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Characterizing the first wave of fish and invertebrate colonization on a new offshore petroleum platform

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Offshore Oil & Gas (O&G) infrastructure creates artificial reef complexes that support marine communities in oceans. No studies have characterized the first wave of colonization, which can reveal information about habitat attraction and ecological connectivity. Here we used opportunistically-collected industrial Remotely Operated Vehicles (ROVs) to investigate fish and invertebrate colonization on a new North Sea O&G platform and trenching of an associated pipeline. We observed rapid colonization of fish communities, with increases in species richness (S), abundance (N), and diversity (H′) over the first four days (the entire study period). By contrast, there was minimal change in motile invertebrate communities over the survey period. After trenching, invertebrate S, N and H′ decreased significantly, whilst fish S, N and H′ increased. This study is the first to report on the pioneer wave of fish and invertebrate colonization on O&G infrastructure, thereby providing rare insight into formation of new reef communities in the sea. These short and opportunistic data are valuable in terms of showing what can be discovered from analysis of 'pre-installation' ROV footage of O&G structures, of which there are terabytes of data held by O&G companies waiting to be analyzed by environmental scientists.

Keywords: decommissioning, fish, industry infrastructure, invertebrates, offshore production platform, oil and gas, rigs to reefs, ROV inspection

Introduction

Sub-sea anthropogenic infrastructure often provide structurally complex hard substrata in contrast to the relatively featureless and sedimentary sea floor (Larcom *et al.*, 2014). In turn, this can accommodate diverse sessile invertebrate communities comprising anemones, hydroids, bryozoans, sponges, mussels, barnacles, soft, and even hard corals (Guerin, 2009; Bergmark and Jørgensen, 2014; Larcom *et al.*, 2014; Todd *et al.*, 2018). Motile invertebrates are also associated with sub-sea infrastructure, using abundant refuge and food availability (Guerin, 2009; Langhamer and Wilhelmsson, 2009; Krone *et al.*, 2013; Lengkeek *et al.*, 2013). Commercially important fish have also been observed living in association with sub-sea infrastructure (Jørgensen *et al.*, 2002; Løkkeborg *et al.*, 2002; Soldal *et al.*, 2002; Guerin, 2009; Friedlander *et al.*, 2014; Fujii *et al.*, 2014), many of which are juveniles that preferentially select structurally complex habitats (Sayer *et al.*, 2005). Marine mammals have also been reported to aggregate around, rest on, and preferentially forage around structures and pipelines (Todd *et al.*, 2009; Russell *et al.*, 2014; Todd *et al.*, 2016; Orr *et al.*, 2017; Delefosse *et al.*, 2018). Cessation of fishing pressure due to fishing exclusion zones, combined with plentiful food and refuge, has led some to suggest that certain sub-sea infrastructure may act as nursery grounds for fish and invertebrates (e.g. Sayer *et al.*, 2005; Love *et al.*, 2006; McLean *et al.*, 2017; Todd *et al.*, 2018). Fish-stock growth is dependent on juveniles reaching reproductive maturity (Sayer *et al.*, 2005), and

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certain infrastructure may have potential to augment local fish populations (Cripps and Aabel, 2002; Jørgensen *et al.*, 2002; Fujii *et al.*, 2014; Fujii, 2015); however, it is disputed currently as to whether fish stocks are enhanced or merely concentrated by such habitat (Bohnsack, 1989; Fujii *et al.*, 2014), also known as the "production vs. attraction" debate.

In 2015, the Dogger Bank (DB) accommodated 79 offshore installations (OSPAR, 2015), in addition to wellheads, manifolds, and pipelines; however, due to diminishing hydrocarbon reserves and aging infrastructure, the number of structures requiring decommissioning is set to increase within the decade (Jørgensen, 2012). Current North Sea decommissioning legislation, principally the Oslo and Paris Convention (OSPAR) Decision 98/3, dictates that all so-called obsolete O&G infrastructure must be removed completely upon decommissioning. This will incur significant cost and likely cause major environmental disruption; consequently, many among the scientific community argue that there is scope in decommissioning obsolete infrastructure to form artificial reefs (e.g. Cripps and Aabel, 2002; Todd *et al.*, 2009; Jørgensen, 2012; Macreadie *et al.*, 2012; Bergmark and Jørgensen, 2014; Fowler *et al.*, 2014; Todd *et al.*, 2018). This is a paradigm referred to collectively as "rigs to reefs" (RTR).

Despite a recent renaissance in North Sea RTR research (Fowler *et al.*, 2018), there is still a profound need for improved scientific understanding of marine life associated with O&G infrastructure to accurately assess RTR applicability to the North Sea (Jørgensen, 2012; Macreadie *et al.*, 2012; Fowler *et al.*, 2014). The majority of literature to date has investigated marine life on mature O&G infrastructure, i.e. which has been in the oceans for decades, whereas no studies (to our knowledge) have characterized the primary wave of colonization when O&G infrastructure is first installed. Characterizing this first wave of colonization can provide key insight into ecological connectivity and can help with understanding what makes O&G infrastructure so effective as reef habitat. Moreover, information on the first wave of colonization is important for RTR discussions because it can help inform whether different types of decommissioning strategies (e.g. "topping" vs. "toppling") might affect ongoing colonization and recruitment of marine life on O&G structures. The present study endeavours to help address the paucity of information on the first wave of colonization by analysing effects of sub-surface jacket installation and pipeline construction on benthic motile invertebrate and fish communities shortly after construction.

