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Reef Catchments – Rubble to Reef Monitoring Report

Post-Deployment - Round 2 and 3

August 2026

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For further information contact:

Josh Potter
Environmental Project Officer – Fisheries and Aquatic Ecosystems
Catchment Solutions
Ph: (07) 4968 4216

Enquiries should be addressed to:
General Manager
Catchment Solutions Pty Limited
PO Box 815, Mackay Qld 4740
Tel: +617 4968 4216
Email: info@catchmentsolutions.com.au

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Contents

1 Background

Catchment Solutions were commissioned by Reef Catchments to undertake post-deployment monitoring at two reef restoration sites near Dangerous Reef, Mackay coast, Queensland. The monitoring forms part of Reef Catchments' Rubble to Reef project, which aims to restore fish habitat through the installation of 30 Habitat Reef (HR) Modules within the Port of Mackay limits, outside the Great Barrier Reef Marine Park. The monitoring aims to assess fish abundance and diversity, structural stability of the HR Modules, invertebrate colonisation and coverage, and the accumulation of marine debris post-deployment, as required under the project's Sea Dumping Permit (Permit No. SD2023-4048).

The approved program requires monitoring to be undertaken over a 30-year period. The monitoring timeframe is as follows:

- Year 1: two rounds of monitoring
- Years 2-5: one round of monitoring annually
- Years 6-30: one round of monitoring every five years

The HR Modules were engineered to provide stable, vertical relief in areas otherwise characterised by low relief, homogenous, sandy and rubble substrates. The modules were designed and built to facilitate colonisation by sessile invertebrates, provide refuge and feeding habitat for a range of marine species, and improve local recreational fishing opportunities. The project was undertaken in response to regional pressures on natural reef systems, including habitat loss associated with cyclones, vessel strikes and fishing activity, by establishing alternative reef habitat intended to support recreationally important fish species and reduce reliance on natural reefs.

Pre-deployment and post-deployment monitoring events have been undertaken across multiple stages of the project using a combination of methods. The pre-deployment monitoring was carried out to provide reference for post-deployment comparisons. Pre-deployment monitoring occurred on two occasions, including an initial survey in October 2022 associated with development approval requirements, and a subsequent event in June 2024. Equipment availability varied between these events, resulting in the use of different monitoring tools, including remotely operated vehicles (ROVs) and Baited Remote Underwater Video Stations (BRUVS). Round 1 post-deployment monitoring was undertaken in July 2025, approximately one year following installation of the HR Modules. Round 2 and round 3 monitoring events were undertaken in May 2026 and June 2026, respectively. The monitoring process has been progressively refined to incorporate improvements such as the use of red lens filters to enhance image quality and species identification while maintaining consistency with established video-based monitoring approaches.

This report presents the findings of round 2 and round 3 post-deployment monitoring and assesses outcomes in relation to the requirements of Sea Dumping Permit SD2023-4048.

1.1 Site Details

The Rubble to Reef sites are located approximately 5 km south-east of the Port of Mackay, near Dangerous Reef. Deployment of the HR modules occurred in June 2024. The sites are also located directly east of the Pioneer River mouth, which is highly seasonal and subject to high flow events (Table 1; Figure 1). River discharge is likely to influence local sediment dynamics and water clarity, particularly during the wet season.

Site A is located in water depths ranging from 11.8 m to 12.6 m relative to Lowest Astronomical Tide (LAT) and approximately 4.8 km from shore. Site B is located in depths of approximately 10.7 m to 11.0 m LAT and approximately 3.6 km from shore. Both sites are characterised by sandy rubble substrate and are separated by approximately 1 km.

Round 2 post-deployment monitoring was conducted on 5 May 2026 under fine weather conditions, with winds ranging from 13 km/h to 15 km/h and gusts of up to 20 km/h. Measured Significant wave height (SWH) at Mackay Harbour wave buoy ranged between 0.42 m and 0.49 m. Monitoring was undertaken from mid-morning to mid-afternoon, three days after the full moon. Underwater visibility was considered very poor, with strong tidal currents and recent wet-season discharge from the Pioneer River likely contributing to elevated suspended sediment levels. Tidal conditions on the day of monitoring were as follows:

- High tide at 00:14 (5.16 m)
- Low tide at 06:46 (1.91 m)
- High tide at 12:21 (3.88 m)
- Low tide at 18:16 (1.62 m)

Round 3 post-deployment monitoring was conducted on 1 June 2026 under fine weather conditions, with wave conditions deteriorating throughout the monitoring event. Winds ranged from 13 km/h to 19 km/h, with gusts of up to 24 km/h. Measured SWH at Mackay Harbour wave buoy ranged between 0.1 m and 0.45 m. Monitoring was undertaken from mid-morning to mid-afternoon, one day after full moon. Underwater visibility was initially considered good but declined to poor/ moderate during the afternoon as weather conditions deteriorated and wave action increased. Visibility was substantially improved compared with Round 2. Strong tidal currents persisted throughout the monitoring event, while increasing wave action appeared to further reduce water clarity. Tidal conditions on the day of monitoring were as follows:

- Low tide at 05:38 (1.50 m)
- High tide at 11:14 (4.14 m)
- Low tide at 17:06 (1.19 m)
- High tide at 23:31 (5.35 m)

Table 1: Coordinates of each HR module at Rubble to Reef sites (WGS84).

Site A			Site B		
Module ID	Latitude	Longitude	Module ID	Latitude	Longitude
HR-A01	-21.1462	149.2667	HR-B01	-21.1396	149.2545
HR-A02	-21.1459	149.2667	HR-B02	-21.1395	149.2545
HR-A03	-21.1461	149.2668	HR-B03	-21.1396	149.2546
HR-A04	-21.1462	149.2668	HR-B04	-21.1396	149.2546
HR-A05	-21.1464	149.2668	HR-B05	-21.1397	149.2545
HR-A06	-21.1464	149.2666	HR-B06	-21.1397	149.2545
HR-A07	-21.1464	149.2665	HR-B07	-21.1398	149.2544
HR-A08	-21.1462	149.2664	HR-B08	-21.1396	149.2543
HR-A09	-21.1462	149.2664	HR-B09	-21.1396	149.2544
HR-A10	-21.1462	149.2659	HR-B10	-21.1397	149.2541
HR-A11	-21.1457	149.2661	HR-B11	-21.1394	149.2542
HR-A12	-21.1456	149.2666	HR-B12	-21.1393	149.2544
HR-A13	-21.1458	149.2671	HR-B13	-21.1394	149.2546
HR-A14	-21.1462	149.2673	HR-B14	-21.1397	149.2548
HR-A15	-21.1469	149.2667	HR-B15	-21.1399	149.2545

