

Contribution to the Themed Section: 'Decommissioned offshore man-made installations' Original Article

Epifauna associated with subsea pipelines in the North Sea

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An increasing number of pipelines across the UK Continental Shelf are reaching the end of their economic life, resulting in a growing impetus on decommissioning. Implicit to the decommissioning process is the evaluation of the environmental impacts of the different decommissioning options, however little is known regarding the epifauna that interact with these structures. This study utilized industry-collected footage from remotely operated vehicle inspections of pipelines to assess the interactions of benthic epifauna with pipelines, and their associated structures, for the first time. Footage was analysed from across the northern and central North Sea to examine relationships between faunal community compositions and pipelines and their protective coverings. The complex habitat of concrete and Link-lok mattresses had the highest numbers of observable taxa. Differences in community composition were largely due to varying proportions of common epilithic species. There was a weak relationship between pipeline covering type and the species composition of the immediately neighbouring substrate. Depth and latitude were the strongest correlators with the observed community compositions. This study has compiled the first dataset on epifaunal associations with subsea pipelines in the North Sea.

Keywords: community composition, decommissioning, epifauna, North Sea, pipeline, ROV

Introduction

Over 260 oil and gas platforms and >45 000 km of subsea pipeline are installed across the UK Continental Shelf (UKCS) (Oil & Gas UK, 2013, 2017). Pipeline infrastructure varies greatly in terms of use (e.g. chemical, export), system type (cables to 40" diameter trunklines), and associated protective structures. Pipelines may be installed resting on the seabed (surface laid) or partially to completely buried in the sediment. Damage to surface laid pipelines caused by trawling activities, debris, and sediment transport can be mitigated through burial of the pipeline or the installation of protective structures, known as coverings, over the pipeline (Oil & Gas UK, 2013).

The North Sea is a marginal, shallow sea on the European continental shelf. Depths range from ~50 to ~200 m, with the maximum depth of >700 m restricted to the Norwegian Channel (Paramor *et al.*, 2009). The seafloor is characterized by soft sediments, with natural hard substrate largely restricted to relatively small areas of gravel and pebbles (Paramor *et al.*, 2009). The presence of pipelines

has the potential to exert a significant influence on local benthic communities by acting as artificial reefs, as found for other hard structures (Wilhelmsson and Malm, 2008; Miller *et al.*, 2013) and by providing protection from trawling damage (Burdon *et al.*, 2018).

Despite increasing knowledge of the capacity for shipwrecks, offshore platforms, and renewables to act as artificial reefs (either primary or *de facto*) by providing novel hard substratum for sessile organisms (Forteath *et al.*, 1982; Baine, 2001; Schroeder and Love, 2004; Gass and Roberts, 2006; Wilhelmsson and Malm, 2008; Macreadie *et al.*, 2011; Coates *et al.*, 2014), no such emphasis has been placed on pipelines. The physical structures of subsea installations are known to modify local water flows and sediment type, further affecting benthic community composition (Wilson-Ormond *et al.*, 2000). Increased sediment heterogeneity and organic enrichment in the immediate vicinity of platforms, resulting from falling detritus (via natural dislodgement of fouling sessile invertebrates or structural cleaning) and faecal pellets, can also impact the local ecology (Schroeder and Love, 2004; Manoukian *et al.*, 2010).

Over 3000 pipelines are expected to require decommissioning from the UKCS (Walker and Roberts, 2013). Potential decommissioning scenarios include leave *in situ* options, including burial via sediment or rock dump, and either complete or partial removal. The current Government guidance recommends that surface laid, un-trenched, small (<16") diameter pipelines are removed (BEIS, 2018). Each decommissioning option is evaluated in terms of the perceived impacts to the marine environment and the fishing industry, as well as safety, cost, and technological implications (BEIS, 2018). Despite this, the environmental interactions between pipelines and marine fauna have received very little attention.

To our knowledge, four studies have been published on the ecological interactions between pipelines and their receiving environment (Love and York, 2005; Glaholt, 2008; Russell *et al.*, 2014; Mclean *et al.*, 2017). These studies suggest that pipelines offer significant habitat that supports increased faunal diversity and commercially important species. However no study to date has provided a targeted investigation of the benthic fauna associated with pipelines, despite representing one of the most spatially extensive installations in the North Sea (Oil & Gas UK, 2013). The degree to which pipelines and their coverings provide a locally novel habitat will depend on the nature of the receiving environment. In soft sediment areas, surface laid pipelines would be expected to create a high degree of local-scale habitat diversity and, potentially, an increase in local-scale biodiversity through the addition of novel hard substrate, as found for other artificial structures (Davis *et al.*, 1982; Reeds *et al.*, 2018).

Health and Safety Executive (HSE) regulations require operators to examine and monitor subsea pipelines as part of their routine maintenance, with the methods and frequency at the operator's discretion (HSE, 1996). In addition to side-scan sonar surveys, operators conduct visual surveys of the infrastructure using video cameras hosted by remotely operated vehicles (ROVs) to identify any potential damage. The length and frequency of the inspections are operator specific, but can range from complete surveys every 5 years, to yearly surveys of short sections of interest (M. Netherway, pers. comm.). Studies of marine growth patterns on platforms have typically used industry inspection footage to identify trends with depth (Krone *et al.*, 2013; Van Der Stap *et al.*, 2016) or to describe the range expansion of species of particular interest (Gass and Roberts, 2006).

The increasing impetus on pipeline decommissioning in the North Sea raises questions as to what extent organisms are interacting with these structures and how will decommissioning impact the local environment. This study aims to use industry ROV inspection footage to determine the composition of species assemblages (including epilithic and mobile benthic fauna) associated with subsea pipelines and identify any specific associations with different types of protective coverings.

