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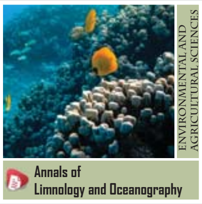

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Research Article

A New Rewilding Paradigm: NEBA-CA Case Study of an End-of-Life North Sea Oil Platform

Victoria LG Todd[1,2]*, **Dianne McLean**[3], **Sean van Elden**[4], **Áine Thomas**[1] **and Ian B Todd**[1]

[1]Ocean Science Consulting, Spott Road, Dunbar, East Lothian, EH42 1RR, Scotland, UK

[2]Institute of Sound and Vibration Research, University Road, Highfield, Southampton SO17 1BJ, UK

[3]Australian Institute of Marine Science, Indian Ocean Marine Research Centre, Crawley, WA 6009, Australia

[4]School of Biological Sciences, The University of Western Australia, Crawley, WA, Australia

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***Corresponding author:** Victoria LG Todd, Ocean Science Consulting, Spott Road, Dunbar, East Lothian, EH42 1RR, Scotland, UK,
E-mail: vt@osc.co.uk; office-hm@osc.co.uk

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Abstract

Some offshore Oil and Gas platforms act as mini *de facto* Marine Protected Areas, supporting diverse marine ecological reef communities. Many policies mandate the removal of most O&G infrastructure at the end of its operational life, potentially harming marine species and removing critical habitat. One unexplored notion is that repurposed offshore platforms could be considered (and/or augmented) as 'nature-in-design reefs' in a variation of the 'rewilding' context, which involves restoring the complexity of food webs, natural disturbances, and the spread of ecosystems so that they need minimal human intervention in the long term.

In 2017, as part of a Net Environmental Benefit Analysis Comparative-Assessment procedure, the subsea ecological importance and optimal jacket cut-off depth of a 34-year-old North Sea platform scheduled for decommissioning were assessed using incidentally collected Remotely Operated Vehicle imagery data.

Species presence, richness, diversity, and vertical distribution were analysed, and 33 taxa across ten phyla were identified, with 23 taxa at species level. Species assemblages varied significantly with depth; algae, mussels, and serpulid polychaetes were abundant in shallow waters, while anemones and soft corals, were prevalent at depths of 15–100 m. Commercially important fish species were found predominantly below 70 m. Optimal jacket cut-off depth was recommended to be 15 m below Lowest Astronomical Tide.

This research demonstrated the extensive diversity of native and protected species on an ageing North Sea oil platform and takes the first step in considering the potential environmental, societal, and economic net benefits of decommissioned platforms in the context of a rewilding paradigm.

1. Introduction

Despite a recent global surge in requirement for offshore Oil and Gas (O&G) Exploration and Production (E&P) due to the presently ongoing Russian-Ukrainian war [1] and sabotage of the Baltic Nord Stream gas pipeline, [2] O&G infrastructure is increasingly reaching end of its operational life [3]. Currently, in the North Atlantic Oslo-Paris Commission (OSPAR) region alone, there are 234 structures Plugged and Abandoned (P&A), or being dismantled [4]. Decommissioning strategies are therefore a major concern for industry, Government, taxpayers, scientists, and non-governmental organisations [5,6].

The growing complexity of environmental challenges has steered progressive emergence of sustainable business models able to embed economic, environmental, and social flows in a unified value network [7]. This, in turn, has led to the concept of alternate 'sustainable decommissioning', where there are potential environmental, societal, and economical benefits of leaving some well situated end-of-life offshore O&G platforms *in situ* at the end of their operational lifetimes, known as the 'Rigs-To-Reef' paradigm [8]. These include proposed schemes such as repurposing offshore O&G installations as renewable energy structures, like Neptune Energy's Q13a O&G green-energy hydrogen platform, or recreational SCUBA-diving attractions [9], and even hotels, such as the dive resort created

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from an offshore platform in the Celebes Sea, near Borneo and the Air BnB 'frying pan' oil platform located 37 km offshore in the Gulf of Mexico. In cases of O&G structures acting as artificial reefs, their ecological function can be enhanced by incorporating nature-in-design concepts blending an understanding of species and community needs with engineering solutions and aesthetic considerations. Where traditional artificial reefs are designed to mimic the topography and porosity of natural reefs, the complexity of offshore rigs and platforms can be attractive to crustaceans, molluscs, small reef fish, and corals. While repurposing these platforms could potentially outweigh (in terms of environmental, societal, and economical benefits) alternative-decommissioning options, in individually assessed cases, complete removal of structures is currently legislated throughout European waters, except for some derogated larger gravity-based installations [10]; however, OSPAR Decision 98/3 does not refer to structures which are determined by the authorising body to be '*serving another legitimate purpose in the maritime area*' which could apply to offshore installations that have been repurposed as artificial reef material. Although the *OSPAR guidelines on artificial reefs about living marine resources* include language that excludes the use of reused or waste material, as subsequent drafts progressed, language expressly forbidding '*post-consumer materials and offshore installations*' was removed. This opens numerous possibilities from a legal perspective, when it comes to decommissioning of offshore assets under current OSPAR regulations.

One notion that has not been explored to date, is the concept that derogated or repurposed offshore platforms that have been demonstrated (with peer-reviewed research) to be acting as *de facto* Marine Protected Areas (MPAs) in the form of artificial reefs, could be considered, *sensu strictu*, an alternative to rewilding which is the practice of returning wild areas, and wildness, to terrain humans have altered [11]. This is the first time this concept has been introduced in an offshore decommissioning scenario, and this study seeks to encourage lively discussion around use of the term rewilding and nature-in-design when considering derogating or repurposing offshore decommissioned installations. It is critical that the concept engender a balanced approach, as there are arguments for and against a new rewilding paradigm.

When using the definition of rewilding, it is important to consider what 'wildness' means in an ecological context. Chapman [12], for example, does not deem wildness as separate from humans with "*creative complexity*" existing in proximity with cities, where areas have been recolonised by vegetation, insect, and mammal populations. This view is supported by Prior and Brady [13] that states "*rewilding, as a specific form of ecological restoration, does not require human abandonment*". Under this notion, offshore structures remaining *in situ*, is not incompatible with the concept of rewilding the seabed. Considering the term rewilding used by du Toit and Pettorelli [14], which states that "*…in contrast with restoration, rewilding has lower fidelity to taxonomic precedent and promotes taxonomic substitutions for extinct native species that once underpinned the delivery of key ecological functions*", these authors place emphasis in ecological function rather than taxa. A reasonable example of this is introduction of the European rabbit (*Oryctolagus cuniculus*) in Australia which took over some of the native bilby's (*Macrotis lagotis*) ecological roles, such as soil turnover and seed dispersal [15]; however, there are already cases in the North Sea, where other functionally similar species have expanded to fill vacant niches already [e.g. 16]. In the strictest confines of this definition of rewilding, it would be challenging to defend that addition of hard substrata (and its faunal assemblages, native or non-indigenous, some of which may be invasive) could be used for rewilding, given that functions derived from these new offshore O&G platform habitats and the assemblages they underpin did not exist at that place before addition of such hard infrastructure – independently of whether the same species were there beforehand or not. Indeed, hard substrata typically replaces soft sediment on the benthos and many of the functions they provide are quite different. Consequently, it could be argued that, rather than rewilding, leaving offshore assets *in situ* creates new habitat for assemblages (that provide functions, and potentially ecosystem services) which were not there before, such as provisioning of planktonic and epibenthic food resources and related trophic pathways, and those associated with life-stage specific habitat use [17], which are critical mechanisms of productive reefs; however, it can be argued equally, that this point of view is only valid from the starting point of a formerly pristine and non-degraded habitat, which is not the case for the heavily overfished and chemically/acoustically polluted North Sea, the habitat of which has been anthropogenically altered irreparably, and despite any future conservation measures, will never return to its former pristine condition regardless of any rewilding effort. Rather it could be considered a new baseline habitat between natural and altered. Indeed, unintentional re-wilding has even been carried out by a well-known, outwardly anti- O&G Non-Governmental Organisation [18], who created hard substrata in a previously soft-substrate environment, by dumping rocks in a trawling zone, to prevent fishing activities, which is arguably the most damaging anthropogenic impact in the North Sea [19,20]. This is especially salient, since MPAs are employed as tools to manage human impacts, especially fishing pressure; by excluding the most destructive activities MPAs can rewild degraded areas of seabed habitat [21]. In this sense, offshore O&G installations are already being considered as *de facto* MPAs [22], so is it not a logical step in a similar direction to thus consider them in a rewilding scenario?