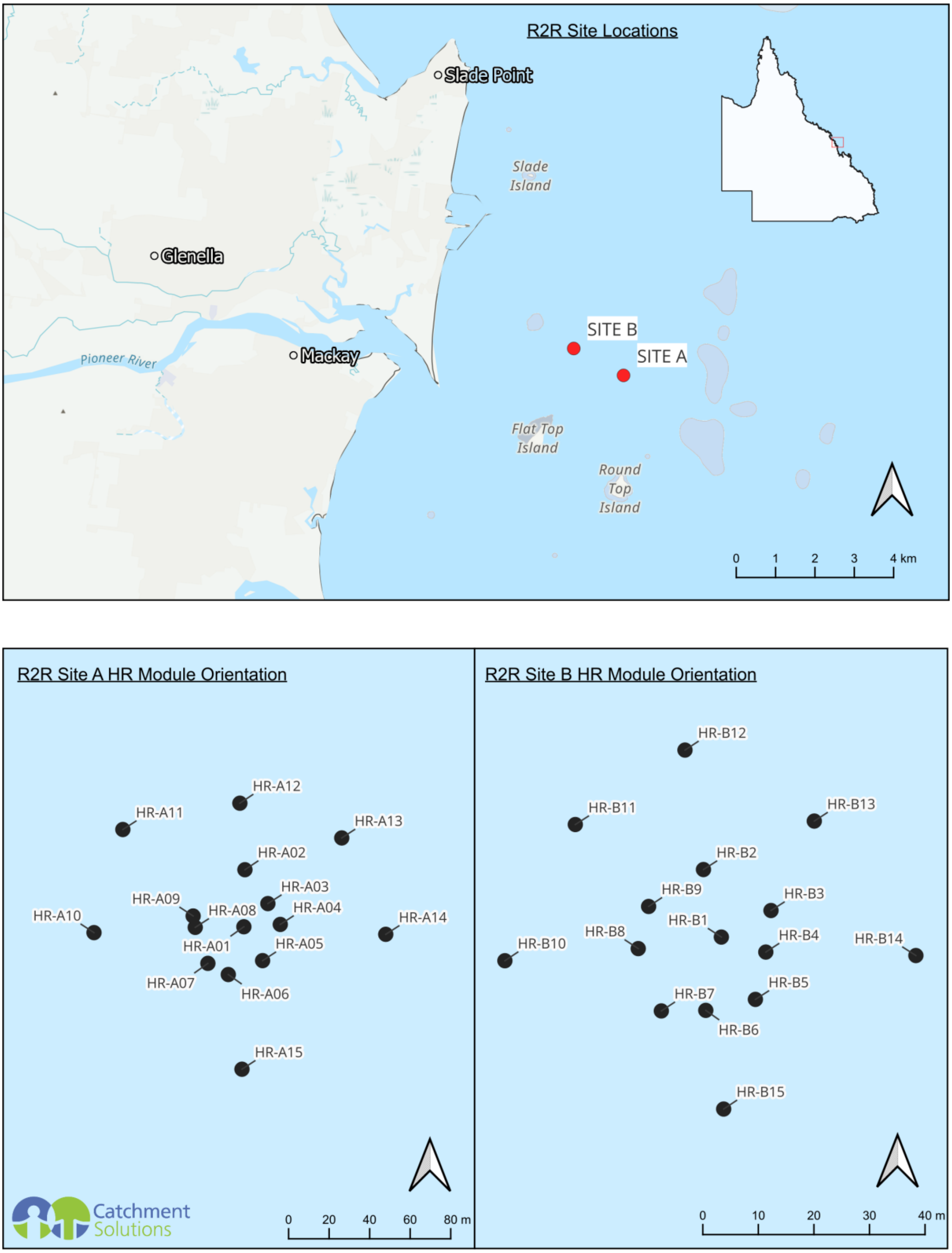

Figure 1: Map showing the location of the Rubble 2 Reef site locations in relation to Mackay Coastline (top); Maps showing the orientation of HR modules at each site verified by Maritime Safety Queensland survey at each site (Bottom).

2 Monitoring Activities

2.1 Methodology

Pre-deployment monitoring was undertaken on two separate occasions. The first event occurred in October 2022, when marine plant surveys were conducted as part of the project's Development Approval requirements. During this event, BRUVS were not operational and could not be deployed, and fish observations were therefore limited to footage collected using a ROV. A second pre-deployment monitoring event was undertaken in June 2024, during which BRUVS were deployed. The ROV was not operational at that time. The results from each of these events were pooled into a single 'Baseline' monitoring round.

Round 1 post-deployment monitoring was undertaken in July 2025, approximately one year after the HR modules were deployed. This monitoring event utilised both BRUVs and a ROV. Subsequent monitoring rounds aimed to replicate the methods applied during round 1, however environmental conditions prevented the ability to do so. The survey methods utilised during each monitoring round are summarised in Table 2.

Table 2: Summary of monitoring methods used at Sites A and B across all monitoring rounds.

Monitoring Round	Site A		Site B	
	No. of BRUVs	ROV	No. of BRUVs	ROV
Baseline	3	✓	3	✓
Round 1	3	✓	3	✓
Round 2	6		6	
Round 3	6		6	✓

<u>Remotely Operated Vehicle (Underwater Drone) Surveys</u>

A Fifish V6 Expert ROV (Underwater drone) was used for both module inspections and fish assemblage monitoring. The survey vessel was anchored at each site and the ROV was deployed and mobilised to the seabed by a trained operator. Video recording occurred continuously for the duration of each deployment.

For fish monitoring, the ROV was operated for one standardised period of 15 minutes per site, commencing once the ROV had reached the seabed and its position was confirmed to be in the vicinity of the HR modules. During this time, the operator manoeuvred the ROV around the reef modules with the aim of recording as many fish species and individuals as possible. A spotter was on board the vessel to ensure safe deployment and retrieval, and to maintain awareness of the ROV position relative to the vessel and surrounding hazards. All underwater video footage was collected using GoPro Hero 10 cameras fitted with a waterproof housing and red lens filters to improve colour correction and image clarity under ambient light conditions at depth.

A lower-resolution ROV (Trident) was used during pre-deployment monitoring, which limited image quality and species identification compared with equipment used in post-deployment surveys.

Baited Remote Underwater Video Station Deployments

For fish monitoring, six Baited Remote Underwater Video Stations (BRUVS) were deployed as close as practicable to reef modules at each site. Pilchards were used as bait in all BRUVS deployments to attract fish to the field of view and standardise sampling across sites. Video recording was initiated prior to deployment and continued for a fixed duration of 30 minutes. Following deployment, the vessel was manoeuvred to a distance of at least 100 m from the BRUVS to minimise disturbance and potential interference with fish behaviour. All underwater video footage was collected using GoPro Hero 10 cameras fitted with a waterproof housing and red lens filters to improve colour correction and image clarity under ambient light conditions at depth.

Red lens filters were not used during pre-deployment monitoring. Their inclusion in post-deployment surveys represents a methodological improvement to enhance image quality and species identification.

Video Analysis

For fish monitoring, Video analysis techniques followed established methods for BRUVS and ROV surveys (Gladstone et al 2012; Hicks et al 2024). BRUVS footage analysis commenced five minutes after camera deployment to ensure that the survey vessel had moved a minimum distance of 100 m from the site. A standardised 15-minute segment of footage was then analysed for each deployment. The ROV analysis commenced once the ROV had reached the seabed and its position was confirmed to be in the vicinity of the HR modules. The ROV analysis then followed standardised period of 15 minutes per site

Fish species were identified and abundance was recorded using the MaxN metric, defined as the maximum number of individuals of a species observed simultaneously within a single video frame. This conservative approach minimises the risk of overestimating abundance due to repeated counts of the same individuals (Gladstone et al 2012). The time of species appearance was recorded, and still images were captured to assist with species identification where required. MaxN was recorded for each species from individual video deployments at each site. Where multiple videos were collected at a site, the highest MaxN value recorded for each species across all deployments was used to represent site-level abundance. Fish species richness was defined as the total number of species observed per site, based on pooled BRUVS and ROV video data. Species abundance was described using MaxN values for each species at each site.

Invertebrate coverage was assessed during ROV inspections of HR Modules and through review of recorded video footage. Settlement was described qualitatively using visual estimates of coverage and dominant invertebrate groups observed on module surfaces.

Data Analysis

Fish species richness and abundance metrics were compared with pre-deployment monitoring data to assess changes in fish assemblages over time. Species accumulation curves were generated to examine rates of species detection and to assess whether species diversity at each site approached a ‘plateau’, indicating potential stabilisation of the fish species composition.

