EXO Engineering

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Exo Engineering Int. Ltd

The Enterprise Centre
University of East Anglia
Norwich Research Park
Norwich NR4 7TJ

Telephone: 0330 80 80 377
Email: info@exo-engineering.co.uk
Websites: www.exo-engineering.co.uk
www.livingwindfarms.com

Partner Information

TotalEnergies EP Nederland (TEPNL)
The Rich North Sea (De Rijke Noordzee)
Offshore Wind Growth Partnership

Authors

Sam Greenhill, MSc (Exo Engineering)
Thijs Kabel, MSc (TEPNL)
Renate Olie, MSc (The Rich North Sea)

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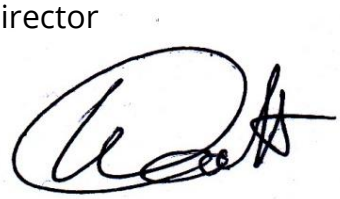
William Coulet
Director



ExoLodge artificial reef unit being deployed at the TotalEnergies North Sea gas platform.

Contents

1. Introduction

As part of the Offshore Wind Growth Partnership (OWGP) funded Living Windfarms Project, and in partnership with TotalEnergies EP Nederland and The Rich North Sea (De Rijke Noordzee), Exo Engineering have designed, manufactured and deployed artificial reef units with nature-inclusive design (NID) features at a test site within the 500-metre safety zone of a TotalEnergies platform in the North Sea. These artificial reef units were named “ExoLodges” and will be referred as this from here on. The ExoLodges will be regularly monitored to assess the biodiversity associated with them and compare this to appropriate control locations at the test site. This report outlines the results from T1 biodiversity monitoring of the site, 12 months following their deployment.

2. Project goal

The main project goals that can be achieved through this pilot are to collect data to help answer the following questions:

- Does the inclusion of nature inclusive designs (NID) benefit the marine life associated with offshore infrastructure?
- Does the additional cost of nature inclusive design translate into a proportional biodiversity gain?
- Can monitoring of the reef units be successfully integrated into the existing ROV survey program of TotalEnergies EP Nederland?

3. Research questions

3.1 Main research question

Is the biodiversity of the ExoLodges significantly different from the biodiversity associated with existing marine infrastructure after 5 years?

3.2 Sub-research questions

- Is the species richness of the ExoLodges different from the species richness of the control locations*?
- Does the community structure associated with the ExoLodges differ from the community structure of the control locations?
- What is the ecological succession of species on the ExoLodges over time? (Assuming that control locations have reached a climax community)
- Will invasive species establish themselves on the ExoLodges?

- Do different concrete material formulations affect marine biocolonisation?

*(ExoAnchor sinker, the jacket leg of the platform, and the surrounding sand habitat)

4. Artificial reef design

The design of the "ExoLodge" artificial reef units was driven by the criteria of a tender for nature-inclusive structures around North Sea windfarms. This outlined the need to increase suitable habitat for species native to the North Sea by deploying appropriately designed artificial reefs to sit within the scour protection of an offshore wind farm operation. Specific design criteria for the artificial reefs were laid out, to optimise the habitat provision for native species, especially Atlantic cod (*Gadus morhua*) and Ross worm (*Sabellaria spinulosa*).

Each artificial reef unit has a weight of 4.5t with dimensions 1.8m x 1.7m x 1.7m.

It contains the following features:

- Large internal cylindrical tunnel (min. diameter 1m).
- Additional voids and tunnels to allow water transfer.
- Holes to provide shelter habitats.
- Surface textures to facilitate biocolonisation.
- Addition of wood and metal features to support a range of communities (Rectangular wood and metal panels 170mm width x 1800mm length).
- Removable reef plugs, for biodiversity monitoring of colonising species (270mm height x 140mm width).

The design and measurements are detailed in Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5.

Five ExoLodge units were manufactured using two different concrete-like material formulations. ExoLodge numbers 1, 2, and 3 were manufactured using concrete mix, which used a low carbon GGBS binder, and ExoLodge numbers 4 and 5 were manufactured using concrete mix 2, using a low carbon GGBS binder and a limestone and granite powder aggregate. In addition, ExoLodge number 3 was coated in a lime solution prior to deployment. The removable reef plugs were manufactured using similar material as concrete mix 2, including a low carbon GGBS binder and granite powder aggregate.

Differences in the concrete formulations have not been assessed alongside T1 monitoring but will be assessed over the lifetime of the project with the additional time series of data.

Figure 1. Design renders of the ExoLodge

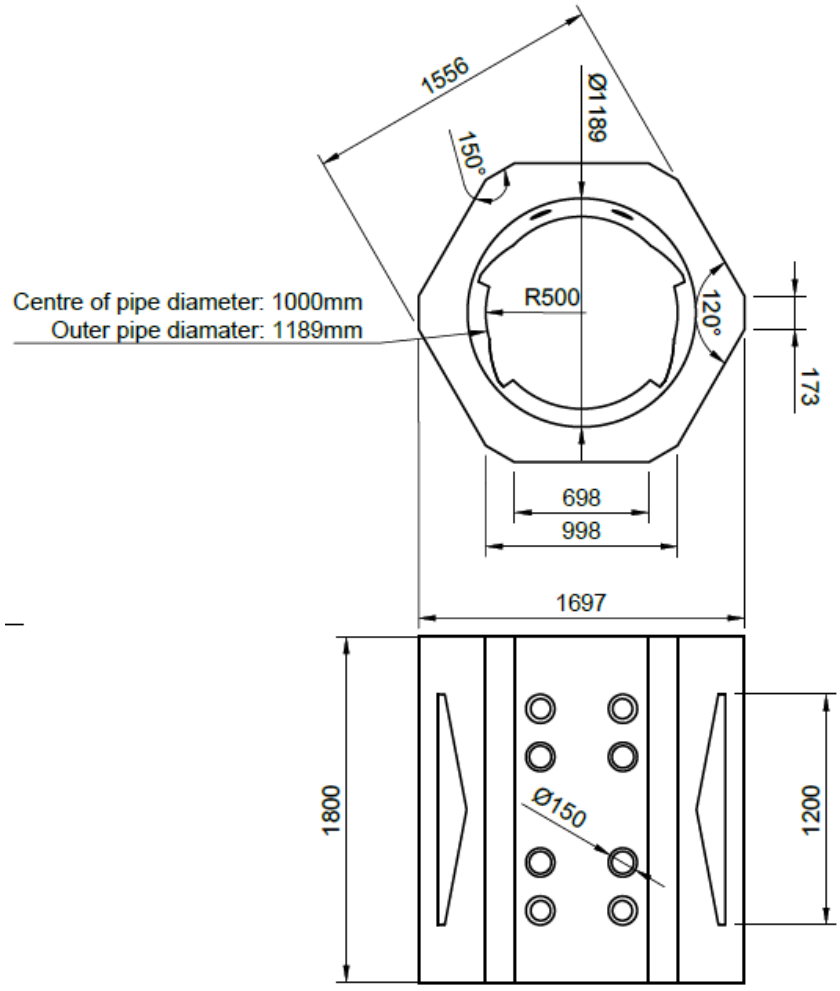


Figure 2. The ExoLodge design drawings with dimensions.

