The Influence of Man-made Structures in the North Sea (INSITE)

Synthesis and Assessment of Phase 1

Prepared by the Independent Scientific Advisory Board (ISAB)

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1 Introduction

1.1 Background for INSITE

History
The first phase of the INSITE (Influence of man-made Structures In The Ecosystem) Programme evolved from the Oil & Gas UK's Decommissioning Baseline Joint Industry Project JIP (2011-2012) aiming to gather knowledge and experience on decommissioning of offshore structures. The JIP concluded that there was a serious lack of data to describe the influence of man-made structures (MMS) on the North Sea (NS) ecosystem.

In 2013 Oil & Gas UK facilitated the creation of an environmental JIP to improve scientific knowledge on the influence of MMS across all aspects of the NS ecosystem. The overall question was: Has the physical presence of MMS had any discernable ecological effect over the past 40-50 years? The research aim of INSITE was to determine the cumulative effect of MMS and compare this with effects of natural variability and other stressors of the NS region, e.g., river and atmospheric pollution, and climate change.

The industry agreement to fund Phase 1 of INSITE (The Foundation Phase) was signed in April 2014. This Phase is being funded by a group of eight international energy companies: BP, Centrica, CNR International, ExxonMobil, Marathon Oil, Shell, Talisman–Sinopec, and Total. The first research contracts were awarded in December 2015. Phase 1 of INSITE terminated in December 2017.

Definition of man-made structures
In the context of INSITE MMS comprise fixed steel and concrete oil and gas installations, pipelines and renewable energy structures (e.g. windfarms). Shipwrecks could be included as an analogue of a structure of known age. Shipping and fishing activity could be included only in so far as it had a direct impact on the influence of MMS on the NS ecosystem.

1.2 INSITE Objectives

The overall objective of INSITE is to provide stakeholders with "*the independent scientific evidence-base needed to better understand the influence of man-made structures on the ecosystem of the North Sea.*" Furthermore, the Programme has two specific objectives:

- **Objective 1 (Effects): "***Investigate the magnitude of the effects of man-made structures compared to the spatial and temporal variability of the North Sea ecosystem, considered on different time and space scales*".
- **Objective 2 (Connectivity): "***Investigate to what extent, if any, do the man-made structures in the North Sea represent a large inter-connected hard substrate system*".

1.3 INSITE Governance

The main governance bodies of the Programme are The Executive Committee, The Independent Scientific Advisory Board (ISAB), and The Independent Audit Group (IAG) (Figure 1).

Figure 1. INSITE Phase 1 Governance Model

INSITE Sponsors/The Executive Committee

A representative from each of the organisations sponsoring the Programme constitutes the Executive Committee of INSITE. It has the following specific responsibilities:

- Reviews and agrees the Request for Proposals (RfP) and Funding Award process with the ISAB
- Reviews and agrees the INSITE Scope Framework with the ISAB.
- Determines overall project philosophies.
- Approves key appointments.
- Sanctions each phase of project and funding request to sponsors.
- Communicates available research funds to the ISAB.
- Approves funding recommendations made by the ISAB, based on agreed procedure and available funds for research.

INSITE ISAB (The Independent Scientific Advisory Board)

The ISAB is appointed by the Executive Committee. ISAB is the independent body responsible for recommending and overseeing the scientific programme, which will deliver the INSITE Programme's objectives. It has specific responsibilities as follows:

- Develops and agrees the request for proposals (RfP) and Contracts Awards process with the Executive Committee.
- Develops and agrees the INSITE Scope Framework with the Executive Committee.
- Reviews research proposals and makes recommendations for funding based on agreed RfP procedure and available budget provided by the Executive Committee.

- Sets and maintains scientific standards.
- Ensures proposals and outcomes are subject to peer review as necessary.

DNV-GL. The Independent Audit Group

DNV-GL was appointed by the Executive Committee, in agreement with the ISAB at the start of the project, to audit the process for requesting proposals, reviewing proposals and recommending funding. It carries the following specific responsibilities:

- Has no other interests in the INSITE Programme and is thus independent of the ISAB, sponsor group and academia
- Primary role is to review execution of the RfP and Funding Award Process and identify non conformance with this process
- Key reference is the RfP and Funding Award Process
- Performs an audit of the process for all contract awards and reports to Executive Committee and the ISAB

2 Phase 1, the Foundation Phase (2014-2017)

2.1 Aims

This initial phase funded studies to

- identify, collect, synthesize, and analyze available data on the NS ecosystem structure and function and (to a lesser extent) generate new data,
- develop, implement, and test appropriate numerical models, and perform model runs with available data to achieve INSITE objectives.