Shannon's Diversity Index (SDI) was calculated for each site to quantify fish assemblage diversity. The index incorporates both the number of species present and how evenly individuals are distributed among those species, providing a standardised and easily comparable measure of diversity between sites and between pre- and post-deployment monitoring periods (Hicks et al 2024).

$$H = -\sum[(p_i) \times \log(p_i)]$$

2.2 Limitations and Challenges

Monitoring activities continue to be affected by several environmental, operational, and logistical constraints.

Similarly to previous reporting periods, unsuitable weather conditions limit the survey opportunities. Wet seasonal flows from the Pioneer River and prolonged high winds resulted in greatly reduced water clarity. This limited the visibility for both ROV and BRUVS footage. This was particularly an issue during the Round 2 monitoring event.

Wave action and tidal movements at the reef sites also created challenges in maintaining vessel position near the modules and reduced the stability and manoeuvrability of the ROV. Although water clarity during round 3 was substantially better than in Round 2, strong currents combined with deteriorating weather conditions limited the ROV's ability to manoeuvre upstream. As a result, modules could not be inspected as thoroughly as intended.

Ongoing operational challenges reflected the logistical complexity of marine monitoring, where suitable weather conditions, favourable tidal windows, and vessel and personnel availability must coincide. These combined constraints limited the number of suitable survey days and reduced scheduling flexibility. During ROV surveys, orientation and navigation were occasionally challenging, making it difficult to consistently identify and distinguish individual reef modules during inspections.

3 Existing Assessment Summary

3.1 Pre deployment Monitoring

A total of five fish species were recorded across both sites during pre-deployment monitoring. Site A supported three species with a total MaxN of five, while Site B supported four species with a total MaxN of four.

3.2 Post-deployment: Round 1 Monitoring

In Round 1 post-deployment monitoring, a total of 23 fish species were recorded across both sites, with species richness increasing from 2 to 14 species at Site A and from 4 to 17 species at Site B compared with pre-deployment monitoring. Fish diversity also increased, with SDI values of 1.73 at Site A and 2.05 at Site B. Nine recreationally important species were recorded, including red emperor (*Lutjanus sebae*), fingermark (*Lutjanus johnii*), goldspotted rockcod (*Epinephelus coioides*), and small-mouth nannygai (*Lutjanus erythropterus*).

Contrary to pre-deployment expectations, Site B recorded greater fish diversity and abundance than the more offshore Site A. This may reflect environmental differences between sites, such as water temperature, or the closer clustering of modules at Site B, which may have enhanced habitat attractiveness.

All reef modules had started establishing ecologically, with sessile benthic invertebrates covering ~70% of module surfaces. Barnacles, encrusting algae, and sponges were the dominant colonising organisms. All modules remained structurally stable with no evidence of movement, sediment accumulation, tilting, or significant marine debris. The observations and results were consistent with early-stage reef development and indicated ongoing ecological use of the deployed structures.

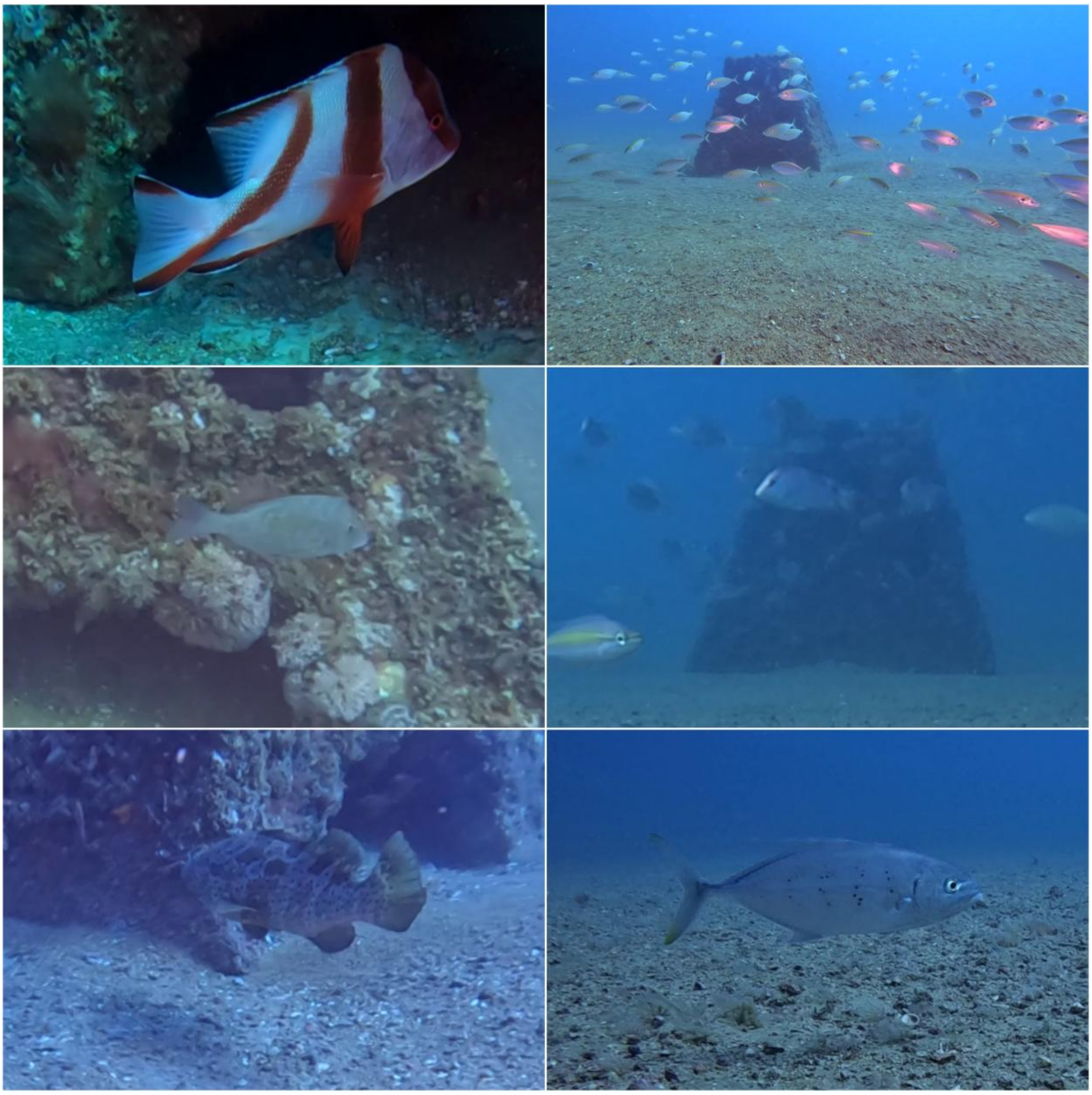

Figure 2: Examples of fish observed during Post-deployment: Round 1. A red emperor (*L. sebae*) in the bottom cave of HR module (top left); yellowstripe scad (*S. leptolepis*) school (top right); A grassy emperor (*L. laticaudis*) against the side of a HR module (middle left); a school of small-mouth nannygai (*L. erythropterus*) around module HRB08 (middle right); goldspotted rockcod (*E. coioides)* swimming towards a HR module (bottom left); a bludger trevally (*C. gymnostethus*). All photographs were obtained post-deployment.

4 Post-deployment: Round 2 and Round 3 Monitoring Results

4.1 Fish Assemblage

The relative fish assemblage metrics recorded at the two sites changed over successive monitoring rounds. While Site B initially recorded higher values during Round 1, Site A exhibited comparable or higher values for several metrics by Round 3. A total of 33 fish species have been identified across both sites through all monitoring events. A table showing current and historical fish assemblage data can be found in Appendix A.

