Benthic Composition Across Inshore and Offshore Reef Sites Along the Saudi Arabian Red Sea: A Baseline for Coral-Reef Monitoring and Management

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Abstract
Coral-reef management requires spatially explicit baselines that describe both living benthic communities and the non-living substrates that shape reef habitat and recovery potential. This study assessed benthic composition across ten reef sites along the Saudi Arabian Red Sea, comprising seven inshore sites and three offshore islands. Standardized Reef Check point-intercept transects were surveyed at approximately 5 and 10 m depth to quantify hard coral, soft coral, recently killed coral, nutrient-indicator algae, sponge, rock, rubble, sand, silt, and other benthic categories. The study aimed to compare benthic patterns among sites, depth strata, and proximity classes and to identify priorities for long-term monitoring and management.
Benthic composition varied markedly among the 20 site-depth transects. Living benthic cover ranged from 13% to 77%, indicating strong site-level heterogeneity. Mean living cover declined from 39.7% at 5 m to 32.5% at 10 m; however, the paired site-level comparison was not statistically significant ($t(9) = 1.97$, $p = 0.080$), and depth responses differed among reefs. Offshore reefs showed higher mean living cover than inshore reefs at both depths, but this pattern should be interpreted descriptively because only three offshore sites were surveyed and substantial overlap occurred among individual sites. Yanbu Factory Beach, an inshore site, equalled Baridy Island for the highest living cover at 5 m (77%). Baridy Island supported the highest hard-coral cover (66% at 5 m and 51% at 10 m), whereas Yanbu Factory Beach was distinguished by high soft-coral cover (33% and 40%, respectively). In contrast, Yanbu Plant Beach was strongly rock-dominated, while sand reached 66% at 10 m at El Badei Coast.
The results demonstrate that neither depth nor distance from shore alone explains reef condition. Instead, site-specific benthic composition and substrate type provide the most informative basis for monitoring and management. Repeated standardized surveys at the same georeferenced transects, supported by environmental measurements and permanent photographic records, are recommended to distinguish persistent habitat characteristics from ecological change and to guide site-specific management priorities.

Keywords: benthic composition; coral reefs; Reef Check; hard coral cover; inshore reefs; offshore reefs; Red Sea; Saudi Arabia.

1. Introduction

Coral reefs are biogenic ecosystems in which benthic composition integrates the outcome of coral growth, mortality, recruitment, competition, physical disturbance, and substrate availability. Reef-building corals create calcium-carbonate frameworks that provide structural complexity and habitat for reef-associated organisms, while algae and sponges contribute to primary production, nutrient processing, and occupation of available space. The relative cover of living corals, other benthic organisms, rock, rubble, sand, and silt therefore provides a practical description of reef state and of the physical template available for future recovery.

Percentage cover is one of the most frequently used coral-reef monitoring metrics because it is repeatable, readily communicated, and responsive to ecological change. Nevertheless, coral cover alone does not fully diagnose the cause of change. A reduction in hard-coral cover may be associated with thermal bleaching, predation, disease, sediment stress, storm damage, or local physical disturbance, while similar amounts of non-living cover can represent very different ecological conditions. Rock may provide consolidated settlement surface, whereas mobile rubble and unconsolidated sediment can restrict recruitment or destabilize newly settled corals. Monitoring results should therefore be interpreted as patterns requiring local environmental context rather than as direct proof of a specific pressure (Flower et al., 2017; Kenyon et al., 2023).

Standardized methods are essential when reef condition is compared among sites and depths. Reef Check uses a point-intercept substrate survey in which the category directly beneath fixed points along the transect is recorded, commonly at 0.5 m intervals. The method was developed for broad-scale, repeatable assessment and has been used internationally to detect spatial and temporal patterns in major benthic categories (Hodgson, 1999; Reef Check Foundation, n.d.). Evaluations of Reef Check data indicate that trained teams can produce useful estimates of broad benthic cover, although precision is influenced by sampling effort, interval length, observer consistency, and habitat heterogeneity (Done et al., 2017; Kuo et al., 2022). Photographic and photogrammetric approaches can provide permanent records and higher spatial resolution, but they require additional processing and do not eliminate the need for a sampling design matched to the monitoring objective (Urbina-Barreto et al., 2021; Carneiro et al., 2024).

The Red Sea contains extensive coral reefs across strong latitudinal, cross-shelf, and local environmental gradients. Temperature, salinity, thermal history, circulation, wave exposure, and coastal influence vary over short and broad spatial scales, producing marked differences in coral assemblages and reef condition. Studies in the central Saudi Arabian Red Sea have demonstrated substantial cross-shelf variation in benthic and fish communities, including differences that cannot be explained by depth alone (Khalil et al., 2017). More recent regional comparisons also emphasize that coral cover, taxonomic composition, and population structure vary between northern and central Red Sea reefs and between reef habitats (Pisapia et al., 2026).