Figure 3. Close up of some of the ExoLodge wood and metal features and removable reef plugs.

Figure 4. The five ExoLodges and the ExoAnchor control block prior to deployment.

Figure 5. The small concrete reef plug elements which sit atop the ExoLodges, including close-up of patterned design.

5. Site

The ExoLodge units were installed at the base of a disused gas platform in the Dutch North Sea, which was first installed in 1992. The units were placed on a sandy seabed adjacent to one of the platform jacket legs. Deployment was completed around existing work scheduled at the platform on 28th July 2024 (Figure 6). The goal is to leave the artificial reefs in place for at least 5 years, possibly longer, to collect sufficient data over time.

Five ExoLodge units, and one ExoAnchor control unit were deployed by crane from the ship Northern Maria and positioned correctly on the seafloor using a work-class Remotely Operated Vehicle (ROV) with a manipulator arm. Reef unit number 1 was placed closest to platform jacket leg A2, then they are positioned in a line sequentially along the north face of the platform from east to west (Figure 7). Each ExoLodge was positioned ~6.5m from each other. Due to the overhang of the platform, the reef units were placed 2.5 – 3.5m from the mudline brace.

Figure 6. Deployment of one of 5 ExoLodge units beside the TotalEnergies North Sea gas platform on 28th July 2024.

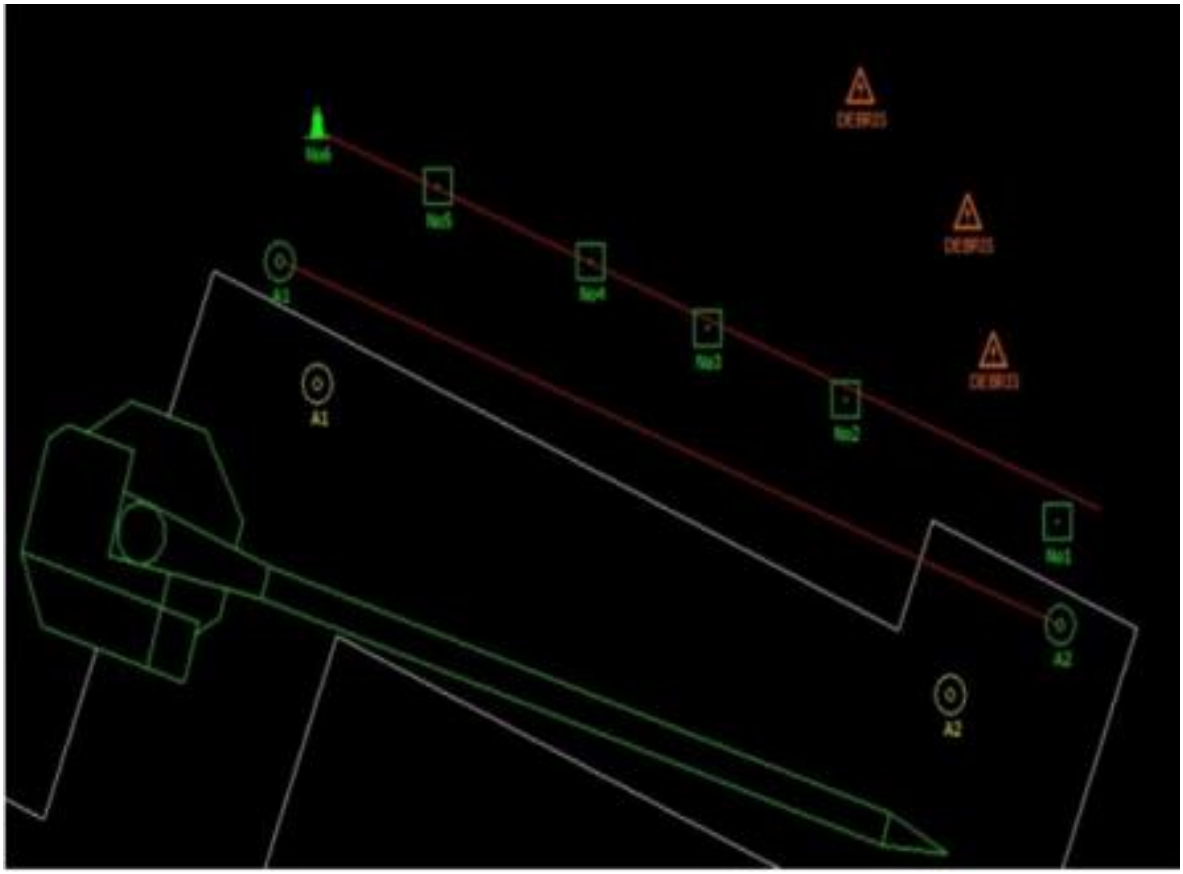


Figure 7. Deployment locations for the five ExoLodges (No. 1 – 5), and the ExoAnchor control unit (No. 6), in relation to the platform, represented by white lines.

In addition to monitoring the treatment site (ExoLodges), three control sites will also be monitored using the same protocols. These are:

- The base of the jacket leg on the opposite side of the platform to the installed reef units.
- 900kg ExoAnchor sinker, deployed alongside ExoLodge units, ~6.5m west of ExoLodge 5 (Figure 7, Figure 8).
- The surrounding sand habitat, devoid of hard infrastructure.

The control jacket leg has been present since initial installation in 1992, so the biodiversity associated with it will likely have already reached a climax community, or close to it. However, at regular intervals during annual maintenance of the platform, areas of the jacket legs are cleaned of all fouling organisms. This may present an opportunity for a comparison of the benthic fouling community on the ExoLodges with a relatively "clean" section of infrastructure, to assess concurrent colonisation.

The ExoAnchor sinker provides a reference structure deployed concurrently with the ExoLodges. They are constructed of a concrete material of a similar formulation to the ExoLodges but lack the range of additional nature-inclusive habitat features, such as holes, tunnels, and additional wood and metal features. Although some surface texturing is present, this is of a different design to texturing on the ExoLodges. Their deployment alongside the ExoLodges allows for the assessment of concurrent colonisation.

Additional environmental data related to the site are detailed in Table 1.

Table 1: Environmental parameters at the site (TotalEnergies Dutch North Sea platform)

Water depth at the site	40 m
Current speed at max depth	1 m/s but depending on tide
Salinity	34.5 PSU
Dissolved oxygen at max depth	8.2 (mg l-1)
Turbidity at max depth	5.5 NTU
Substrate type	Fine to medium sand

Figure 8. ExoAnchor sinker, deployed alongside the ExoLodge units as a control site.

6. Biodiversity Monitoring

To capture the biodiversity associated with the installed units, several complimentary methods are being used. Monitoring of the artificial reef units at the platform is planned to be undertaken every year for 5 years during the annual ROV campaign of TotalEnergies EP Nederland. The following monitoring techniques are being used: eDNA analysis from waters (including laboratory analysis of samples), ROV footage (video and still photographs), taxonomic identification of species on recovered reef plugs.