Objectives

This study made scientific use of routine industrially collected remotely operated vehicle (ROV) visual inspection data during trenching (the process of burying pipeline below the seafloor in a trench) of cylindrical concrete pipeline, CCP (henceforth "pipeline") from the newly constructed "A-18" (55°06.406′N 3°50.045′E) satellite platform to the pre-existing "A-12" platform (55°23.654′N 3°48.484′E) located 32.6 km at a bearing of 357° from A-18, with an aim to quantify effects of platform on benthic-motile invertebrate and fish-community similarity, species richness (S), abundance (N), and diversity (H′) to contribute to wider evaluation of the utility of a North Sea RTR scheme. The diversity index is a mathematical measure of species diversity in a community (Magurran, 2004) that provides more information about community composition than simply species richness (i.e. the number of species present), taking the relative abundances of different species into account. Our analyses aimed to test the null hypotheses that there would be no significant variation in benthic-motile invertebrate and fish-community similarity, S, N, or H′, related to installing the A-18 satellite platform or trenching of the A-18 to A-12 pipeline. We acknowledge that our ability to make robust comparisons between the new (A-18) and mature (A-12) platforms is somewhat limited—having multiple new and mature platforms would make for a much more robust design; however, this study is opportunistic in nature, capitalizing on an opportunity to extract rare and brief industry data to improve ecological understanding.

Material and methods

Site description

Surveys were performed in the Dutch sector of the DB, which is a vast expanse of submerged glacial moraine forming an offshore sandbank, situated between the thermally stratified north and isothermal southern North Sea (Pingree and Griffiths, 1978). This transitional location induces frequent frontal circulation systems that promote nutrient upwelling and facilitate year-round plankton production (Pedersen and Hansen, 1993). Such consistent and plentiful primary productivity nourishes the DB's silt-sand substratum, supporting a diverse benthic (seafloor) community (Wieking and Kröncke, 2005), which in turn, supports rich invertebrate (Callaway *et al.*, 2002), fish (Sell and Kröncke, 2013), and marine mammal assemblages (Matthiopoulos *et al.*, 2004).

A new satellite gas production platform (A18) was installed and a CCP laid between the A18 and the existing A12 platform 32.6 km away (Figure 1).

Videographic sampling and timings

ROV general visual inspection (GVI) footage of the A-18 satellite platform and pipeline was provided by Petrogas E&P Netherlands B.V, collected by Allseas Group SA and Bluestream Offshore BV using Ultra-High Definition (UHD)-42 and Seaeye Cougar XT ROVs. Pre-platform placement ROV footage was collected during "as-laid" and "as-trenched" pipeline surveys between 8 September 2015 and 27 September 2015. A18 platform legs were piled, and the platform placed into position over a construction period spanning 4–13 October 2015; consequently, ROV "pre-installation" and "post-installation" debris inspections of the A-18 location occurred between 10 October 2015 and 14 October 2015. These short timelines are typical of industry data collection studies, which are not designed to quantify biotic interactions with offshore infrastructure. As such, these data are considered rare and opportunistic.

Motile invertebrate and fish sampling

To quantify motile invertebrate and fish communities living in association with sub-surface infrastructure, ten separate 5-min sections of footage were extracted, using a random stratified technique, as per Todd *et al.* (2018), from both "as-laid" and "as-trenched" inspections of the pipeline and "pre-installation" and "post-installation" inspections at A-18. Five-minute timed-count surveys were then conducted, in which observed organisms were identified to the lowest possible taxonomic group, as per Hughes *et al.* (2010), Söffker *et al.* (2011), and Todd *et al.* (2018), and enumerated. Sessile organisms had not had time to establish on sub-surface infrastructure, and the newly installed platform was considered to be "clean".