Inshore reefs may experience stronger direct exposure to coastal development, recreation, suspended sediments, and land-based inputs, whereas offshore reefs are often less influenced by the mainland. This distinction is useful but not universal. Urban and nearshore reefs can retain substantial coral populations, and offshore reefs remain vulnerable to marine heatwaves, storms, predator outbreaks, and fishing pressure. Reviews of urban reefs show that cross-shelf patterns are highly site-specific and may include both degradation and persistence under chronic environmental variability (Heery et al., 2018). Consequently, management requires site-level baselines rather than assuming that all inshore reefs are degraded or that all offshore reefs are in good condition.

The present study provides a comparative benthic baseline for ten sites distributed along the Saudi Arabian Red Sea coast. Seven sites were classified as inshore and three as offshore. The objectives were to: (1) quantify the percentage cover of major living and non-living benthic categories at 5 and 10 m; (2) compare spatial patterns among individual reefs and between proximity classes; (3) evaluate the direction and magnitude of depth-related change; and (4) identify site-specific benthic states relevant to long-term monitoring and management.

2. Materials and Methods

2.1 Study area and site classification

Ten coral-reef sites were surveyed along the Saudi Arabian Red Sea coast. The inshore group comprised Obhur Resort Beach, New Jeddah Front Beach, Yanbu Factory Beach, El Badei Coast, Yanbu Plant Beach, Shuaiba Plant Beach, and Rabigh Plant Beach. The offshore group comprised Duqis Island, Ras Al-Kabeer Island, and Baridy Island. The locations span the central and north-central Saudi Arabian Red Sea and include recreational beaches, sites adjacent to coastal or industrial areas, and island reefs. Geographic coordinates and site codes are provided in Table 1 and Figure 1.

Table 1. Geographic coordinates and proximity classification of the surveyed reef sites.

No.	Site	Code	Proximity	Latitude (N)	Longitude (E)	Depth codes
1	Obhur Resort Beach	OR	Inshore	21.7320556	39.0689445	OR-1 (5 m); OR-2 (10 m)
2	New Jeddah Front Beach	JF	Inshore	21.6059444	39.1060000	JF-1 (5 m); JF-2 (10 m)
3	Yanbu Factory Beach	YF	Inshore	24.2728190	37.5357900	YF-1 (5 m); YF-2 (10 m)
4	El Badei Coast	BC	Inshore	21.2613889	39.1173611	BC-1 (5 m); BC-2 (10 m)
5	Yanbu Plant Beach	YP	Inshore	23.8364490	38.3877260	YP-1 (5 m); YP-2 (10 m)
6	Shuaiba Plant Beach	SP	Inshore	20.6980910	39.4986820	SP-1 (5 m); SP-2 (10 m)
7	Rabigh Plant Beach	RP	Inshore	22.7829870	38.9575410	RP-1 (5 m); RP-2 (10 m)
8	Duqis Island	DI	Offshore	21.8797223	38.9059167	DI-1 (5 m); DI-2 (10 m)
9	Ras Al-Kabeer Island	RI	Offshore	21.8049660	38.9306950	RI-1 (5 m); RI-2 (10 m)
10	Baridy Island	BI	Offshore	24.2513060	37.6639450	BI-1 (5 m); BI-2 (10 m)

Figure 1. Geographic distribution of the ten study sites along the Saudi Arabian coast of the Red Sea based on the recorded field coordinates. Site locations were plotted using the reported latitude and longitude values on a satellite basemap.

2.2 Field team and quality assurance

The field team consisted of two scientific divers and one observer. All personnel received training in the standardized Reef Check protocol before fieldwork. The divers conducted transect deployment and underwater classification, while the observer supported field coordination and data recording. Underwater photographs and video were collected with a GoPro 10 camera to document the reef habitat and support verification of classifications. The same benthic categories and procedures were used at all sites and both depths to improve consistency.

2.3 Benthic survey

Benthic composition was assessed using the Reef Check point-intercept approach at approximately 5 and 10 m depth at each site. At each depth, a 100 m transect line was deployed along a consistent depth contour following the Reef Check Tropical Program design. Benthic substrate was assessed within four 20 m survey segments separated by 5 m gaps. Substrate categories were recorded at 0.5 m intervals within each segment, yielding 40 point-intercept observations per segment and a total of 160 observations per depth at each site. The recorded categories were hard coral (HC), soft coral (SC), recently killed coral (RKC), nutrient-indicator algae (NIA), sponge (SP), rock (RC), rubble (RB), sand (SD), silt (SI), and other substrate or organisms (OT).

For summary purposes, HC, SC, NIA, SP, and OT were combined as living benthic cover, following the grouping used in the compiled field report. RKC, RC, RB, SD, and SI were combined as non-living cover. OT never exceeded 1% in any transect; therefore, its grouping did not materially influence the principal patterns. RKC was retained as a distinct category in detailed analyses and was not treated as synonymous with all non-living substrate.