Regardless of any philosophical exploration of semantics or ecological services justification for rewilding, it is undisputable that [10] subsea anthropogenic infrastructure provides hard, structurally complex substrate that can accommodate diverse sessile invertebrate fouling communities such as cnidaria, hydroids, bryozoans, porifera, bivalves, cirripeds, soft and hard corals, etc. [23-26]. These assemblages, in turn, attract motile invertebrates, such as crabs and molluscs [27], that support fish [28-32], and marine megafauna, such as sharks [33,34], marine reptiles [35], birds [36], and marine mammals [37-42]. An understanding of the marine communities that have come to associate with O&G structures over their operational life is important at end-of-life, as decommissioning practices should be designed and implemented to minimise negative impacts

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to marine ecosystems, particularly to sensitive and protected species and critical habitats. Such information is required on a case-by-case basis, and when it comes to conservation of the marine environment, all options, including potentially 'reefing as rewilding' should be on the table.

Visual underwater study of marine life is costly, challenging, risky, and prohibitive in terms of gaining access to within the 500-m fisheries exclusion zone around offshore O&G platforms; however, one important source of data is Remotely Operated Vehicles (ROVs), which are used extensively by O&G industries for Inspection Maintenance & Repair (IMR), and intervention of offshore infrastructure. Industry-science partnerships that enable scientists to utilise and augment industry ROVs and access collected data, have very high intrinsic value [43,44]. Industry is thus facilitating scientific research by providing historically collected General Visual Inspection (GVI) ROV video data to scientists to better understand impacts (both positive and negative) of static anthropogenic structures on marine ecology [45], and how this changes with time [46-48].

Use of incidentally collected ROV video data for scientific purposes has advantages (*e.g.* reduced effort, risk, cost, *etc.*) and disadvantages (provided videos collected mainly for maintenance purposes rather than scientific analysis, poor video resolution, distance/scale indication, limiting assessment of animal size and species identification, ROV/camera models undisclosed, *etc.*). Nonetheless, previous use of GVI ROV data has yielded significant insights into marine life associated with offshore infrastructure [e.g. 44,49]. Over the past few years, industry has shifted to more routine use of high definition cameras on ROVs that has led to vast improvements in image quality for ecological assessment [50].

Collection of offshore ROV data provide important insight into the ecology and trophic hierarchy of O&G infrastructure, which can inform operator 'end-of-life' decision-making, such as decommissioning plans, which identify specific options for subsea structures within a field. Infrastructure includes a wide range of elements, such as platform jackets, production flowlines, bundles, risers and their turrets, towheads, wellheads along with their protective units, production manifolds, umbilicals, pipeline-end manifolds, concrete mattresses, mooring anchors, and chains, among others. In the realm of offshore decommissioning, the concept of a Comparative Assessment (CA) was introduced, initially in policies and guidelines of the Oslo and Paris Convention (OSPAR) in 1998 [10]. This process is used to evaluate and identify the best decommissioning options for assets that may be considered for derogation (leaving *in situ*) based on specific criteria. The term CA refers to the overall method of assessing decommissioning alternatives and selecting the most suitable choices. Guidelines for conducting CAs have been issued by O&G UK in 2020 [51] and the Department of Energy and Climate Change (DECC), now known as the Offshore Petroleum Regulator for Environment & Decommissioning (OPRED), in 2018 [52]. These procedures align with OSPAR's regulatory requirements for CA, including derogation scenarios; however, detailed procedures for the CA process are not specified in OSPAR Decision 98/3, O&G UK guidance, or DECC guidance, which adds to the arcane, not-repeatable nature of the CA process.

When determining decommissioning options for subsea structures, CAs generally consider certain key factors, typically in order of priority: safety, environmental impact, social implications, technical feasibility, and economic consequences of the various decommissioning options [53,54]; however, traditional CAs have several disadvantages, Nicolette, Nelson [55], even though operators are obligated to release CAs into the public domain. Consequently, a more recent Net Environmental Benefit Analysis-Comparative Assessment, (NEBA-CA) approach, developed first by Efroymson, Nicolette [56], has been developed to compare advantages of different, in this case, decommissioning management actions. Net environmental benefits refer to improvements in the value of environmental services or other ecological attributes achieved by an action, minus the value of any negative environmental impacts caused by that action [56]. These measures can include a variety of environmental interventions such as restoration, remediation, conservation, and development. It is within the terms 'remediation' and 'conservation' that there is mileage considering the terms 'rewilding', and 'nature-in-design' when derogating a decommissioned platform that has a demonstrated net-gain effect on its surrounding environment, and this may be able to be effected through the formal NEBA framework, now acknowledged by several organisations, including the United States Environmental Protection Agency (USEPA) and its Science Advisory Board [57], the National Oceanic and Atmospheric Administration [58], and the Australian Marine Safety Authority (AMSA), for its effectiveness in providing a robust basis for decision-making; therefore, NEBA evaluates the overall positive or negative impact of proposed or implemented actions and helps manage site-specific risks. NEBAs are now being carried out worldwide routinely around offshore O&G decommissioning infrastructure.

1.1 Rationale

The aim of this study was to invite discussion around the concept of 'rewilding' in an offshore-decommissioning context by presenting data used in a real-world NEBA-CA [55,59] case study of an established (aging) offshore North Sea oil-production platform. Using incidentally collected industrial GVI ROV imagery to assess species presence, richness, biodiversity, and vertical distribution this study introduces the concept (and explores the possibility), that some, well-placed disused offshore installations could offer quantifiable environmental, societal, and economical 'net benefit' to the environment which could be considered in the context of a potential ocean 'rewilding' paradigm, and could enhance biodiversity, as there are already established complex marine communities. The study touches on the concept of 'nature-in-design', in terms of augmenting new offshore anthropogenic infrastructure at the deployment stage, to facilitate the decision-making process at the decommissioning stage.

2. Materials & methods

2.1. Platform & location

The offshore drilling and production platform is supported on a four-leg steel jacket structure with a total of 14 production wells. The installation is situated within the United Kingdom Continental Shelf (UKCS), in the central North Sea *ca.* 200 km Northeast of Aberdeen, UK (Figure 1). This area supports a constellation of offshore installations and several additional fields [60]. The platform has been *in situ* since 1992, and is in a water depth of 144 m, on a seabed composed of mud and muddy sand [61]. This platform ceased production in 2014 and is due for decommissioning and potential derogation in 2026.