A total of 15 and 22 fish species were recorded across both sites during post-deployment monitoring Rounds 2 and 3, respectively (Figure 3). Species richness decreased at both sites during Round 2, from 14 to 9 species at Site A and 17 to 9 species at Site B, when BRUVS were the only survey method used. During Round 3, species richness increased to 17 species at Site A and 15 species at Site B, comparable with those observed during Round 1.

Relative abundance (Total MaxN) declined substantially at both sites during Round 2, decreasing from 48 to 28 at Site A and from 113 to 27 at Site B (Figure 4). During Round 3, Total MaxN increased to 41 at Site A and 52 at Site B (Figure 4). While Site A returned to a level comparable with Round 1, Site B remained below the abundance recorded during Round 1.

The SDI differed between sites. At Site A, SDI increased progressively from 0.693 during pre-deployment monitoring to 2.41 by Round 3. In contrast, Site B exhibited a decrease in SDI from 2.05 to 1.41 in Round 2 before returning to 2.12 by Round 3 (Figure 5).

Fish species continued to accumulate at both sites throughout the monitoring program. Species accumulation at Site B increased from four species during pre-deployment monitoring to 25 species by Round 3, while Site A increased from three to 28 species over the same period. Site B recorded greater cumulative richness than Site A during Rounds 1 and 2; however, by Round 3, Site A had greater cumulative richness than Site B (Figure 6).

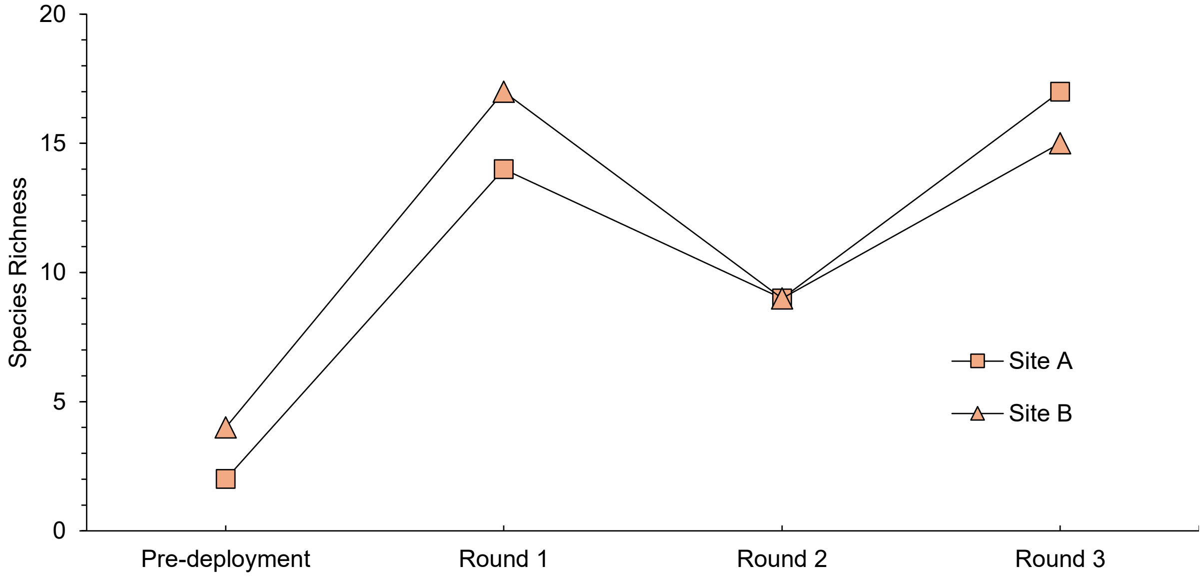

Figure 3: Fish species richness recorded at Sites A and B during baseline and post-deployment monitoring.

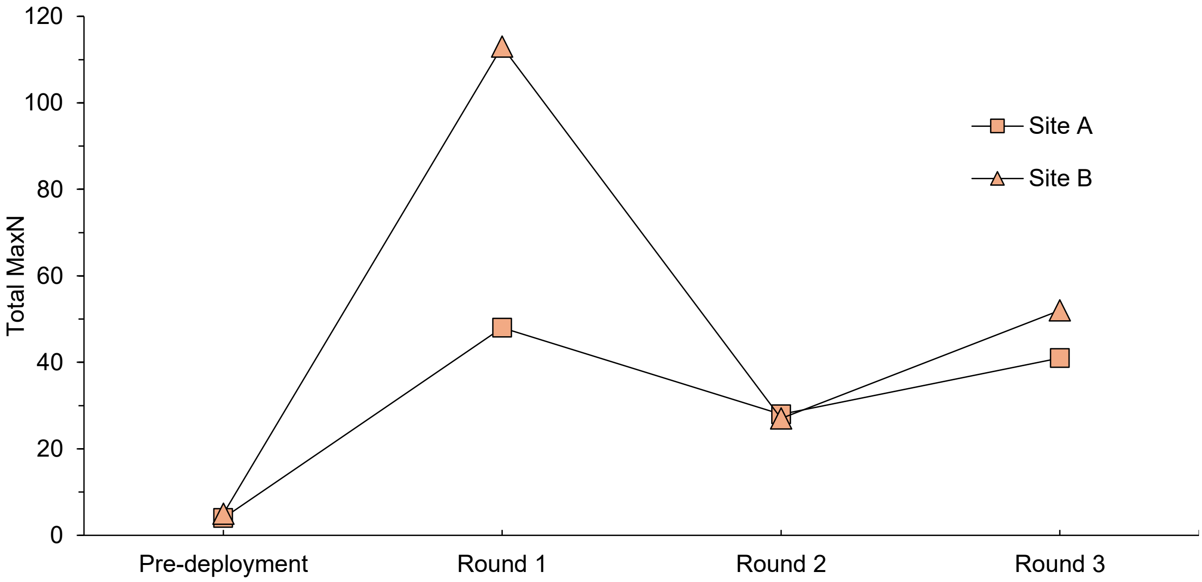

Figure 4: Relative abundance (Total MaxN) recorded at Sites A and B during baseline and post-deployment monitoring.

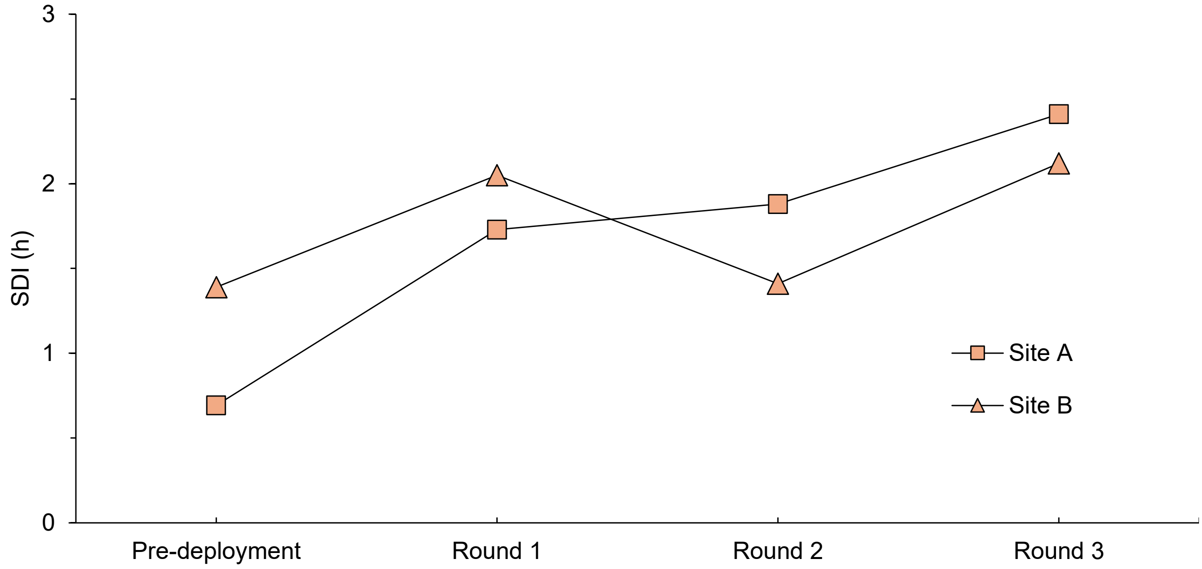

Figure 5: Shannon's Diversity Index recorded at Sites A and B during baseline and post-deployment monitoring.