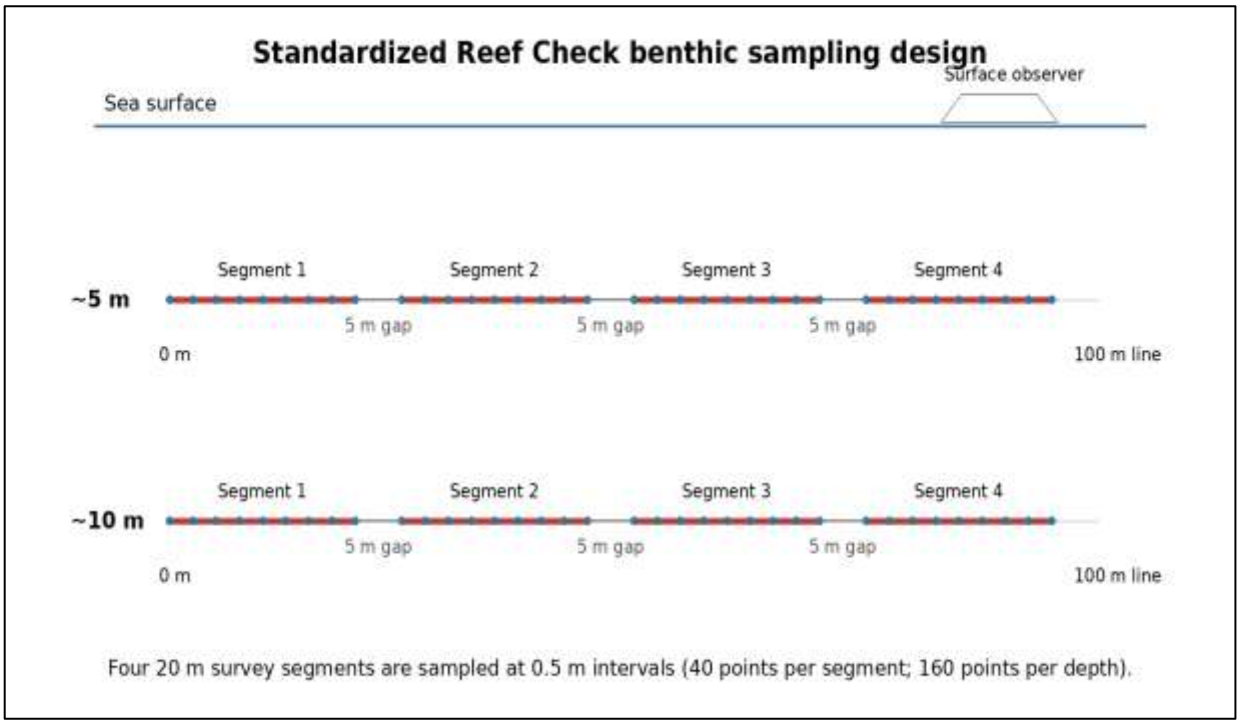

Figure 2. Schematic of the benthic sampling design. At each depth (approximately 5 and 10 m), a 100 m transect line contained four 20 m survey segments separated by 5 m gaps. Substrate categories were recorded at 0.5 m intervals within each segment, yielding 160 point-intercept observations per depth at each site.

2.4 Data processing and statistical analysis

Percentage cover was calculated for each benthic category at every site-depth combination. Descriptive summaries included ranges, means by depth and proximity class, dominant substrate categories, and depth-related changes expressed as the 10 m value minus the 5 m value. Because each site was observed at both depths, a two-sided paired t-test was used to compare site-level living benthic cover between 5 and 10 m. Mean living cover averaged across the two depths was compared between inshore and offshore sites using Welch's two-sample t-test because of unequal group sizes. Given the small number of sites, particularly in the offshore group, these site-level inferential comparisons were considered exploratory and were interpreted alongside effect magnitude and descriptive patterns rather than as definitive tests of broad regional differences. Data summaries and statistical analyses were performed in Python using pandas, SciPy, and Matplotlib; the original field report also used Microsoft Excel, SPSS, PRIMER, GraphPad Prism, ArcGIS Pro, and Google Earth Pro for data management and visualization.

3. Results

3.1 Overall spatial patterns

Benthic composition varied markedly among the 20 site-depth transects (Figure 3). Living benthic cover ranged from 13% at Obhur Resort Beach at 10 m and Yanbu Plant Beach at 5 m to 77% at Yanbu Factory Beach and Baridy Island at 5 m. Across all sites, mean living cover was 39.7% at 5 m and 32.5% at 10 m, a mean decline of 7.2 percentage points. The paired site-level comparison did not reach the conventional 0.05 significance threshold ($t(9) = 1.97$, $p = 0.080$), reflecting the strong variation in the direction and magnitude of depth responses among sites.

When the two depths were averaged, offshore sites had higher mean living cover than inshore sites (48.3% versus 30.9%). This difference was not statistically significant in the small site-level comparison (Welch $t = 1.31$, $df = 3.33$, $p = 0.275$). The result should therefore be interpreted as a descriptive inshore–offshore pattern rather than a general rule. Yanbu Factory Beach, an inshore site, equaled Baridy Island for the highest living cover at 5 m, demonstrating that proximity class alone did not determine reef condition.

