity. Also, salinity in the bottom is not much different from a surface condition which has a bit higher value (+0.2 psu). The concentration of dissolved oxygen in the bottom is slightly higher from the surface which ranges from 4.47 - 5.24 mg/L, even though the patterns are still similar. Higher DO found in coral plantation areas (close to coastal) and also found in the middle of area survey. The condition in the bottom area is slightly different from the surface. Chlorophyll in the bottom increases up to 1.21 μg/L.

Bottom temperature in 2020 has a higher temperature since it is measured on a bright day, meanwhile in 2022, it is measured with a cloudy day (Figure 3). Moreover, the strong mixing layer in Nusa Dua (can reach 40 m in deeper areas) makes the bottom have similar temperature spatially, except for point 25-4, 25-5, and 25-6. The temperature on these three points can drop 2 -3 °C from the surface. This condition can be seen in both years. In 2022, particularly in point 20-2, 20-3, 25-2, and 25-3, the bottom temperature is a bit higher than the rest area. This is due to well mixing since it can be seen in the bathymetry that this area is relatively shallow although located in open sea. There is not much difference for the salinity in both years. Value of pH in 2020 is around 7.9 while in 2022 is 8.1, but this value is considerably normal for seawater pH. Furthermore, Figure 4 shows that turbidity still has a small value (below 5 FTU) between 2 years, even though some locations in 2022 have a higher turbidity in the bottom. Chlorophyll in the bottom is not rich as in 2020. Less marine tourism activities when covid-19 may affect the resources for chlorophyll.

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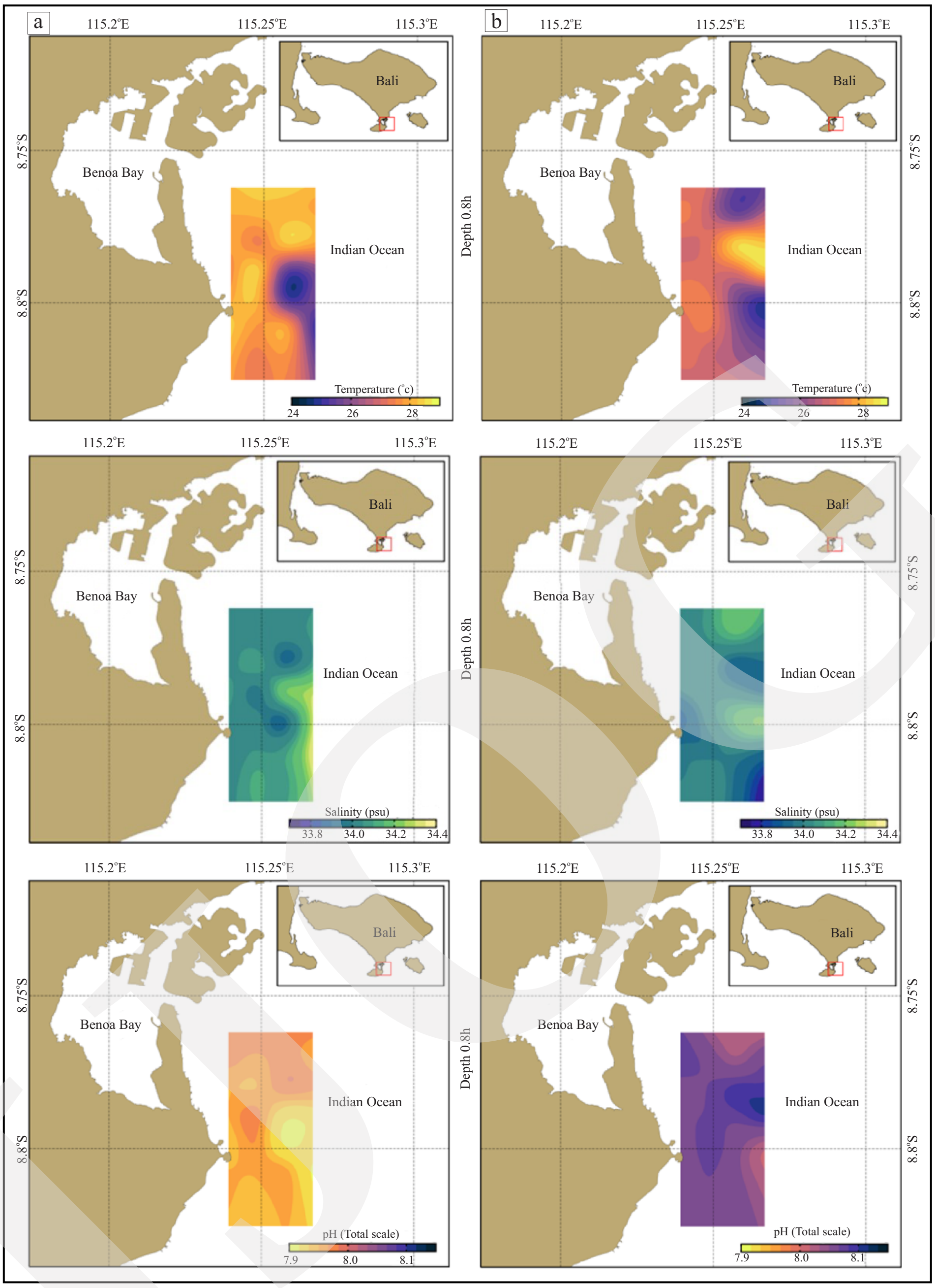