2.2 Definition of terms

A description of these types of offshore O&G structures can be found in Goodlad, Garden [62]; a summary is presented here in the Section 1.1. of the Supplementary materials.

2.3 Footage sources

Between 11 and 28 August 2017, commercial work-class ROV pilots performed GVIs and Close Visual Inspections (CVI) around the platform legs, conductors, caissons, WHPUs, and bundles. On 1–2 November 2017, an additional seabed structure (towhead manifold) was surveyed. ROVs were equipped with cameras throughout, make and models unknown. Data were provided to analysts on hard drives, as opposed to marine scientists performing dedicated ROV surveys, consequently, control over factors such as date, time, areas surveyed, distance between the camera and the substratum, *etc.* was not possible, and is typical of industry studies.

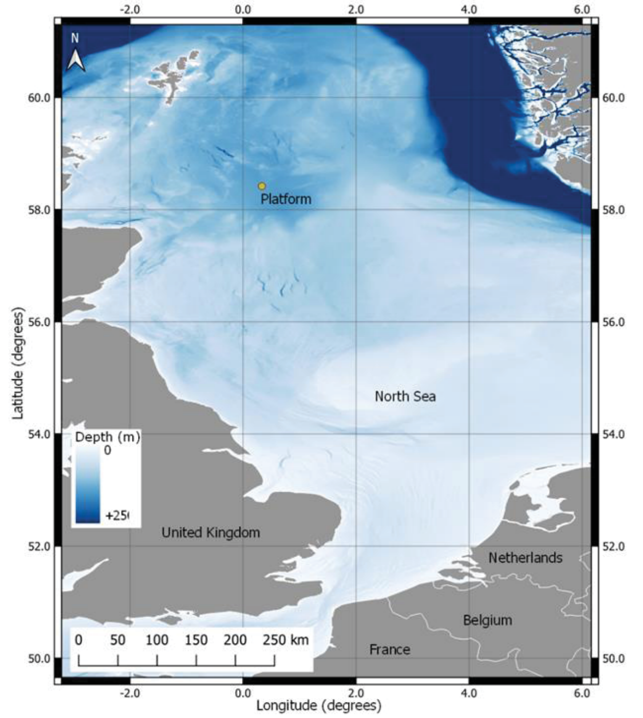

Figure 1: Platform location in the North Sea. Coordinates in WGS'84 decimal degrees.

2.4 Video screening & selection

Footage was viewed through VLC Media Player 3.0.6 Vetinari (Video Lan, Boston MA), which was able to read all files, typically in Packet file Fidonet (.pkt) format. Data were screened by several experienced marine science analysts working in parallel (e.g. viewing different videos concurrently) to maximise efficiency.

The first stage of analysis involved data screening for simple 'accept' or 'reject' criteria based on a qualitative assessment of suitability, including brightness, turbidity, visibility, *etc.*, followed by a further quality-assessment-scoring method adapted from McLean, Gates [63] and listed in Tables S1-S3. After this process, useable GVI footage, with occasional sections of CVI interspersed, was selected that covered the entire water column of the platform (0 m to seabed at 144 m). Since ROV footage focussed primarily on vertical structures and was unavailable or unreliable at positions away from the platform, with regards to assessment of any non-vertical habitat (such as seabed, or seabed-based structures), analysis considered only vertical 'sweeps' performed by the ROVs along a sample of each structure type, including caissons, conductors, and platform legs. Consequently, useable GVI footage was collected in depth bands following Guerin, Jensen [64], with 5 m depth bands near the surface, 10 m depth bands from 20-80 m and 20 m depth bands past 80 m (Figure S3). Only vertical habitat of the jacket was included in analysis because vertical sweeps were not performed on towheads, WHPUs, and bundles, which were all seabed structures, positioned at *ca.* 140–144 m depth.

Accepted footage was then assessed further for species-identification feasibility for both motile and sessile species (see Online Resource1 Section 1.2 for video assessment criteria).

2.5 Video analysis & taxonomic identification

Video footage that passed the screening stage was then used to compile a library of all taxa detected, following formal-assessment protocols to avoid observer bias (see Online Resource1 Section 1.3). Most videos were five-minutes long and analysed as a whole; longer files were also analysed in five-minute sections, for comparability.

Taxonomic identification of species present was performed according to Todd, Lavallin [25; 2020], using identification guides and keys [e.g. 65,66 etc.], and various peer-edited online marine databases (listed in Online Resource1 Section 1.4). During analysis, which predated standardisation techniques outlined in Horton, Marsh [67], species sighted in video footage (and stills; see Section 3.6) were compared with morphometric data/photographs (and for fish, meristics) presented in peer-reviewed literature, identification guides, and online databases. These were also cross-referenced to known recorded habitat, distribution, ecology, and depth preference for each identified taxon. For most obvious and common species (such as fish), identification was certain; however, for others, like smaller Cnidaria, Porifera, Crustacea, a sample would have been required to verify taxonomic status to species level. Moreover, while some specimens could not be identified reliably to species

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level, due to cryptic nature of species, oblique viewing angles, partially obscured identification features, poor footage quality, or distance at which most surveys were performed from the structure, *etc*., confidence for larger or very well documented species, such as sharks or cold-water corals, was certain. All species were grouped into the lowest possible taxonomic rank as per Lacey and Hayes [68]. For example, individual brittle stars (*Ophiothrix fragilis* or *Ophiocomina nigra*) could only be counted and identified to species level when the ROV approached the structure for contact Cathodic Protection (CP) readings or during depth-of-coverage estimation for biofouling surveys. Consequently, the two species were grouped together into one 'brittle star' category for data analysis. Both species are also often associated together [69], which further justified this analysis method.

All identified species were divided into motile and sessile species (see Online Resource1 Section 1.2) according to the species' ability to move, with exception of highly prevalent brittle stars, which could not be differentiated or counted at an individual level, so were obliged to be categorised as a fixed 'sessile' group.

2.6 Still-image analysis

Randomly timed stills were captured from each video [as per 68,70] by using a random number generator to select a still image for every minute of footage (rounded up or down to the nearest minute for each video). These stills were assessed in PhotoQuad v1.4 [71] by four analysts, again following the same analysis protocol to avoid observer bias. A stratified-random grid of one hundred points was overlaid onto each image (Figure S2) as per Gormley, McLellan [72], ensuring even coverage. Using the species-identification (ID) library compiled during video analysis, each point was then assigned to a species or structure type (*e.g.* platform, towhead, water column, *etc.*). Number of points identified per species, or structure was calculated for each still image and used for further analysis (e.g. out of 100 points in total, 50 could have corresponded to species A, 25 to species B, 10 to species C, and 15 to water, *etc.*). Note, if two or more points fell on the same individual (say, a large fish that took up a high portion of the frame), it was ignored. Similarly, for the avoidance of bias in this type of grid-point analysis and focal distances (*i.e.* a fish up close may fall under three points, but the same size fish farther from the camera may only fall under one point), these stills were discarded. Where possible, at least ten stills were analysed from each of the 13 depth bands used for analysis, though stills with no species sighted were removed from further study.

2.7 Data analysis

Statistical analysis was performed in R version 3.5.1 [73] and RStudio version 2022.02.01+461 using packages vegan [74], Modern Applied Statistics with S MASS [75] and Mixed Generalised Additive Model (GAM) Computation Vehicle, MGCV [76].