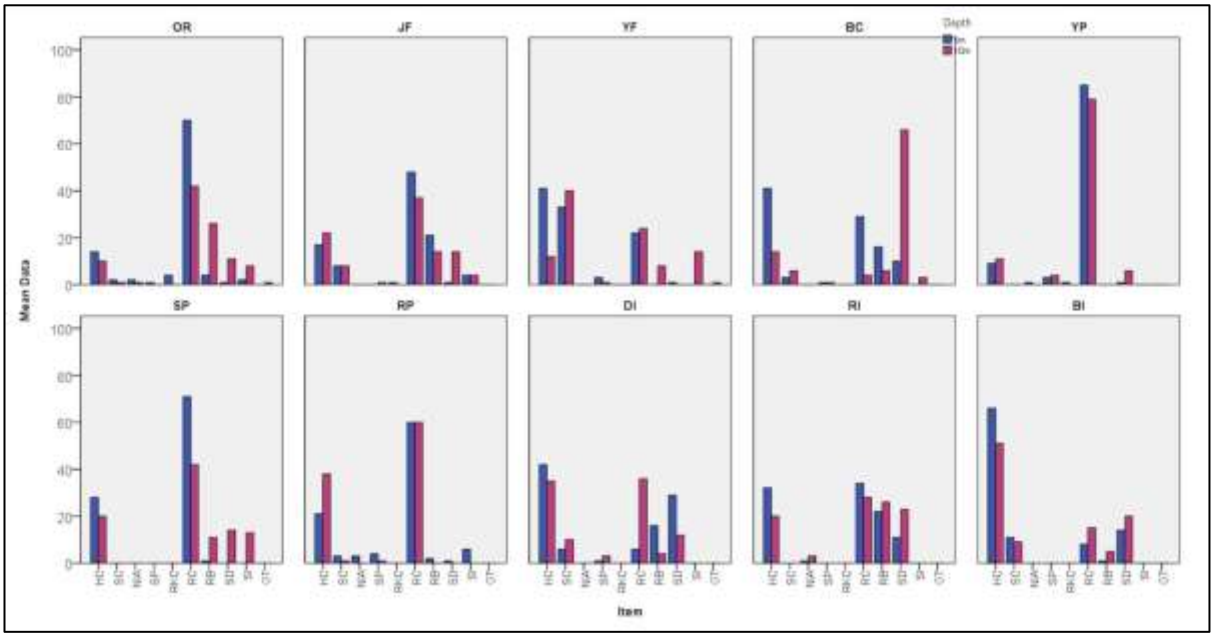

Figure 3. Living and non-living benthic cover at the ten reef sites at 5 and 10 m. Site-depth labels use the site code followed by depth in meters.

Table 2. Key benthic metrics and the dominant non-living category at each site and depth.

Site	Depth	HC	SC	Living total	Dominant non-living category	Dominant cover	Non-living total
OR – Obhur Resort Beach	5 m	14%	2%	19%	RC	70%	81%
OR – Obhur Resort Beach	10 m	10%	1%	13%	RC	42%	87%
JF – New Jeddah Front Beach	5 m	17%	8%	25%	RC	48%	75%
JF – New Jeddah Front Beach	10 m	22%	8%	31%	RC	37%	69%
YF – Yanbu Factory Beach	5 m	41%	33%	77%	RC	22%	23%
YF – Yanbu Factory Beach	10 m	12%	40%	54%	RC	24%	46%
BC – El Badei Coast	5 m	41%	3%	45%	RC	29%	55%
BC – El Badei Coast	10 m	14%	6%	21%	SD	66%	79%
YP – Yanbu Plant Beach	5 m	9%	0%	13%	RC	85%	87%
YP – Yanbu Plant Beach	10 m	11%	0%	15%	RC	79%	85%
SP – Shuaiba Plant Beach	5 m	28%	0%	28%	RC	71%	72%
SP – Shuaiba Plant Beach	10 m	20%	0%	20%	RC	42%	80%

Site	Depth	HC	SC	Living total	Dominant non-living category	Dominant cover	Non-living total
RP – Rabigh Plant Beach	5 m	21%	3%	31%	RC	60%	69%
RP – Rabigh Plant Beach	10 m	38%	1%	40%	RC	60%	60%
DI – Duqis Island	5 m	42%	6%	49%	SD	29%	51%
DI – Duqis Island	10 m	35%	10%	48%	RC	36%	52%
RI – Ras Al-Kabeer Island	5 m	32%	0%	33%	RC	34%	67%
RI – Ras Al-Kabeer Island	10 m	20%	0%	23%	RC	28%	77%
BI – Baridy Island	5 m	66%	11%	77%	SD	14%	23%
BI – Baridy Island	10 m	51%	9%	60%	SD	20%	40%

3.2 Coral-cover patterns

Hard coral was the dominant living category at most sites, but its distribution was highly uneven (Figure 4). Baridy Island had the highest hard-coral cover, reaching 66% at 5 m and 51% at 10 m. Duqis Island also supported relatively high hard-coral cover (42% and 35%), and El Badei Coast and Yanbu Factory Beach each recorded 41% at 5 m. In contrast, hard-coral cover was low at Yanbu Plant Beach (9% and 11%) and Obhur Resort Beach (14% and 10%).

Figure 4. Underwater view of the benthic community at Yanbu Factory Beach, characterized by relatively high soft-coral cover.