Some monitoring methods will be more appropriate for capturing certain biodiversity, such as either sessile species (e.g. algae and attaching invertebrates), or mobile species (e.g. fish and crustaceans). By combining these methods, we will better understand the full impact of the units and the associated biodiversity gain.

6.1 Monitoring Schedule

Biodiversity monitoring will be undertaken during annual ROV maintenance campaigns, following the schedule detailed in Table 2 below. Following T0 baseline surveys, undertaken alongside deployment in July 2024, the first monitoring campaign (T1) was undertaken in September 2025. This will then be followed by subsequent monitoring campaigns repeated annually, at the best time to allow the monitoring to be undertaken concurrently with ongoing operations and maintenance (O&M).

Table 2. Monitoring schedule for deployed artificial reef units and control sites.

Date	ROV video surveys and photographs	eDNA water sampling	Reef plug visual analysis
T0 July 2024	✓	✓	
T1 September 2025	✓	✓	✓
T2 April 2026	✓	✓	✓
T3 Summer/Autumn 2027	✓	✓	✓
T4 Summer/Autumn 2028	✓	✓	✓
T5 Summer/Autumn 2029	✓	✓	✓

6.2 Baseline Monitoring (T0)

To provide a baseline assessment of the biodiversity currently present at the site at Time Zero (T0), two monitoring methods were used at the site, analysis of ROV video footage and laboratory analysis of environmental DNA (eDNA) from water samples. Where possible results of T1 Biodiversity Monitoring of the ExoLodges have also been compared to results obtained during T0, as well as to controls. The full T0 Deployment and Baseline Monitoring Report is available on The Rich North Sea's Toolbox.

6.3 T1 ROV video surveys

6.3.1 Methods

On 30th September 2025, video surveys were undertaken using TotalEnergies' work-class ROV, fitted with a high-definition camera. Surveys of each of the 5 ExoLodges were undertaken, along with the ExoAnchor Control block. In addition, two other control areas were monitored, the platform jacket leg, and the surrounding seabed. It should be mentioned that the T1 seabed survey was undertaken close to the ExoLodges and platform jacket and did not follow the same flight path as the seabed survey during the T0 monitoring campaign, which was undertaken at a greater distance from the jacket. During future monitoring campaigns, the seabed survey will be undertaken further from the ExoLodges and existing infrastructure to ensure a more accurate representation of the natural seabed community is surveyed.

A minimum 15-minute roving survey of each site was undertaken (ExoLodges 1-5, Control habitats - Jacket Leg and Sandy Seabed), along with a 12-min survey of the ExoAnchor Control. All the high-definition footage and stills were taken with timestamps and location information attached, and flightpaths were recorded for comparison with past and future monitoring campaigns.

6.3.2 Methods of Analysis

All ROV videos were provided to The Rich North Sea for analysis. They were categorized as 'ExoLodge 1 – 5', 'Control block', 'Jacket' and 'Seabed' habitats. Per habitat type, species that could be recognized (>2 cm) were noted during inspection of the video footage. Taxonomic groups recorded included epifauna, mobile invertebrates, and fish species, and were identified to the lowest taxonomic level possible, mostly species.

Along with presence, an indication of abundance was given to the taxa using the scale that the ANEMOON foundation uses for divers that perform citizen science

for the MOO-project (Monitoringproject Onderwater Oever) in the Netherlands (van der Loos & Gmelig Meyling, 2019). In this case, only the classifications of 'Z' = 'Rare' ('Zeldzaam', 1-9 individuals/colonies), 'A' = 'Common' ('Algemeen', 10-99 individuals/colonies) and 'M' = 'Abundant' ('Massaal', >100 individuals/colonies) were used. In addition, for the ExoLodge surveys, the most common location of each species was recorded during video analysis, e.g. associated with certain design features (large central tunnel, void spaces, metal panels, etc.), or on sand in front of the ExoLodge.

Species richness data analysis was undertaken on the total number of species and the mean number of species as applicable. Analysis of abundance data was undertaken on the midpoint of each abundance range, i.e., 'Z' (1-9): Midpoint = 5, 'A' (10-99): Midpoint = 54.5, 'M' (>100): Midpoint assigned = 150 (as a conservative estimate) (following van der Loos & Gmelig Meyling, 2019). To calculate means on these data the grouped mean of the midpoints was used.

Community analyses were undertaken using PRIMER 6 (Clarke & Gorley, 2005), with differences between sites ascertained using PERMANOVAs using Site as a fixed factor. Visualising where those differences lied was presented using CAP (Canonical Analysis of Principal Coordinates) plots (Anderson & Willis, 2003). The abundance data ascertained using the method described above was square root transformed, and a Bray Curtis resemblance matrix was applied.

6.3.3 Results and Discussion

In total, 28 species were recorded on video from all sites, 5 more than the total from T0 baseline surveys. 21 of those species were recorded on the ExoLodges overall, with a 12.8 mean species richness per ExoLodge. In comparison, 19 were recorded on the jacket, only 9 on the control block, and only 4 from the survey of the surrounding seabed. Considering that the jacket will have a much more mature community than the ExoLodges, after close to 33 years in situ, results seem very promising after only 1 year since deployment of the ExoLodges. The video survey of ExoLodge 5 specifically found 18 species, which is only 1 fewer than was recorded on the jacket overall.

For the community comparison between the sites, there was a significant difference between the sites (PERMANOVA, $p = 0.013$). The Canonical Analysis of Principal Coordinates (CAP) plot helped visualising where those differences lie (Figure 10). The 5 ExoLodges clustered relatively close together and apart from communities of either the jacket or surrounding seabed. These results show us that after 1 year on the seabed the ExoLodges are providing a fairly unique habitat

in comparison to the jacket, seabed or control block, albeit they are currently at an early successional stage.