For consistency, the majority of data analysis was performed according to Todd et al. [25,47], where species richness (*S*), and Shannon diversity (*H'*) of stills were assessed at different depths. Data were grouped into 13 depth bands (*i.e.* not a continuum), as per Guerin, Jensen [64] and Guerin [31]; these were 0–5, 5–10, 10–15, 15–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–100, 100–120, and >120 m (see Figure S1 and additional details in Online Resource1 Section 1.5). Depth transects were replicated spatially, *e.g.* different legs of the platform were sampled. Depth of video footage was analysed against hour of day, across both August and November 2017, and a GAM was used to plot smoothed depth (explanatory variable, *i.e.* depth treated as a continuum) against time of day that footage was collected (response variable) to investigate diel trends. Following this, presence of non-biotic factors in the field of view (*e.g.* water column, surface structures, *etc.*) was excluded, and remaining % cover values for observed species were scaled (carefully, to avoid bias) to one for each depth band (*i.e.* % cover is related to number of points in the grid assigned to that spp./grouping, such as algae spp.). From these, *S* and *H'* were then calculated per depth band, separately for both sessile and motile species. Kolmogorov-Smirnoff tests were used to determine if *S* and *H'* were normally distributed, after which *t*-tests, with equal variance, and Kruskal-Wallis tests were used on normally and non-normally distributed data respectively, to determine if these variables were related to depth. All videos were time stamped, and as such, an assessment was made as to diel survey effort.

Since ecological data (like species abundance) are often non-normally distributed and zero-inflated, data were tested for normality, and if necessary, any relevant transformations for any non-normally distributed data (*e.g.* fourth root, *etc.*) were applied. An ANalysis of SIMilarity (ANOSIM) test was performed as per Todd, Susini [48]), on all data (both sessile and motile combined) to determine fouling community similarities across depth bands. Non-metric MultiDimensional Scaling (NMDS) ordination analysis tests per Todd, Susini [48]), were applied to a corresponding Bray-Curtis similarity matrix, to identify groupings of similar species between depth bands.

3. Results

A total of 3,030 videos (458 GB of data) was available for analysis, of which a subset of 128 videos (4.2%) was analysed (h_{Tot} = 08:55). Analysis of each hour of video footage took approximately ten hours. ROVs focussed on platform legs, caissons, conductors, bundles, pipes, and towheads. Most videos (n = 109) were collected between 11th and 28th August 2017, during which all platform depths were covered. Nineteen videos from 1st and 2nd November 2017 were also analysed, which focused solely on seabed structures, with a mean ± Standard Deviation (SD) depth of 141.96 m ± 2.63 m. A total of 289 high-quality stills were analysed. Of the 13 depth bands, ROV video footage at >120 m (band 13) had the most stills analysed (72, followed by 40–50 m, band seven; 47 stills) and 10–15 m (band three; 37 stills); at least ten stills were analysed for each depth band, except 0–5 m (band 1), which had six stills (see Figure S4 in Online Resource1).

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Videos used in analysis were collected typically by ROV pilots in shallower areas overnight, and deeper areas during the day (Figure 2). This bias was unavoidable during data analysis, as there was no choice in data provided by pilots and is typical of commercial datasets worldwide.

3.1 Taxa recorded

During video analysis, 33 taxa, across ten phyla were observed. Twenty-three of these were identified to species level, six to genus or family level, and the remaining to a wider class or phyla (Table 1). Utilising this species library, 20 of the 33 taxa were also recorded in stills. Still images of each species can be seen in Figures 3-5. Most of these stills were recorded in August, and not November footage, though some were only recorded in November. These included two fish, cod (*Gadus morhua*, Figure 4o) and a labrid (Figure 5c), one Northern Henricia starfish (*Henricia sanguinolenta*, Figure 4h), and turf Bryozoa (Figure 4e).

In addition to taxa observed in selected videos and stills (Figures S5-7), two additional protected species were also seen during initial exploration of video footage. These were a porbeagle shark (*Lamna nasus*) at 124 m (Figure 3 a,b) and five confirmed sightings of the cold-water coral (*Lophelia pertusa*, synonym *Desmophyllum pertusum*) at 54 m (Figure 3c). Neither species were observed in analysis of randomly selected stills.

3.2 Species richness, diversity & depth preference

The most common taxa were soft coral and anemone cnidarians, primarily white and orange morphs of *M. senile* and *A. digitatum.* While species richness did not differ significantly with depth (Table S6), it is clear from Figure 4, that high-level diversity differed with depth, with cnidarians dominating midwater, with higher diversity in both shallower and deeper portions. Specifically, cnidarians dominated species assemblages from 15–120 m (depth bands 4–12; Figure 4). Fish were observed in deeper areas, most frequently >120 m (depth band 13). *Pollachius virens* comprised approximately 50% of marine life cover at this depth and was observed making foraging attempts (Figure 5). Algae, *Mytilus* spp., and serpulids were most prevalent at shallower depths, while echinoderms were found in comparably lower numbers at all depths (Figure 4). Highest densities of arthropod cirripeds were recorded in deep waters of >100 m (bands 12–13), likely representing different species than those in shallower water. Arthropods were recorded in deep water (Figure 4), especially barnacles, potentially *C. hameri*, were recorded in deep water while shallower observations were more likely to be a different species, and those in the first 50 m of the water column were likely intertidal species, which were not identifiable with any degree of confidence.

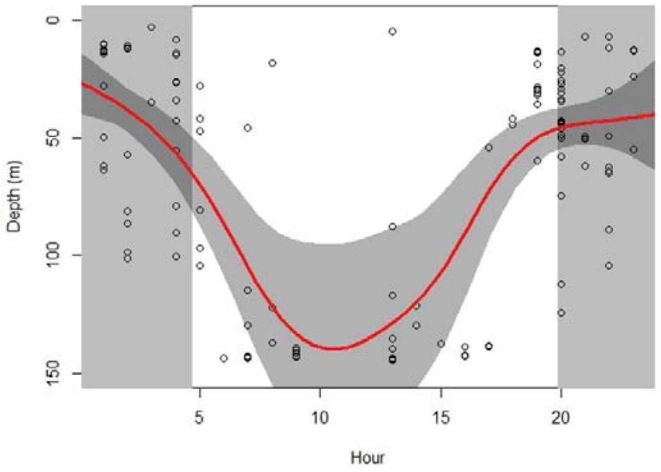

Figure 2: Depth of video footage analysed against hour of day, across both August and November 2017. Red line indicates smoothed prediction from a Generalised Additive Model (GAM) and grey curve represents 95% confidence interval. Grey vertical shading indicates night phases.

Species richness (S) and diversity (H') were calculated for each depth band (shown in Table S6). Between five and 15 species were observed in any given band, though no motile species were observed at 0–5 m (depth band 1). S was normally distributed for sessile species (Kolmogorov-Smirnov $D = 0.31$, $p = 0.57$), but non-normally distributed for motile species (Kolmogorov-Smirnov $D = 0.83$, $p = <0.01$). S did not change significantly with depth for either sessile ($t = -0.60$, $p = 0.58$), or motile species (Kruskal-Wallis $\chi^2 = 11$, $p = 0.44$). H' was non-normally distributed for both sessile species (Kolmogorov-Smirnov $D = 0.92$, $p = 5x10^{-6}$), and motile species (Kolmogorov-Smirnov $D = 1$, $p = 1.2x10^{-5}$), and was also invariant with depth (sessile: Kruskal-Wallis $\chi^2 = 12$, $p = 0.45$; motile: Kruskal-Wallis $\chi^2 = 11$, $p = 0.44$.