Methods

This study acknowledges the provision of certain ROV inspection footage by Shell U.K. Limited. The video footage was taken from inspections conducted by SubSea UK for Shell U.K. Limited, of 12 pipelines in the central and northern North Sea between 2012 and 2013. Pipelines were distributed between the Brent and Penguins fields in the northern North Sea (NNS) and within the Shearwater, Fulmar, and Gannet fields in the central North Sea (CNS) (Table 1, Figure 1). Pipeline selection was made by Shell U.K. Limited based on the availability of footage. All footage was collected in high definition (HD, 720p) format from three ROV

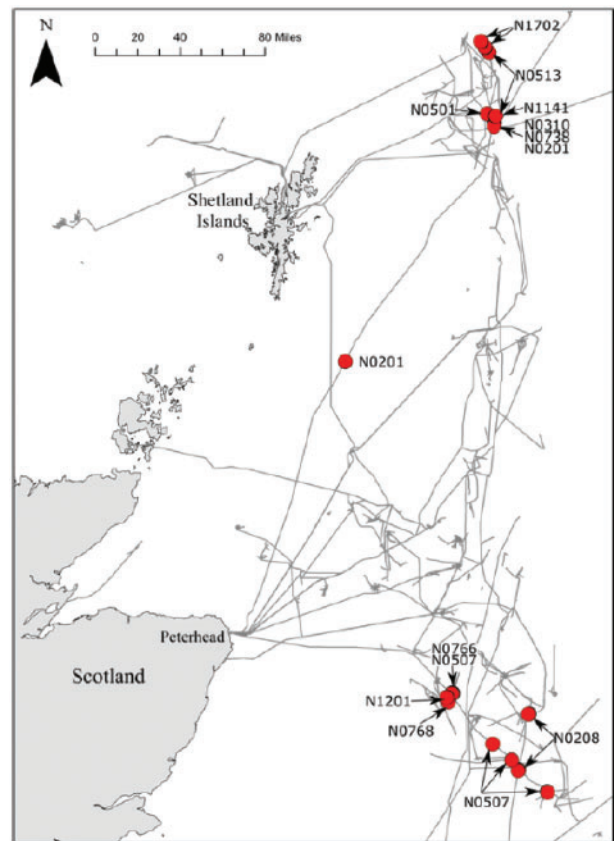


Figure 1. Circles (Red circles) denote the sample locations, lines (grey) denote pipelines. Color version of this figure is available at ICESJMS online.

mounted cameras, providing top and side views of the pipelines and the immediate substrate (Figure 2). Available footage was concentrated within the 500 m safety zones surrounding platforms. Where available, footage was used up to 600 m distance from platform and of sections located extended distances along the pipelines (mid-line sections).

The footage was initially viewed to characterize the visible pipeline, record protective structures, and buried sections, characterize sediment type and discard unsuitable footage due to low lighting, poor visibility, or the presence of other infrastructure. Six types of protective structure were identified and used for analysis; (i) exposed pipeline, surface laid, and with no additional protection; (ii) buried, completely covered by sediment; (iii) concrete mattress, concrete blocks linked by wire or rope; (iv) Link-lok mattress, plastic pots filled with concrete and linked by wire or rope; (v) rock dump, otherwise known as "riprap"; and (vi) 3-layer polypropylene (3LPP), a yellow plastic sheath (Figure 3). Sediment type was visually estimated using five broad character types; rock, coarse sediment, mixed sediment, sand and muddy sand, and mud and sandy mud, following Parry (2015). Any additional surface deposits were noted.

Screenshots, displaying ~1 m length of pipeline ("samples"), were taken from the top and side cameras at 20 m intervals. The start and end of each sample was calculated using the Kilometre Point information displayed in real-time. If a sample was unsuitable then the next available section was analysed. All fauna visible in the sample were manually identified and recorded. The video was then replayed to better visualize fauna and aid identification.

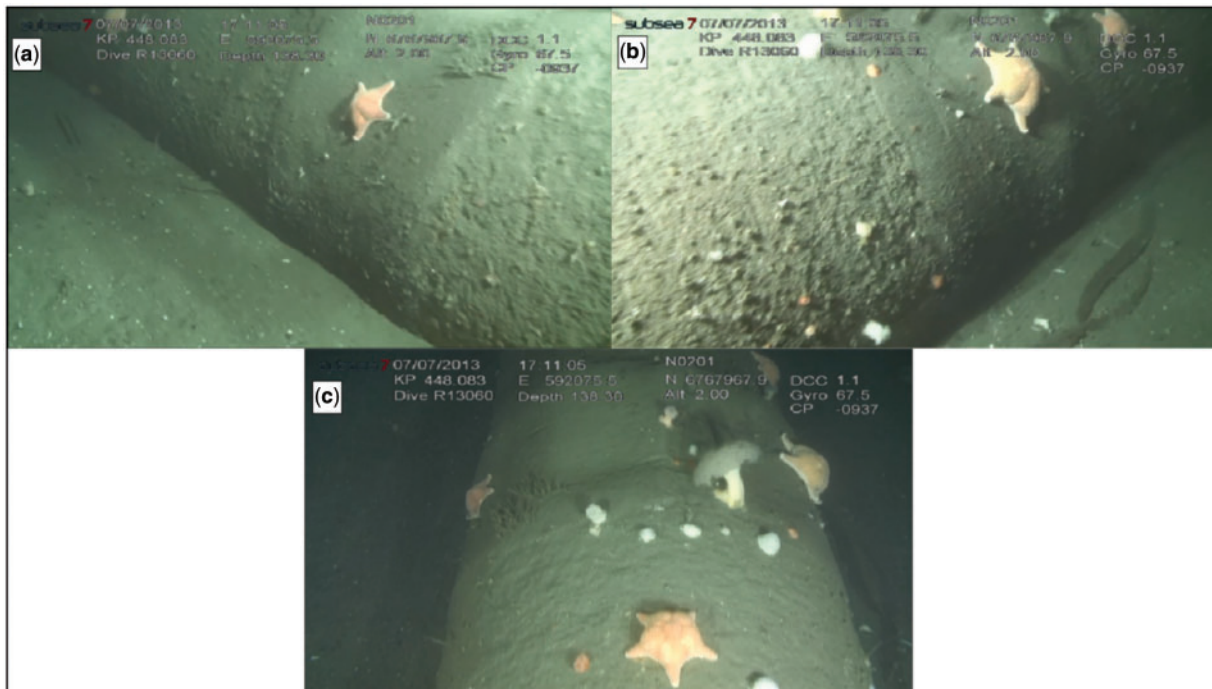


Figure 2. Example view of an exposed pipeline and neighbouring sediment showing (a) port, (b) starboard, and (c) central camera views.