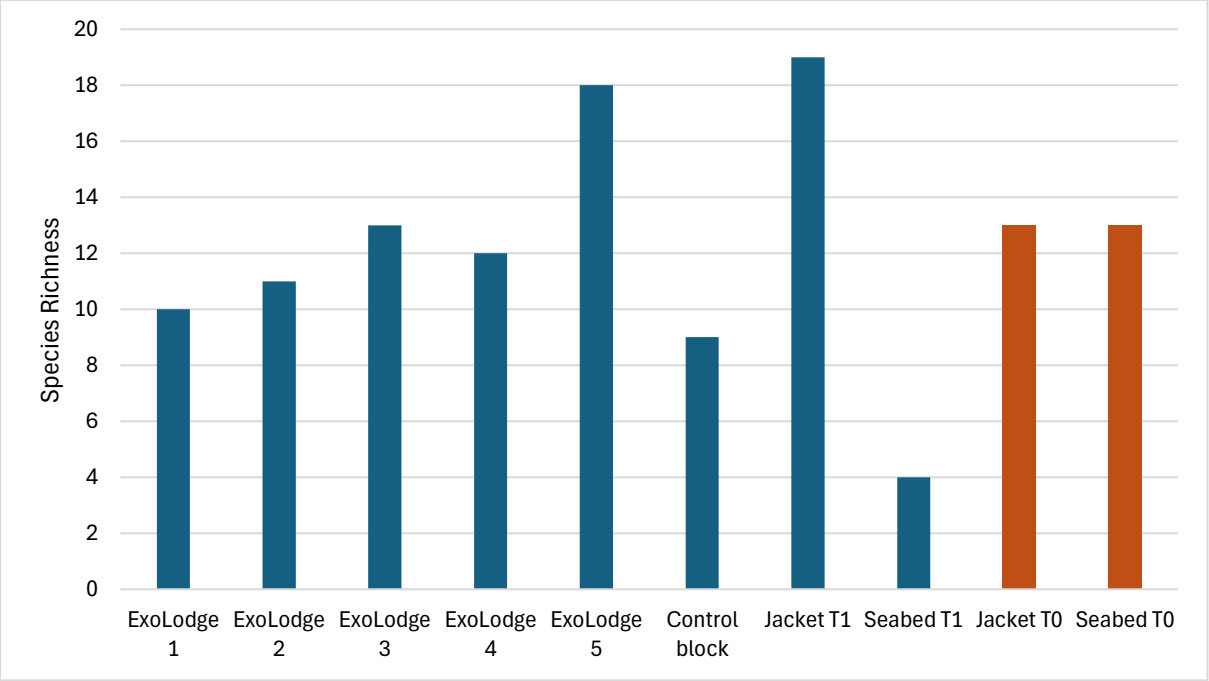


Figure 9. The total number of species recorded at each site during ROV video surveys during T1 monitoring in September 2025 (Blue) and during T0 baseline surveys (Orange).

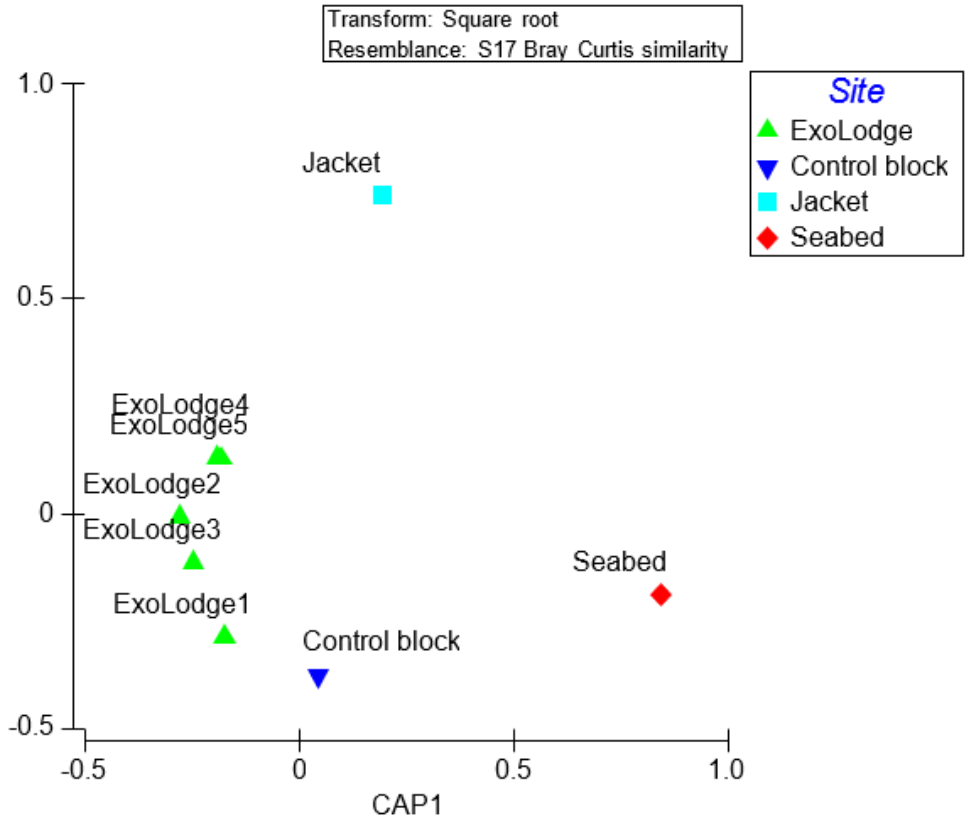


Figure 10. A CAP (Canonical Analysis of Principal Coordinates) plot, visualising how closely correlated the communities associated with the different sites were during T1 ROV video surveys in September 2025.

A full breakdown of the different species recorded at each site is displayed in Table 3.

In comparison to the jacket survey, a greater richness of all mobile taxonomic groups was recorded (fish, crustaceans, echinoderms) as well as bivalves. For echinoderms and bivalves, no species of either group were recorded on the jacket during the ROV survey. However, for echinoderms, the ExoLodges' location on the seabed may explain this, as they were unlikely to be recorded on the jacket itself.

Of the fish and crustaceans recorded, greater abundances of Pouting (*Trisopterus luscus*), a small shoaling species of the cod family, and Velvet swimming crabs (*Necora puber*) were recorded on the ExoLodges. Although fewer species of most sessile biofouling groups were recorded, that is to be expected after only one year, in comparison to the more mature community developed on the jacket itself. The exception here was with calcareous tubeworms, for which a greater abundance was recorded at the ExoLodges. However, this result may in part be due to the survey method used. As the jacket has multiple layers of sessile species growth, including large sea anemones, this may make it harder to spot these tubeworms on the structure.

A much greater number of species were recorded at the ExoLodges in comparison to either the Control block or the surrounding seabed. Higher abundances of Edible crabs (*C. pagurus*), Velvet swimming-crabs (*N. puber*), and European lobsters (*Homarus gammarus*) were also recorded.

During video analysis, additional observations were made about which species were recorded using which of the design features of the ExoLodge, making use of the various niche habitats created. Pouting (*T. luscus*) were recorded using the large central tunnel of the ExoLodges and also occasionally using the triangular voids to enter and exit the tunnel. European lobsters (*H. gammarus*) were also recorded using the large central tunnel, plus especially were seen sat on the ledge of the triangular void. Edible crabs (*C. pagurus*) were similarly recorded in the triangular voids (Figure 11), as well as commonly being recorded sat within the holes atop the ExoLodges. In contrast, Velvet swimming-crabs (*N. puber*) favoured sitting underneath the raised metal panels of the ExoLodges.