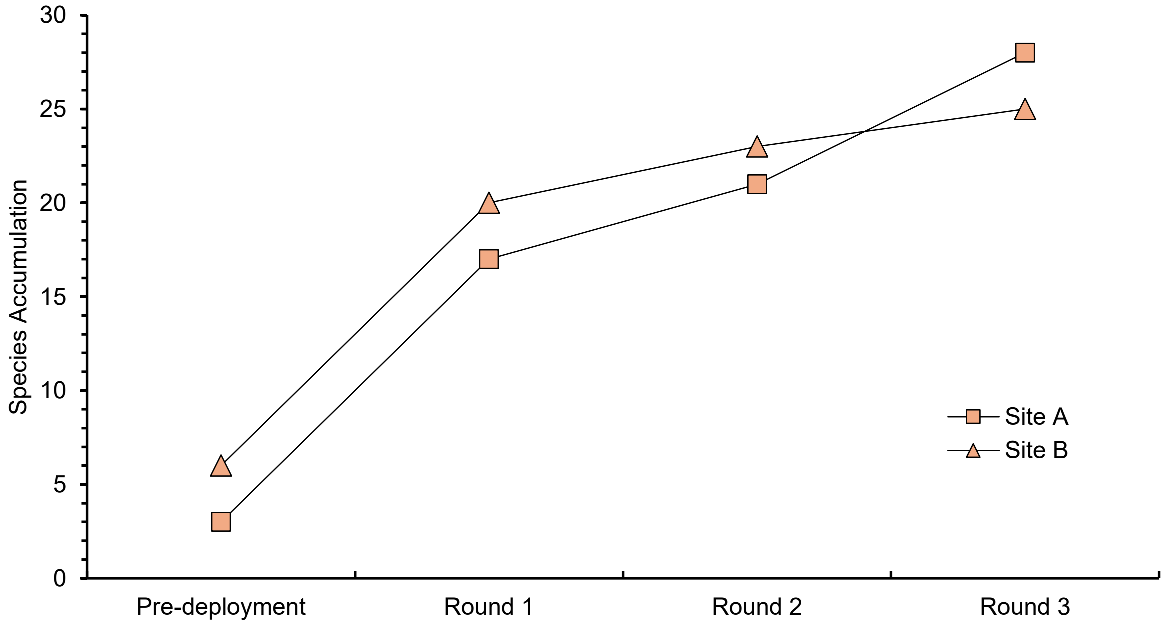

Figure 6: Fish species accumulation recorded at Sites A and B during baseline and post-deployment monitoring.

4.1.1 Influence of the ROV on Results

To assess the influence of the ROV on the results, plots were generated that compare the complete dataset with a dataset excluding ROV observations. No ROV surveys were conducted during Round 2 or at Site A during Round 3.

Excluding ROV observations from Round 1 reduced species richness by 57% at Site A and 55% at Site B. In Round 3, the influence of the ROV was less prominent with a reduction in richness of 12% when excluded (Figure 7).

Relative abundance (Total MaxN) decreased when ROV data was excluded. In Round 1 the Total MaxN was reduced by 88% and 47% at Site A and B, respectively. During Round 3, the Total MaxN at Site B saw a reduction of 57% when ROV results were excluded (Figure 8).

The influence of ROV observations on SDI was less pronounced than for the other fish assemblage metrics and varied between sites and monitoring rounds. During Round 1, excluding ROV observations slightly increased SDI at Site A from 1.73 to 1.79, but reduced SDI at Site B from 2.05 to 1.40. During Round 3, excluding ROV observations increased SDI at Site B from 2.12 to 2.40 (Figure 9).

Excluding ROV observations reduced fish species accumulation from 28 to 21 species at Site A and from 25 to 20 species at Site B by Round 3. The ROV contributed nine additional species at both sites during Round 1, and although several of these species were subsequently recorded during later BRUV surveys, species accumulation remained higher in the complete dataset throughout the monitoring program (Figure 10).

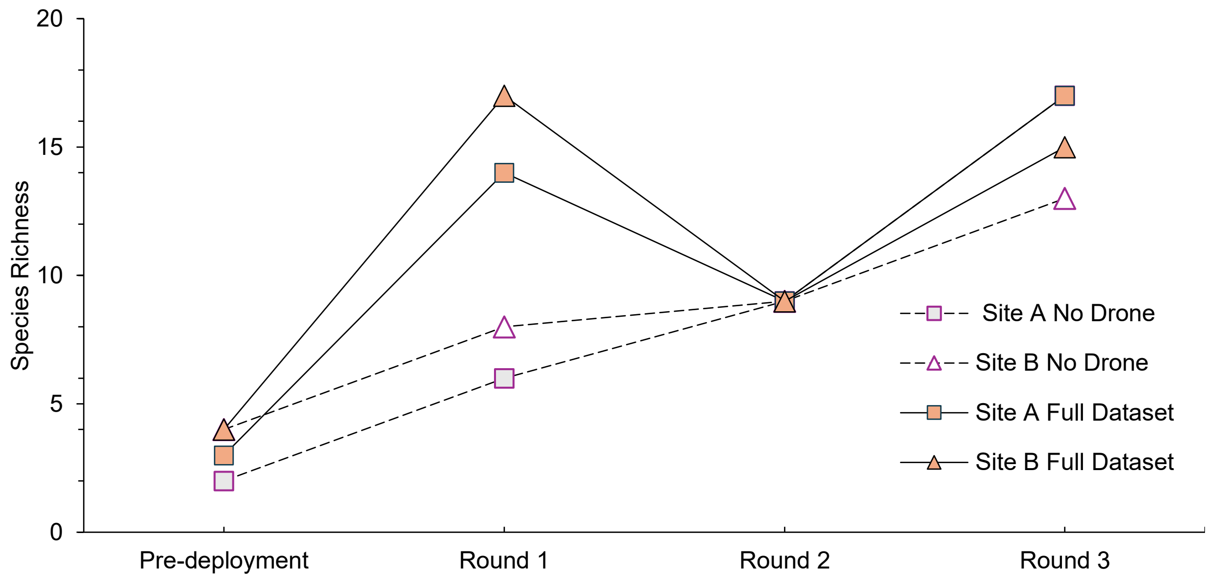

Figure 7: Fish species richness recorded using the complete dataset and the dataset excluding ROV observations.