Cnidaria were the most observed phylum overall, with different species showing preference for specific depths (Figure 6). *M. senile* was common throughout the entire water column, being observed in 210 of 289 stills and present across all depth bands, with two notable peaks in % cover of *ca.* 50% and 83% at 15–20 m (depth band 4) and 60–100 m (depth bands 9–11), respectively. *A. digitatum* was observed in 127 of the 289 stills and was present in all but the shallowest region (0–5 m; depth band 1). *A. digitatum* had a peak of *ca.* 50% cover at 30–60 m (depth bands 6–8) – higher than that of *M. senile*. *Sagartia* spp. were detected mostly at 15–40 m (depth bands 4–6). The remaining two cnidaria, *B. tuediae* and *U. felina*, were found primarily in deeper areas, at much lower abundance (hence not included in Figure 6).

3.3 Species assemblages

Fouling-assemblage similarity between depth bands was statistically significant (ANOSIM, R = 0.3391, $p = 0.001$). Non-metric multidimensional scaling analysis grouping (groups A–D) of depth bands and species based on similarities is shown in

Figure 7. *Mytilus* spp., algae and Serpulidae were more commonly identified in shallower regions up to 15 m (depth bands 1–3, group A; Figure 7), while *Sagartia* spp., *A. digitatum* and the colonial tunicate *B. schlosseri* were grouped together in the upper-middle depths of 15–60 m (depth bands 4–8; group B). The lower-middle water column, 60-120 m (bands 9–12;

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Table 1: Taxa observed in ROV video footage. Ranges denoted by a hyphen, e.g. 1-5, mean that the taxa were observed from 1, and inclusive of bands in between, 5. 1While 'marine algae' is not a phylum, since algae were not identified to red or green status, they are included here under the nomenclature 'Phylum'. 2The two brittle star species were also combined during further analysis, as it was not possible to distinguish between them on all occasions. Grey cells indicate a high confidence of taxonomic identification, whereas taxa listed in white cells require either morphometric or genetic confirmation to identify taxonomically to species level. Blanks in recording on offshore structures indicate unknown.

Phylum	Scientific name	Common name	Motile or sessile	Video, still or both	Depth (m)	Depth band	Recorded on North Sea platforms previously
Marine algae[1]		Algae	S	Both	0–30	1–5	
Porifera	*Antho dichotoma*	Common sponge	S	Both	60–144	9–12	
Cnidaria	*Aurelia* sp.	Moon jelly	M	Video	13–144	3–12	
	Aequorea vitrina	Crystal Jellyfish	M	Video	100	11	
	Cyanea capillata	Lion's mane jellyfish	M	Video	95	11	[48]
	Tubularia indivisa	Oaten pipes hydroid	S	Both	10–141	3–12	[48,77]
	Alcyonium digitatum	Dead man's finger	S	Both	5–144	1–12	[48]
	Bolocera tuediae	Deeplet anemone	S	Both	60–144	8–12	[48]
	Urticina felina	Dahlia anemone	S	Both	40–143	7–12	[77]
	Metridium senile	Plumose anemone	S	Both	5–144	1–12	[77]
	Sagartia spp.	Elegant anemone	S	Both	15–143	3–12	[77]
	Lophelia pertusa	Cold-water coral	S	Video (incidental)	54	8	[78,79]
Ctenophora	Ctenophora	Comb jelly	M	Video	16–144	4–12	
Annelida	Serpulidae	Tube worm	S	Both	0–144	1–12	[48,80]
Arthropoda	*Cirripedia* spp.	Barnacle	S	Both	15–144	3–12	[48]
	Euphausiid spp.	Free-swimming shrimp	M	Video	10–144	2–12	[48]
	Lithodes maja	King crab	M	Video	138–143	12	
	Cancer pagurus	Edible crab	M	Video	12–44	3–7	[48,77,80]
	Maja brachydactyla	Common spider crab	M	Video	67–144	9–12	
	Necora puber	Velvet crab	M	Video	15	3	[77,80]
Bryozoa		Bryozoa/Hydrozoa turf biotope	S	Both	>120	12	[48]
Mollusca	*Mytilus* spp.	Blue mussel	S	Both	0–50	1–7	[77,81,82]
Echinodermata	*Asterias rubens*	Common starfish	M	Both	14–140	3–12	[48,77,80]
	Henricia sanguinolenta	Northern Henrecia	M	Both	144	12	
	Porania pulvillus	Cushion star	M	Video	130	12	
	Ophiothrix fragilis	Common brittle star[2]	M	Both	0–60	1–8	[77,80]
	Ophiocomina nigra	Black brittle star[2]	M	Both	0–50	1–7	
	Echinus esculentus	Common sea urchin	M	Video	45–120	7–12	[77]
Chordata	*Botryllus schlosseri*	Star ascidian	S	Both	15–130	4–12	
	Pollachius virens	Saithe	M	Both	74–140	10–12	[83-86]
	Gadus morhua	Cod	M	Both	144	12	[48,77,83,85,86]
	Sebastes norvegicus	Rose fish	M	Video	139–144	12	
	Chelidonichthys lucerna	Tub gurnard	M	Video	144	12	
	Labridae spp.	Unidentified wrasse	M	Both	13–144	3–12	
	Lamna nasus	Porbeagle shark	M	Video (incidental)	124	12	[40,87]

group C) contained other species of Cnidaria (in particular, *M senile*), Echinodermata, Cirripedia, and the poriferan sponge, *A. dichotoma*. The deepest band (>120 m) contained *A. rubens*, *T. indivisa*, mixed Bryozoa/Hydrozoa turf biotope, and all fish species (group D; Figure 7).

Only 19 of the 34 taxa recorded in video were detected in stills. Remaining 19 taxa were therefore not included in analysis of species assemblages, were relatively rare, but are discussed in Section 3.1.1. of the Online Resource1.

4. Discussion

One hundred and twenty eight ROV videos and 289 stills were analysed to assess diversity of fouling assemblages on an end-of-life hydrocarbon offshore production platform, to inform decommissioning options *via* a Net Environmental Benefit Analysis-Comparative Assessment, NEBA-CA [55,59]. A detailed discussion on limitations of industry data is provided in Section 3.1. of the Supplementary data; however, with these limitations in mind, this study has shown that

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industry data can yield valuable insights into the importance of platforms as artificial reefs in remote locations, as evidenced by the increasing number of studies of this nature [e.g. 25,44,46,63,88,89]. For example, such imagery can extend the known ranges of species [90], record associations of species with structures [91], and provide first *in situ* observations of others [90,92]. Moreover, while many industrial ROV surveys concentrate on certain elements only, CVI and GVI often cover the entirety of the sub-surface structure, providing a good overview from surface to seabed.

4.1 Taxa recorded

During its 25 years *in situ*, the platform accumulated a wide diversity of well-established reefing assemblages; for full taxonomic species descriptions, see Section 2.2. in the Supplementary information. With an effort of 128 videos (hTot = 08:55), and 289 stills, a total of 33 unique taxa were recorded across nine phyla (plus algae as a separate group). Thirty of these were identified to class (of 12 in total, including Cirripedia), 29 to family (of 23 in total, including Labridae, Serpulidae, Euphausiidae), 26 to genus (including *Aurelia* spp., *Sagartia* spp., and *Mytilus*, spp.), and 23 to species. Several of these taxa have not been reported previously on O&G installations. The diversity of taxa present at the platform is likely much higher than that documented here, with measures likely limited by the extent of suitable imagery for analysis and the snapshot of imagery obtained (single points in time).