Epifauna were identified to the lowest taxonomic level possible and species nomenclature follows the World Register of Marine Species (WoRMS Editorial Board, 2017). Individual small taxa (< ~3 cm) cannot always be reliably observed in ROV footage and organisms which could not be readily identified had to be grouped. Anemones and sea squirts were identified to subphylum level (Actiniaria and Ascidiacea, respectively), as were small crabs (Decapoda) due to poor video resolution of fine-scale taxonomic detail. Individual organisms were counted and colonial organisms were recorded as percentage cover of the pipeline visible in the screenshot. Species with less than two recorded occurrences were excluded from the dataset. Species abundance was assigned an ordinal value (1–9) following an adapted version of the Braun-Blanquet scale (Table 2) (Lewis *et al.*, 2000; Coolen, Bos, *et al.*, 2015; Van Der Stap *et al.*, 2016).

All statistical analyses were performed in PRIMER v.7.0.13 with PERMANOVA+ 1 (Clarke and Gorley, 2015). Taxa identities and their abundance values were converted into Bray–Curtis similarity matrices (Bray and Curtis, 1957). Similarity of percentage (SIMPER) analysis revealed the percentage contributions of species accounting for >5% of the similarity within, and dissimilarity between covering types. The percentage columns of the resulting tables show the contribution of each characterizing species to the dis/similarity within the group, i.e. the higher the contribution, the higher the importance of the species. The explanatory variables used were depth (m), distance from platform (m), eastings, northings, altitude of the ROV (m), and year the pipeline was installed (Laid date). Altitude was displayed in real time and provided a non-subjective indicator of video quality. Relationships with the epifaunal community structure, were investigated using distance-based linear modelling (DistLM) and visualized using distance-based redundancy analysis (dbrDA). The distributional influence of taxa with an r -value ≥ 0.1 was visualized on the dbrDA plot. Species richness (number of

identified taxa) per sample was calculated using the DIVERSE function. Where groupings were identified within the dbrDA, PERMANOVA was used to investigate whether there was a significant effect of covering type on species richness ($p \leq 0.01$).

Results

A total of 435 sections of footage were analysed from the available video footage of which 215 included a suitable view of the seafloor for analysis.

Pipeline community

Species richness

A total of 46 taxa recorded on the pipelines were used for community analyses. Records of *Aphrodita aculeate* and aff. *Salmacina dysteri* (Annelida), *Pennatula phosphorea* (Cnidaria), *Porania pulvillus* (Echinodermata) and aff. *Phakellia ventilabrum*, and *Suberites ficus* (Porifera) were rare ($n \leq 2$) and were removed from the analysis. The most commonly observed fauna (n records >100) were *Caryophyllia smithii* (Cnidaria, individual), Turf (bryozoa/hydroid) (colonial), Actiniaria, *Spirobranchus triqueter* (Annelida, colonial), *Asterias rubens* (Echinodermata, individual), and Paguridae (Crustacea, individual). The remaining taxa belonged to Bryozoa/Hydroidea/Porifera, Cnidaria, Annelida, Echinodermata, Arthropoda, Mollusca, Chordata, and Proteobacteria (Beggiatoa).

The highest average levels of species richness were recorded for the Link-lok and concrete mattresses, with the rock dump and buried samples showing the lowest observed richness (Figure 4, Supplementary Table S1). There were significant differences in the number of observed taxa (richness) associated with each covering type [$df = 5$, Pseudo- $F = 52.12$, $p_{(perm)} = 0.001$, Table 3]. No significant differences were detected between exposed pipes and concrete and Link-lok mattresses and 3LPP coverings. Due to

Table 1. Pipeline and video survey details.