Figure 3. Spatial distribution of temperature (top), salinity (middle) and pH (bottom) on depth 0.8h: a) 2020 and b) 2022 measurements.

2021 concerning Implementation of Environmental Protection and Management (GRRI, 2021a; 2021b), pH and turbidity in Nusa Dua meet the requirement. Less turbidity (maximum 5) is favorable since high turbidity can indicate higher sediment or particles that can make less visibility and make the sun penetrate lower. This condition could influence coral growth. Salinity is suitable for the coral ecosystem. However, temperature is a bit colder in the plantation area and the DO almost meet the ideal criteria for coral area. Although the value does not reach ideal criteria, the condition is still good for coral areas.

Benthic mapping and geomorphologic mapping, provided by Allen Coral Atlas (2022), is freely accessible (Figure 5). This dataset identifies the locations of coral/algae, rock, rubble, sand,

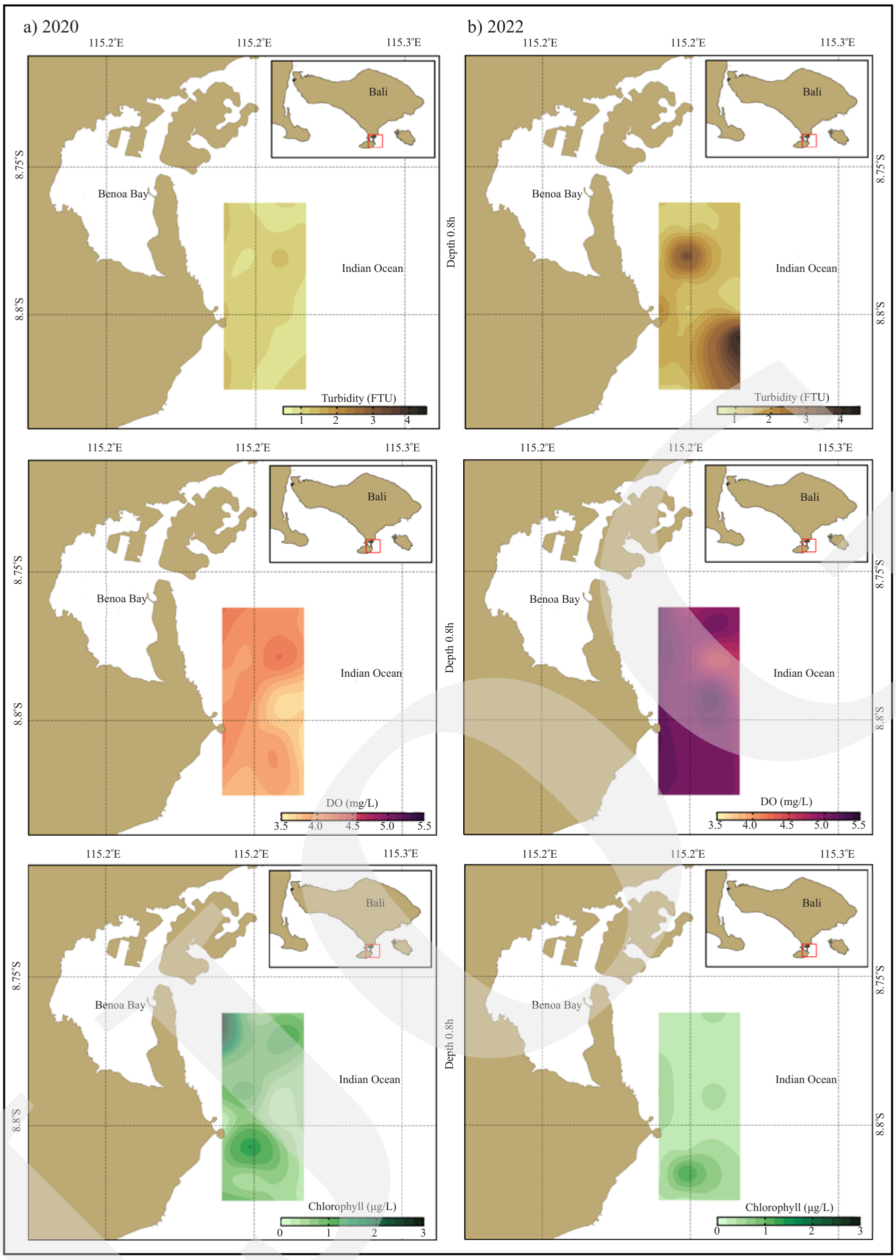

Figure 4. Spatial distribution of turbidity (middle), dissolved oxygen (middle) and chlorophyll (bottom) on depth 0.8h: a) 2020 and b) 2022 measurements.