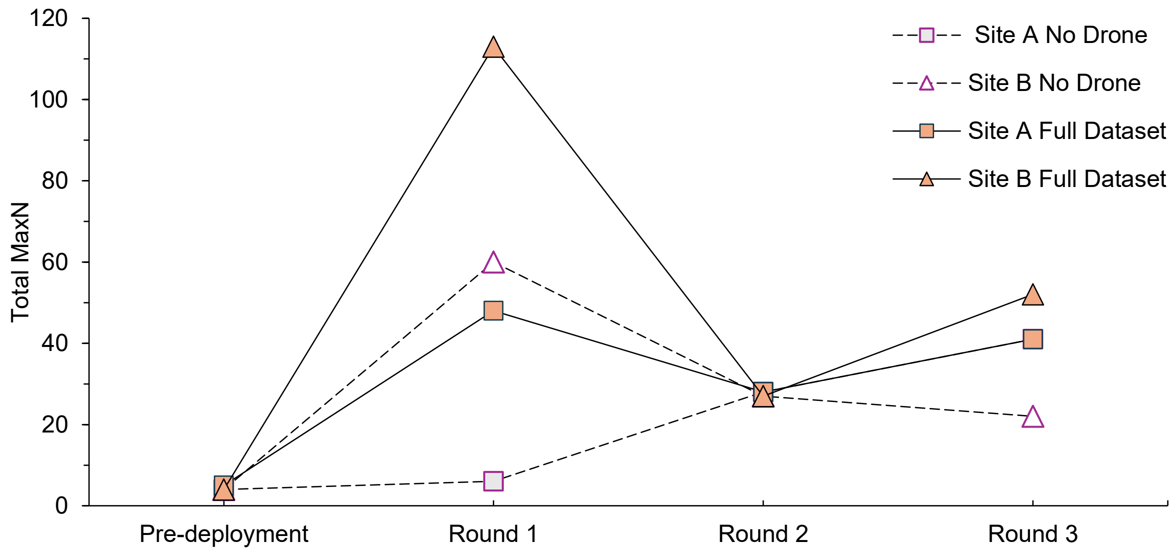

Figure 8: Relative abundance (Total MaxN) recorded using the complete dataset and the dataset excluding ROV observations.

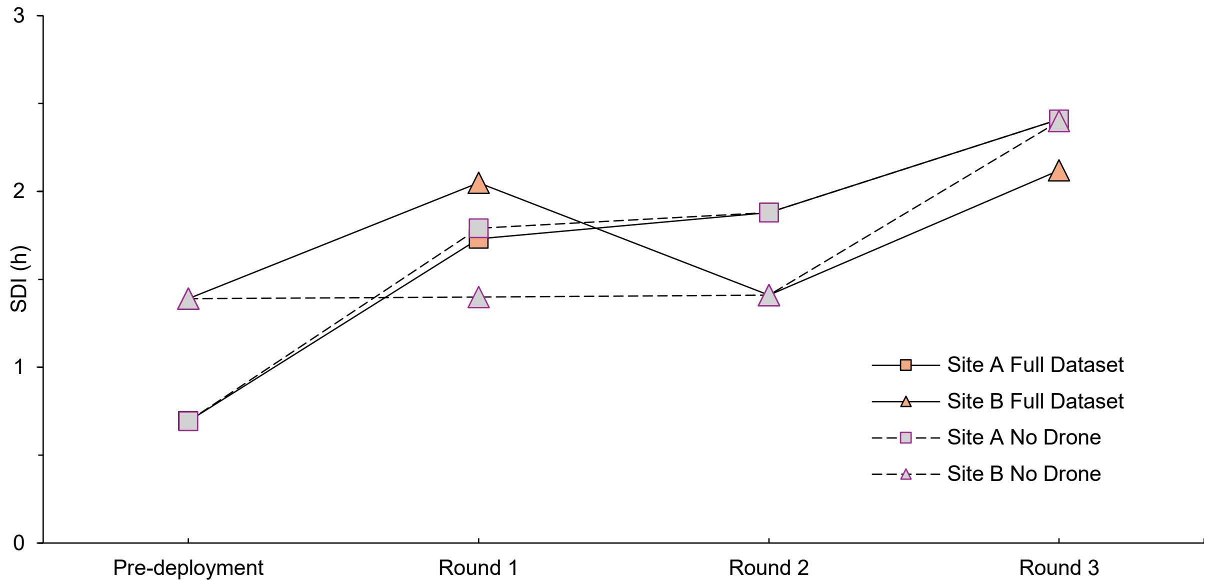

Figure 9: Shannon's Diversity Index recorded using the complete dataset and the dataset excluding ROV observations.

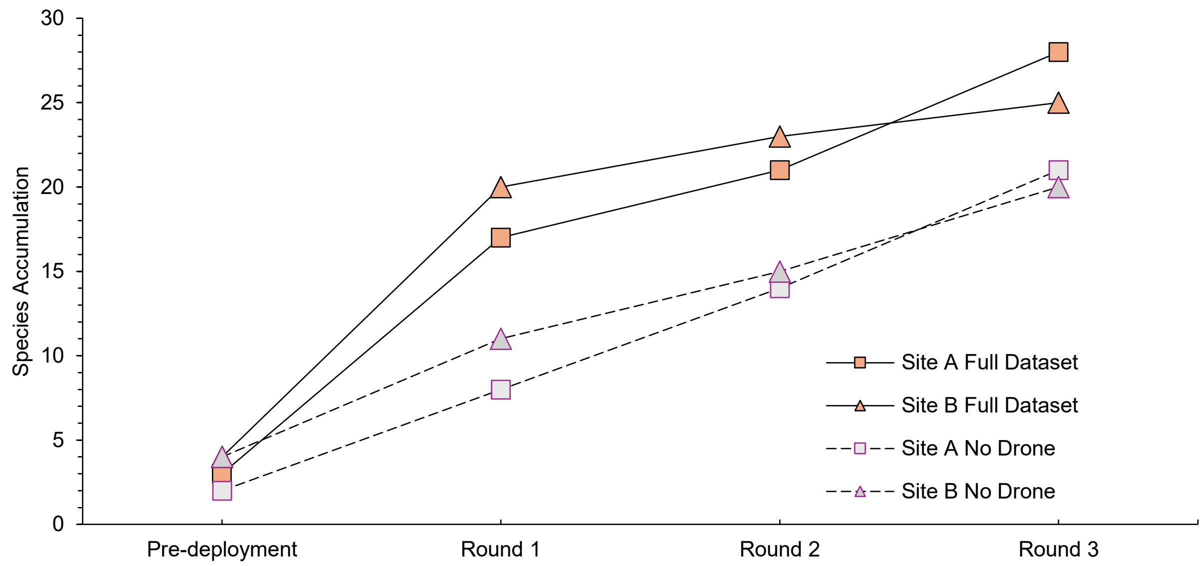

Figure 10: Fish species accumulation using the complete dataset and the dataset excluding ROV observations.

4.2 Recreationally Important Fish Species

Two additional recreationally important fish species, bar-cheeked coral trout (*Plectropomus maculatus*) and blackspotted rockcod (*Epinephelus malabaricus*), were recorded at Site A during Round 3. The total number of recreationally important species observed across both sites since module deployment is 11 (Table 3).

Table 3: Fish species recorded at Sites A and B during baseline and post-deployment monitoring. (● indicates species presence during the monitoring round.)