Pipeline	Year laid	Diameter (inch)	Observed external coverings/protection	Water depth (m)		Study area	Location (lat, long)	Footage (KP)		Dist. (m)	No. 1 m stations
				Min.	Max.			Start	End		
N0201: Brent Alpha to VASP	1976	36	Concrete, wrapping	137.0	128.5	Brent A	1°42'13.59"E 61°2'3.17"N	447.973	448.126	153	16
N0208: Shearwater to Bacton	1999	34	Concrete, 3LPP	84.8	88.9	Mid-line Shearwater	0°21'54.69"W 59°26'37.725"N	232.54	232.7	160	9
N0310 Brent Alpha to Brent Bravo SSIV	2002	14	Concrete mattress, 3LPP	132.8	140.5	Mid-line Brent A	1°48'15.458"E 56°39'1.468"N	49.28	50	720	19
N0501: Brent Charlie to Cormorant A	1975	30	Concrete, wrapping, concrete mattress, Link-lok	137.2	142.2	Brent B SSIV Brent C	1°42'41.394"E 61°3'14.183"N	0.005	0.6	599	20
N0507: Gannet A to Fulmar A	1990	16	Concrete, wrapping, concrete mattress, burial	79.2	96.2	Mid-line Fulmar A	1°43'7.642"E 61°5'44.897"N	0.01	0.3	291	27
N0513: Brent Charlie to Penguins DC5	2002	16	Concrete, concrete mattress, 3LPP, Pipeshield	138.5	157.5	Mid-line Brent C	1°36'45.975"E 61°6'50.779"N	6.2	6.27	70	8
N0738: Brent Alpha to Brent South	1994	10	Concrete, wrapping, concrete mattress, burial, trenched	137.8	140.2	Brent A	2°9'5.941"E 56°29'43.594"N	106.51	107.143	633	32
N0766: Gannet E to Gannet A	1997	8	Concrete mattress, burial, 3LPP	90.9	92.4	Gannet A	0°59'59.5"E 57°10'54.749"N	0.001	0.85	849	24
N0768: Gannet Intersection to Gannet F	1997	8	Concrete mattress, rock dump, 3LPP	91.0	94.3	Gannet E/F	1°29'32.049"E 56°49'56.39"N	50.724	50.795	71	8
N1141: Brent Charlie to Penguins DC2	2002	4	Concrete, wrapping, concrete mattress, rock dump	139.4	140.4	Intersection Brent C	1°43'22.917"E 56°43'12.717"N	69.553	69.71	157	9
N1201: GC1/GC3 to Gannet A	1992	36	Concrete, wrapping, 3LPP	88.1	91.4	Gannet C3	1°43'35.97"E 61°5'46.422"N	0.02	0.54	539	16
N1702: Penguin DC3 to Penguin DC4	2002	16	Concrete mattress, 3LPP	160.1	164.2	Penguins DC5 Brent A	1°39'37.738"E 61°31'46.991"N	51.58	51.754	174	9
							1°42'16.231"E 61°1'56.728"N	0.04	0.54	500	29
							0°59'52.336"E 57°10'57.464"N	0.03	0.61	580	29
							0°56'48.454"E 57°7'30.988"N	0.016	0.58	564	31
							1°43'37.056"E 61°5'48.118"N	0.005	0.6	595	33
							0°55'40.451"E 57°9'18.814"N	5.42	5.84	420	13
							1°33'3.585"E 61°36'22.107"N	5.25	5.805	555	31
							1°36'12.755"E 61°33'59.49"N	0.002	0.54	538	30

Year, year laid *in situ*; Diameter, diameter of pipeline (inches); Study area, <600 m to platform or Mid-line; Location, footage location; Lat., latitude; Long., longitude; KP, kilometre point; Dist., distance surveyed; No. 1 m samples, number of 1 m screenshots.

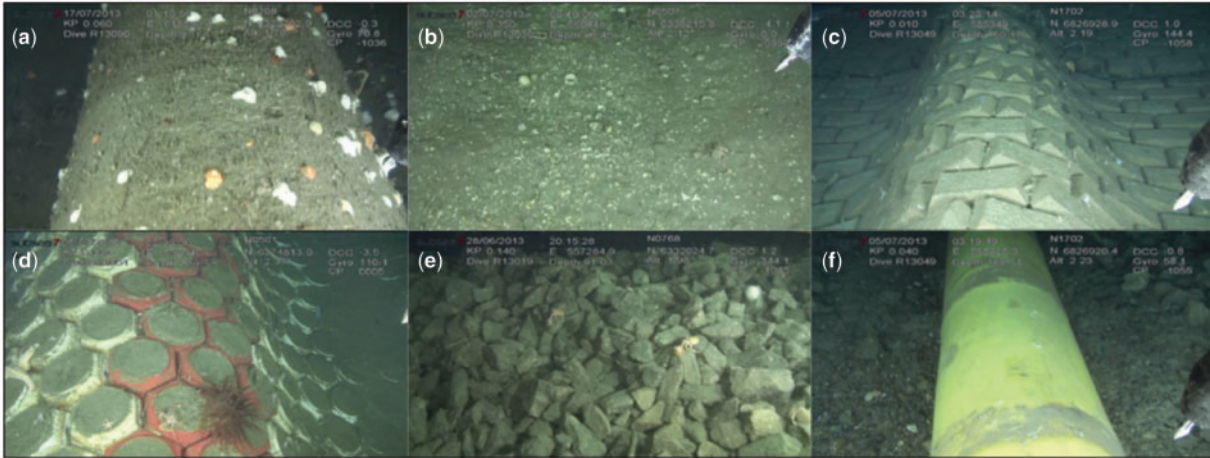


Figure 3. Central camera ROV views of the pipeline protective covering types investigated in this study. (a) Exposed concrete pipe, (b) buried, (c) concrete mattress, (d) Link-lok mattress, (e) rock-dump, (f) 3-layer polypropylene (3LPP). Refer to [Supplementary Table S1](#) for frequencies.

Table 2. Abundance classes with corresponding analysis value.

Abundance class	Abundance value
1 individual	1
2–5 individuals	2
6–50 individuals	3
>50 individuals/<5% cover	4
5–15% cover	5
16–25% cover	6
26–50% cover	7
51–75% cover	8
76–100% cover	9

the limitations inherent in observing fauna via ROV video, the numbers of observed taxa are underestimates of the true diversity, as organisms that could not be reliably identified often had to be grouped and small taxa (< ~3 cm) may not always be observable in the footage.

Community composition

There was a strong influence of covering type on the community composition of the pipeline taxa ([Figure 5](#)). The concrete and Link-lok mattresses showed tight groupings and were distributed along axis 2. The greatest variation was observed for the overlapping bare pipe and 3LPP samples to the left of the plot. Both the rock dump and buried samples were split between two groupings. The buried samples were restricted to the top right of the plot, with separation along axis 2. The rock dump samples were predominantly restricted to the bottom of the plot and split along axis 1. Separation along axis 1 was primarily driven by the relative coverage of bryozoan and hydroid turf. Separation along axis 2 was influenced by the relative abundances of Actiniaria and *C. smithii*. Higher abundances of *Tessaradoma boreale* (Bryozoa) and Paguridae were associated with samples higher on axis 2, whereas encrusting Bryozoa/Porifera and *S. triqueter* were associated with lower values on both axes.

