Baseline UVC-Based Mapping and Condition Scoring of Fish Apartment Units: A Case Study from Situbondo, Indonesia

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Received: 6 February 2026 | Revised: 18 April 2026 | Accepted: 30 April 2026

 DOI: https://doi.org/10.48084/etasr.18001

ABSTRACT

Artificial reef performance depends on structural stability after deployment, yet site-level post-deployment assessments remain limited. This study evaluated 32 deployed reef modules at Karang Mayit, Situbondo, East Java, Indonesia, through underwater visual inspection conducted on 17–19 August 2025. Relative module positions were reconstructed from distance–bearing measurements linked to a seabed baseline and surface GPS, whereas physical status was assessed using breakage/collapse, debris/net coverage, inclination, and sediment accumulation integrated into a Total Condition Score (TCS). The modules occupied a nearshore depth range of 6–14 m and formed five depth zones. No units showed breakage/collapse or net/debris coverage, whereas variability was mainly associated with inclination (4–42°) and sediment accumulation (0–25 cm). TCS classified 15 units (47%) as Good and 17 units (53%) as Moderate, with no Severe category recorded. These findings provide a practical post-deployment assessment framework for structural integrity evaluation, maintenance prioritization, and long-term monitoring of artificial reef installations.

Keywords-artificial reef monitoring; post-deployment assessment; structural integrity; module inclination; sediment burial; habitat rehabilitation; maintenance prioritization; coastal fisheries management

I. INTRODUCTION

Fish Apartments (FAs) are artificial reef structures used to increase habitat complexity and support fisheries management [1]. Their design can enhance structural heterogeneity and promote colonization by marine organisms [2]. However, their effectiveness depends on post-deployment physical condition, because tilting, sediment burial, structural failure, and net or debris entanglement can reduce habitat functionality [3]. Therefore, baseline assessment of structural condition and spatial distribution is important for routine monitoring, maintenance planning, and deployment optimization [4].

Karang Mayit Beach, Situbondo, East Java, Indonesia, is one of the coastal sites where FAs have been deployed for habitat rehabilitation [5]. The nearshore area is characterized by a sandy-to-muddy substrate and relatively sheltered conditions [6]. However, although these structures have been installed at the site, a systematic post-deployment baseline assessment integrating spatial mapping and physical-condition scoring has not been reported. This gap is important because information on module position, inclination, sediment accumulation, and structural condition is needed to support monitoring and maintenance after deployment.

The novelty of this study lies in integrating Underwater Visual Census (UVC)-based spatial mapping with a practical Total Condition Score (TCS) framework to produce a site-level post-deployment baseline for early condition assessment and maintenance prioritization of FA units. Therefore, this study presents a UVC-based assessment of the spatial distribution and physical condition of FA units in Karang Mayit waters as a baseline for future monitoring and management.

II. MATERIALS AND METHODS

A. Study Site

The survey was conducted at Karang Mayit Beach, Situbondo Regency, East Java, Indonesia (7.684378°S, 113.830987°E). The monitoring area covered nearshore depths of approximately 6–14 m, which are suitable for artificial reef deployment [7]. The FA units assessed in this study were originally deployed in 2023, providing approximately two years of post-deployment exposure before the August 2025 survey. Fieldwork was conducted over three days (August 17–19, 2025) during the east monsoon period in the northern coastal region.

B. Data Collection

FA units were surveyed using a UVC-based approach adapted to document the physical condition and spatial distribution of artificial reef modules rather than fish assemblages [8]. In this study, the UVC approach was applied through direct underwater visual inspection of each module to record its relative position, inclination, sediment accumulation, breakage/collapse, and net/debris coverage, supported by underwater photographic documentation. Each survey dive involved two certified divers: one observer responsible for recording all condition and spatial data, and one buddy diver for safety assistance. The same observer recorded all primary observations throughout the survey period, whereas buddy divers could vary among dives. This arrangement was intended to minimize inter-observer variation in the assessment of module condition and spatial records. The UVC-based field setup used in this study is illustrated in Figure 1.

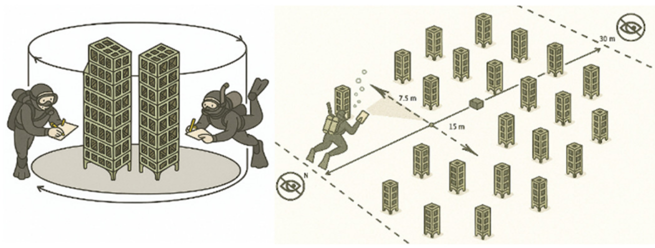

Fig. 1. UVC-based field setup for physical-condition assessment and spatial recording of FA units.