seagrass, and various seabed conditions. However, it covers only shallow areas where satellite imaging is feasible, while deeper regions remain unmapped. It may provide interactive information, but it is crucial to be utilized carefully since cross checking in the field is necessary. Although the atlas offers interactive data, it must be used with caution, as field verification is essential. The mapping reveals extensive coral/algae coverage in shallow zones, while rubble, seagrass and sand predominantly characterize much of the Nusa Dua shoreline. Nusa dua has 406 ha potential area for coral transplantation with 25 ha restoration area having been done (DPKRL, 2021). The plantation area is located far from the coast (green box icon) since in Nusa Dua the tidal area is wide. Based on the divers who took part in the ICRG program, many artificial corals with variant shapes sank in front of the blue (line) area or near the outer of the earlier plan.

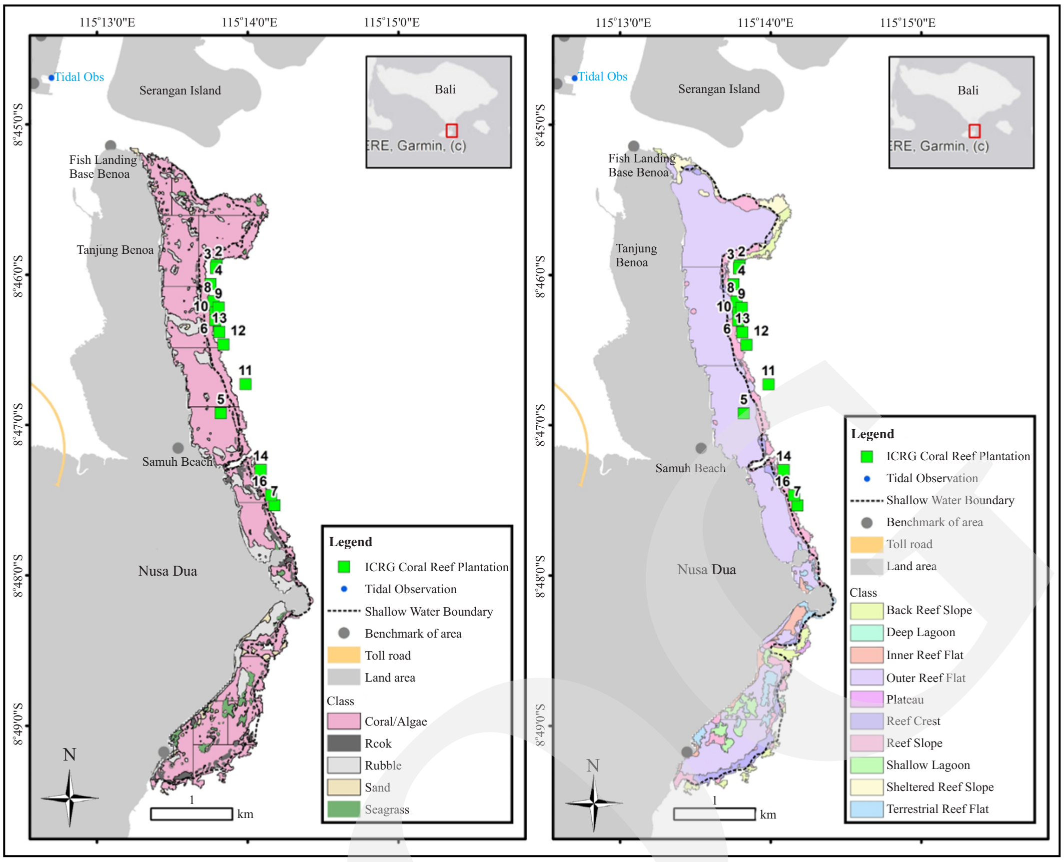

Figure 5. Benthic mapping (left) and geomorphologic mapping (right) based on Allen Coral Atlas (2022).