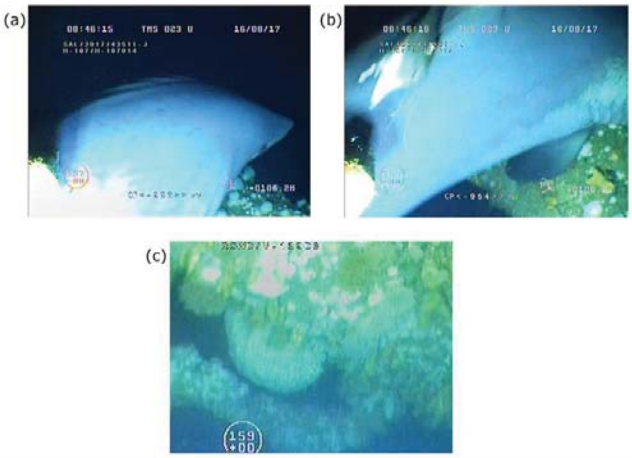

Figure 3: Species sighted incidentally during ROV video footage, including a porbeagle shark (Lamna nasus, a and b) and the cold-water coral, Lophelia pertusa (c).

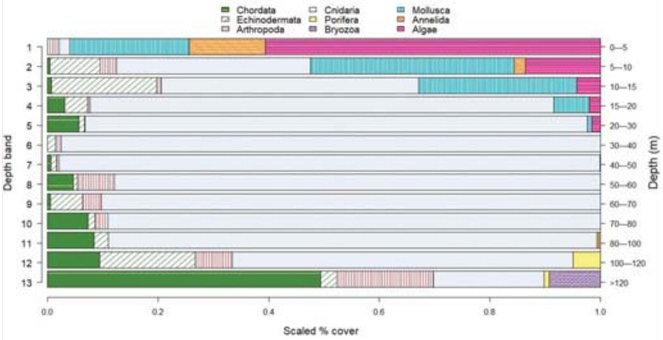

Figure 4: Scaled percentage cover of phyla in each depth band.

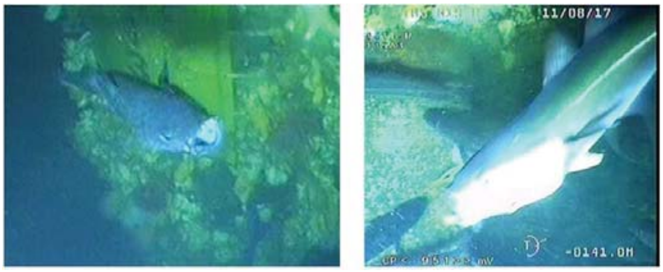

Figure 5: Examples of saithe (*Pollachius virens*) foraging, detected in ROV video footage.

4.1.1 Taxa not previously recorded on offshore installations: Several taxa observed on this study have not previously been recorded on O&G infrastructure in the North Sea, based on a thorough review of the literature.

Alcyonium digitatum was one of the most observed taxa in this study. The lack of data of offshore sightings for this species in the peer-reviewed literature might be linked to limited access of academic scientists to offshore installations; the same applies to all records of offshore taxa presented here.

The common sponge, *A. dichotoma*, is encountered frequently in deeper European waters [93], having been reported, for instance, at the Norwegian continental shelf border at 200–400 m [94], and the Trondheim fjord in Norway at 60m [95]. Nonetheless, while *A. dichotoma* was observed in ROV footage of trawled habitat around gas fields in the Barents Sea [96], there are currently no records of its presence on O&G platforms. As such, its confirmed presence on the platform represents, to the best of our knowledge, a new sighting. Unidentified branching sponges have been recorded previously on platforms in southern California, but individuals were grouped by morphology rather than to species level [97]. Additionally, this recording corroborates the use of opportunistic ROV data for study of fouling communities and demonstrates that offshore platforms generally can provide a useful method of further study on species for which the ecology remains relatively unknown.

H. sanguinolenta has been recorded previously on hard, exposed habitats in the north Atlantic Ocean, at depths of 0–365 m [98], filter feeding on detritus and plankton *H. sanguinolenta* is known to feed on sponges [99], so its presence on the platform is likely not unusual, although to the best of our knowledge, this species has not been recorded on O&G installations previously; however, without genetic confirmation to species level [100], its presence as a first record on an offshore platform cannot be stated with a high level of confidence.

The jellyfish *A. vitrina* was also detected in one video, at a depth of 100 m. *A. vitrina* has been documented previously throughout the north eastern Atlantic in pelagic and coastal areas [101], though in limited detail; a thorough literature search revealed that this may be its first documented sighting off an offshore hydrocarbon platform.

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4.1.2. Other notable taxa: *A. rubens* feeds primarily on benthic organisms also observed in this study, including bivalve molluscs, polychaete worms, and barnacles, with a preference for mussel epibionts [102]. Biomarkers can be used to analyse pollutants in *A. rubens*, which bioaccumulate due to the species' predatory behaviour [103]. As such, this species is an important potential indicator species and may be used to inform the study of temporo-spatial trends in water quality of the North Sea.

The commercially important, semi-pelagic schooling *P. virens* was the most frequently observed fish in ROV footage. This species occurs throughout the eastern Atlantic and North Sea, with a depth range of 37–364 m [104]. In this study, the shallowest detection was at 74 m, though most individuals were observed in large schools, at depths of >140 m. In European waters, *P. virens* is a migratory species with a life expectancy of up to 25 years [105]. The exponential increase in abundance of *P. virens* observed near the seabed highlights the importance of offshore platforms to the species, in areas where the otherwise may be limited habitat complexity, *i.e.* the absence of platforms may result in less complex habitats that do not favour the spreading of species [e.g. 106]. Furthermore, this predatory species likely benefits from the fouling organisms inhabiting the structure [107]. During this study, *P. virens* were observed feeding in water depths of more than 100 m; however, their prey could not be identified. Analysis of stomach contents of *P. virens*, from individuals sampled at British Petroleum's North Sea Miller platform, were found to contain a high proportion of euphausiids (Fujii, 2016), swarms of which were observed in this study between 40–130 m. The high abundance and foraging detected suggests these areas are important for the adult populations of this species.

The commercially important *G. morhua* was also observed in the lower depth group, in six videos at 142–143 m, totalling 11 individuals. *P. virens* were also observed exhibiting shoaling behaviour in all six videos, suggesting possible associations between the two fish species, as has been recorded with other predatory species [108]. *G. morhua* is well-documented throughout the north Atlantic and North Sea, at depths of 0–600 m [104,109]. The species exhibits large variation in abundance and distribution between feeding and breeding sites, with spawning occurring typically between November and May [110]; a major *G. morhua* spawning site is the central-southern North Sea [111-113]. It has been hypothesised that during the planktonic stage, North Sea stocks spill over into Norwegian and Greenland waters [113,114], suggesting their relative importance in stock recovery for other locations. Severe effects of overexploitation have been documented for this commercially valuable apex predator, and slow recovery has had knock-on effects for numerous species [115,116]. Hence, this study demonstrates the importance of anthropogenic structures as habitat/breeding grounds for recovery (due to absence of fishing in surrounding areas) and refuge of important fish species.

There was a single sighting of the commercially important velvet crab (*N. puber*) at 20 m. *N. puber* is documented throughout the east Atlantic and the North Sea with a depth range 0–80 m [117]. *N. puber* have planktotrophic larvae, with tidal flow playing a large part in their dispersal [118].