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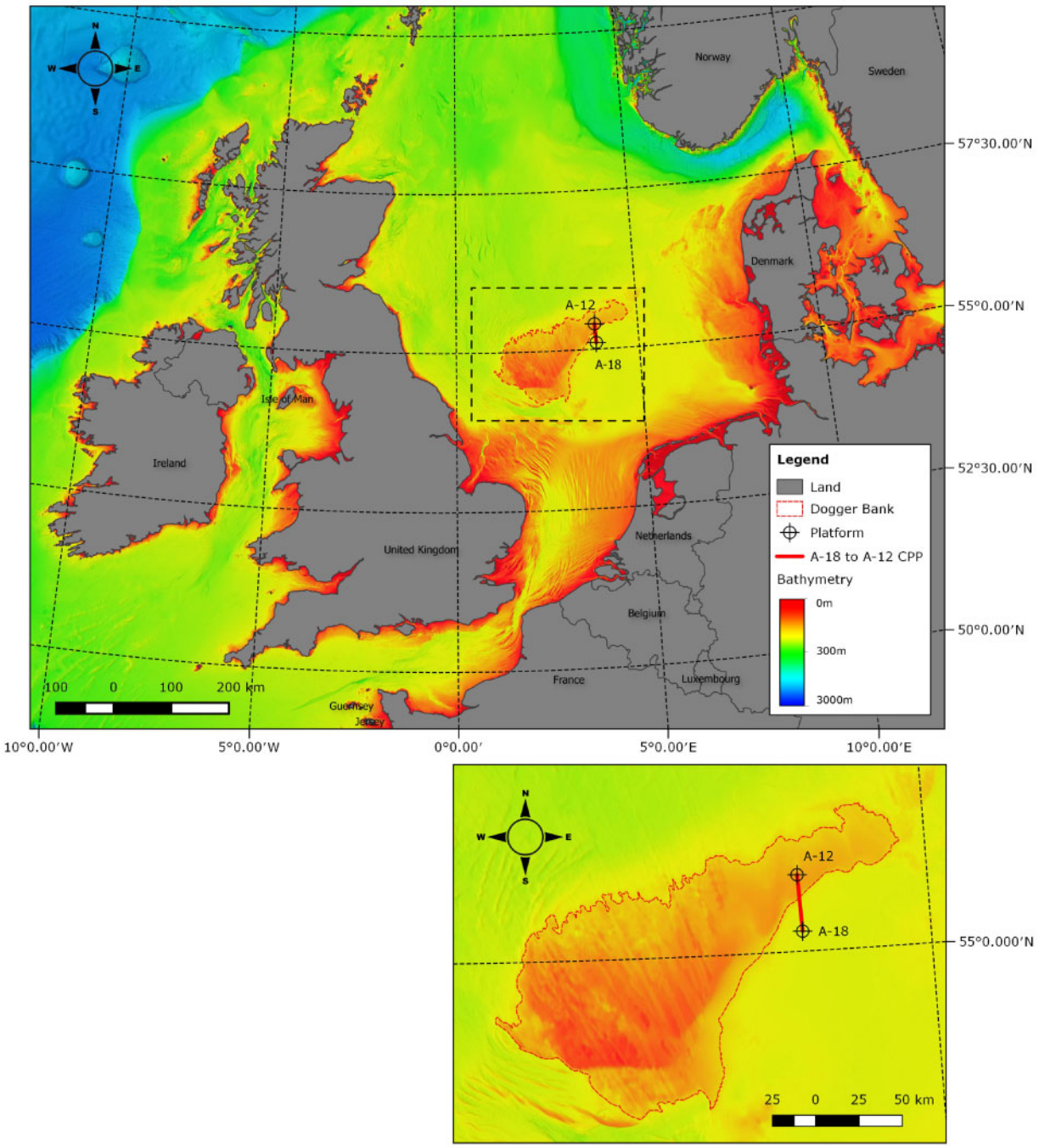

Figure 1. (a) Chart of North East Atlantic, highlighting locations of A-18 and A-12 platforms in relation to bathymetry. (b) Inset shows approximate chart of DB (outline varies with season, and there is thus no accepted delineation), highlighting the red line of the A-18 to A-12 CCP.

Data analysis

Statistical tests were performed using PRIMER-E v.7.0 (PRIMER-E Ltd., Ivybridge, UK) and Minitab v.17.0 (Minitab Ltd., Coventry, UK). In order to deduce motile invertebrate and fish community diversity indices (S, N, and H′), α-diversity analysis, as described by Magurran (2004), was applied to timed-count data using PRIMER-7. To assess significant differences between motile-invertebrate and fish-community similarity and diversity indices, between both "pre-installation" and "post-installation" inspections at A-18, in addition to "as-laid" and "as-trenched" inspections of the pipeline, parametric, and non-parametric tests with appropriate *ad hoc* tests were employed.

Diversity indices which conformed to normal distribution (Kolmogorov–Smirnov tests, $p > 0.05$) and expressed equal variance (Levene's tests, $p > 0.05$) underwent parametric *t*-tests assuming equal variances (Dytham, 2011; Fowler *et al.*, 2013). Indices that conformed to normal distribution (Kolmogorov–Smirnov tests, $p > 0.05$) yet expressed unequal variances

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(Levene's tests, $p < 0.05$) underwent parametric *t*-tests assuming unequal variances. Diversity indices which did not conform to normal distribution (Kolmogorov–Smirnov tests, $p < 0.05$) after appropriate normalization transformations underwent non-parametric Mann–Whitney *U* tests (Dytham, 2011; Fowler *et al.*, 2013).

To represent difference in motile invertebrate and fish-community similarity graphically between both "pre-installation" and "post-installation" inspections at A-18 in addition to "as-laid" and "as-trenched" inspections of the pipeline, four multidimensional scaling (MDS) ordination analysis tests were applied to corresponding Bray–Curtis similarity matrices (PRIMER-E, 2001). To determine if community similarity differed significantly, three analysis of similarity (ANOSIM) tests were applied to corresponding Bray–Curtis similarity matrices (PRIMER-E, 2001). Where community similarity was significantly different, Similarity of Percentages (SIMPER) analysis tests were also performed to elucidate which organisms expressed the greatest contribution to defining respective communities (PRIMER-E, 2001).

Results

The following is a simplified summary of comprehensive statistical analysis of community ecological dynamics. Full results can be found in the Supplementary Material. To serve as a reminder again here, S = species richness (total number of species in the community), N = abundance (or numbers), and H′ = diversity (index).

A-18 satellite platform

Motile invertebrates

Motile invertebrate communities were dominated by the hermit crab (*Pagurus bernhardus*) followed to a lesser degree by starfish (Asteroidea), the gastropod whelk (*Buccinum undatum*), and the blue jellyfish (*Cyanea lamarckii*), all of which decreased in abundance once the A-18 jacket had been installed (Figure 2).

Fish

Installation of the A-18 sub-surface jacket had a much more profound effect on the benthic fish community: S, N, and H′ all expressed statistically significant increases once the jacket had been installed (Student *t*-test, Student *t*-test and Mann–Whitney *U* test, $p < 0.05$, respectively). As such, fish community similarity expressed a significant difference between pre- and post-installation samples (ANOSIM, $p < 0.05$).