C. Research Stages

The main stages of field observation, spatial mapping, and condition assessment are summarized in Figure 2. To support spatial mapping, a seabed baseline reference point was established and marked by a buoy placed above the central/first module. Divers descended along the buoy line to the baseline, identified each FA unit, and recorded its relative position from the reference using distance-and-bearing measurements. Bearings were measured with an underwater compass, and distances were measured along the seabed using a measuring tape. During the same observations, divers visually assessed the physical condition of each unit, including breakage/collapse, net/debris presence, inclination, and sediment accumulation, while also documenting representative conditions with underwater photographs. All measurements and notes were logged on standardized underwater datasheets and complemented with simple sketches to capture module layout [9]. After each dive, records were transferred to surface sheets and used to generate a site-scale distribution map based on the measured distances and bearings.

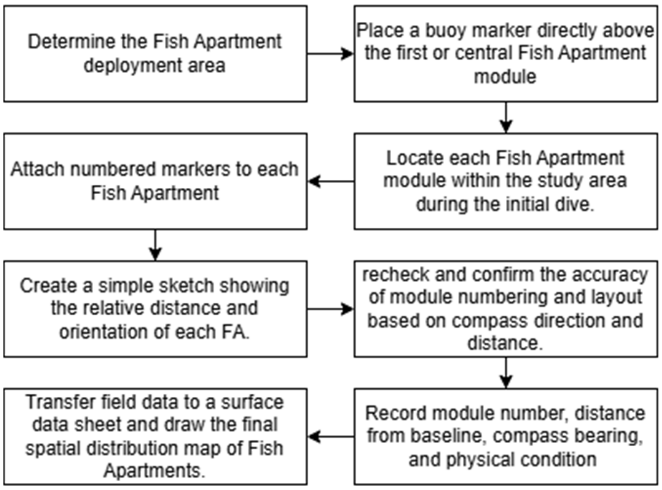

Fig. 2. Main stages of field observation, spatial mapping, and condition assessment.

D. Spatial Mapping and Positional Accuracy

FA module positions were mapped by combining surface handheld GPS fixes with underwater distance–bearing measurements referenced to a seabed baseline. GPS points provided georeferenced control for the deployment area, and module locations were reconstructed from the relative underwater offsets. Positional uncertainty in this approach may arise from several sources, including handheld GPS inaccuracy at the sea surface, underwater compass reading error, distance measurement error along the seabed, and diver-related observational limitations such as underwater visibility and local current conditions. Therefore, the resulting map is intended to describe the relative spatial configuration of modules rather than high-precision absolute coordinates. Accordingly, depth-related grouping and shore–offshore sequencing are interpreted as relative, zone-based patterns for survey stratification and reporting, in line with reef-fish assessments that integrate habitat mapping and assemblage structure in survey design [10].

E. Parameters Observed and Condition Scoring

Four physical parameters were used to evaluate the condition of each FA: structural damage (breakage/collapse), net/debris coverage, sediment accumulation, and inclination (Figure 3). Based on in situ observations and photographic records, each parameter was quantified and scored using a scheme adapted from authors in [11]. The four indicators were selected because they represent the main observable forms of post-deployment physical change in FA modules, including structural failure, external obstruction, positional instability, and seabed burial. The threshold ranges used in this study follow the adapted scoring framework of authors in [11] and were applied here as a practical basis for baseline physical-condition assessment.

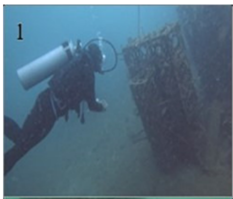 1	Structural damage (breakage/collapse) and Net or debris coverage was assessed by conducting a 360° visual inspection around each FA unit. The extent of damage was then recorded as a percentage of the total surface area that showed physical
 2	Sediment accumulation was assessed by comparing the FA's visible height above the seabed with its original design height. Divers measured the exposed height using a measuring tape, and the difference from the known total height indicated the portion buried in sediment.
 3	Inclination was determined by measuring the tilt angle of each FA from its original vertical orientation. Waterpass was used to estimate the angle of deviation, and the readings were replicated several times to ensure accuracy.

Fig. 3. Physical parameters used for FA condition scoring: breakage/collapse, net/debris coverage, sediment accumulation, and inclination.