The commercially important, deepwater trawled, long-lived, and gregarious [119] rose fish (*S. norvegicus*) was recorded in three videos, each of a single individual on seabed structures at 140–144 m depth. *S. norvegicus* is well-documented throughout the eastern Atlantic and North Sea with a depth range of 100–1,000 m [120]. *S. norvegicus* is classified as Vulnerable and is at risk of over-exploitation from commercial fisheries due to its slow growth rate and late maturity (IUCN Red List).

There was a single sighting of porbeagle shark *L. nasus*. The Northeast Atlantic *L. nasus* population is classified as Critically Endangered (IUCN Red List: Ellis, Farrell [121]) and has declined significantly in this region due to commercial fishing pressure [122]. *L. nasus* is a highly migratory species, traveling up to thousands of kilometres annually through European waters from northern Norway through to Spain [123,124], however there is limited information on their presence at offshore structures. The (now sadly defunct) North Sea Bird Club [125], an initiative led by the University of Aberdeen to encourage oil and gas workers to document birds and other marine life, reported 14 records of *L. nasus*, with almost all records occurring from 1996-1998 (Weir, 2001). This record includes an aggregation of 25 individuals in August 1997. Haugen and Papastamatiou [126]) documented a rare aggregation of at least 20 individuals at the Alba platform in the North Sea, swimming slowly at the surface. No mating behaviour was observed, though some sharks were reported as female, suggesting they may have been present for parturition. All reported observations around offshore structures, including our incidental observation, occurred during the boreal summer, suggesting their presence may be seasonal, though it is not known if this is balanced against effort, *i.e.* more observations in the summer, and in better weather conditions. The observation of *L. nasus* at the platform therefore supports the burgeoning body of evidence that offshore structures are highly important locations for marine megafauna, including other shark species [34,38,40,127]. Furthermore, while *L. nasus* is at risk of being caught as bycatch in commercial fisheries, they are protected from fishing activity while near offshore structures due to the *de facto* MPA effect of safety zones.

The protected [128,129], dome-shaped, cold-water coral *L. pertusa* was detected on five occasions at depths of between 53.5–124.3 m, in a similar depth range to when first observed on offshore installations by Roberts [78], at depths of between 75 and 114 m, by Gass and Roberts [79] at depths of 48–109 m and by Guerin, Jensen [64] at depths between 55 and 140 m. This species has also been observed on pipelines [130]. Remotely Operated Vehicle surveys on other platforms have noted this species' absence above a depth of 43 m [25,48,80] possibly due to warmer shallower waters created by summer-thermocline stratification, which may limit the species vertical distribution. The *L. pertusa* sighting in this study was found in a slightly sheltered location (between the platform and an anode), again as in the study of Gass and Roberts [79]. The ROV narrator noted that *L. pertusa* had been detected previously at

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this platform in 2011 at a depth of 117 m, on a clamp, on riser caisson two, although it was no longer present at this location in 2017. In studies by Roberts [78] and Gass and Roberts [79], *L. pertusa* reefs detected in this paper lack the polychaete worm *Eunice norvegica*, which in natural reefs share parasitic and mutualistic relationship with the deep-water coral. Studies have not determined why *E. norvegica* is not present in reefs found on offshore structures while other typical polychaete worm species do. This presents some uncertainty about the completeness of the coral communities that develop on artificial reef structures, with more information the lacking needs of *E. norvegica* could be addressed, potentially through a nature-in-design approaches. The ecology of this species is somewhat arcane, due to its depth preference and inaccessibility In the lab, *L. pertusa* has been shown to feed opportunistically on available microalgae, zooplankton, bacteria, and dissolved organic matter [131]. Using growth rates and areal coverage, Dahl, Pereyra [132] calculated ages of some colonies to be over 3,000 years old. Assuming the ROV pilot was experienced in identification of this species, even a handful of detections on the platform supports the notion that it may be an important location for this slow-growing species, and indeed still fall under IUCN 'red list' protection laws. Addamo, Vertino [133] suggested that the genus *Lophelia* is synonymised with *Desmophyllum* so that *L. pertusa* becomes a synonym of *D. pertusum* however, the molecular evidence is considered uncertain by JNCC and MarLIN, as such we have not applied the revision across this paper.

4.2 Species richness & diversity

While species richness (*S*) and diversity (*H'*) did not exhibit a significant relationship with depth for either motile or sessile organisms, the deepest regions had highest overall *S*, though this is likely because comparably more data from this depth was analysed, due to the presence of additional seabed structures (*e.g.* towhead and bundles), and because more complexity at depth can often (but not always) mean more diversity. Similarly, while not significant, lowest *S* was reported in the shallowest depth band (0–5 m), which is likely because surface waves and currents at this depth made it difficult for the ROV to approach the structures closely, resulting in low video quality for motile species (Table S6 in Online Resource1). While we cannot eliminate unbalanced sampling, as a consequence of using industry data, there are resampling methods and discovery curve analysis that could be considered on future studies of this nature; however, this bias in low surface *S* at platforms has been reported by others [e.g. 80,134]. In summary, the patterns observed on this platform are consistent with the findings of Van der Stap, Coolen [80] on five offshore North Sea platforms, who reported that species richness showed a significant non-linear relation with water depth; from a low richness in shallow waters it increases with depth until 15–20 m, after which richness decreases again.

Finally, though not significant across all depths, there was an obvious decrease in overall *H'* in depth bands 9–11, before it increased again in bands 12–13. This could be explained by the prevalence of *M. senile* at depth bands 9–11, which dominated the taxa mixture, accounting for approx. 84% cover (Figure 6). *M. senile* is known to outcompete other fouling community species [135], which explains the overall decrease in *H'*.

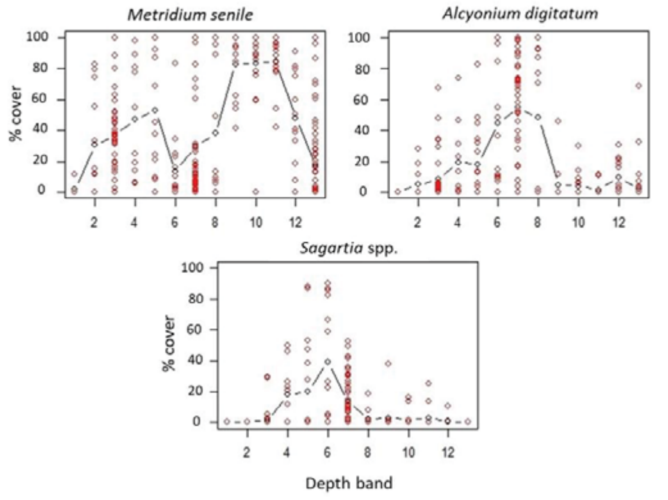

Figure 6: Percentage cover of the three most observed cnidarians across depth bands. Red circles represent values from each individual ROV still image analysed, and black circles and lines represent the mean.

4.3 Species assemblages

There was no significant difference in number or diversity of species with depth, however the composition of fouling communities varied significantly across depth bands (ANOSIM, R=0.3391, p = 0.001%). Dissimilarity was greater between depth bands that were further apart, and lesser between close bands. For example, dissimilarity between bands 1 and 12 was 0.99 (where 1 refers to completely different assemblages), largely due to *Mytilus* sp. and algae (found in shallower areas), and *P. virens* and *Cirripedia* sp. (found in deeper areas). In contrast, bands 9–10 and 10–11 had a dissimilarity of 0.27 and 0.24 respectively.