Common dab (*Limanda limanda*) and common dragonet (*Callionymus lyra*) dominated both communities (Figure 3); however, whiting (*Merlangius merlangus*) were present only during post-jacket installation. All species expressed greater abundance once the A-18 jacket had been installed.

A-18 to A-12 pipeline

Motile invertebrates

Trenching of the pipeline had a clear effect on the local motile invertebrate population. Invertebrate S, N, and H′ all expressed statistically significant decreases after trenching (Student *t*-test, Mann–Whitney *U* test and Mann–Whitney *U* test, $p < 0.05$, respectively). As such, invertebrate community similarity expressed a significant difference between "as-laid" and "as-trenched" samples (ANOSIM, $p < 0.05$).

P. bernhardus, swimming crab (*Liocarcinus holsatus*), edible crab (*Cancer pagurus*), and *B. undatum* all decreased in abundance after trenching, whereas, Asteroidea increased in abundance (Figure 4).

Fish

Trenching of the pipeline also had a clear effect on the local benthic fish population. Fish community S, N, and H′ all expressed statistically significant increases after trenching (Mann–Whitney *U* tests, $p < 0.05$). As such, fish community similarity expressed a significant difference between "as-laid" and "as-trenched" samples (ANOSIM, $p < 0.05$).

L. limanda, *C. lyra*, and the grey gurnard (*Eutrigla gurnardus*) were all more abundant after trenching, whereas, *M. merlangus* were more abundant when the pipeline was exposed (Figure 5).

Discussion

A-18 satellite platform

Motile invertebrates

There was no significant variation in motile invertebrate community similarity immediately after installation of the A-18 satellite platform; therefore, in this instance, the null hypothesis was accepted. This is likely influenced by the short time period of the study.

Langhamer and Wilhelmsson (2009), Krone *et al.* (2013), and Lengkeek *et al.* (2013) all observed increased abundance of hard substrata dwelling invertebrates as a result of refuge provided by the addition of solid sub-surface infrastructure. The limited change in invertebrate community composition observed here is likely because the jacket had only been *in situ* for 4 days when GVIs were conducted; therefore, sessile invertebrates, which form the base of hard substrata communities (Whomersley and Picken, 2003), would not have had time to establish, reducing habitat value for motile invertebrates. Langhamer and Wilhelmsson (2009) only observed a significant increase in motile invertebrate abundance 3 months after installation of artificial substrata.

Fish

Installation of the A-18 sub-surface jacket had a much clearer immediate effect on local fish communities. S, N, and H′ all expressed significant increases leading to significant variation between pre- and post-communities. These findings are similar to previous studies (e.g. Soldal *et al.*, 2002; Love *et al.*, 2006; Langhamer and Wilhelmsson, 2009; Martínez, 2011; Fujii, 2015), all of which observed increased fish abundance associated with sub-surface infrastructure. For example, Løkkeborg *et al.* (2002) conducted gillnet surveys at two North Sea platforms and documented a clear increase in fish density within 100 m of structures. Moreover, both Picken and McIntyre (1989) and Aabel *et al.* (1997) reviewed interactions between fish and sub-surface infrastructure and observed consistent patterns of association.

Associations between fish and sub-surface infrastructure have been attributed to increased structural complexity (Guerin, 2009), refuge (Lengkeek *et al.*, 2013), food availability (Fabi *et al.*, 2004), and more recently reproduction (Todd *et al.*, 2018). Sayer *et al.* (2005) demonstrated that fish, particularly juvenile gadoids, select preferentially the most complex habitat, concordant with the 88% increase observed in *M. merlangus* after A-18's installation. Abundance of juvenile gadoids supports

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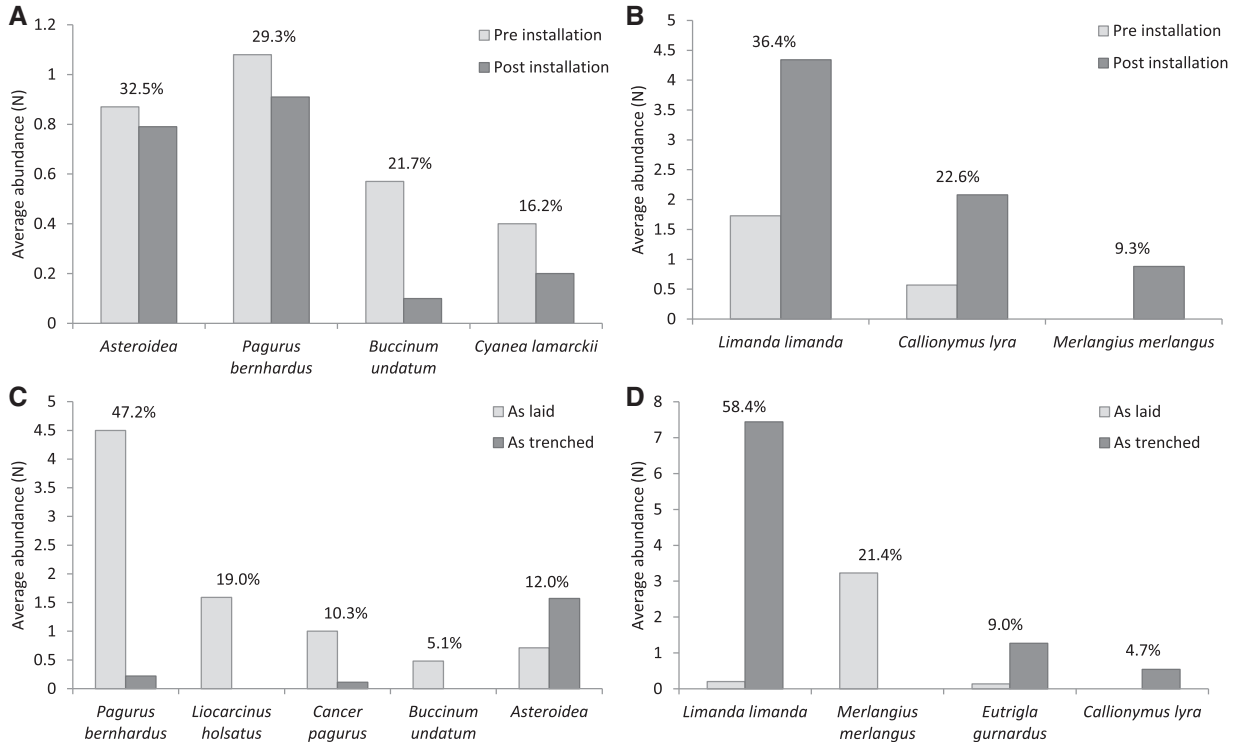