		Site A				Site B			
Common name	**Species Name**	Pre	R1	R2	R3	Pre	R1	R2	R3
Australian Goatfish	*Upeneus australiae*						●		●
Barrier reef chromis	*Chromis nitida*		●	●	●		●		●
Barcheeked coral trout	*Plectropomus maculatus*				●				
Blackspotted rockcod	*Epinephelus malabaricus*				●				
Bludger trevally	*Carangoides gymnostethus*		●	●	●				
Brown striped husser	*Lutjanus vitta*		●	●	●		●		●
East-Australian Stripey	*Microcanthis joyceae*		●						
Fingermark	*Lutjanus johnii*		●						
Goldspotted rockcod	*Epinephelus coioides*		●	●	●		●		●
Grassy emperor	*Lethrinus laticaudis*			●	●		●	●	●
Gunther's wrasse	*Pseudolabrus guentheri*		●						●
Longfin batfish	*Platax teira*				●				
Moses perch	*Lutjanus monostigma*						●		
Muller's coralfish	*Chelmon muelleri*		●	●	●		●		●
Painted sweetlip	*Diagramma pictum*		●		●		●	●	●
Paradise threadfin bream	*Pentapodus paradiseus*			●		●	●	●	●
Pempheris sp.	*Pempheris sp.*		●				●		
Pink Banded grubfish	*Parapercis nebulosa*	●				●			
Plagiotremus sp.	*Plagiotremus sp.*						●		●
Red emperor	*Lutjanus sebae*		●	●	●				●
Remora	*Remora remora*	●						●	
Rusty spotted toadfish	*Torquigener pallimaculatus*				●	●			
Sandbar Shark	*Carcharhinus plumbeus*		●						
School mackerel	*Scomberomorus queenslandicus*	●			●	●		●	●
Scribbled angelfish	*Chaetodontoplus duboulayi*				●				
Small-mouth nannygai	*Lutjanus erythropterus*				●		●	●	●
Smallmouth Scad	*Alepes apercna*							●	
Starry Puffer	*Arothron stellatus*		●				●		●
Striped Cardinalfish	*Ostorhinchus fasciatus*				●		●		●
Tawny nurse shark	*Nebrius ferrugineus*							●	
Wrasse sp.	*Halichoeres sp.*		●				●		
Yellowstripe scad	*Selaroides leptolepis*			●			●	●	
Yellowtail demoiselle	*Neopomacentrus azysron*				●		●		

4.3 HR Module Condition and Stability

Assessment of HR Module condition during Rounds 2 and 3 was limited by poor water clarity, strong currents and reduced ROV deployment. Where modules could be adequately observed, sessile benthic invertebrate colonisation remained broadly consistent with observations from Round 1, with no notable changes in overall coverage or dominant colonising groups identified (Figure 11).

All HR Modules that could be visually assessed remained upright, with no evidence of tilting, burial, displacement or structural damage. However, reduced visibility and limited close range inspection meant that module condition and small scale changes in benthic cover could not be assessed with the same level of detail as during Round 1. No significant marine debris accumulation was identified on the modules that could were observed.

Figure 11: Appearance of HR modules at the time of deployment (top left), one year post-deployment (top right), and two years post-deployment (Bottom left & right).

5 Assessment of Round 2 and Round 3 Monitoring Results

The results from post-deployment Rounds 2 and 3 indicate ongoing ecological development associated with the HR modules. Cumulative species richness continued to increase at both sites with each successive monitoring round. In conjunction with increased species diversity observed over the monitoring period, these findings suggest that the modules are supporting the progressive development of fish assemblages rather than only a short-term response following module deployment. The invertebrate coverage on the HR modules appears mostly unchanged. This is not unexpected considering the high level of coverage previously observed in Round 1.

Underwater visibility varied considerably between each round and appeared to influence the observed fish assemblage metrics (Figure 12). Round 1 had the most favourable underwater visibility and recorded the highest fish abundance and fish species richness. In contrast, Round 2 experienced the poorest visibility and recorded substantially lower richness and abundance at both sites. Improved visibility during Round 3 coincided with a recovery in these metrics, but not to levels observed in Round 1. Therefore, it is likely that the poorer underwater visibility observed in the current monitoring period reduced the detectability and identification of fish during sampling, possibly resulting in lower recorded species richness and abundance.

Figure 12: Typical footage recorded from BRUVs in post-deployment monitoring Round 1, 2, and 3 (left to right).

Fish assemblage differences between Sites A and B have also varied between monitoring rounds. During Round 1, Site B recorded greater species richness and abundance than Site A, despite pre-deployment expectations that the deeper and more offshore Site A may support a greater fish assemblage. Subsequent monitoring has not demonstrated a consistently greater response at either site, with the relative performance of the sites varying among metrics and monitoring rounds. The differences observed during Round 1 may have reflected temporal variability, environmental conditions or differences in species detectability rather than a persistent site specific effect. Continued monitoring will provide greater confidence in determining whether consistent differences between the two sites emerge over time.

Environmental conditions during Rounds 2 and 3 highlighted the operational limitations of the ROV. During Round 2, poor underwater visibility and unfavourable sea conditions prevented effective deployment, resulting in no usable observations. Although visibility improved during Round 3, strong tidal currents exceeded the propulsion capability of the drone and restricted surveys to Site B. Wave action also made anchoring difficult and frequently caused the survey vessel to drift from the sampling location. Consequently, ROV survey effort was reduced during Rounds 2 and 3, limiting direct comparisons with Round 1, which was undertaken under more favourable environmental conditions. These constraints reduced the contribution of the drone to fish assemblage monitoring and limited visual inspection of individual HR Modules. The difficulties encountered also reinforced the Round 1 recommendation to pair a suitable depth sounder with GPS positioning to confirm module locations and orientation when conditions prevent effective ROV deployment. Inclusion of this equipment is therefore considered a priority for future monitoring.

The comparison of the complete dataset with a dataset excluding ROV observations (i.e., BRUVS only) demonstrated that inclusion of the drone increased the values recorded for each fish assemblage metric. Although the overall trajectory of the species accumulation curves remained similar, indicating that the underlying pattern of fish assemblage development was unchanged, excluding the ROV reduced species richness, total abundance, and species accumulation. This suggests that the ROV increased the probability of detecting species present within the fish assemblage and accelerated species accumulation. While excluding ROV observations also reduced overall survey effort, which likely contributed to the observed differences, the comparable accumulation trajectories indicate that BRUVS alone were still capable of detecting the broader ecological trends. Therefore, the absence of ROV surveys does not prevent interpretation of the broader long-term trends, although inclusion of the ROV provides a more comprehensive assessment of fish assemblage composition when environmental conditions permit.

No notable changes in benthic colonisation were identified during the current monitoring rounds compared with Round 1. However, the reduced availability of ROV footage limited the ability to undertake close inspection of module surfaces, and therefore restricted detailed assessment of changes in benthic community composition and coverage.

All HR modules observed during the current monitoring rounds remained upright, with no evidence of displacement or structural instability. This is consistent with observations from Round 1 and indicates that the modules have remained stable throughout the monitoring period to date. Although environmental conditions prevented detailed inspection of every module during each survey, there was no evidence from the modules that could be observed to indicate broader structural issues at either site.

Since deployment in 2024, multiple reports have been received from recreational fishers successfully catching fish at the reef sites, including small mouth nannygai, grassy emperor and Spanish mackerel (Figure 13). Spanish mackerel have not yet been recorded during formal monitoring. As monitoring is primarily focused on the seabed and the HR modules, the methods are less likely to detect highly mobile pelagic species that predominantly utilise the upper water column.