The distinct separation of the rock dump samples along axis one was due to the relative coverage of hydroid/bryozoan turf. The samples towards the left of the plot were samples in the

southern extent of the study area, along the N1201 and N0768 pipelines which were laid in 1992 and 1997, respectively. The samples towards the right of the plot were from the N1141 pipeline, at a higher latitude and laid in 2002.

The community composition differed by covering type ($p < 0.01$, [Supplementary Table S2](#)). The highest percentage dissimilarities were between the buried samples and all other covering types ($\geq 79\%$) with the exception of rock dump (69%). The compositions responsible for the within group similarities and between group dissimilarities are detailed in [Supplementary Table S3](#). The influence of the taxa with the greatest correlations with the data structure is visualized in [Figure 5](#).

The remaining abiotic factors were investigated using DistLM ([Table 4](#)). Individually, depth, northings, and ROV altitude accounted for the greatest variance in the community data (5%, $p < 0.0001$), however, when included in the full model, depth accounted for the greatest variance (6%, $p < 0.0001$). The best model included all variables and accounted for 21% of the total variance. In addition to the environmental indicators, the altitude of the ROV accounted for a minor but significant proportion of the variance (3%, $p < 0.0001$).

Seafloor community

The neighbouring seafloor was visible in 347 samples ([Supplementary Table S5](#)) of which 200 provided a clear view for community analysis. Sediment was not visible neighbouring the Link-lok mattresses but was visible for 13/67 concrete mattress samples. All of the samples were taken from regions of mud and sandy mud, however deposits of shells, stone, and other detritus were often observed to have accumulated immediately next to the pipeline ([Supplementary Table S5](#)).

Species richness

Thirty-six taxa were observed on the sediment neighbouring the pipelines. Of these, 13 taxa were rare. The most common taxa were Actiniaria, Paguridae, and *Munida rugosa* (Crustacea). Species richness was low, averaging two per station. Maximum numbers of taxa were recorded for sediment neighbouring exposed pipes (n. taxa = 5 or 6, n. samples = 2) and 3LPP samples

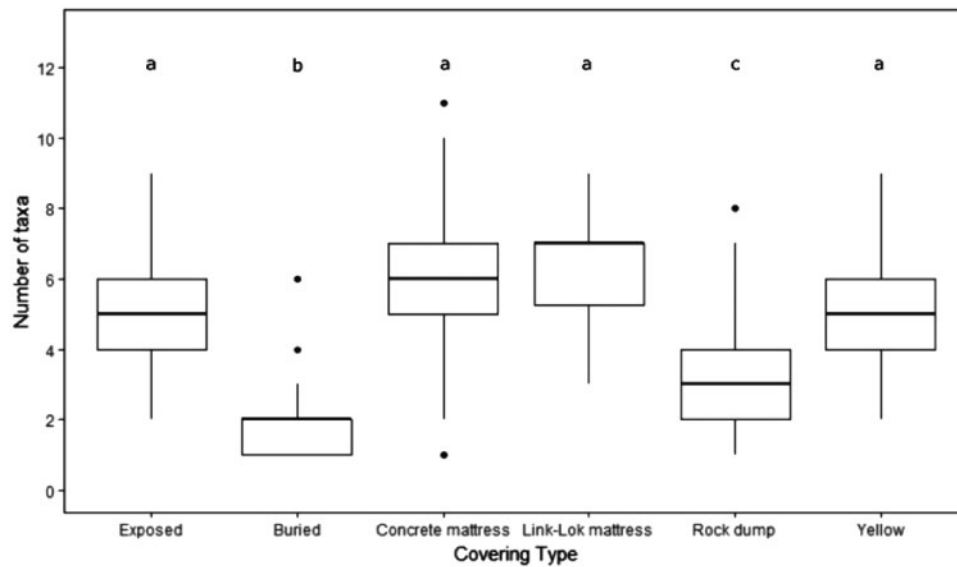


Figure 4. Number of taxa recorded for each covering type. Letters denote non-significant pairwise comparisons ($p < 0.01$) (Table 4).

Table 3. Number of taxa observed on the pipelines and the immediate sediment by covering type.

Comparisons	Pipeline			Sediment		
	<i>t</i>	$P_{(perm)}$	No perms	<i>t</i>	$P_{(perm)}$	No. perms
Buried–concrete mattress	11.62	<0.0001	9859	0.07	1	18
Buried–exposed	14.74	<0.0001	9901	0.7	0.47	97
Concrete mattress–exposed	1.71	0.073	9924	0.96	0.37	274
Buried–Link-lok mattress	8.088	<0.0001	4597	–	–	–
Concrete mattress–Link-lok mattress	0.976	0.33	7061	–	–	–
Exposed–Link-lok mattress	2.0037	0.036	6048	–	–	–
Buried–rock dump	4.46	<0.0001	5451	–	–	–
Concrete mattress–rock dump	5.39	<0.0001	9800	–	–	–
Exposed–rock dump	6.23	<0.0001	9691	–	–	–
Link-lok mattress–rock dump	4.25	<0.0001	6359	–	–	–
Buried–3LPP	12.98	<0.0001	9846	0.72	0.51	144
Concrete mattress–3LPP	2.51	0.0071	9924	1.069	0.29	512
Exposed–3LPP	1.35	0.17	9904	4.13	0.0001	4353
Link-lok mattress–3LPP	2.55	0.0097	5395	–	–	–
Rock dump–3LPP	5.15	<0.0001	9432	–	–	–

Comparisons give results of PERMANOVA pairwise comparisons. No. perms, number of permutations.

(n. taxa = 5, n. samples = 1) (Supplementary Table S1). Significant differences in species richness were only found between the exposed and 3LPP pipe sections [$p_{(perm)} = 0.0001$, Table 3].