Figure 2. SIMPER analysis highlighting average abundance (N) of most influential motile invertebrate species and percentage contribution to the overall 52.1% dissimilarity between pre- and post-installation communities.

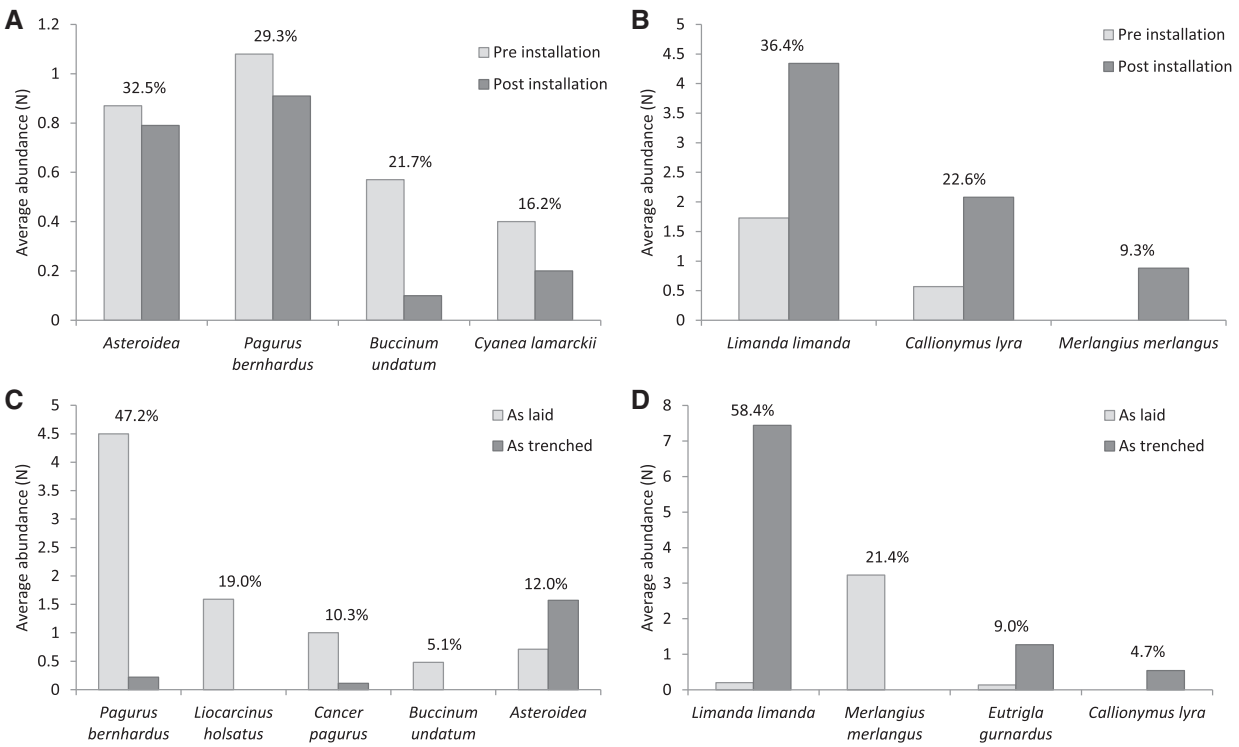

Figure 3. SIMPER analysis highlighting average abundance (N) of most influential fish species and percentage contribution to the overall 57.4% dissimilarity between pre- and post-installation communities.