Table 1. Measurement Result from Water Sample and National Threshold (GRRI, 2021) Quality Standard

Parameter	Measurement on depth 0.8h	Standard for sea Biota (GRRI, 2021)
Temperature (°C)	24.89 – 28.69	Natural
Salinity (psu)	33.75 – 34.22	Natural
pH	8.01 – 8.1	7.0 – 8.5
Turbidity (FTU)	1.19 – 4.27	<5
DO (mg.L^{-1})	4.47 – 5.24	>5

Figure 2 (green box icon) shows location or points where the artificial coral was installed in 2020. The dashed line shows the shallow water boundary in Nusa Dua. This area can be explored by walking when the low tide occurs each day. Coral seedling or block 5 (in Figure 2) is located also in shallow area, however this point is only temporary before the artificial coral moved into the deeper location. This coral seedling could not be found in 2022 meaning that it has no function anymore.

Many corals grow on artificial reef structures, it might be species of *Montipora sp., Acropora sp., Alcyonacea sp.*, etc. the structure was made to make it easier for coral monitoring. In the future, it is suggested to have scientific diving activities to monitor more specifically, such as calculating the growth, preventing disease, and checking regularly.

In the Nusa Dua area, it is found the "Rumah Batako (Concrete Block Housing)" Site, "Blok Meja 1 (Table Block 1)" Site, "Patung Nusantara

(Indonesia Statue)" Site, and "Meja Biorock (Biorock Table)" Site.

Several sites namely Rumah Batako and Patung Nusantara are using the plantation methods by placing structures on the seabed as the house for the coral reef growth without the existing parts of the coral fragment body attached to the structure. This method is less effective for growing the coral reef since there is no existing coral reef fragment body in the structure. The existing coral reef near the artificial structure needs some adaptation in its "new home" for growing. On the other hand, several sites namely Meja Biorock and Blok Meja 1 are using the plantation methods by dropping the structure below the seawater that has been attached by coral fragment bodies. This method can more successfully grow the fragmented coral body into the adult organism coral as if the seawater condition and environment are supporting the