For sessile species, the various design features were also used by different species. Colonial sea squirts (*Diplosoma listerianum*) were recorded most frequently on the raised wooden panels. Barnacles were commonly recorded on and underneath the raise wooden panels, as well as on the textured concrete surfaces on the sides of the ExoLodges. Large numbers of Plumose anemones

(*Metridium senile*) were recorded using the ceiling of the large central tunnel, plus further dispersed throughout the structure's sides. In comparison, the Orange anemone (*Diadumene cincta*) was mostly recorded on the brain coral texture, and Mud sagartia sea anemone (*Cylista troglodytes*) was mostly recorded on the rock texture and raised metal panels. In addition, the rock and brain coral patterned concrete surfaces, as well as the wooden and metal panels, were home to a diverse range of anemones, hydroids, bryozoans, tubeworms, and sponges. The Control block lacked all these functions and contained significantly less diversity and abundances.

Table 3. List of species recorded from ROV surveys at the ExoLodges, Control block, platform jacket leg and surrounding seabed habitat during T1 surveys in September 2025. Abundance scores follow MOO-project classifications from the ANEMOON Foundation, Netherlands. The 5 ExoLodge scores were averaged using method described in 6.3.2.

Taxonomic group	Scientific name	English common name	ExoLodges	Control block	Jacket	Sand
Fish	*Trisopterus luscus*	Pouting	A	M	Z	M
	Trisopterus minutus	Poor cod	Z		A	
	Taurulus bubalis	Long-spined sea scorpion	Z			
Crustaceans	*Cancer pagurus*	Edible crab	A	Z	A	Z
	Necora puber	Velvet swimming crab	A	Z	Z	
	Homarus gammarus	European lobster	Z		Z	
	Sessilia	Barnacles	M	M	M	
Echinoderms	*Asterias rubens*	Common starfish	Z	Z		A
	Astropecten irregularis	Sand star	Z			Z
Cnidarians	*Metridium senile*	Plumose anemone	M	A	M	
	Cylista troglodytes	Mud sagartia sea anemone	A	Z		
	Cylista elegans	Elegant sea anemone			M	
	Diadumene cincta	Orange anemone	A	A	M	
	Alcyonium digitatum	Dead man's fingers			A	
Sponges	*Protosuberites denhartogi*		Z		A	
Bryozoans	Bryozoa		A		M	
	Bicellariella ciliata				A	
Hydrozoans	Hydrozoa		A		A	
	Obelia sp.	Sea fur			A	
	Halecium halecinum	Herring-bone hydroid			Z	
	Hydractinia echinata	Snail fur hydroid	Z		A	
Ascidians	*Diplosoma listerianum*	A colonial compound sea squirt	Z		A	
Annelids	Serpulidae	Tubeworms	A		Z	
Bivalves	Mytilida	True mussels	Z	Z		
	Pectinidae	Scallops	Z			
	Arctica islandica	Icelandic cyprine/ Ocean quahog	Z			
Total species richness			21	9	19	4

Z' = 1-9 individuals/colonies; '**A**' = 10-99 individuals/colonies; '**M**' = >100 individuals/colonies

Figure 11. Edible crabs (Cancer pagurus) using one of the triangular voids of the ExoLodges during T1 ROV video surveys.

Figure 12. Large shoals of pouting and poor cod using the central 1m tunnel of the ExoLodge during T1 ROV video surveys.

6.4 Removable reef plug

6.4.1 Methods

On 30th September 2025, TotalEnergies' work-class ROV was utilised to remove one of the reef plugs from ExoLodge 1 using its multipurpose arm (Figure 13). Once aboard the survey vessel, the reef plug was fully submerged in a preservative solution of 4% formaldehyde with borax within a sealed container. Once the vessel docked, it was delivered to Eurofins Aquasense for a taxonomic analysis of the colonising species present and their abundances.

Figure 13. The reef plug recovery using a work-class ROV during T1 monitoring in September 2025.

6.4.2 Results and Discussion

The novel method for retrieval of a small removable section of the ExoLodge has proved successful. From this taxonomic analysis 40 colonising taxa were recorded (Table 4). Of these, 33 taxa had not been recorded from ROV video analysis. The additional species recorded were from a variety of taxonomic groups but especially included species which would have been too small to identify from video footage alone. These included several species of marine worms, as well as amphipods, bivalves, molluscs, bryozoans, hydrozoans, sea urchins, and the smaller crab species.

New records from the reef plug analysis included the tube-building ecosystem engineer, *Sabellaria spinulosa*, one of the target species for the project. Very large numbers of the Long-clawed porcelain crab (*Pisidia longicornis*) were also recorded, as well as the juveniles of many species, including worms, sea urchins, sea anemones, bivalves, and crabs, such as the Edibe crab (*Cancer pagurus*). Adult *C. pagurus* were also recorded using the holes and voids in the ExoLodges during the ROV video surveys. Although it is difficult to draw strong conclusions after only 1 year, these results highlight the ability to include design features to both target certain species, as well as provide niche habitats for the juveniles of a wide range of marine life.

Table 4. A list of species recorded from taxonomic analysis of the recovered reef plug during T1 monitoring during September 2025.

Species	Species group	Amount (n)	Coverage (%)
Balanus crenatus	acorn barnacles	550	30
Gitana sardi	amphipods	15	
Jassa herdmani	amphipods	16	
Phtisica marina	amphipods	19	
Caprella linearis	amphipods	1	
Stenothoe monoculoides	amphipods	2	
Aoridae	amphipods	2	
Hiatella arctica	bivalves	2	
Mytilus edulis	bivalves	11	
Musculus discors	bivalves	2	
Anomiidae	bivalves	1	
Pectinidae	bivalves	1	
Sabellaria spinulosa	Ross worm	11	
Eumida	bristle worms	4	
Platynereis sp.	bristle worms	3	
Eunereis longissima	bristle worms	4	
Phyllodoce mucosa	bristle worms	5	
Syllidae	bristle worms	1	
Bicellariella ciliata	bryozoans	>0	< 1%
Electra pilosa	bryozoans	>0	< 1%
Alcyonidium parasiticum	bryozoans	>0	< 1%
Diplosoma listerianum	compound ascidians	>0	1
Pisidia longicornis	crabs	706	
Pilumnus hirtellus	crabs	7	
Cancer pagurus	crabs	5	
Spirobranchus triqueter	fanworms	1	
Stylostomum ellipse	flatworms	1	
Notoplana atomata	flatworms	5	
Epitonium clathatulum	gastropods	1	
Anthoathecata	hydrozoans	>0	< 1%
Campanulariidae	hydrozoans	>0	< 1%
Onchidoris bilamellata	nudibranchs	17	
Nemertea	ribbon worms	2	
Harmothoe impar	scale worms	19	
Harmothoe globifera/extenuata	scale worms	2	
Sagartia undata	sea anemones	29	
Cylista elegans	sea anemones	37	
Metridium senile	sea anemones	6	
Actiniaria	sea anemones	24	2%
Psammechinus miliaris	sea urchin	19	

6.5 eDNA analysis of water samples

6.5.1 Methods

Three sampling locations were chosen at the site within an approximate 500m zone from the target site at the platform. These locations were upstream of the current direction at the time of sampling (Location 1), downstream of the current direction at the time of sampling (Location 2), and the ExoLodge artificial reef unit deployment location (Location 3), (Table 5, Figure 14). Samples were collected on 21st August 2025 between 13:00 – 14:30. Samples were collected at the end of the flooding tide, at around slack water at high tide, which ensured the least water movement when collecting the samples.