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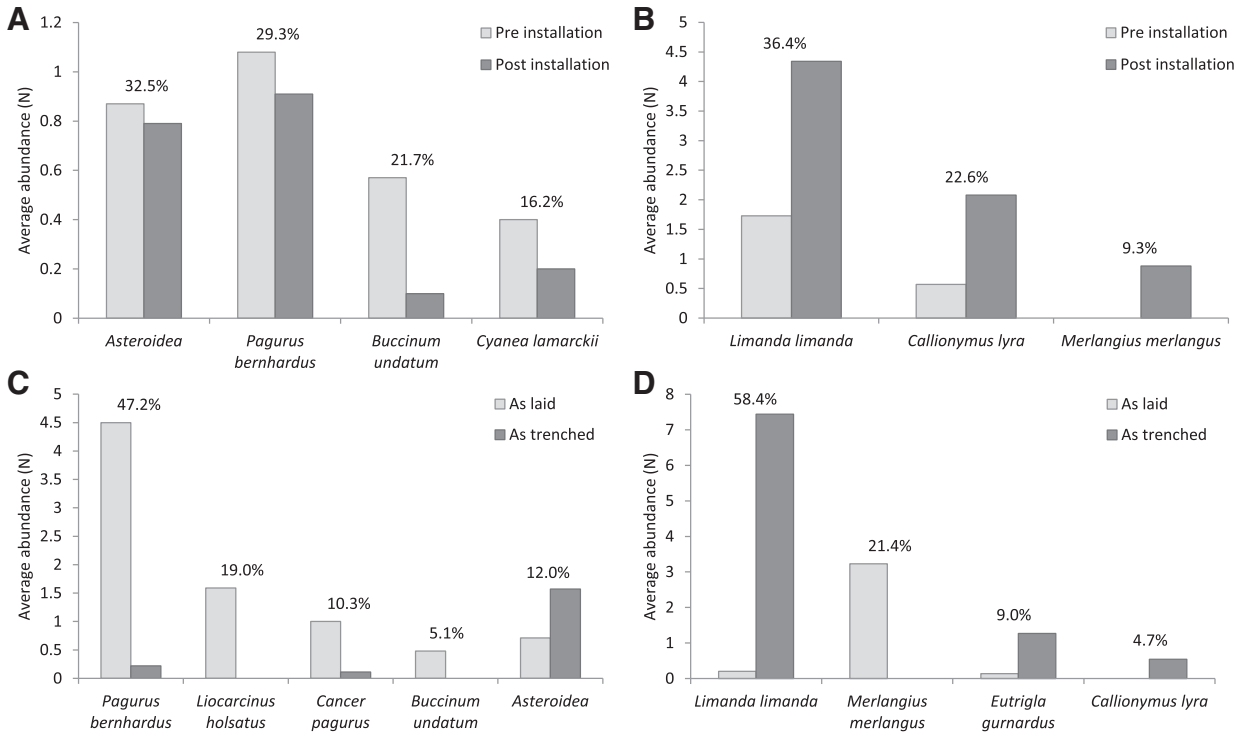

Figure 4. SIMPER analysis highlighting average abundance (N) of most influential invertebrate species and percentage contribution to the overall 94.2% dissimilarity between "as-laid" and "as-trenched" communities.

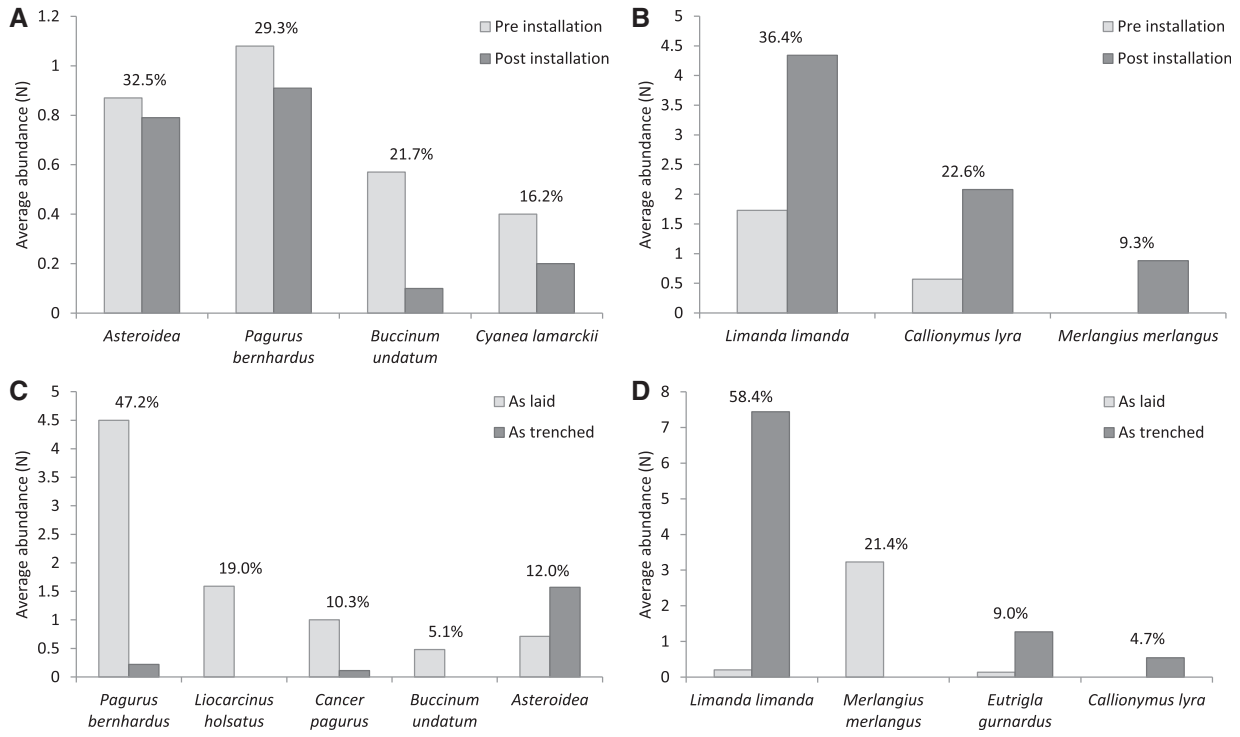

Figure 5. SIMPER analysis highlighting average abundance (N) of most influential fish species and percentage contribution to the overall 82.5% dissimilarity between "as-laid" and "as-trenched" communities.