Soft coral was strongly concentrated at Yanbu Factory Beach, where cover increased from 33% at 5 m to 40% at 10 m and offset part of the sharp decline in hard coral. Soft coral reached 11% and 9% at Baridy Island and 6% and 10% at Duqis Island, but it was absent or represented only a small proportion at most other sites. NIA and sponge cover were generally low. NIA never exceeded 3%, and sponge cover reached a maximum of 4%. RKC was also uncommon, reaching 4% only at Obhur Resort Beach at 5 m and 1% at New Jeddah Front Beach and Yanbu Plant Beach at 5 m.

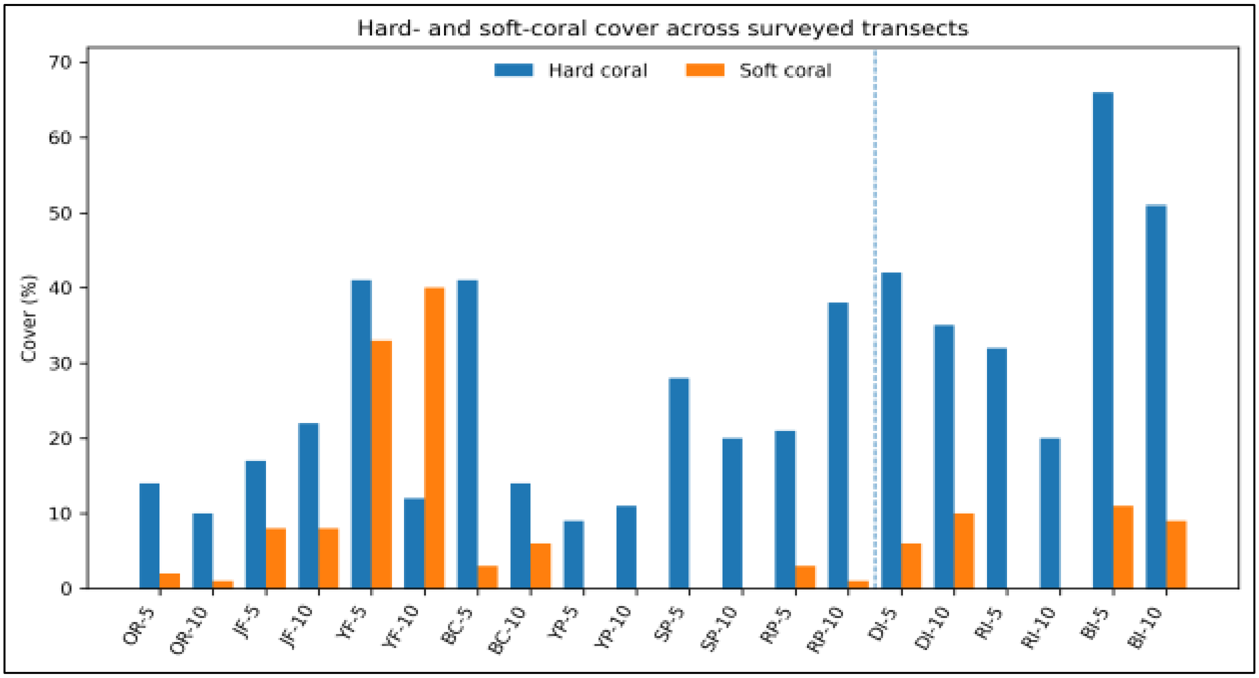

Figure 5. Hard- and soft-coral cover at each site-depth transect. The concentration of soft coral at Yanbu Factory Beach contrasts with the high hard-coral cover at Baridy and Duqis islands.

3.3 Non-living substrate patterns

Rock was the most widespread dominant non-living substrate. Yanbu Plant Beach was strongly rock-dominated at both depths (85% at 5 m and 79% at 10 m), while rock reached 70% at Obhur Resort Beach at 5 m, 71% at Shuaiba Plant Beach at 5 m, and 60% at Rabigh Plant Beach at both depths. Several reefs showed a shift away from rock with depth. At Obhur Resort Beach, rock declined from 70% to 42% while rubble, sand, and silt increased. At Shuaiba Plant Beach, rock declined from 71% to 42% and the deeper transect included 11% rubble, 14% sand, and 13% silt.

Figure 6. Underwater view of the deeper transect at El Badei Coast, where sandy substrate was prominent and reached 66% cover at 10 m.

Sand produced the strongest single depth-specific substrate signature. At El Badei Coast, sand increased from 10% at 5 m to 66% at 10 m, coinciding with a decline in living cover from 45% to 21%. Sand was also prominent at Duqis Island (29% at 5 m), Ras Al-Kabeer Island (23% at 10 m), and Baridy Island (14% and 20%). Rubble reached 26% at Obhur Resort Beach and Ras Al-Kabeer Island at 10 m.

3.4 Site-specific depth responses

At Obhur Resort Beach, living cover declined from 19% to 13%. Hard coral decreased from 14% to 10%, while rock declined from 70% to 42% and rubble, sand, and silt increased to 26%, 11%, and 8%, respectively.

At New Jeddah Front Beach, living cover increased from 25% to 31%. Hard coral increased from 17% to 22%, soft coral remained at 8%, rock and rubble declined, and sand increased from 1% to 14%.