Community composition

Sediment community composition differed between covering types [df = 3, Pseudo- $F = 6.82$, $p_{(perm)} = 0.001$] with <21% similarity between all covering types (Supplementary Table S4). The community associated with 3LPP differed from that of all other covering types ($p \leq 0.01$). SIMPER analysis showed that within group similarities were relatively low, ranging from 20% (Concrete mattress) to 44% (Buried). Proportions of Actiniaria, *M. rugosa*, Paguridae, and Beggiaota (Proteobacteria) accounted

for most of the within group similarities and between group dissimilarities (Supplementary Table S6).

Separation between samples was primarily driven by relative abundances of Actiniaria, *M. rugosa*, Paguridae, and *Astropecten irregularis* (Echinodermata) ($r > 0.2$) as well as Sabellidae (Annelida) and *Hippasteria phrygiana* (Echinodermata) ($r > 0.1$) (Figure 6). Higher abundances of *M. rugosa*, *A. irregularis*, and Paguridae were correlated with the 3LPP covering. Proportions of Actiniaria correlated with axis 1, accounting for 26% of the total variation and *M. rugosa* and Paguridae corresponded with axis 2, accounting for 19% of the total variation.

Laid date, northings, depth, and altitude all correlated with the community data ($p < 0.05$) (Table 5). Eastings showed a marginal, non-significant correlation ($p > 0.05$). Depth accounted for the largest proportion of the variance in the data (7%). The best model contained all of the abiotic variables and accounted for

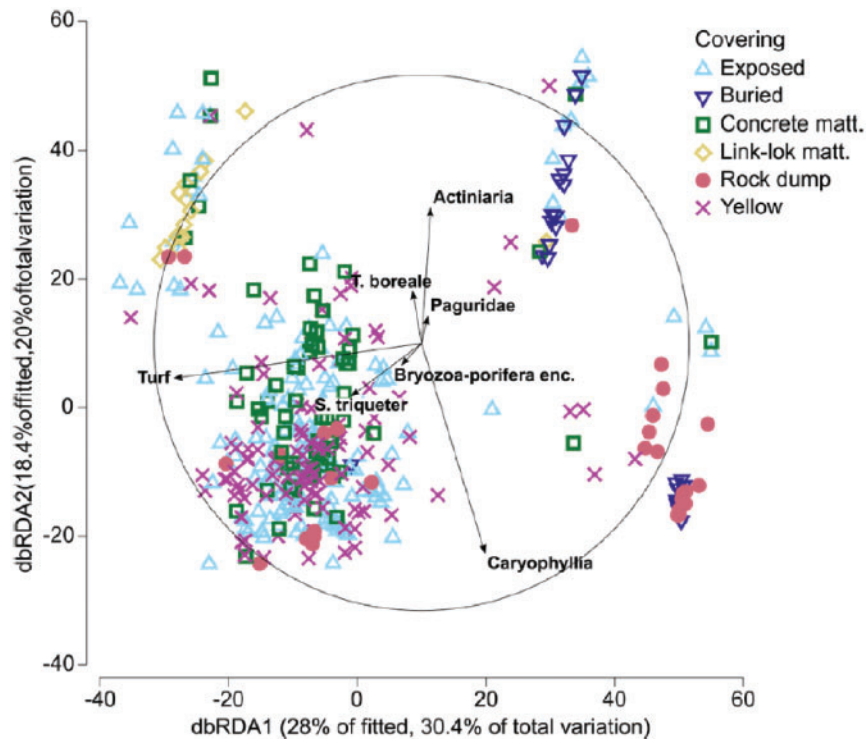


Figure 5. dbRDA plot of the variance in the pipeline community dataset. Symbols represent each sample and are denoted by the covering type. Overlaid vectors are of the taxa with the greatest correlations with the dataset structure (Pearson, $r \geq 0.2$).

Table 4. Results of the DistLM analysis of pipeline community composition.

Parameter	Prop.	Prop. (cumul.)	$R^2_{(adj)}$ (cumul.)
Marginal tests			
Laid date***	0.04		
Eastings**	0.01		
Depth***	0.05		
Northings***	0.05		
ROV altitude***	0.05		
Sequential tests			
Northings***	0.05	0.05	0.05
+ Depth***	0.06	0.11	0.11
+ Laid date***	0.04	0.15	0.15
+ Eastings***	0.03	0.19	0.18
+ ROV altitude***	0.03	0.21	0.20

Prop., proportion of variance accounted for; Prop. (cumul.), cumulative proportion of explained variance; $R^2_{(adj)}$ (cumul.), cumulative $R^2_{(adj)}$.
 *** $p \leq 0.0001$. ** $p \leq 0.001$.

20% of the variance. Altitude of the ROV accounted for a marginal proportion of the variance (0.5%, $p > 0.05$) in the full model.

Discussion

Despite the known role of subsea installations as *de-facto* artificial reefs (Schroeder and Love, 2004; Macreadie *et al.*, 2011), to the authors' knowledge this study represents the first targeted investigation of epifaunal communities associated with pipelines. Epifauna typically observed on hard substrates (epilithic fauna) were observed on the pipelines. Surface laid pipelines and all

associated coverings showed higher abundances of taxa than buried pipelines, with greater numbers of species. Northings, eastings, depth, date of installation, and altitude of the ROV all accounted for significant but low levels of variance in the pipeline community structure. Similar results were found for the sediment community data, though ROV altitude showed no significant effect. There was a weak relationship between pipeline covering type and the community structure.