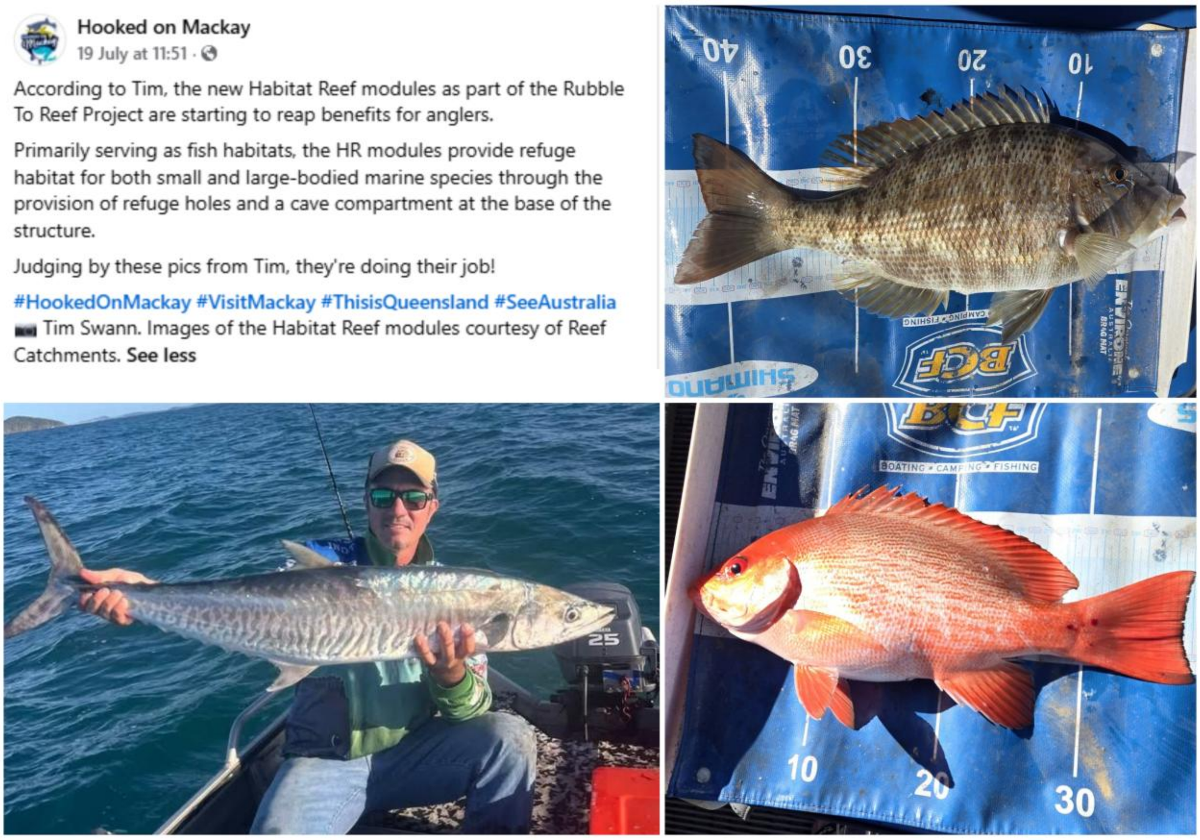

Figure 13: Social media post from the local recreational fishing group 'Hooked on Mackay' promoting the Rubble to Reef sites, showing a local fisher with a Spanish mackerel (*Scomberomorus commerson*) caught at the site (left); grassy emperor and small-mouth nannygai caught by a local recreational fisher at the site (right). (Source: Hooked on Mackay; and D. Radovic)

6 Future Recommendations

- Incorporate down-imaging sonar or a suitable depth sounder paired with GPS to confirm HR Module locations and upright orientation in all future monitoring. Continue undertaking detailed inspections when conditions are suitable for drone.
- Maintain consistency in core monitoring methods, including BRUV deployment duration, analysis windows, and use of conservative abundance metrics such as MaxN, to ensure comparability between monitoring rounds.
- Where practicable, undertake monitoring during favourable visibility, tidal and sea conditions to improve survey effectiveness.

7 Conclusion

Overall patterns observed across post-deployment monitoring Rounds 1 to 3 remain consistent with the expected ecological development of fish assemblages associated with the HR Modules. Continued increases in cumulative species richness, together with sustained fish abundance and diversity, indicate ongoing utilisation of the structures by a developing fish assemblage. High levels of benthic colonisation have been maintained, and all observed modules have remained stable and upright.

Although environmental conditions affected survey effectiveness during Rounds 2 and 3, particularly the deployment of the ROV, the broader ecological trends remained consistent across the monitoring period. The results therefore continue to indicate that the HR Modules are functioning as intended at this stage of the project. Ongoing monitoring in accordance with the approved program will be required to confirm longer-term ecological trends and structural performance.

8 References

Gladstone, W, Lindfield, S, Coleman, M & Kelaher, B 2012, 'Optimisation of baited remote underwater video sampling designs for estuarine fish assemblages', *Journal of Experimental Marine Biology and Ecology*, vol. 429, pp. 28–35.

Hicks, D, Getz, E, Kline, R & Cintra Buenrostro, C 2024, 'A Decade of Monitoring Reveals a Dynamic Fish Assemblage on a Substantial Artificial Reef in the Texas Gulf of Mexico', *Fisheries Management and Ecology*, Wiley.

9 Appendix A: Fish Assemblage Data

Common name	Species Name	Predeployment		Round 1		Round 2		Round 3	
		SITE A	SITE B	SITE A	SITE B	SITE A	SITE B	SITE A	SITE B
Australian Goatfish	*Upeneus australiae*				**2**				**1**
Barrier reef chromis	*Chromis nitida*			**4**	**2**	**2**		**3**	**13**
Barcheeked coral trout	*Plectropomus maculatus*							**1**	
Blackspotted rockcod	*Epinephelus malabaricus*							**1**	
Bludger trevally	*Carangoides gymnostethus*			**4**		**1**		**1**	
Brown striped husser	*Lutjanus vitta*			**27**	**9**	**5**		**8**	**1**
East-Australian Stripey	*Microcanthis joyceae*			**2**					
Fingermark	*Lutjanus johnii*			**1**					
Goldspotted rockcod	*Epinephelus coioides*			**1**	**1**	**1**		**1**	**1**
Grassy emperor	*Lethrinus laticaudis*				**1**	**2**	**1**	**1**	**3**
Gunther's wrasse	*Pseudolabrus guentheri*			**1**					**1**
Longfin batfish	*Platax teira*							**1**	
Moses perch	*Lutjanus monostigma*				**1**				
Muller's coralfish	*Chelmon muelleri*			**2**	**2**	**2**		**1**	**2**
Painted sweetlip	*Diagramma pictum*			**1**	**3**		**1**	**5**	**1**
Paradise threadfin bream	*Pentapodus paradiseus*		**1**		**1**	**4**	**2**		**5**
Pempheris sp.	*Pempheris sp.*			**1**	**5**				
Pink Banded grubfish	*Parapercis nebulosa*	**2**	**1**						
Plagiotremus sp.	*Plagiotremus sp.*				**1**				**1**
Red emperor	*Lutjanus sebae*			**1**		**1**		**1**	**3**
Remora	*Remora remora*	**1**					**1**		
Rusty spotted toadfish	*Torquigener pallimaculatus*		**1**					**1**	
Sandbar Shark	*Carcharhinus plumbeus*			**1**					
School mackerel	*Scomberomorus queenslandicus*	**2**	**1**				**1**	**1**	**1**
Scribbled angelfish	*Chaetodontoplus duboulayi*							**1**	

Common name	Species Name	**Predeployment**		**Round 1**		**Round 2**		**Round 3**	
		SITE A	SITE B	SITE A	SITE B	SITE A	SITE B	SITE A	SITE B
Small-mouth nannygai	*Lutjanus erythropterus*				**30**		**2**	**5**	**2**
Smallmouth Scad	*Alepes apercna*						**1**		
Starry Puffer	*Arothron stellatus*			**1**	**1**				**1**
Striped Cardinalfish	*Ostorhinchus fasciatus*				**30**			**1**	**16**
Tawny nurse shark	*Nebrius ferrugineus*						**1**		
Wrasse sp.	*Halichoeres sp.*			**1**	**1**				
Yellowstripe scad	*Selaroides leptolepis*				**20**	**10**	**17**		
Yellowtail demoiselle	*Neopomacentrus azysron*				**3**			**8**	
Species Richness		3	4	14	17	9	9	17	15
		4		23		15		22	
Total MaxN		5	4	48	113	28	27	41	52
Shannons Diversity Index (H)		0.693	1.39	1.73	2.05	1.88	1.41	2.41	2.12