Yanbu Factory Beach supported high living cover at both depths, although total living cover declined from 77% to 54%. Hard coral declined from 41% to 12%, while soft coral increased from 33% to 40%. Silt reached 14% at 10 m.

El Badei Coast exhibited one of the strongest depth-related shifts. Living cover declined from 45% to 21%, hard coral decreased from 41% to 14%, and sand increased from 10% to 66%.

Yanbu Plant Beach remained strongly rock-dominated. Living cover changed only from 13% to 15%, and rock declined slightly from 85% to 79%.

At Shuaiba Plant Beach, living cover consisted entirely of hard coral and declined from 28% to 20%. The deeper transect had a more heterogeneous non-living assemblage than the shallow transect.

Rabigh Plant Beach showed the largest positive response with depth. Living cover increased from 31% to 40%, largely because hard coral increased from 21% to 38%, while rock remained constant at 60%.

Duqis Island maintained nearly stable living cover (49% and 48%), although hard coral declined and soft coral, sponge, and rock increased at 10 m.

At Ras Al-Kabeer Island, living cover declined from 33% to 23%, accompanied by greater rubble and sand at 10 m.

Baridy Island retained the highest hard-coral cover in the survey, but living cover declined from 77% to 60% as rock, rubble, and sand increased with depth.

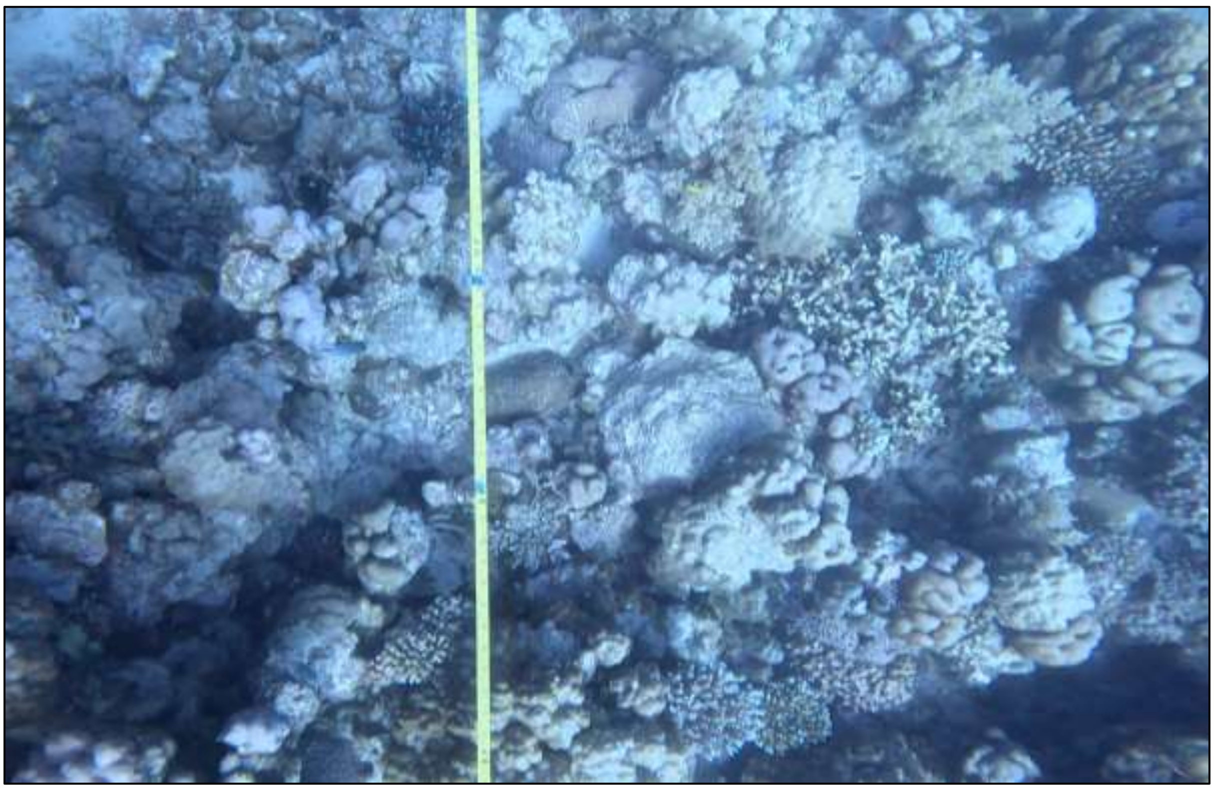

Figure 7. Underwater view of Baridy Island, which supported the highest hard-coral cover recorded in the survey.

3.5 Inshore–offshore summary

Table 3. Mean percentage cover by proximity class and depth.