Pipeline covering type

The epifaunal communities were dominated by varying abundances of hydroid/bryozoa turf, filter-feeding sessile organisms; *Alcyonium digitatum*, *C. smithii*, and *S. triqueter*, generalist mobile feeders; Ophiocomina and mobile predators; Actiniaria and *M. rugosa*. The identifiable anemones were primarily *Metridium dianthus* and *Bolocera tuediae* with smaller individuals expected to be primarily *Sagartia* spp. There was higher species richness on the surface laid pipelines, including all protective coverings, compared to the buried stations. This indicates the role of pipelines as *de-facto* artificial reefs, providing attachment potential for sessile organisms that would otherwise be absent in soft sediments environments and attracting benthic predators (Forteath *et al.*, 1982; Gass and Roberts, 2006), which would be lost with the removal of the pipeline during decommissioning.

Link-lok and concrete mattresses showed higher relative abundances of sessile *C. smithii* and *T. boreale* and mobile Ophiocomina and *M. rugosa*, likely due to the habitat complexity provided. Habitat complexity has been shown to drive increased abundance and species richness of epilithic species at multiple spatial scales by providing refugia and altering hydrodynamics (Sebens, 1991; Hunter and Sayer, 2009). Mobile invertebrates

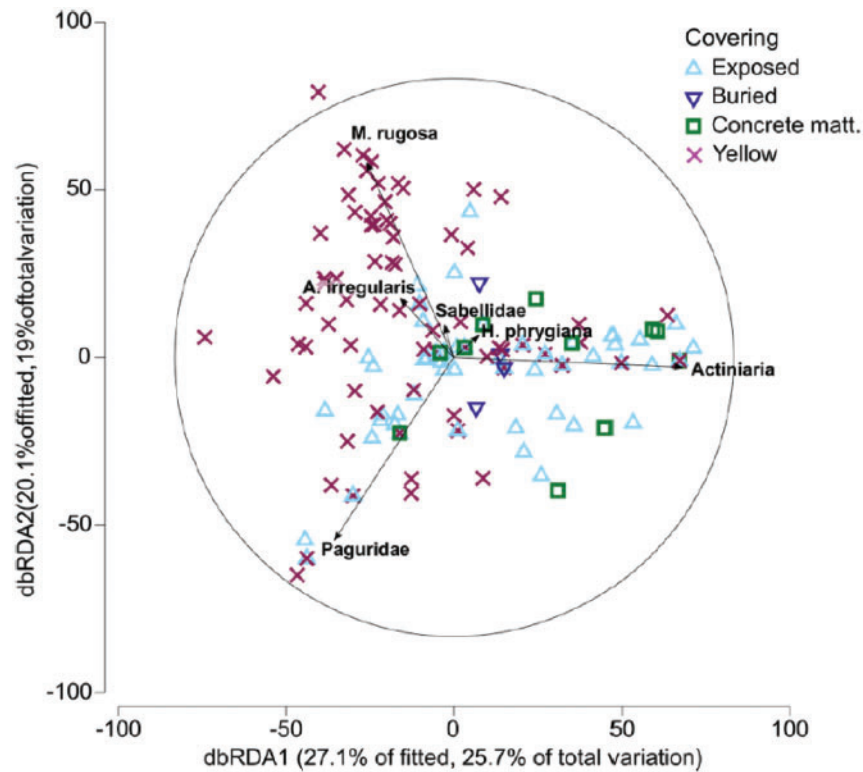


Figure 6. dbRDA of the sediment community composition data. Symbols denote individual samples. Correlating taxa $r > 0.1$. The length of taxa vectors (arrows) represents correlation strength with the dataset.

Table 5. Results of the DistLM analysis of the sediment community composition data.

Parameter	Prop.	Prop. (cumul.)	$R^2_{(adj)}$ (cumul.)
Marginal tests			
Laid date**	0.05		
Eastings	0.01		
Northings**	0.06		
Depth**	0.07		
Altitude*	0.01		
Sequential tests			
Depth**	0.07	0.07	0.07
+ Northings**	0.07	0.15	0.14
+ Eastings**	0.05	0.19	0.18
+ Laid date*	0.01	0.20	0.19
+ ROV altitude	0.005	0.21	0.19

Prop., proportion of variance accounted for; Prop. (cumul.), cumulative proportion of explained variance; $R^2_{(adj)}$ (cumul.), cumulative $R^2_{(adj)}$. * $p \leq 0.05$; ** $p \leq 0.001$.

have been shown to preferentially colonize smooth substrates whereas mobile fauna prefer small crevices in artificial reefs (Lavender *et al.*, 2017). The smooth surfaces of the bare concrete pipe and 3LPP accounts for the similarity of these samples, characterized by high proportions of sessile/low mobility *C. smithii*, Actiniaria, turf, and *S. triqueter*.

The compositional materials of substrates can influence the initial attachment potential for biofilms (Rummel *et al.*, 2017 and references therein), influencing the successional development of epilithic communities. Surface texture also affects colonization by sessile fauna, with rough, soft, and porous surfaces typically

promoting settlement over hard, smooth surfaces (Hixon and Brostoff, 1985). The separation of Link-lok and concrete mattress samples was largely due to the increased proportions of *C. smithii* on the concrete, potentially reflecting a preference for concrete over the plastic component of the Link-lok structures. Structural materials may also leach chemicals, influencing settlement potential (Pawlik, 1992). Interestingly, many rock dump stations grouped with both the concrete mattresses and exposed pipeline samples, despite the highly complex nature of the habitat.

The ROV footage of the rock dump stations was typically of a higher speed, resulting in blurred imagery. As there is little risk to the structural integrity of a pipeline under rock dump, detailed inspection at low speed is unnecessary. The complex habitat of rock dump would be expected to promote high levels of biodiversity; however, the very nature of this complex habitat also prevents observation of organisms. The date of placement of the rock dump is also unknown, which if recent would be unlikely to be highly colonized. The relatively low levels of species diversity observed on the rock dump are also expected to be an artefact of the ROV footage quality, rather than a true representation of the diversity and abundance of the epifaunal community.