2.2 Awarded projects

A Request for pre-proposals was agreed between the Executive Committee and the ISAB and was published internationally in July 2014. A total of 35 pre-proposals were submitted to INSITE for reviewal by the ISAB. A shortlist of 17 responders were invited to submit full proposals by November 2014. These submissions were also evaluated by the ISAB and recommendations for funding of seven projects were submitted to the Executive Committee. The projects addressed one or both of the special objectives (Figure 2). In addition ISAB recommended that two special projects were commissioned to supplement the programme. Public announcement of project awards was made in February 2015.

The following seven projects were awarded.

- Appraisal of network connectivity between North Sea subsea oil and gas platforms. (**ANChor**, *University of Edinburgh*).
- Coupled Spatial Modelling - trophic effects due to structures and habitat change in the North Sea. (**COSM**, *CEFAS*).
- Assessing the ecological connectivity between man-made structures in the North Sea (**EcoConnect**, *CEFAS*).
- Man-made structures and Apex Predators: Spatial interactions and overlap. (**MAPS**, *Sea Mammal Research Unit (SMRU), University of St Andrews*).
- Reef effects of structures in the North Sea: Islands or connections? (**RECON**, *IMARES, Wageningen University & Research*).
- Measuring the shadow effect of artificial structures in the North Sea on the surrounding soft bottom community. (**SHADOW**, *Royal Netherlands Institute for Sea Research, NIOZ*).
- Understanding the influence of man-made structures on the ecosystem functions of the North Sea. (**UNDINE**, *Helmholtz Centre for Polar and Marine Research, Alfred Wegener Institute AWI*)

The two additional projects commissioned for the programme were:

- Influence of man-made structures in the ecosystem: Is there a planktonic signal? (**Signal**, *Sir Alistair Hardy Foundation for Ocean Science, SAHFOS*).
- INSITE Data Initiative. (*University of Edinburgh*).