Proximity	Depth	HC	SC	NIA	SP	Living	RC	RB	SD	SI	Non-living
Inshore	5 m	24.4	7.0	0.9	1.7	34.0	55.0	6.3	2.1	1.7	66.0
Inshore	10 m	18.1	8.0	0.1	1.1	27.7	41.1	9.3	15.9	6.0	72.3
Offshore	5 m	46.7	5.7	0.3	0.3	53.0	16.0	13.0	18.0	0.0	47.0
Offshore	10 m	35.3	6.3	1.0	1.0	43.7	26.3	11.7	18.3	0.0	56.3

Offshore reefs had higher mean hard-coral and living cover and lower mean rock cover than the inshore group at both depths (Table 3). However, the proximity groups overlapped substantially because Yanbu Factory Beach had high living cover despite its inshore classification, while Ras Al-Kabeer Island had moderate to low living cover. Depth-related declines occurred in both groups, with inshore mean living cover decreasing by 6.3 percentage points and offshore mean living cover decreasing by 9.3 percentage points.

4. Discussion

The central finding of this study is that benthic composition was highly heterogeneous at the scale of individual reefs. Living cover varied sixfold, from 13% to 77%, and the dominant benthic state ranged from hard-coral dominance at Baridy Island to soft-coral prominence at Yanbu Factory Beach, rock dominance at Yanbu Plant Beach, and sand dominance at El Badei Coast at 10 m. Such variation is consistent with the environmental heterogeneity of the Red Sea, where reef communities respond to differences in regional thermal history, cross-shelf position, hydrodynamic exposure, substrate structure, and local coastal influence (Khalil et al., 2017; Pisapia et al., 2026).

The offshore sites showed higher average living and hard-coral cover, but the pattern was not universal and did not reach statistical significance with only three offshore sites. Baridy and Duqis islands supported relatively high hard-coral cover, consistent with the possibility that some offshore reefs experience lower direct mainland influence. However, Yanbu Factory Beach equaled Baridy Island for the highest total living cover at 5 m, whereas Ras Al-Kabeer Island had only 33% and 23% living cover. These contrasts demonstrate why cross-shelf classification should be treated as a contextual factor rather than a direct reef-health score. Khalil et al. (2017) similarly reported cross-shelf structuring in the central Saudi Arabian Red Sea but also emphasized variability among reefs. Studies from other regions have likewise shown that inshore–offshore differences depend on the disturbance regime and local setting (Fabricius et al., 2008; Sutthacheep et al., 2019).

The inshore sites displayed diverse outcomes rather than a uniform degraded state. Yanbu Factory Beach contained high coral cover but shifted from a hard-coral-rich shallow assemblage to a soft-coral-dominated deeper assemblage. Rabigh Plant Beach showed higher hard-coral cover at 10 m than at 5 m. Conversely, Obhur Resort Beach and Yanbu Plant Beach were dominated by non-living substrates. Urban and developed coastal reefs can show both persistence and ecological compression, and their condition is shaped by the interaction of chronic local stress, environmental variability, and the tolerance of the resident assemblage (Heery et al., 2018). The present data therefore identify priorities for targeted assessment but do not independently establish causation.

Mean living cover was lower at 10 m, but the depth comparison was not statistically significant at $p < 0.05$ and the direction of change differed among reefs. Six sites declined, three increased, and one remained nearly stable. This non-uniform response is ecologically plausible because the difference between 5 and 10 m can alter light, wave energy, sediment retention, and habitat position differently depending on reef geometry. A deeper transect may occur on a consolidated reef slope at one site and on a sand apron or sediment-accumulation zone at another. Accordingly, depth cannot be interpreted independently of geomorphology and substrate availability.

El Badei Coast provides the clearest example: the 10 m transect was dominated by sand and had substantially less hard coral than the 5 m transect. This pattern is compatible with a transition from consolidated reef habitat to an unconsolidated sedimentary zone, but sedimentation rate was not measured and should not be inferred directly from percentage cover. At Obhur Resort Beach and Shuaiba Plant Beach, deeper transects contained more rubble, sand, and silt, suggesting greater representation of loose substrate. In contrast, Rabigh Plant Beach had higher hard-coral cover at 10 m and no recorded sand, rubble, or silt at that depth. Recent work in the Saudi Arabian Red Sea has also shown that habitat type and regional setting interact with depth to structure coral assemblages (Pisapia et al., 2026).

Rock dominance characterized Yanbu Plant Beach and several other inshore transects. Consolidated rock can provide settlement surface for corals and other sessile organisms, but high bare-rock cover may also reflect limited recruitment, grazing history, recent disturbance, or the classification of old dead reef framework as rock. Reef Check categories intentionally provide a broad field classification, and they should be complemented by coral recruit counts, algal functional groups, and repeat photography when recovery potential is evaluated (Flower et al., 2017).

Rubble and sand have different implications from consolidated rock. Mobile rubble can abrade recruits and remain unsuitable for coral recovery until it is stabilized or bound, although rubble beds are dynamic and may eventually consolidate under favorable conditions (Kenyon et al., 2023). Sand-dominated zones offer limited stable attachment area for reef-building corals. The high sand cover at El Badei Coast at 10 m and elevated rubble at Obhur Resort Beach and Ras Al-Kabeer Island at 10 m therefore identify locations where substrate stability should be measured directly before restoration is considered. Restoration should not be recommended solely from low coral cover; it should follow assessment of the disturbance source, substrate mobility, recruitment, water quality, and connectivity.