The results of NMDS analysis plotted taxa and depth bands based on similarity, resulting in the manual selection of four groups with similar taxa/depths (Figure 7). Details of taxa in each depth group are briefly presented below, as well as those that were not detected in still images and therefore excluded from species assemblage analysis. The four groups align roughly with current proposed decommissioning options of removing the platform between 10–16 m, 26–55 m, 55–106 m or 106–144 m; each option equates approximately to removing a depth group. No taxa detected were unique to depth group, although, individual species of Cirripedia and Labridae which could not be identified to species level have not been reported elsewhere, and thus may be unique. Groups B, C, and D, however, each supported between 1–6 potentially unique species, detected nowhere else on the platform. Therefore, removing these deeper sections would likely result in the loss of biodiversity.

Contribution of upper layers to the diversity of lower layers must also be considered. For example, much of the organic material found around the base of the platform at 144 m likely originated from much shallower areas, as has also been shown to occur at the base of platforms in California [136]. There was an accumulation of *Mytilus* spp. shells around the base of the platform that had fallen from near the surface, and any storm damage that causes sections of fouling assemblage

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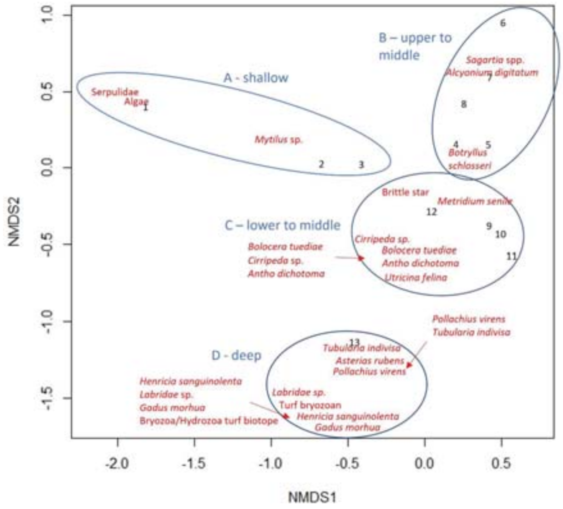

Figure 7: Non-metric MultiDimensional Scaling (NMDS) of species and depth bands. Black numbers indicate depth bands, and red text denotes species/groups. Ellipses have been added to demonstrate groupings, identified by letters A–D.

to be knocked off may further support other opportunistic/scavenging species near the seabed.

Finally, industrial studies on the topic of this paper are dependent strongly on time and budget, both of which are at a premium, compared to academic timelines. Work presented here had to follow previous methodology from other platforms using similar data and depth bands, for consistency [25,47,48]. Consequently, the number of images (samples) from some of the depth bands was low for statistical analysis, while some depth bands afforded the luxury of more images (*e.g.* only six images analysed for the upper depth band, and >70 viewed for the deepest). It could be argued that, using 5 m depth bands thus limited availability of observations, which may have had the unavoidable consequence of 'unbalancing' the survey. Moving forward a way to solve this issue would be to consider the planned decommissioning of different sections of the structure (four main depth bands). Further assessment could be modified to address this from the opposite perspective, in that the focus could be based on four main depth bands to highlight what organisms/assemblages could be lost, widening the depth bands, and balancing deign. Work from the shallowest zone could be noted to include predominantly algae, so none of the work would be lost.

4.4 NEBA-CA, re-wilding and nature-in-design

While the Rigs-to-Reefs paradigm remains controversial [137-139], research is starting to elucidate importance of, and intricacies within, offshore-installation ecology [44,46,84,140]. Installations surrounded by exclusion zones can act as *de facto* marine protected areas [22,141], which have potential to aid conservation of endangered sessile invertebrates [23] and ichthyofauna, including sharks, and marine mammals [37,127]. Additionally, adjacent stocks of commercially-exploited species, including *G. morhua, P. virens*, and *C. pagurus*, may be augmented [32,142], potentially to the benefit of fishers [143], and socio-economically, of benefit to wider marine stakeholders. Reproductive strategies of taxa reported here varied considerably from broadcast spawning, budding, to brooding; however, many species recorded include larval phases, which are capable of being transported considerable distances by currents [e.g. A. digitatum, >10 km; 144]. These communities can act as a source of individuals for nearby areas which may now facilitate development/recovery of other locations [145,146].

As a consequence of analysis performed during the NEBA-CA in the Nicolette, Nelson [55] – based on the data from this study – full removal of the jacket was determined to create negative environmental impacts with the predicted risks, such as reducing commercial fishing value by 60%, outweighing any potential benefits. Instead, the NEBA-CA recommended a Protect-in-Place option where the jacket is cut at 15 m below Lowest Astronomical Tide (LAT) with the cut section placed on the seabed beside the standing jacket and the exclusion zone maintained at 500 m (note, engineering simulations for proposed reef modifications were available for the NEBA-CA but are not presented here). Further improved understanding of installation ecology provides the scientific underpinning for planning and implementation of environmentally beneficial decommissioning strategies [22]. Offshore installation communities are inherently dynamic [26] and vary considerably between geographical locations, depths, structural designs and orientations [26,31,64,147-152]. Consequently, derogations permitted under current legislation should be considered case-by-case on the premise of multi-criteria evaluation [153], taking into account environmental, social and economic outcomes, as suggested by Jørgensen [138], Macreadie, Fowler [137], and Fowler, Macreadie [139].

This study introduced a hitherto unconsidered concept that certain, well-placed, thoroughly researched (and well published) offshore installations scheduled for decommissioning could be considered as a form of 're-wilding' of artificial reefs, especially if augmented nature-in-design alternatives to make them more effective as artificial reefs. It follows that to formulate a long-term cradle-to-grave decommissioning strategy with the greatest ecological benefit, the concept of nature-in-design at the offshore platform design and subsequent phase should be considered to create structures that enhance marine biodiversity and ecosystem resilience. While the offshore wind sector is further advanced in these abstractions [e.g. 154], the idea is gaining traction in the offshore O&G sector [e.g. 155,156]. By integrating nature-based solutions at the design (and potentially decommissioning) phase offshore platforms can serve as long-term ecological assets, benefiting both the environment and the industry.

5. Conclusion

In summary, this platform in the northern North Sea supported a range of species with distinct zonation of fouling communities, some of ecological (porbeagle, *Lophelia pertusa*) and commercial (gadoids) importance, and formed a valuable contribution to the NEBA. This platform could benefit from implementation of a Rigs-To-Reefs decommissioning regime (possibly with implications for fisheries, ecotourism, and biodiversity) within the North Sea. Comparable information

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from installations in different geographical locations would be required to reinforce this theory.

Discussions and findings of this study should be considered during discussions surrounding OSPAR Decision 98/3 and what purposes are considered legitimate by regulators. The 're-wilding' concept should be explored thoroughly, by independent organisations such as the United Nations Global Rewilding Alliance (GWA). Governments should investigate this option further by opening funding to universities and research organisations worldwide working actively in this space.

Declarations

Ethics approval

This study did not involve any human participants, animal subjects, or sensitive data requiring ethical approval. Therefore, no ethical approval was necessary for the conduct of this research.

Data/code availability

All relevant data are included within the manuscript and supplementary materials. Additional data, if required, can be made available upon request.

Authors' contribution

VLGT conceived, designed, co-supervised the original commercial project, oversaw taxonomic procedures/identification, performed elements of analysis, and drafted the initial, intermediate, and final manuscripts. DM peer-reviewed drafts, AT contributed to writing, formatting and submitting the final manuscript, and amendments, as required, SvE peer-reviewed an early draft, and IBT contributed financial and administrative support and supervision throughout the process.

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(**Supplementary-Materials**)

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