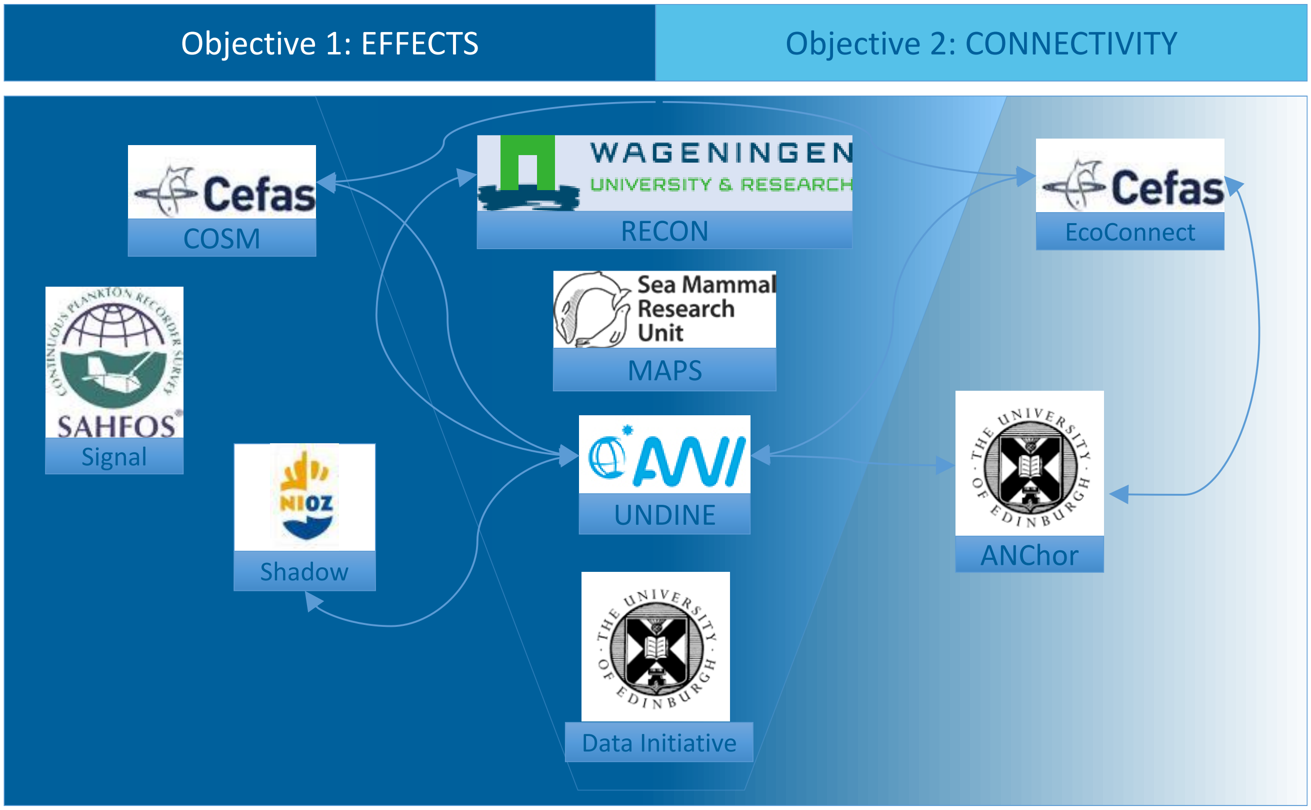

Figure 2 Mapping the Phase 1 projects to the INSITE Objectives. Arrows indicate inter-project connections. The many collaborations with other scientific institutes outside of the INSITE projects are indicated in the project summaries.

3 Project abstracts

This chapter presents short abstracts of the final reports for all projects prepared by the Project PIs. Executive summaries are annexed to the report.

3.1 Projects mapped to Objective 1

COSM (CEFAS Laboratory)

MMS have been present in the NS for many decades and these have been colonised by benthic communities and attract fish, seals and seabirds looking for prey, rest, or refuge from predators. Activities at and around structures may also cause disturbance to the marine environment locally that can result in avoidance by mobile organisms. The presence of structures can lead to a shift in the species composition locally and through predator-prey interactions potentially alter the functioning of the marine food web. The COSM project built a food web model of the NS ecosystem and used this model to test scenarios of change relating to removal of structures. Model simulations indicate that MMS have an effect on the local community composition and these effects can disperse throughout the NS ecosystem through species interactions. The complete removal of oil and gas platforms and pipelines may ultimately contribute to declines in some groups (rays and sandeels), but increases in others (sharks, flatfish and roundfish). However, the model also suggests that the presence of wrecks and wind turbines can have a much greater impact than oil and gas infrastructure on rays, sharks, sandeels, flatfish and demersal roundfish. Importantly all modelled effects of structures appear relatively minor compared to the potential effect of other pressures, such as an increase in temperature on the ecosystem or an increase in fishing effort to historic levels. Although the additional habitat provided by platforms and pipelines may be relatively small, this difference should not be disregarded at this stage for non-commercial species of conservation concern, since natural variability is by its very nature unmanageable and the removal of other structures such as wrecks is unlikely to occur in great amount. This model tool has enabled us to suggest likely impacts on the NS ecosystem, but the model hypotheses now require validation or falsification through direct observation. Once refined following analyses of additional data, the model may be used to address the impact of specific management measures.

SHADOW (Royal Netherlands Institute for Marine Research (NIOZ))

Artificial structures in the NS like oil and gas platforms and windfarms offer a substrate for rich and diverse epifauna communities in an environment dominated by soft sediments. The active and passive suspension feeders attract higher trophic levels, forming reef like systems. We hypothesized that the epifauna acts as a biofilter, which will contribute to the persistence of rare and endangered species throughout the heavily trawled NS and at the same time affect the soft bottom environment around the platform.

Since very little is known about the effect of the filter feeders on local carbon cycling we examined the “shadow” of this biofilter on the immediate surroundings hereby affecting the soft bottom community directly around the platform. Our observations around oil and gas platforms suggest that the platform, providing substrate for epifauna, plays a major role for at least local carbon cycling. This is expressed in organic matter respiration and faunal abundances around the platform. The more distant effect through the potential enhanced release of nutrients, although still feasible, has not been proven with the current set of observations.