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suggestions that sub-sea infrastructure may act as nursery areas (Sayer *et al.*, 2005; Love *et al.*, 2006); however, without site fidelity studies, such as those by Ridgway *et al.* (1991), Anthony *et al.* (2012), and Lowe *et al.* (2009), a conclusive outcome remains tenuous. Nevertheless, recent research conducted by Todd *et al.* (2018) on a platform distanced 26 km from A-18, suggests that certain obligate hard-substrata species actually use sub-surface infrastructure directly as vectors for reproduction. It should also be noted that obligate soft-sediment dwelling species are attracted to sub-surface infrastructure (Aabel *et al.*, 1997; Guerin, 2009; Martínez, 2011) consistent with the 39% rise in *L. limanda* and 27% rise in *C. lyra* abundance observed post installation of A-18.

Despite literature highlighting associations between fish and sub-sea infrastructure, Bohnsack (1989) and Fujii *et al.* (2014) discuss the paucity of information surrounding ecological dependency; specifically, if fish populations are attracted or are enhanced by sub-sea structures (the attraction vs. production debate). In this instance, the limited time A-18 had been *in situ*, and consequential lack of sessile life and invertebrate prey, would suggest the jacket was only attracting fish rather than actively supporting the local fish population. Nevertheless, it is highly probable that with time, sessile communities will establish (Whomersley and Picken, 2003; Meyer *et al.*, 2018), attracting motile invertebrates (Langhamer and Wilhelmsson, 2009), which in turn support fish populations (Cowan and Rose, 2016), and possibly even marine mammals (Todd *et al.*, 2009, 2016).

When considered in the context of the RTR paradigm, if these findings, and supporting suggestions by De Groot (1982) and Osmundsen and Tveterås (2003) that sub-sea infrastructure may be acting as a network of *de facto* marine-protected areas (MPAs) and augmenting North Sea fish populations (Sayer *et al.*, 2005; Fujii *et al.*, 2014), the gradual loss of structures due to decommissioning legislation may remove refuge for many already depleted fish stocks; however, it should be noted that the dataset was small and only represented a short temporal scale. Moreover, image quality was poor on account of the ROV camera specification and light configuration, thus, smaller inconspicuous organisms may have been overlooked contributing to inaccurate representation of the community. In order to assess accurately the fish population, a greater volume of high-resolution footage over a longer temporal period is required.

A-18 to A-12 pipeline

Motile invertebrates

Trenching of the A-18 to A-12 pipeline resulted in a significant decrease in motile invertebrate S, N, and H′, contributing to significant community variation between "as-laid" and "as-trenched" samples. The null hypothesis was therefore rejected.

Despite representing a significant proportion of sub-sea infrastructure, pipelines have received little attention within RTR literature, a point stressed by Culwell and McCarthy (1998) and Lacey and Hayes (2019). As such, there are no peer-reviewed scientific studies documenting effects of pipeline trenching on benthic communities. Literature that discusses organisms associated with exposed pipelines (Allen *et al.*, 1976; Lacey and Hayes, 2019) observed significant aggregations of motile invertebrates, comparable to the findings of this study. Both Allen *et al.* (1976) and Love and York (2005) suggested that invertebrates are attracted by abundant refuge and food compared to that of surrounding seabed.

Reduction in decapod (crab) and mollusc (snail) presence is likely attributed to pipeline burial during trenching, resulting in loss of refugia. Furthermore, perturbation of the seabed is likely to have either evoked an avoidance response or buried invertebrates living in close association with the pipeline. Nevertheless, De Groot (1996) concluded that pipelines have minor impact on benthic communities, as disturbance of the seabed is restricted to the time of laying and burial. In practice, lack of scientific information regarding effects of pipeline construction and, in this case, absence of "pre-lay" footage to provide a control community, leave any conclusions tenuous until further research has been conducted.

Whilst trenching reduced most benthic invertebrate presence, the abundance of Asterioids—specifically sand sea stars (*Astropecten irregularis*)—increased. *A. irregularis* are crepuscular, and feed only during twilight hours. Between periods of feeding activity, they remain buried in the substrate (Christensen, 1971). By chance, the majority of "as-trenched" footage was collected during twilight hours, whereas, "as-laid" footage was collected during periods of complete darkness or daylight. As such, it is likely that *A. irregularis* abundance was underrepresented during "as-laid" surveys. This issue was exacerbated by the limited quantity of useable GVI footage. It is also possible that usually buried *A. irregularis* were unearthed by the "digging Donald" during trenching and lay exposed on the seabed along with razor shells (*Ensis* sp.). *A. irregularis* may have also been attracted to the area due to the abundance of bivalve prey unearthed during the post-trenching process.

Considering the paucity of information surrounding exposed pipelines, no definitive conclusions can be made regarding their importance as invertebrate habitat; however, the present study demonstrates that invertebrates are attracted to these structures. As pipelines contribute a significant proportion of sub-surface infrastructure, they may play a significant role in structuring benthic communities (Lacey and Hayes, 2019). Nevertheless, additional analysis over longer temporal scales using focused high-quality footage is required to determine accurately the significance of such habitat.

Fish

Trenching of the A-18 to A-12 pipeline had a significant effect on fish communities. S, N, and H′ all expressed significant increases post trenching resulting in significant variation between "as-laid" and "as-trenched" samples. The null hypothesis was therefore rejected.