TCS was calculated by summing the four indicator scores to provide a simple composite index of overall module condition while retaining the contribution of each individual indicator. Structural damage and net/debris coverage were expressed as the percentage of affected surface area, inclination as deviation angle (°), and sediment accumulation as burial height (cm). Scores were assigned to three severity levels: light (1), moderate (3), and severe (5), using the following thresholds: breakage/collapse and net/debris coverage (≤25%, 26–75%, ≥76%); inclination (≤10°, 11–30°, ≥31°); and sediment accumulation (≤10 cm, 11–20 cm, ≥21 cm). The TCS for each FA was calculated as:

$$TCS = S_{BC} + S_{DN} + S_I + S_S \quad (1)$$

where S_{BC} is the score for breakage/collapse, S_{DN} is the score for debris/net coverage, S_I is the score for inclination, and S_S is the score for sediment accumulation. Based on TCS, modules were classified as Good (4–7), Moderate (8–12), or Severe (13–20). TCS was used as an aggregated index to represent overall module condition; therefore, a module may still fall into the Good class when one indicator is Moderate, provided the total score remains within 4–7. Indicator-level classes were retained and summarized alongside TCS to ensure transparency in interpreting the drivers of each category.

III. RESULTS AND DISCUSSION

A. Overview of Fish Apartment Distribution

The spatial distribution of FAs in Karang Mayit waters is presented in Figure 4. A total of 32 FA units were recorded within the nearshore monitoring area at depths of 6–14 m, approximately 300 m from the shoreline, on a gently sloping sandy-to-muddy seabed that is generally suitable for artificial reef placement [12]. The modules formed five depth zones (6, 8, 10, 12, and 14 m) arranged in a shore-to-offshore sequence that followed the coastline contour. Figure 4 also shows that most units were located at intermediate depths (8–14 m), whereas only a few occurred at 6 m, indicating that deployment favored mid-depth areas that offered suitable installation space while remaining accessible for monitoring and maintenance.

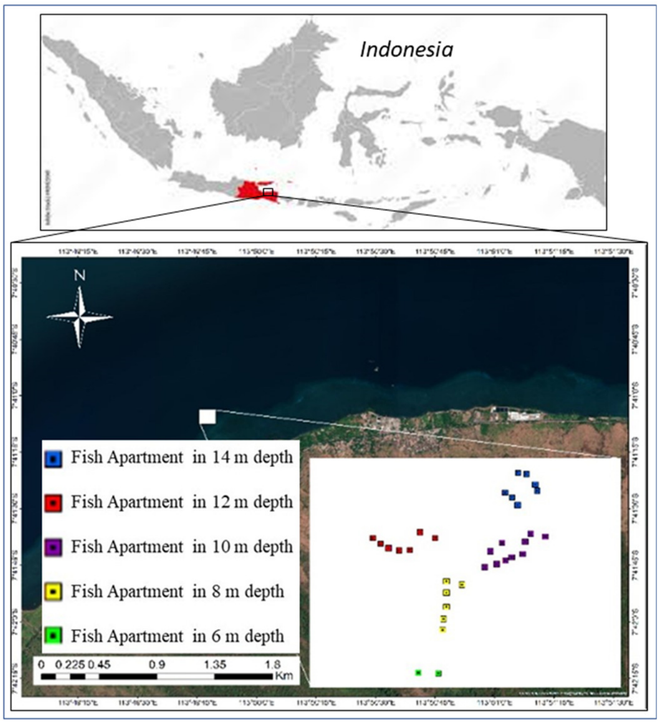

Fig. 4. Spatial distribution of 32 FA units in Karang Mayit waters, showing their shore-to-offshore arrangement across five depth zones (6, 8, 10, 12, and 14 m).

B. Physical Condition of Fish Apartments

The physical condition of FAs at Karang Mayit varied across depth zones, but all units remained structurally intact during the survey. A total of 32 units (6–14 m) were assessed using four physical indicators: breakage/collapse, net/debris coverage, inclination, and sediment accumulation. No units exhibited breakage/collapse or net/debris coverage, indicating that the observed within-site variation was primarily associated with inclination and sediment accumulation under local near-bottom flow, flow–structure interaction, localized scour, and seabed characteristics [13]. The indicator values for all units are summarized in Table I.