We developed a model in which the hydrodynamics, geochemical and mechanistic descriptions of faunal activity are coupled. It is hypothesized that the shadow effect on the sediments will be less pronounced in deeper water, due to general attenuation of particle fluxes with depth. Impact on the water column and nutrient fluxes might, however, have a similar or even larger impact due to the effect of the structure itself on local hydrodynamics. Whereas amount of oil and gas platforms is scattered, model quantifications is needed to extrapolate fluxes to a basin-wide scale. So far, we observed that MMS affect their surroundings, although models show questionable whether this effect will have an imprint on the wider NS. Clearly more research is needed on which processes are important as numerical models suggest a very local impact only (<100m), whereas observations show trends locally (several 100's m) around the structure.

Signal (Sir Alistair Hardy Foundation for Ocean Science (SAHFOS))

In the NS the presence of MMS, such as oil platforms, has greatly expanded. The SIGNAL project, part of the INSITE Programme, examined whether there has been an impact on the abundance, distribution and seasonal timing of the plankton community in the Greater NS. The research has focused on trying to identify whether MMS have had an impact on the plankton community at large scales in space (local to regional) and in time (month to decade). At those scales, it is well documented that the main factors driving the plankton are environmental (e.g. temperature of the sea or wind strength and direction) and this is why the core of the study uses statistical methods to distinguish the effects of those factors, called drivers, from any potential interactions of the plankton with the MMS. Plankton respond to their environment in a very complex way, over different space and time scales. Plankton is the collective name for the myriad of, mostly microscopic, plants (phytoplankton) and animals (zooplankton) that inhabit the sea and drift at the mercy of the currents: planktos is the Greek word for 'drifter'. Plankton lie at the base of the marine food web and as such they initiate and sustain all marine ecosystems - many commercially important organisms such as fish are dependent upon them. In addition, many marine creatures spend at least a part of their life in the plankton (such as crabs, lobsters and starfish). The abundance of these organisms change over time, each producing a long term pattern, or signal. The signal produced is composed of a quantity of entangled sub-signals, in a similar way as a song is composed by many instruments, each having its own rhythm, tone and intensity. To achieve our goal, it was of prime importance to be able to identify the different signals for each planktonic group, to quantify how much they contribute to the main signal, to finally be able to assess whether or not MMS have an impact on the plankton community. The study shows that when a change of plankton dynamic, either a long-term or a seasonal one, is found, it is most of the time correlated by a change in the dynamic of the sea surface temperature and/or the wind patterns. Those results indicate that, if oil and gas platforms have an impact on plankton, this impact is marginal at the selected spatio- temporal scales (local to regional, month to decade). Even in areas "colonised" by a huge amount of structures, the plankton dynamic can most of the time be explain by the environment. Furthermore, when biological patterns cannot be explained by the SST or the wind, we cannot detect any clear link with either the presence or the quantity of MMS at the study scale.

3.2 Projects mapped to Objective 2

ANChor (University of Edinburgh)
Living and non-living resources in the NS have been exploited for millennia, and the region is rapidly undergoing climate change including warming sea surface temperatures and acidifying oceans. NS ecosystem dynamics will be tracking shifts in resource exploitation as well as climate change, but the cumulative ecosystem impacts at the scale of the NS are not well understood. The large-scale distribution of oil and gas infrastructure on the seafloor of the NS offer unique in situ "observatories" from which this scientific understanding can advance, as these structures may now be playing a significant role in the structure and functioning of the NS ecosystem.

In line with the more specific goals of the INSITE programme, the ANChor project set out to understand whether these structures now form a novel inter-connected hard substrate ecosystem in the NS, and what magnitude these structures are having on the wider regional ecosystem and its resilience to climate change and man-made impacts. ANChor also explored new approaches to optimise how one would keep networks of hard substrate ecosystems connected under future decommissioning scenarios.

Simulations showed that oil and gas structures now form an inter-connected system of hard substrate ecosystems. Broadly, ecological networks corresponded to large "super-clusters" in the northern, central and southern NS, with patterns that generally match the predominant flow regimes in the NS. Certain structures seem to act as key sources of larvae to other structures, and some as critical bridges connecting the different super-clusters. Connectivity varied with species' biology: shorter larval durations and spawning in the summer months generally correlated with lower connectivity, and more fragmented networks. Corals on platforms that are protected by international ocean policies were shown to have great potential to disperse to naturally occurring populations in the deep sea, continental shelf, fjords and even a coral marine protected area in Norwegian waters that had been historically degraded by fisheries.