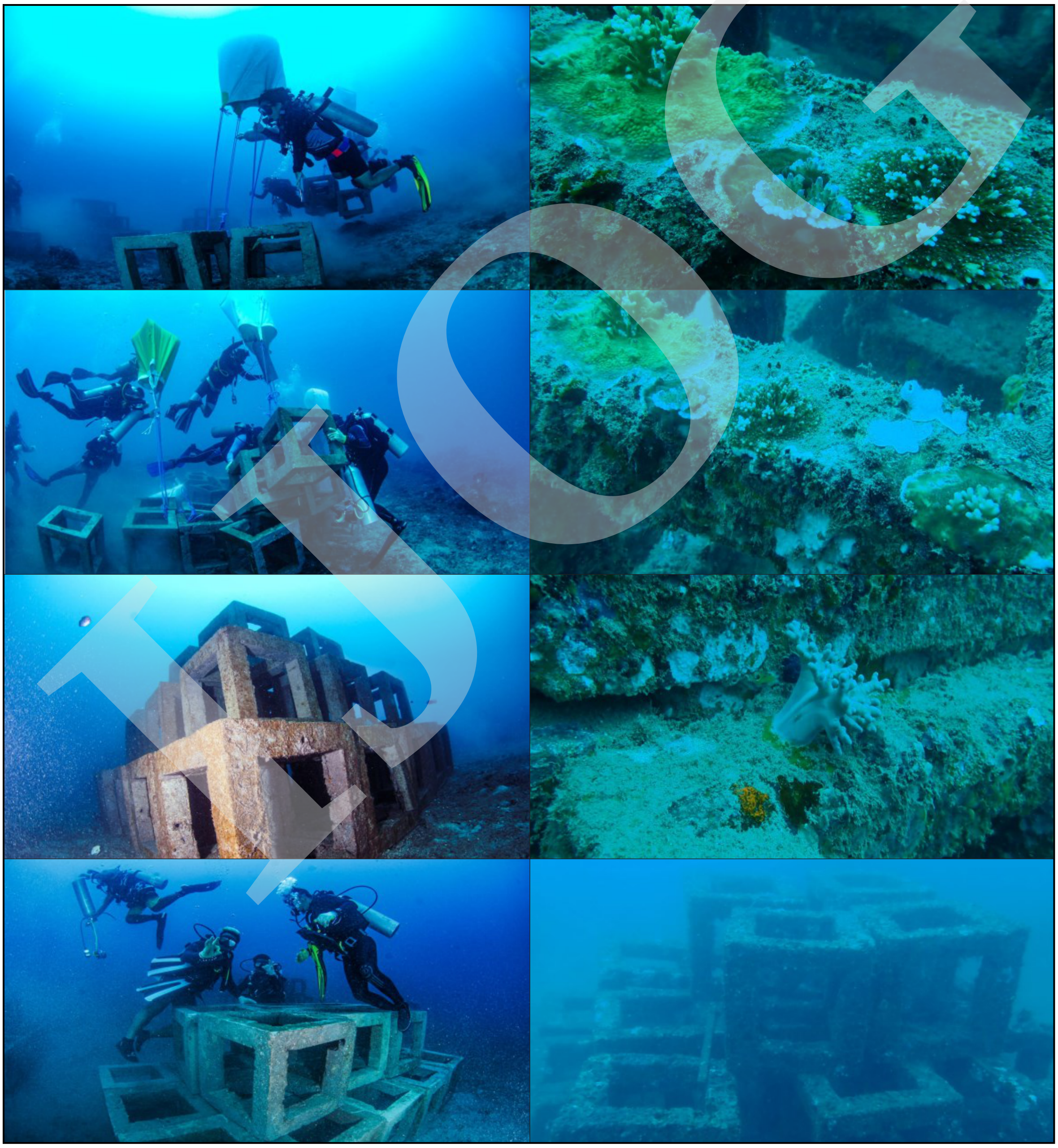

Figure 6. Site of Rumah Batako in Nusa Dua, Bali.