The bottom current direction at the site at the time of sample collection, and over the previous 6 hours, was SW to NE, which determined the specific locations chosen for water sample collection. Water samples for the target location were 86m north of the ExoLodges. The downstream samples collected from Location 2 were likely to have picked up water from the platform, as well as the surrounding area, whereas the upstream samples (Location 1) can be treated as semi-independent from the platform, as water collected from this location will be unlikely have passed through the platform or artificial reef site within the past 6-12 hours, so the effect of their proximity will be minimal. The 400-500m distance between the artificial reef units and the upstream samples is likely to be far enough away from the target site to not be influenced by the platform. However, tidal mixing at the site, coupled with the movement of pelagic species between locations, and DNA persisting at detectable levels for up to 48 hours in the marine environment (Collins et al., 2018), will mean that the water samples cannot be truly independent, so this should be borne in mind when interpreting these results.

Table 5. Location coordinates for water sampling for eDNA analysis (WGS84), along with current direction/speed at time of sampling, using vessel dynamic positioning system.

Sampling location	Approx. distance from artificial reefs (m)	Coordinates (Lat, Long, DMM)	Current Direction/ Speed (Surface)	Depth (m)
1: Upstream	554m South	53°41.44 'N 003°20.06 'E	045° / 1.3 kts	41 m
2: Downstream	475m North	53°42.05 'N 003°20.38 'E	050° / 1.0 kts	41 m
3: Platform (target site)	86m North	53°41.84 'N 003°20.33 'E	038° / 1.4 kts	41 m

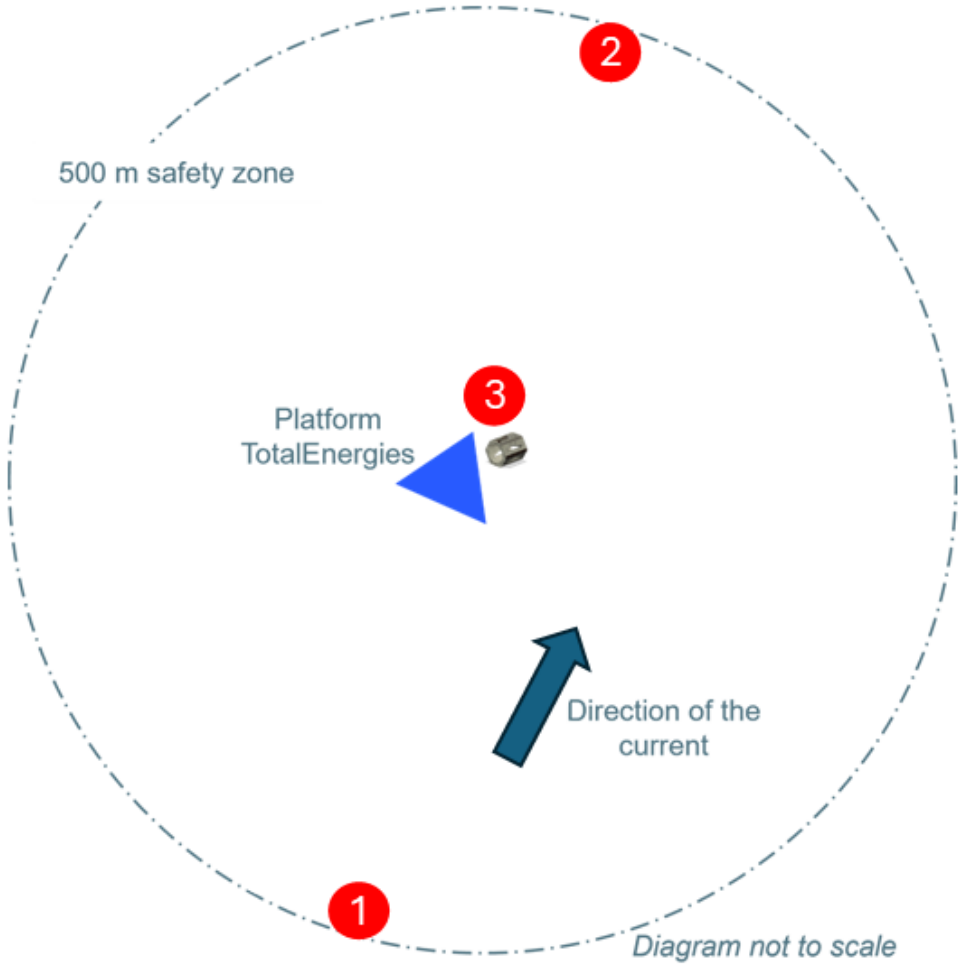


Figure 14. Diagram visualising the sampling locations for T1 eDNA water sampling at the TotalEnergies platform in the Dutch North Sea undertaken in August 2025.

Water samples were collected from the vessel Bibby Wavemaster 1 at the site using a Niskin bottle (Figure 15). The 5 litre Niskin bottle was attached to a steel cable with 5kg lead weights hanging from the bottom. The bottle was lowered to the bottom, then lifted up by approximately 1.5m. A messenger was then sent down the cable to close the valves. Three water samples were collected from each sample location, which were filtered on board the vessel, using a setup which included an Erlenmeyer flask, tube, filter paper, magnetic cup, overflow bottle, and pump (Figure 16). 1.2l of water was filtered from each sample. The filter was then removed and placed in a 2ml screwcap tube, prefilled with 400ul Zymo DNA/RNA shield preservation solution. Nine eDNA samples were collected, and a tenth water sample was filtered as a blank using fresh water from the same source as the rinsing water used during the filtration steps.

Fresh latex/nitrile gloves were worn for each sample collected, and all sampling equipment was disinfected with a 1% chlorine solution between sample collection, then rinsed with fresh water.

Once collected and filtered, all samples were stored in the freezer. The frozen samples were sent for laboratory analysis of the eDNA present by Eurofins once the vessel returned to dock. Extracted DNA was quantified by Qubit (Invitrogen) fluorescence measurement. Mitochondrial targets were PCR amplified from sample DNA extracts using target specific NGS primers and analysed by sequencing on the Illumina MiSeq platform. For targeting vertebrates, the 12S gene was analysed. For metazoan invertebrates, the COI gene was analysed. For each PCR reaction a negative control was performed. If enough amplicons were generated, it was sequenced.

During bioinformatical analysis, sequences were sorted into sequence sets (ASVs) according to their similarity. Sequences were cleaned from adapter and primer sequences and quality filtered by base quality and fragment length of the ASV representing sequence (min. 90% of the query sequence). Only database hits with a similarity value equal or higher 98% were included. For vertebrates, all non-vertebrate and non-marine species and human sequences were filtered. For the invertebrates dataset, vertebrates (Chordata), plants, and fungi were filtered.

Figure 15. Niskin bottle used for water sample collection for eDNA.