EcoConnect (CEFAS Laboratory)
MMS including rigs, pipelines, cables, renewable energy devices and ship wrecks, offer hard substrate in the largely soft-sediment environment of the NS. These structures become colonised by sedentary organisms and non-migratory reef fish, and form local ecosystems that attract larger predators including seals, birds, and fish. From an environmental perspective, it is possible that MMS form a system of interconnected hard substrate in the NS. Two main mechanisms drive connectivity: (1) the 'planktonic dispersal' of the pelagic stages of organisms between the structures by ocean currents; and (2) 'movement' of mobile organisms. Changes to the arrangement of hard substrate areas through decommissioning of MMS may affect the interconnectivity and could impact on the ecosystem of the NS. However, the scientific evidence needed to understand the role of hard substrate provided by oil and gas infrastructure in the NS ecosystem and to generate evidence-based approaches for decommissioning is lacking.

EcoConnect was funded to assess the ecological connectivity between MMS in the NS. This was delivered through the collation of existing data, modelling the importance of pelagic dispersal, assessing interactions between mobile organisms (fish, sea birds and marine mammals) and MMS, and evaluating the impact of removal of oil and gas infrastructure. Data on MMS and natural habitats were compiled, showing the area of oil and gas infrastructure to be very small in comparison with other hard substrates. Modelling the planktonic dispersal of dead man's fingers, common sea urchin, cold water coral, plumose anemone, sponges, blue mussel, and slipper limpet, showed differences in connectivity between years and species. Structures in the western edge of the central NS were found to be important for connectivity so retention should be considered, whereas many wrecks are found in the Southern NS making this area less sensitive to removal of oil and gas structures. The impact of MMS on fish, sea birds and marine mammals was generally negative during construction and positive during operation. Limited evidence exists about the impacts of decommissioning in the NS, but the pressures are similar to the construction phase and habitat will be removed, so negative impacts on mobile organisms are likely. Network analysis was used to test decommissioning scenarios, and showed strategies that removed more oil and gas infrastructure had a larger impact on connectivity between hard substrate. Generic derogations had little impact on the network, probably due to the small changes in area, indicating that bespoke derogations should be considered to maximise the ecological benefits based on the location and function of specific platforms. The findings are based on models with many assumptions and there were limitations to the data available. Therefore, future effort should focus on acquiring additional new data, particularly about individual structures, pelagic dispersal, and community composition. In addition, further modelling is needed to increase the robustness of the predictions by using several different models, assessing the order in which decommissioning occurs, and accounting for social and economic benefits alongside environmental effects.

3.3 Projects mapped to both Objectives

MAPS (Sea Mammal Research Unit (SMRU), University of St Andrews)

The impact of MMS on apex predators will vary with structure life-stage from construction, operation, decommissioning and ultimately removal. For example, construction can lead to displacement of marine mammals. Once structures are installed they have the potential to attract apex predators, through associated fishing restrictions and artificial reefs. The MAPS project sought to increase our understanding of the effects of MMS on apex predators in the NS and specifically to address INSITE Objective A, with regard to these species. Data were available for the two UK seal species, three cetacean species, and five common seabird species. We built statistical models to quantify the comparative influence of MMS and the dynamic environment on species' distributions. We found an association between structure presence and distribution for three of these species: grey seal and northern fulmars (negative association), and harbour porpoise (positive association). Data suitability issues led to doubts as to the robustness of results for the remaining cetacean and seabird species. The distributions of grey seals and northern fulmar were driven by environmental covariates, with the presence of structure having a very weak association with distribution. The apparent influence of structure on harbour porpoise distribution was comparable to the influence of other environmental covariates. To examine fine-scale behaviour in relation to structures, we used GPS location data from animal-borne tags deployed on seabirds. At a population level, proximity to structures did not lead to increased foraging in any of the seabird species. Overall, our results suggest that structure presence is not a key driver of the distribution of apex predators, or the behaviour of seabirds at a population level. Additional data on fine scale movements of apex predators and on structures (e.g. which sections of pipelines are exposed) are required to determine the impact of different structure types and ages on species' distributions and behaviour.