TABLE I. PHYSICAL CONDITION OF FA UNITS

No	Depth (m)	Physical condition			
		Break/collapse (%)	Debris/net coverage (%)	Inclination (°)	Sediment accumulation (cm)
1	6	-	-	25	0
2		-	-	21	0
3	8	-	-	20	4
4		-	-	23	9
5		-	-	22	8
6		-	-	6	0
7		-	-	21	0
8		-	-	28	0
9	10	-	-	10	10
10		-	-	24	13
11		-	-	41	0
12		-	-	8	17
13		-	-	8	12
14		-	-	8	7
15		-	-	5	21
16		-	-	18	25
17		-	-	4	20
18		-	-	21	0
19	12	-	-	12	11
20		-	-	29	7
21		-	-	16	16
22		-	-	27	12
23		-	-	22	9
24		-	-	18	14
25		-	-	25	6
26	14	-	-	36	0
27		-	-	42	0
28		-	-	40	0
29		-	-	40	0
30		-	-	36	0
31		-	-	34	0
32		-	-	32	0

Depth-wise patterns were further supported by the summary in Table II. Inclination differed significantly among depth zones (Kruskal–Wallis, $p = 0.003$), with the highest median value recorded at 14 m (36.0°; range 32–42°), indicating that deeper units were more consistently associated with pronounced tilting. Sediment accumulation also differed significantly ($p = 0.001$), with the highest median values observed at 10 and 12 m (both 11.0 cm), whereas no measurable accumulation was recorded at 6 and 14 m. TCS likewise varied significantly across depth zones ($p = 0.025$), with higher median scores at 10–14 m than at 6–8 m. Overall, these results indicate that the main depth-related physical changes were expressed through increasing inclination in deeper modules and localized sediment deposition at intermediate depths. Representative underwater photographs across depth zones are shown in Figure 5.

TABLE II. DEPTH-WISE SUMMARY OF INCLINATION, SEDIMENT ACCUMULATION, AND TCS

Depth (m)	n	Inclination, median (range)	Sediment accumulation (cm), median (range)	TCS, median (range)
6	2	23.0 (21–25)	0.0 (0–0)	6.0 (6–6)
8	6	21.5 (6–28)	2.0 (0–9)	6.0 (4–6)
10	10	9.0 (4–41)	11.0 (0–25)	8.0 (4–10)
12	7	22.0 (12–29)	11.0 (6–16)	8.0 (6–10)
14	7	36.0 (32–42)	0.0 (0–0)	8.0 (8–8)

Note: Values are presented as median (minimum–maximum). Differences among depth zones were tested using the Kruskal–Wallis test.

From a functional perspective, tilting and partial sediment burial may reduce internal void space, modify entrance geometry, and lower refuge effectiveness. Accordingly, the observed pattern of higher inclination in deeper units and greater sediment accumulation at intermediate depths is consistent with near-bottom processes such as flow–structure interaction, turbulence intermittency, and seabed reworking [14]. Although these processes were not measured directly, the tilt–sediment signals provide an early indication of physical changes that may precede longer-term reductions in habitat functionality.

Fig. 5. Representative FA conditions in Karang Mayit waters: (a) shallow-zone unit, (b) mid-depth unit, and (c) unit near natural coral.

C. *Classification of Fish Apartment Condition and Management Implications*

The condition of each FA unit was classified using the TCS, an aggregated index integrating breakage/collapse, net/debris coverage, inclination, and sediment accumulation. Because TCS represents overall module condition, a unit may still be classified as Good when one indicator falls in the Moderate class, provided that the total score remains within 4–

7. The indicator-level scores, TCS values, and condition categories for all units are summarized in Table III. Based on TCS, the 32 observed units were classified into two categories: Good (n = 15; 47%) and Moderate (n = 17; 53%), with no Severe units recorded. Good-condition modules were more common at 6–10 m depth, whereas Moderate-condition modules occurred more frequently at 10–14 m and were primarily associated with severe inclination (≥31°) and/or sediment accumulation >10 cm, rather than structural failure or debris/net entanglement. Since no breakage/collapse or visible net/debris coverage was observed, the differences in condition category are best explained by variation in inclination and sediment dynamics under local seabed and near-bottom forcing [15].