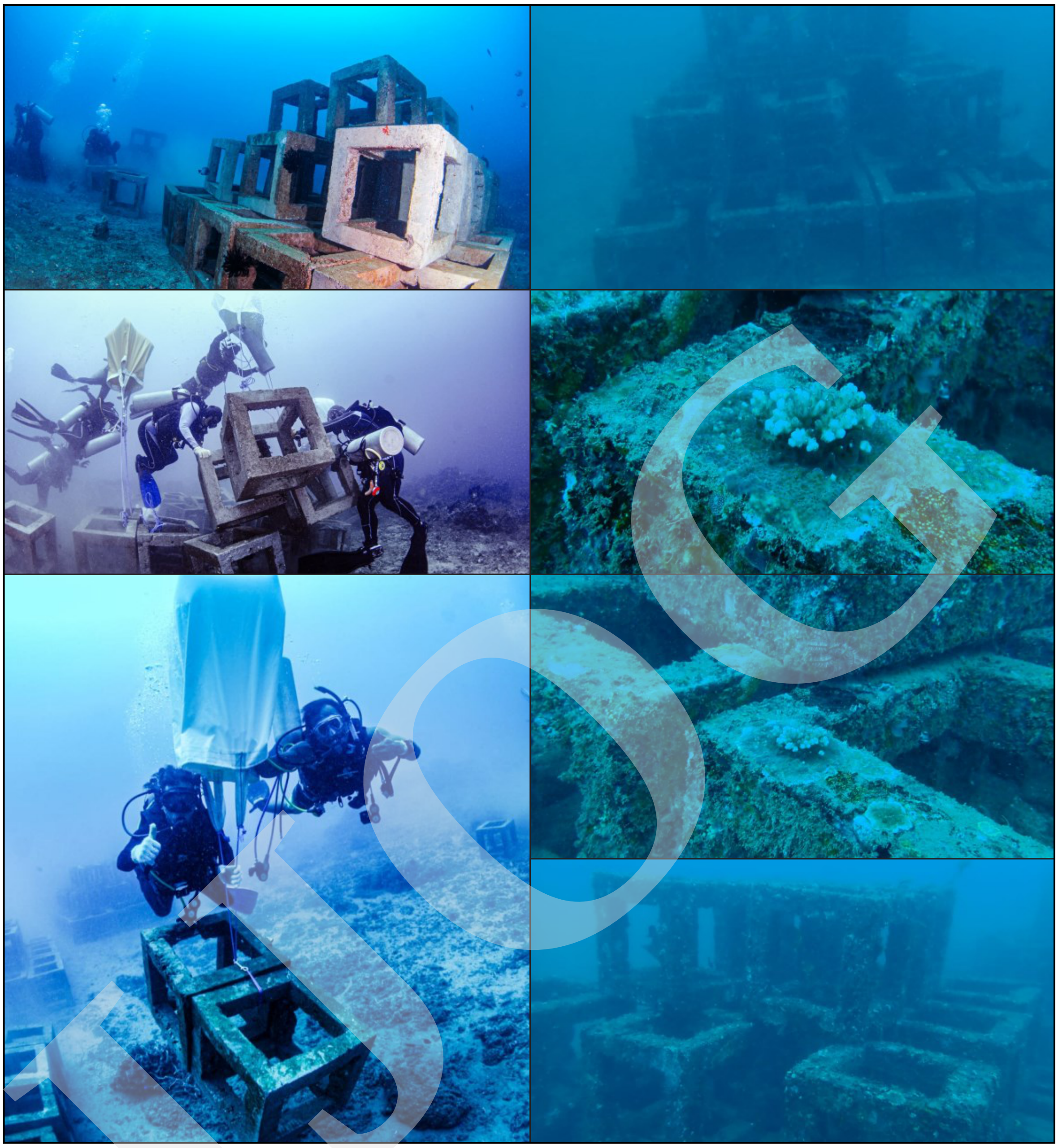

Figure 6. Continued...

growing process. Comparison between the 2020 plantation and the current condition of 2022 can be seen in Figures 6-9.

Discussion

The ocean parameter measurements are located approximately 400 - 1,200 m from the coral plantation area. Measurements cannot be taken closer to the plantation site because the proximity to the wave-breaking zone makes vessel access are challenging. Moreover, the monitoring activity 2022 following same point of preliminary in 2020, so it can be compared well for each parameter. In 2022, monitoring was conducted at the same points as in the initial 2020 survey, allowing for consistent comparison of parameters. This distance may introduce slight spatial variations in seabed conditions, influenced