RECON (IMARES, Wageningen University & Research)

The RECON project investigated patterns in fouling species on oil and gas platforms and wind farms in the North Sea and studied the exchange of blue mussel larvae between such structures.

RECON investigated patterns in species composition using video images taken on Dutch and Danish oil and gas platforms by a remotely operated vehicle. Divers collected fouling species samples from five platforms in the Dutch North Sea. The sampled species communities were compared to those on wind turbine foundations and a natural rocky reef. Results in both studies showed that communities differed between locations and with increasing water depth. Species composition on deeper parts of the platforms and rocks around them was similar to natural rocky reef composition. Species that were unknown to be present in the Netherlands were observed on the platforms.

RECON also studied whether blue mussel larvae use water currents to travel from parental populations on man-made structures to other man-made structures. This was studied using DNA barcoding and particle tracking models. Given that mussels were present on the studied locations, larvae must have been introduced from other locations, e.g. by currents. This was also shown by the particle tracking model, which indicated a flow of larva roughly parallel to the North Sea coasts. The genetic analysis also showed connectivity between locations, but these patterns did not follow those predicted by the model. Furthermore the migration rate between the populations was very low. Possibly the locations studied were too far apart for direct larval exchange.

The amphipod species *Jassa herdmani* was studied genetically in RECON to compare it with blue mussels. While mussels live close to the surface and drift freely in the water as larvae, *Jassa* lives down to the bottom and can complete its life cycle locally. Many offshore populations of *Jassa* were found to be very different genetically, which means that, as expected, there is little exchange between locations for this species.

The studied installations harbour a high biodiversity. Since deep communities on platforms are similar to protected natural reefs, the leaving in place of deep parts of installations should be considered in decommissioning decisions. To enlarge the scientific base for these decisions, additional locations with a wider spread throughout the North Sea should be investigated. The inclusion of installations with concrete foundations is advised since fouling species on concrete may differ from steel communities. Understanding of larval exchange could be improved by studying locations in closer proximity using higher resolution molecular methods. To study locations beyond diving depth, methods to sample fouling species remotely should be developed.

UNDINE (Alfred Wegener Institute)

The increased introduction of MMS in the NS has resulted from the need to generate rapid and clean energy. These MMS such as oil and gas platforms, buoys, wrecks and wind turbines provide additional artificial habitats in predominantly soft-bottom areas. The currently expected effects from MMS in shallow shelf seas will modify benthic communities (defined as organisms living in and within sediments) over various spatial and temporal scales. These modifications will likely have repercussions for ecosystem processes and functions. The research that was carried out in the framework of the UNDINE project concentrated on understanding how large introduced offshore structures have modified the ecology of these areas.

Our results indicate that MMS modify the community structure and secondary production (defined as the transfer of material and/or energy across differ levels). These changes manifest in an overall increase in biodiversity on the structures over time, but not in the soft-bottom areas surrounding these structures. The functional structures within the communities revealed the persistence of biological traits (defined as species' attributes) over time and across all structures tested. Furthermore, our calculations showed that the highest production and the potential biomass export from the upper parts of structures to surrounding soft-bottoms areas had a clear footprint of efficiency (translated by the overall consumption of matter by each trophic level over matter 'lost' to detritus) of the offshore wind farms, when these processes were compared to oil and gas platforms in the southern NS.

Further analyses validated the stepping-stone theory, where the introduction of MMS can increase connectivity (defined as the ability of species to disperse and/ or connect) between populations. Species which are able to travel long distances, such as the blue mussel *Mytilus edulis* (characterised to be a spring spawner with a long larval stage) and the common limpet *Patella vulgata* (winter spawner, short larval stage) reach the MMS at an intermediate distance from coastal populations. The next species generations then can reach the MMS further offshore installed in these areas. The European oyster *Ostrea edulis* has a short-lived larval stage and is restricted to structures much closer to shore, taking more generations to reach further MMS that are installed in a longer distance to the shore.

Overall our approaches contributed towards an initial understanding of key ecological processes and wider repercussions resulting from the introduction of MMS over soft-bottom areas, thus providing scientific knowledge to support licensing and more specifically decommissioning practices.