TABLE III. TCS-BASED CLASSIFICATION OF FA CONDITION

No	Depth (m)	Physical condition score				Total score	Category
		B/C (%)	D/N (%)	I (°)	S (cm)		
1	6	1	1	3	1	6	Good
2		1	1	3	1	6	Good
3	8	1	1	3	1	6	Good
4		1	1	3	1	6	Good
5		1	1	3	1	6	Good
6		1	1	1	1	4	Good
7		1	1	3	1	6	Good
8		1	1	3	1	6	Good
9	10	1	1	1	1	4	Good
10		1	1	3	3	8	Moderate
11		1	1	5	1	8	Moderate
12		1	1	1	5	8	Moderate
13		1	1	1	3	6	Good
14		1	1	1	1	4	Good
15		1	1	1	5	8	Moderate
16		1	1	3	5	10	Moderate
17		1	1	1	5	8	Moderate
18		1	1	3	1	6	Good
19	12	1	1	3	3	8	Moderate
20		1	1	3	1	6	Good
21		1	1	3	5	10	Moderate
22		1	1	3	3	8	Moderate
23		1	1	3	1	6	Good
24		1	1	3	3	8	Moderate
25		1	1	3	1	6	Good
26	14	1	1	5	1	8	Moderate
27		1	1	5	1	8	Moderate
28		1	1	5	1	8	Moderate
29		1	1	5	1	8	Moderate
30		1	1	5	1	8	Moderate
31		1	1	5	1	8	Moderate
32		1	1	5	1	8	Moderate

B/C: Break/Collapse, D/N: Debris/Net Coverage, I: Inclination, S: Sediment Accumulation.

The absence of Severe units indicates that the deployed modules remained functionally intact during the monitoring period. However, the dominance of the Moderate category suggests that follow-up monitoring should prioritize early physical change signals, particularly severe inclination and higher sediment accumulation, because these conditions may reduce functional void space over time. In the present dataset, inclination values reaching 42° indicate substantial module tilt that may interfere with structural stability and habitat functionality by reducing internal shelter space, altering entrance geometry, and lowering refuge effectiveness. Therefore, units exhibiting severe inclination should be regarded as priority targets for continued monitoring and maintenance evaluation and may warrant repositioning if future surveys indicate progressive tilt or associated structural instability. Modules with higher sediment accumulation should likewise be monitored for progressive burial linked to resuspension and settling processes, whereas future deployment optimization may benefit from site-specific evaluation of configuration, spacing, and flow-field conditions [16].

D. Limitations and Future Monitoring

This study is based on a three-day UVC snapshot (17–19 August 2025) and does not include direct measurements of near-bottom hydrodynamics, detailed bathymetry/slope gradients, or sediment properties. Therefore, the inferred drivers of inclination and sediment accumulation should be interpreted as pattern-based rather than directly validated mechanisms. Future monitoring should incorporate seasonal repeat surveys, hydrodynamic observations, and high-resolution seabed mapping to validate causal processes, quantify change rates, and refine deployment and maintenance strategies. Standardized image-quality control may also improve the consistency of future visual assessments [17]. In addition, semi-automated image-based approaches may support more efficient reef monitoring workflows [18]. Comparable post-deployment monitoring across reef designs in East Java may further help develop cross-site baselines for management [19].

IV. CONCLUSIONS

A three-day Underwater Visual Census (UVC) survey (17–19 August 2025) assessed 32 Fish Apartment (FA) units at Karang Mayit, Situbondo, East Java, Indonesia (6–14 m). The UVC-based mapping provides a baseline depth-zoned layout (6, 8, 10, 12, and 14 m) for routine spatial reporting, monitoring, and maintenance planning. All units were structurally intact, with no observed breakage/collapse and no visible net/debris coverage. Condition variability was mainly associated with inclination and sediment accumulation. Based on the Total Condition Score (TCS), 15 units (47%) were classified as Good and 17 units (53%) as Moderate, with no Severe category recorded. The Moderate status was primarily driven by severe inclination (≥31°) and/or sediment accumulation >10 cm, indicating that follow-up monitoring and maintenance should prioritize units showing these indicators. Beyond reporting site-specific conditions, this study provides an integrated baseline framework that combines spatial mapping and physical-condition scoring to support routine monitoring and maintenance prioritization of FA deployments.

DECLARATION OF COMPETING INTERESTS

Not applicable to this work.

ACKNOWLEDGMENT

The authors sincerely acknowledge the financial funding for the research project provided by the Directorate of Research and Community Service through the DPA (Budget Implementation Document) under Universitas Brawijaya's

PTNBH scheme, Contract No. 01046.21/UN10.A0501/B/KS/2025.

DATA AVAILABILITY

The datasets generated and analyzed during the current study are not publicly available but can be available from the corresponding author upon reasonable request. All figures presented in this manuscript are original and have not been previously published.

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