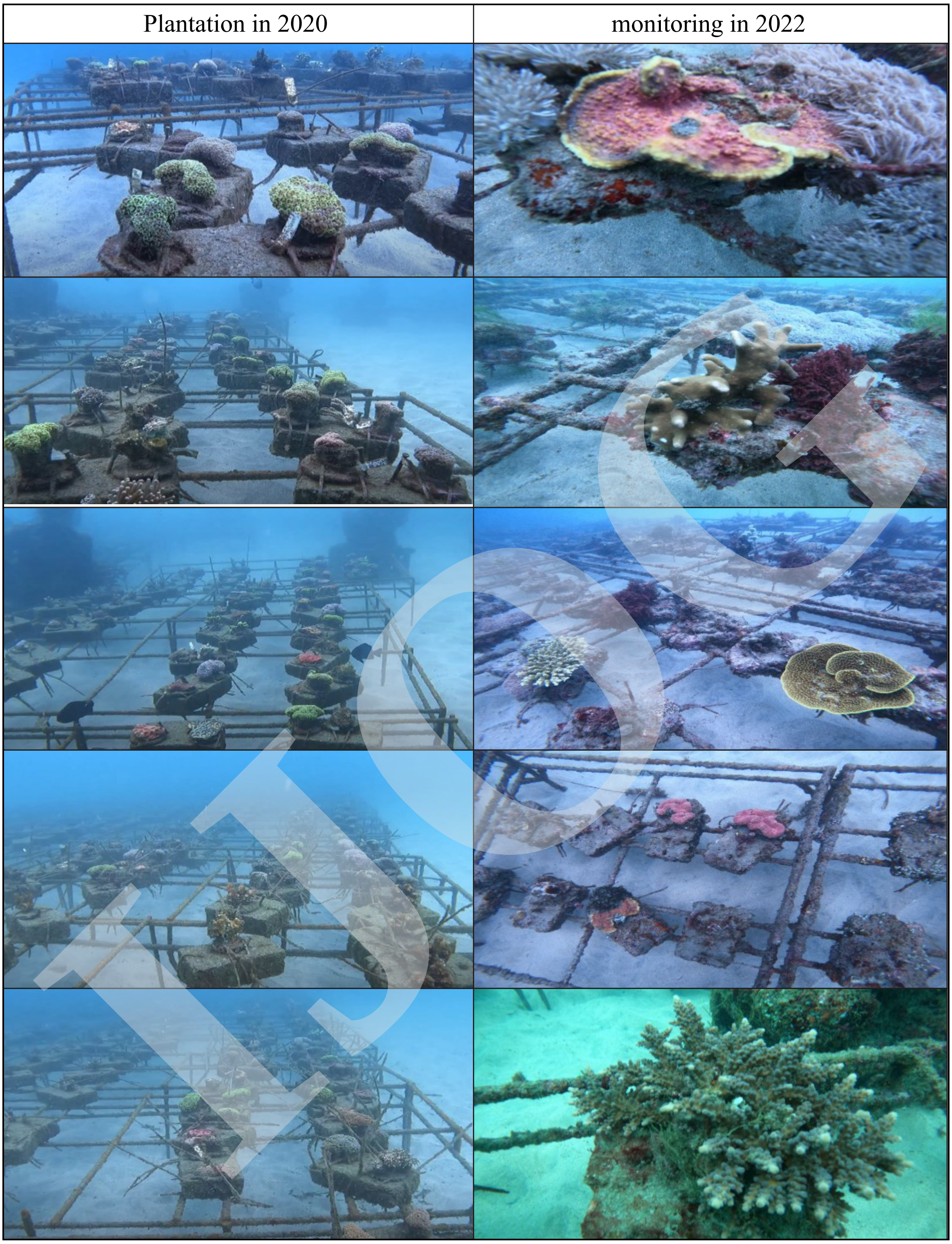

Figure 7. Site of Blok Meja 1 in Nusa Dua, Bali.

by factors like currents, wave dynamics, and coastal features. However, the spatial variation between the measurement points and the coral site remains smaller than the natural differences observed between surface and bottom layers. Shallow water conditions (inside shallow water boundary line), as recorded by Rajabson *et al*. (2023), differ from our deeper measurements.

Figure 8. Site of patung Nusantara in Nusa Dua, Bali.

In areas with minimal physical disturbances, parameters like temperature, salinity, and pH are generally consistent along flat or gently sloping seabeds (Lentz and Fewings, 2012). Currently, there is limited information on ocean parameters across the entire Nusa Dua area, with only scattered measurements, highlighting the need to address this data gap.