Sediment communities

The most frequently observed organisms on the sediment were those commonly associated with soft, muddy, and gravely sediments of the northern North Sea (Avant, 2008; Neumann *et al.*, 2008; Reiss *et al.*, 2011). Only marginal differences in sediment community composition were observed between different covering types, suggesting a limited influence on hydrographic regime, nutrient supply, and predator attraction (Coates *et al.*, 2014). The

water current direction was not assessed, however the observation of dead, coarse material including shells and fragments of *Lophelia pertusa* suggests a reduction in local current speeds in the wake of the pipeline, which could influence infaunal communities (Glaholt, 2008). Changes to the hydrodynamic conditions directly around artificial structures alter sediment characteristics, including grain size distribution and organic matter, in turn impacting the associated soft sediment communities (Wolfson *et al.*, 1979; Davis *et al.*, 1982; Coates *et al.*, 2014).

The view of the seafloor was very limited, restricted to ~1 m either side of the pipeline, limiting our ability to investigate the effect of the structures on the local ecology. Moreover, visualization of the seabed was often entirely prevented by the presence of mattresses and rock dump.

Age, depth, and geography

Laid date, depth, and northings were consistently shown to account for high proportions of variance in the community data. The rock dump communities split between northern and southern stations, largely due to a lack of turf growth in the southerly samples. However, this also corresponded to differences in age and depth. As with naturally occurring hard substrate, artificial reef communities undergo successional development. Initial colonization by pioneer hydroid species may be expected to occur relatively quickly, however the development of a complex turf community, particularly at a scale observable by ROV, may take 10–15 years (Aseltine-Neilson *et al.*, 1999; Boaventura *et al.*, 2006). The pipelines were all ≥ 10 years old at the time of inspection, but mattresses and rock dump can be installed throughout the lifetime of a pipeline as and when remedial action is required. No data on the time-line of these events was available, but the potential variation of these events, and similar age of the structures, may contribute to the low proportions of explained variance across the data set.

The depth and geographical distributions fall within the known ranges for these species. Depth acts as a proxy for pressure, temperature, nutrient availability and light, and exerts a strong influence on the distribution of benthic fauna. The deepest samples were towards the northern extent of the study region, resulting in a strong correlation between latitude and depth. The results suggest a gradual shift in composition with depth and latitude, as has been reported for natural habitat communities (Heip and Craeymeersch, 1995; Rex *et al.*, 2000). This study does however provide new information on the distribution of seldom observed species.

Antedonidae, tentatively identified as *Leptometra celtica* (Northern sea star), were only observed at greater latitudes and depths. On the east coast of the UK, the known distribution of *L. celtica* is typically restricted to the coasts of the Shetland Islands and is largely absent from more southerly areas (Scottish Natural Heritage, 2015). *Tessardoma boreale* (bryozoa) were also recorded in higher numbers in the NNS, >140 m depth. Little information exists on the distribution of *T. boreale*, however within UK waters, most records come from Shetland (Rouse, 2011). Species in the CNS areas, not recorded in the NNS samples, included *P. phosphorea* (Phosphorescent sea pen) and *Echinus esculentus* (common urchin).

Protected and non-native species

The presence of habitats and features of conservation interest are a key component of the decision-making process during decommissioning (BEIS, 2018) and many pipelines fall within conservation areas (Scottish Government, 2018). Operators must demonstrate how decommissioning activities will may significantly impact the designated conservation features (BEIS, 2018). The East of Gannet and Montrose Fields Nature Conservation Marine Protected Area (MPA) in the CNS was the only protected site to be covered by the sampling in this study (JNCC, 2018). This MPA is designated for the Ocean Quahog, *Arctica islandica* of which no individuals were observed. However, five species of conservation interest were recorded, indicating the potential for interactions within MPAs. *Leptometra celtica* was recorded from the NNS and the sea pens *Virgularia mirabilis* and *P. phosphorea* were observed in the CNS. *Leptometra celtica* is listed as a low or limited mobility species in the Priority Marine Feature (PMF) list (Wilding *et al.*, 2016). Both species are listed within the PMF biotope “Seapens and burrowing megafauna in circalittoral fine mud” and are considered conservation priorities in Scottish waters (Scottish Natural Heritage, 2013; Wilding *et al.*, 2016). The sea anemone *Actinauge richardi* was observed attached to both pipelines and on the nearby sediment and is included on the Scottish Biodiversity List (Scottish Government, 2013). The results suggest that pipelines provide additional habitat for low-mobility species of conservation importance. Pipeline removal would impact these organisms through habitat (and organism) removal and disturbance to surrounding sediments.

No non-native species were observed. Offshore infrastructure has been posited as a possible pathway for the transport of non-native species (IPIECA and OGP, 2010). Platforms have been found to act as “stepping-stones” for *L. pertusa* larvae (Sammarco *et al.*, 2004; Fox *et al.*, 2015) and may facilitate range expansions of local populations of *C. smithii* (Coolen, Lengkeek, *et al.*, 2015). However, many of the non-native species recorded in the UKCS are small invertebrate species (Eno *et al.*, 1997) and, if present, would not be observable using non-targeted ROV video footage.

Conclusions

This study compiled the first dataset on the epifauna community compositions on and adjacent to pipelines in the northern and central North Sea. The species associated with these structures were typical epifaunal species of natural hard substrate and fell within known species ranges. Infrastructure type influenced community compositions with different structural complexities promoting different community compositions. There was no strong evidence of an influence of infrastructure type on the epifauna associated with the immediately neighbouring soft sediments. Depth and latitude were found to be the strongest correlators with the observed community composition. Data on faunal interactions with pipelines will aid our understanding of the ecological consequences of decommissioning decisions and ensure informed continued management of subsea infrastructure.

Supplementary data

Supplementary material is available at the ICESJMS online version of the manuscript.

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