The low cover of RKC and NIA is also important. Non-living cover in this study should not be described as "dead coral cover," because most non-living substrate consisted of rock, rubble, sand, or silt. RKC reached only 4% at one transect and was absent from most sites. Similarly, NIA was generally absent or low. The dataset therefore does not support claims of widespread recent coral mortality or nutrient enrichment without additional observations. This distinction improves ecological interpretation and avoids converting broad Reef Check categories into unsupported diagnoses.

Figure 8. Underwater view of Duqis Island, which supported relatively high hard-coral cover at both surveyed depths.

Baridy Island and Duqis Island are suitable candidates for long-term reference monitoring because of their comparatively high hard-coral cover. Yanbu Factory Beach is equally important because its high living cover and unusual soft-coral dominance provide a contrasting inshore reference. These sites should not be assumed to be free of pressure; rather, their baseline condition makes them valuable for detecting future change and understanding why some reefs retain high living cover.

Obhur Resort Beach, Yanbu Plant Beach, Shuaiba Plant Beach, and the deeper El Badei Coast transect warrant focused investigation. Monitoring at these sites should combine repeat benthic transects with turbidity, suspended solids, sedimentation rate, temperature, salinity, dissolved oxygen, and hydrodynamic observations. Permanent photoquadrats or structure-from-motion surveys would provide visual records and measurements of colony demography and structural complexity that are not captured by point-intercept cover alone (Urbina-Barreto et al., 2021; Carneiro et al., 2024).

A standardized repeated survey design is preferable to isolated restoration action. Reef Check provides an efficient broad-scale framework, and trained teams can produce useful monitoring data (Done et al., 2017). Nevertheless, finer intervals and greater replication improve precision in heterogeneous habitats (Kuo et al., 2022; Carneiro et al., 2024). Future surveys should document the exact number and arrangement of replicate segments, preserve point-level observations, and use the same permanent or georeferenced transect locations whenever possible.

This study provides a broad spatial baseline; however, several limitations should be considered. First, Reef Check is a point-intercept method in which benthic observations are recorded at fixed intervals along each transect. Consequently, ecologically important substrates or small-scale features occurring between sampling points may not be detected, even where they are locally important. Although Reef Check has been widely used and supported as a reliable approach for broad benthic-cover assessment, complementary whole-reef assessments—such as photoquadrats, belt transects, or image mosaics—would strengthen future interpretation by documenting substrate variation beyond the fixed sampling points.

Second, the survey followed the standard Reef Check approach by assessing two shallow depth strata. This provides a consistent basis for comparison among sites but does not represent deeper reef habitats or the full depth-related variation within each reef. Field surveys were conducted at different times among regions because of operational constraints, and revisiting exactly the same sites and coordinates was challenging. These conditions highlight the value of a larger research team and greater field capacity to enable synchronized and repeated surveys.

Third, water temperature was measured during the surveys; however, concurrent comprehensive measurements of water quality, sedimentation, hydrodynamics, and coastal pressures were not available. Therefore, the environmental drivers of the observed benthic patterns cannot be determined conclusively. Fourth, the present analysis used summarized percentage-cover values rather than complete point-level field records, limiting the range of inferential analyses and preventing a full assessment of observer- or segment-level variance. Finally, Reef Check categories are intentionally broad and do not resolve coral taxonomy, colony size, coral recruitment, structural complexity, or detailed algal composition. The study relied primarily on simple researcher-led field techniques implemented by trained divers. Future studies would benefit from a larger multidisciplinary team, repeated monitoring, and complementary photographic and spatial-mapping approaches.

5. Conclusion

Benthic composition varied strongly among ten Saudi Arabian Red Sea reef sites and between the two surveyed depths. The highest living cover occurred at both an inshore site, Yanbu Factory Beach, and an offshore site, Baridy Island, demonstrating that distance from shore alone did not determine reef condition. Offshore reefs had higher average living and hard-coral cover, but the small number of offshore sites and substantial overlap among individual reefs limited broad generalization. Depth-related changes were similarly site-specific: living cover declined at six sites, increased at three, and remained nearly stable at Duqis Island.

The results identify distinct benthic states with different management relevance. Baridy and Duqis islands supported high hard-coral cover; Yanbu Factory Beach supported high soft-coral cover; Yanbu Plant Beach and Obhur Resort Beach were dominated by rock; and the deeper El Badei Coast transect was dominated by sand. These patterns provide a baseline for repeated monitoring, but they should not be interpreted as proof of specific environmental pressures in the absence of water-quality, sediment, and hydrodynamic measurements. Long-term standardized monitoring, permanent photographic records, preservation of point-level data, and targeted environmental measurements are required to distinguish persistent habitat characteristics from ecological change.

6. Recommendations

1. Repeat standardized surveys at the same georeferenced transects at least annually and, where possible, across contrasting seasons.
2. Preserve point-level data and record the exact transect segmentation and replicate structure to support robust statistical analysis.
3. Combine benthic monitoring with water-quality, sedimentation, temperature, and hydrodynamic measurements. Assess substrate stability, coral recruitment, and the source of disturbance before initiating restoration at rubble- or sand-dominated locations.
4. Add permanent photoquadrats or photogrammetry to provide repeatable visual and structural records.

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