Figure 16. Water filtration kit used to filter eDNA from seawater samples.

6.5.2 Results and Discussion

A total of 33 vertebrate and invertebrate taxa were recorded from eDNA analysis of the water samples collected at each sampling location, which are listed in Table 6 and Table 7 below.

For vertebrate species, this method proved to be less species rich than during T0 surveys, when 21 species were recorded from all sampling locations, compared to only 6 species during T1 surveys. From T0 monitoring, pelagic species were recorded including herrings (*Clupea* spp.), anchovies (*Engraulis encrasicolus*), and codfish (Gadidae), as well as benthic and demersal species, including several flatfish and goby species (see T0 report for further detail). Of the 6 species recorded during T1 monitoring, only Atlantic horse mackerel (*Trachurus trachurus*), and Sprat (*Sprattus sprattus*) were also recorded during T0 monitoring, so these results are mostly independent from those obtained in the previous year. Although only 6 vertebrate species were recorded during T1 monitoring, none of these species were recorded from either the ROV video surveys or from the reef plug analysis, so including this method provided further information about the additional species present within the broader vicinity of the platform.

From the samples collected closest to the jacket, only Atlantic horse mackerel (*T. trachurus*) was recorded, whereas 5 species were recorded from the downstream sample, from which the species may also have been associated with the jacket itself. As well as Atlantic horse mackerel, these included Sprat (*S. sprattus*), Whiting (*Merlangius merlangus*), Bluejack mackerel (*Trachurus picturatus*), and European plaice (*Pleuronectes platessa*). From the upstream samples, which we can assume are relatively independent from the target location, due to its distance away from the site and the current direction at the time of sample collection, 3 species were recorded. As well as Sprat and Whiting, the Starry smooth-hound (*Mustelus asterias*) was also detected from these samples.

For invertebrates, 27 species were recorded overall, 14 from the samples collected closest to the jacket, including various bristle worms, bivalves, jellyfish, brittle stars, and nudibranchs. In comparison, 9 species were recorded from the downstream control samples, whilst 15 species were recorded from the upstream control sample (the location most independent from the platform). Comparatively, a total of 41 invertebrate taxa were recorded from T0 monitoring (20 from the platform, and 25 each from the up- and down-stream samples). However, eDNA results from T1 are difficult to compare to T0, because it was decided to filter out planktonic species from results during T1 eDNA analysis, as these species formed a large part of the T0 invertebrate results, and are unlikely to be affected over time by the presence of the artificial reef units.

Table 6. Vertebrate results from eDNA analysis of water samples collected during T1 monitoring in August 2025.

Phylum	Class	Order	Family	Genus	Species	Common name	Jacket	1: Upstream	2: Downstream
Chordata	Actinopteri	Carangiformes	Carangidae	Trachurus	Trachurus trachurus	Atlantic horse mackerel	✓		✓
Chordata	Actinopteri	Clupeiformes	Clupeidae	Sprattus	Sprattus sprattus	Sprat		✓	✓
Chordata	Actinopteri	Gadiformes	Gadidae	Merlangius	Merlangius merlangus	Whiting		✓	✓
Chordata	Chondrichthyes	Carcharhiniformes	Triakidae	Mustelus	Mustelus asterias	Starry smooth hound		✓	
Chordata	Actinopteri	Carangiformes	Carangidae	Trachurus	Trachurus picturatus	Blue jack mackerel			✓
Chordata	Actinopteri	Pleuronectiformes	Pleuronectidae	Pleuronectes	Pleuronectes platessa	European plaice			✓
Total species richness							1	3	5

Table 7.. Invertebrate results from eDNA analysis of water samples collected during T1 monitoring in August 2025.

Phylum	Class	Order	Family	Genus	Species	Common name	Jacket	1: Upstream	2: Downstream
Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Phyllodoce	*Phyllodoce rosea*	Rose paddle worm	✓		
Annelida	Polychaeta	Spionida	Spionidae	Laonice	*Laonice bahusiensis*		✓		
Annelida	Polychaeta	Eunicida	Lumbrineridae	Lumbrineris	*Lumbrineris latreilli*	Latreille's threadworm	✓		
Annelida	Polychaeta	Terebellida	Pectinariidae	Amphictene	*Amphictene auricoma*			✓	
Annelida	Sipuncula	Golfingiida	Golfingiidae	Golfingia	*Golfingia vulgaris*	Common peanut worm		✓	
Annelida	Polychaeta	Phyllodocida	Polynoidae	Harmothoe	*Harmothoe glabra*	Smooth scale worm		✓	
Annelida	Polychaeta	Terebellida	Pectinariidae	Pectinaria	*Pectinaria auricoma*		✓	✓	✓
Cnidaria	Hydrozoa	Leptothecata	Eirenidae	Eirene	*Eirene viridula*	A jellyfish	✓		
Cnidaria	Scyphozoa	Semaeostomeae	Pelagiidae	Chrysaora	*Chrysaora hysoscella*	Compass jellyfish	✓	✓	✓
Cnidaria	Hydrozoa	Leptothecata	Clytiidae	Clytia	*Clytia sp.*			✓	
Cnidaria	Hydrozoa	Leptothecata	Campanulariidae	Eucheilota	*Eucheilota maculata*	Spotted medusa		✓	✓
Cnidaria	Hydrozoa	Leptothecata	Aequoreidae	Aequorea	*Aequorea vitrina*	Crystal jellyfish			✓
Echinodermata	Ophiuroidea	Amphilepidida	Amphiuridae	Amphiura	*Amphiura filiformis*	Grey brittle star	✓	✓	✓
Echinodermata	Echinoidea	Spatangoida	Loveniidae	Echinocardium	*Echinocardium cordatum*	Sea potato		✓	
Mollusca	Gastropoda	Nudibranchia	Dotidae	Doto	*Doto coronata*	Crowned doto	✓		
Mollusca	Bivalvia	Adapedonta	Pharidae	Phaxas	*Phaxas pellucidus*	Sabre shell	✓		
Mollusca	Bivalvia	Cardiida	Semelidae	Abra	*Abra alba*	White furrow shell	✓	✓	
Mollusca	Bivalvia	Cardiida	Semelidae	Abra	*Abra nitida*	Glossy furrow shell	✓	✓	
Mollusca	Bivalvia	Galeommatida	Montacutidae	Tellimya	*Tellimya ferruginosa*	Rusty montacutid	✓		
Mollusca	Bivalvia	Myida	Corbulidae	Varicorbula	*Varicorbula gibba*	Basket shell	✓	✓	✓
Mollusca	Gastropoda	Nudibranchia	Cuthonidae	Cuthona	*Cuthona pallida*	Pale cuthona	✓		
Mollusca	Gastropoda	Nudibranchia	Eubranchidae	Eubranchus	*Eubranchus exiguus*	Minute aeolis		✓	
Mollusca	Gastropoda	Nudibranchia	Fionidae	Rubramoena	*Rubramoena amoena*	Beautiful aeolis		✓	
Mollusca	Bivalvia	Venerida	Mactridae	Mactra	*Mactra stultorum*	Rayed trough shell			✓
Mollusca	Gastropoda	Nudibranchia	Facelinidae	Facelina	*Facelina bostoniensis*	Boston facelina			✓
Mollusca	Gastropoda	Nudibranchia	Tergipedidae	Tergipes	*Tergipes tergipes*	Tergipes nudibranch			✓
Chaetognatha	Sagittoidea	Aphragmophora	Sagittidae	Parasagitta	*Parasagitta setosa*	Arrow worm		✓	
Total species richness							14	15	9

7. Conclusion

Monitoring of the ExoLodges was able to be successfully integrated into the existing ROV survey program of TotalEnergies EP Nederland, without hindering their ongoing operations and maintenance schedule. The use of ROV video surveys allowed for a comprehensive analysis of the mobile species, as well as larger sessile biofouling species associated with the ExoLodges and controls. High richness of mobile species was recorded at the ExoLodges, as well as a greater abundance of crabs and lobsters, making use of the novel niche habitats provided through the ExoLodge design.