As with invertebrates, there are no peer-reviewed scientific studies documenting effects of pipeline trenching on fish communities. Likewise, literature discussing fish associated with exposed pipelines is also limited; nevertheless, significant aggregations of fish, around exposed pipelines have been reported (Allen *et al.*, 1976; McLean *et al.*, 2017). Greatest concentrations were observed in areas of high complexity. Allen *et al.* (1976) found this was primarily around nodes, terminals, and protective rocks, whereas Love and York (2005) noted highest concentrations in undercut areas, in some cases supporting seven times greater abundance than surrounding seabed. High proportions of fish associated with pipelines have been reported to be juveniles and larvae,

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supporting the theory that pipelines may act as nursery areas (Love and York, 2005; McLean *et al.*, 2017).

Post trenching, despite loss of habitat provided by the pipeline, there was a notable increase in benthic fish, predominantly *L. limanda*, *C. lyra*, and *E. gurnardus*, all of which are obligate bottom feeders that prey on small interstitial and epibenthic invertebrates (e.g. De Gee and Kikkert, 1993; Hinz *et al.*, 2005; Griffin *et al.*, 2012). Trenching is likely to have unearthed significant concentrations of interstitial invertebrate prey, increasing local food availability temporarily, and possibly contributing to increased abundance of benthic fish. Nevertheless, this phenomenon would have been ephemeral and would not sustain high concentrations of benthic fish for prolonged durations. Conversely, *M. merlangus* abundance decreased post trenching. *M. merlangus* is a member of the gadoid (cod) family and thus expresses strong affiliation with complex habitat (Sayer *et al.*, 2005). Burial of the pipeline resulted in potential loss of refugia and reduced habitat, potentially explaining reduced abundance of this species.

As with motile invertebrates, lack of information surrounding exposed pipelines and their interactions with fish make any conclusions regarding their importance as habitat premature; however, this study demonstrates that fish, particularly gadoids, are attracted to these structures. Given that pipelines contribute a significant proportion of offshore anthropogenic, sub-surface infrastructure, they may also play a significant role in structuring fish communities. This particular pipeline is now predominantly buried, and offers little habitat value, with the exception of exposed lay-down and start-up heads.

Future research should build upon the findings of Love *et al.* (2006) by investigating significance of structures as feeding and spawning grounds for mature invertebrates and fish in addition to acting as nursery areas for juveniles. Considering the volume of sub-sea infrastructure currently due for decommissioning (OSPAR, 2015), combined with strong and consistent association with marine organisms (Picken and McIntyre, 1989; Aabel *et al.*, 1997), there is an urgent need to elucidate roles these structures play within marine ecosystems.

Future recommendations

There are several disadvantages of using industry-obtained ROV footage for studying ecological interactions of O&G structures, as opposed to scientifically-collected ROV footage. In this section, we consider these disadvantages and frame them in terms of recommendations for future improvements to the way industry ROV footage could be collected to improve its scientific value. We recognize, however, that our recommendations add an effort burden to industry, so for suggestions to be implemented realistically by industry, there would need to be industry-academic partnerships (e.g. SEA SERPENT, Macreadie *et al.* 2018).

Future studies should always include "pre-installation" footage and survey over longer temporal scales; this study only covered a 4-day period, due to limited availability of industry-collected ROV footage. It is also important to understand the benthic-community growth on both the structure (at different depth levels) as well as under and around the platform (including cuttings piles), which can constitute reefs within themselves. Again, because we were using industry footage that was collected for operational purposes—as opposed to ecological monitoring—we were limited in the data coverage of the structure.

ROV surveys often use other technologies (pipe tracker, multibeam, blueview, obstacle avoidance sonar, etc.) over visual footage, resulting in image quality being of lower priority. As such, lighting configuration and camera specification are often sub-optimal. The key information to pass on to ROV pilots for this study is the importance of footage quality (camera specifications, lighting configuration, image stability, etc.) that is likely to yield greatest improvements in accuracy (Macreadie *et al.*, 2018).

In order to quantify fish throughout the water column, ROV pilots should also collect as much close visual inspection (CVI) and GVI footage as practicably possible. Many surveys concentrate simply on certain elements; however, CVI and GVI often cover the entirety of the sub-surface structure providing a good overview of the water column from the surface to the sea bed. It would also be beneficial to have data from different times of day and year for suitable comparisons to be made.

In short, to improve the quality of data for the continuation of this study, ROV pilots should collect more high-definition (HD) footage, to enable the user to identify to species level, and also to differentiate between recreational and commercial fish species. This footage should be at timed intervals at various depths, to account for species differences due to depth and time of day. Footage should be collected so that a full range of vision (close up and at a distance) is achieved, to assess species composition.

Conclusions

- Installation of the A-18 jacket had a strong and immediate aggregating effect on fish, but effects on invertebrates were inconclusive;
- Trenching of the A-18 to A-12 pipeline reduced abundance of motile invertebrates associated with the area, whilst temporally increasing local fish abundance;
- Post trenching, it is unlikely the pipeline will offer any meaningful habitat because it will predominantly be buried;
- Whilst the A-18 jacket was observed attracting only fish, drawing inference from literature, in time the structure is likely to accrue sessile life and in turn begin to support a diverse marine community; and,
- Collection of further high-quality video footage during CVI and GVI surveys would enhance the capacity of using industry-collected ROV data to answer scientifically-relevant questions.

Supplementary data

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

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