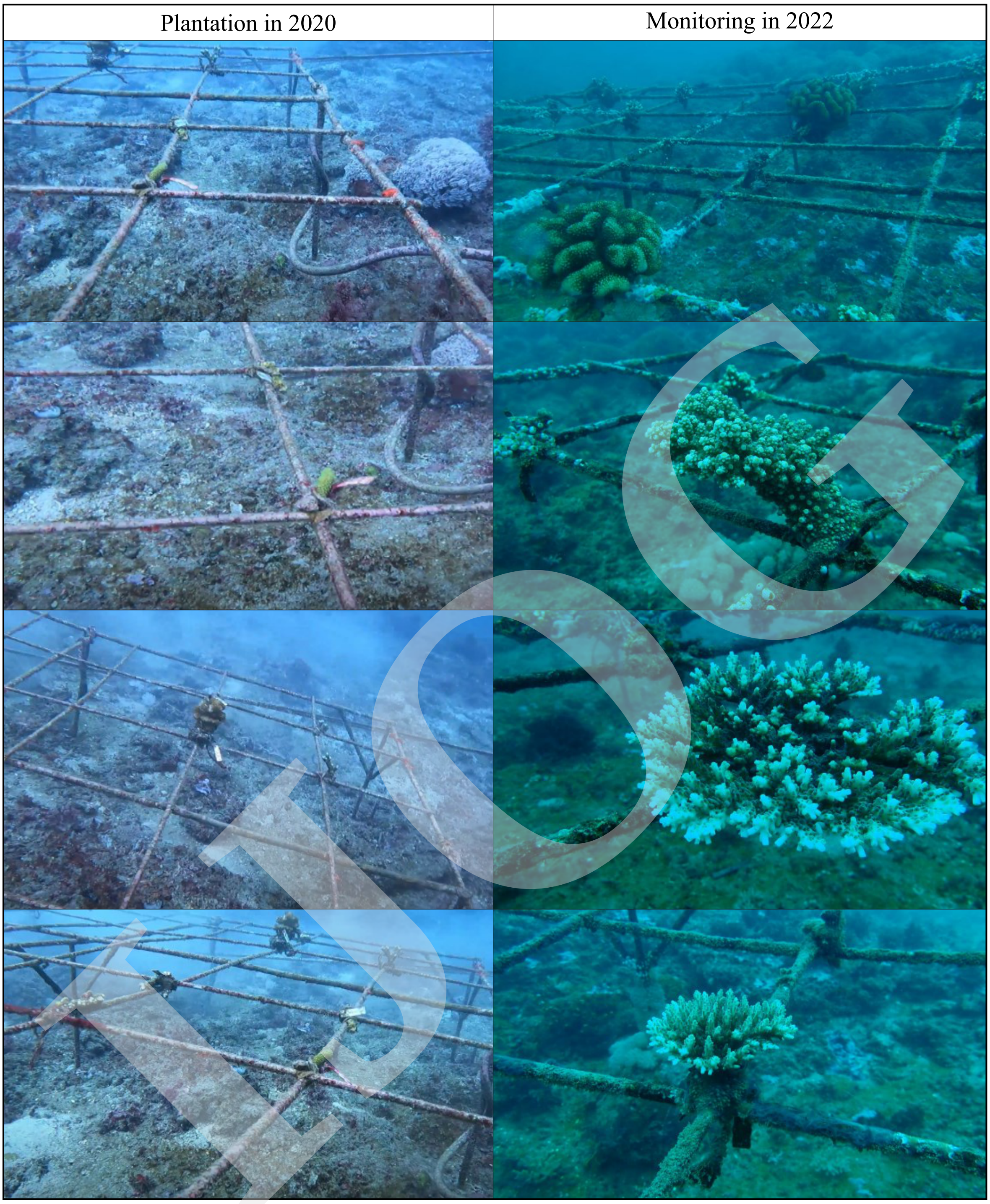

Figure 9. Site of Biorock table in Nusa Dua, Bali.

Upwelling along southern Bali had been investigated and annually exist in June to October, however the strength may vary influenced by South East monsoon (Purba and Khan, 2019) and atmosphere-ocean circulation associated with ENSO and IOD (Ningsih *et al.*, 2013). Conditions such as El Niño or a positive IOD phase can amplify upwelling strength, while La Niña or a negative IOD phase tends to weaken it. Recent research highlights that this period brings cooler, nutrient-rich waters with high chlorophyll levels to the surface, boosting coastal productivity and supporting marine ecosystems in Bali (Wijaya *et al.*, 2020; Suprianto *et al.*, 2021; Rintaka and Priyono, 2021), even in early November. The ITF flows consistently through Lombok strait year-round, though its intensity varies with seasonal wind (Sprintall, *et al.*, 2009; Gordon *et al.*, 2010). Together, ITF and upwelling provide nutrient-rich, cool waters that support coral recruitment and growth, enhance phytoplankton production, and sustain biodiversity by lowering coral thermal stress (Alongi *et al.*, 2013).

Coral reef restoration methods in the Nusa Dua area look very promising. From the observation, coral reefs starting to grow on the structures can be seen. In several sites namely “Blok Meja 1” and “Meja Biorock”, the coral reef fragment body that has been planted in 2020 starting to grow bigger in 2022 also can be recognized. Various corals are planted and the environmental conditions are very favorable to grow. The joints of the transplanted iron structures are seen to be connected and covered by a hard coral substrate. Some structures were also seen to be covered by soft coral which showed very good transplant growth conditions. In several sites namely “Patung Nusantara” and “Rumah Batako”, the growing rate is not as high as the other sites. It is because there is no fragmented coral body planted on the structure and just count on the structure as a “home” for the coral reef growth. But if we look closer, we can see that the structures start to be covered by the coral reef and some little tiny soft corals start to grow on the structures.

However, one of the drawbacks is that in the Nusa Dua area, coral reef restoration is carried out in a fairly deep area, allegedly at a depth of about 5 m and a relatively difficult distance to easy-access. Scuba gear may also be indispensable, while snorkeling gear is difficult to use to monitor. Location information is also very minimal and may be bad for monitoring. Stakeholder involvement is also very limited because of it. The availability of detailed information on the location of coral transplantation is one of the evaluations for the Nusa Dua area, while the restoration growth shows convincing progress.

Artificial reefs depend on long-term processes and may take approximately 20 years for some coral fragments to form mature colonies and develop complex symbiosis with reef fish and other organisms (White *et al.*, 1990; Edrus *et al.*, 2018). A routine monitoring activities related to coral status (*i.e.* every 2 - 6 months), cleaning the structure (*i.e.* every 3 months), water quality samples (at least representing the seasonal variation), scientific studies of growth, health, disease, ocean modeling and other related matters in artificial coral reefs and its surroundings is necessary as part of monitoring (Ampou *et al.*, 2019).

Conclusions

A first monitoring for ICRG in Nusa Dua is done with no difference of ocean parameter changes in survey area. All ocean parameters are within national threshold for marine biota and considerably good for coral. Coral plantation program in Nusa Dua Bali shows promising progress and potential to be expanded with the importance of regular monitoring. Corals growing on artificial reef structures, such as *Montipora sp., Acropora sp.,* and *Alcyonacea sp.* Further seasonal measurement and monitoring activities to check coral growth scientifically is preferable.

Acknowledgments

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