Results from the recovered reef plug proved that this novel method was very successful, providing much greater detail regarding the abundance and species richness of the smaller sessile and mobile species present on the ExoLodge, including juveniles of many species. This may point to the potential for the ExoLodges to provide habitat that improves production, as well as simply attracting species from the surrounding habitat.

Although fewer species were recorded from the T1 eDNA results, in comparison to T0, these results still provided additional detail on species found at the site and surrounding area that were not already recorded using the other methods.

No non-native invasive species were recorded from any of the surveys undertaken, which is positive, considering concerns are often raised that both artificial reefs and oil and gas platforms can act as stepping stones for these pioneering species (Fenner, 2001; Sammarco et al., 2012).

Although results which focus on species richness and greater abundances of target species provide part of the picture for enhanced biodiversity, in future monitoring campaigns more could be done to further evidence the ability of the ExoLodges to support additional ecological functions. These can include their provision of nursery, spawning and shelter functions, enhancing processes such as trophic interactions and secondary production, or ensuring that unintended negative effects, such as colonisation by non-native species are prevented (Degraer et al., 2026). Some of these, such as identifying and recording abundances of non-native species are simple to incorporate, whereas for others, methods of data collection or analysis may need to be adapted. Results from both the ROV video and reef plug monitoring point to the potential that these units may be having on increases in secondary production, and the provision of nursery and shelter functions, but this is currently solely based on qualitative data, and analysis methods could be adapted to provide quantitative data and stronger empirical evidence of their positive effects on ecological functioning.

Overall, results from biodiversity monitoring 1 year after deployment of the ExoLodges have been very positive and have helped to highlight the potential benefits ExoLodges have provided to the biodiversity of the site, and functioning of the ecosystem, even after such a short time. Repeat monitoring will be undertaken annually, which will provide results on the ecological succession of species on the ExoLodges over time, and help to provide further evidence on whether the artificial reef structures deliver additional biodiversity benefits when compared to the existing infrastructure alone.

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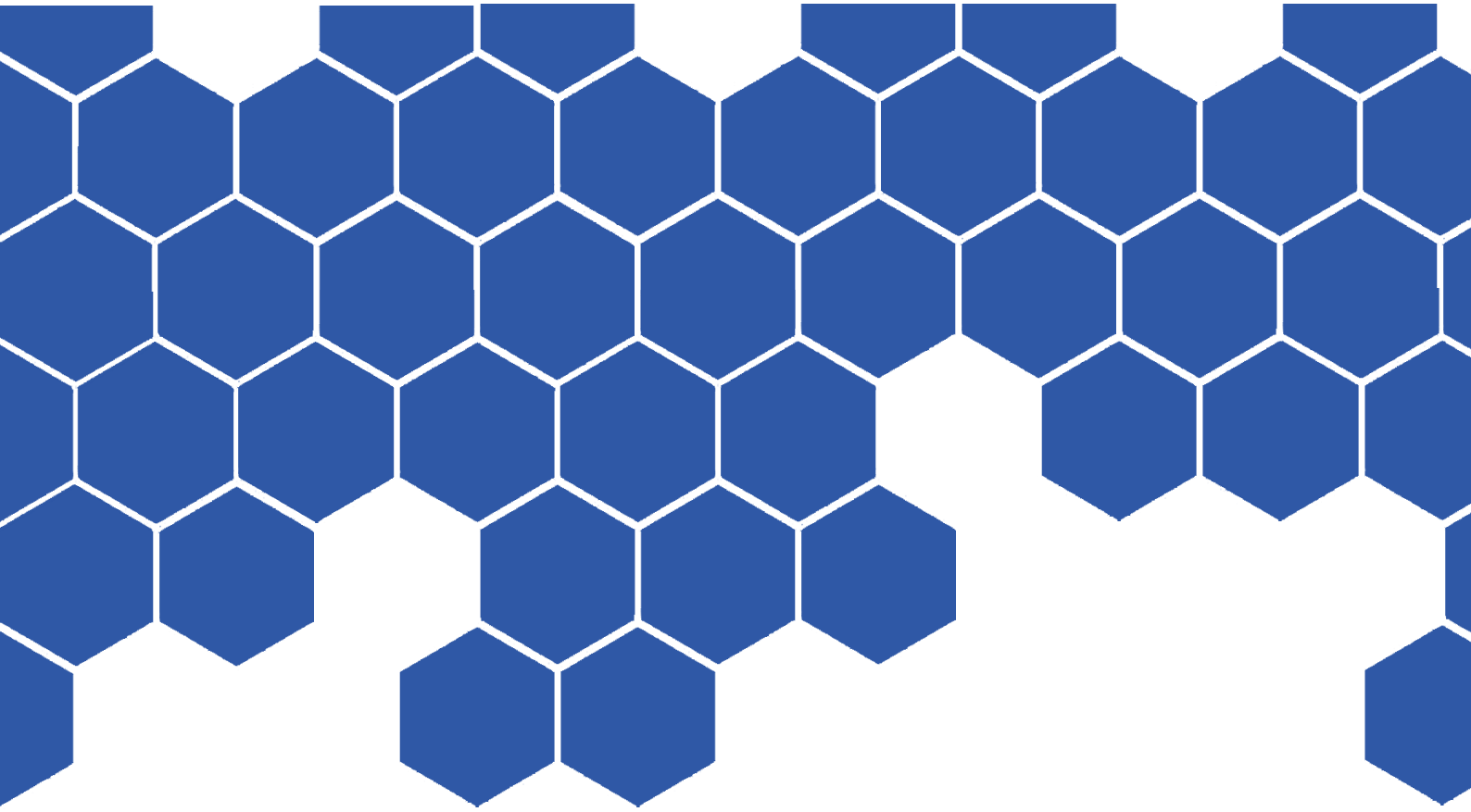

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www.livingwindfarms.com

+44 (0) 330 80 80 377

info@exo-engineering.co.uk

Exo Engineering Ltd,
The Enterprise Centre,
University of East Anglia,