INSITE Data Initiative (University of Edinburgh)

The oil and gas industry has been a dominant presence in the North Sea for over 50 years, and in that time has amassed a wealth of knowledge about the North Sea environment. As the industry begins to decommission its offshore structures, an important environmental and economic issue with competing priorities from a myriad of stakeholders, this information will be critical. The INSITE research programme aims to fill a key gap in our understanding of the role of man-made structures on the North Sea ecosystem.

Comprehensive environmental datasets will be required to manage decommissioning activities sustainably and to facilitate future blue growth. The INSITE Data Initiative was tasked with the primary objectives: 1) to compile a list of known data sources and metadata relevant to understanding the role of structures in the marine environment; 2) to survey oil and gas operators to identify sources of environmental data that the industry has collected but is not widely available; and 3) to investigate mechanisms for long term data management and storage of industry environmental data and to make it more widely accessible. The team achieved these goals by creating a "Data Roadmap" Access database that details 74 identified data sources; a questionnaire survey of eight major oil and gas operators and two stakeholder workshops. The first targeted workshop was held in Edinburgh and attending by representatives from: oil and gas operators; oil and gas environmental consultancies; the key UK regulatory and management bodies for oil and gas decommissioning; open-access data facilitators; innovation centres; and academic institutes. The second was as part of the 2017 European Maritime Day, and included speakers from the European Marine Board, the World Ocean Council and the Crown Estate.

The Data Roadmap database and results of the industry data survey are available via the University of Edinburgh DataShare portal (https://datashare.is.ed.ac.uk). The outcomes of the stakeholder workshops are reported in a position paper entitled "(Ecological) Data challenges and opportunities from decommissioning in the North Sea to support blue growth", submitted to the academic journal Marine Policy.

4 Synthesis against Objectives.

4.1 Objective 1

The magnitude of the effects of MMS compared to the spatial and temporal variability of the North Sea ecosystem

It is obvious that the physical presence of MMS has changed the substrate composition in the NS. A large number of hard substrates of different complexity (steel, concrete) and age covering the complete water column from the bottom to above the sea surface have been introduced gradually over the last 40-50 years. These in fact represent small offshore islands that support hard bottom communities. The geographical distribution of hard bottom communities has changed from mainly coastal regions bordering the NS to offshore regions as well. Hard bottom communities have a completely different species composition and structure than the surrounding, natural sediment ecosystem, and hence the MMS presence has altered the overall NS biodiversity pattern.

A major step has been made to compile available data on physical features of MMS, their associated fauna and flora, and the biological characteristics of the surrounding benthos. The INSITE projects have compiled historical (from e.g. ROV surveys) and new data (from diver surveys) from about 80 UK (ANChor), Dutch (RECON, SHADOW), and Danish (RECON) oil and gas and windfarm installations. These studies have significantly improved our knowledge of the geographical and depth distribution of offshore hard bottom biodiversity. Detailed descriptions of epigrowth communities have, however, only been obtained from the Dutch and Danish regions in the southern, shallow region of the NS (primarily RECON). Corresponding data from the deeper central and northern NS may be present in the domain of the operators, but has not yet been available or analysed within INSITE. An ongoing challenge is to make existing environmental data from the operators available to the projects.

For the Dutch and Danish sectors having water depths of 70 m or less, the ROV footage analysis revealed three clusters of installations with similar communities: a southern shallow, a northern shallow, and a northern deep region (RECON). According to RECON there is also a vertical zonation of community structure from the sea surface to the bottom. Community structure on wind farms seems to differ from that on oil and gas installations, and age of the MMS seem to have a slight effect on species composition, but not species richness (RECON).

The prime part of INSITE Objective 1 is whether the presence of the MMS with their epigrowth communities also affect the surrounding ecosystem, locally and on a wider scale. There may be several mechanisms in play. The physical presence may change the water circulation around the installation and thereby change local patterns of sedimentation, erosion and transport of matter. Suspended matter depletion due to hard substrate filter feeders may alter the particle characteristics and possibly reduce the organic carbon available for sedimentation in the wake of the MMS. Sinking of dead organisms, faeces and other particular organic/inorganic substances from the installations may on the other hand increase the organic input to the near-zone sediment ecosystem. These alterations may influence sediment structure and function locally. Dispersion of hard bottom propagules (spores, eggs, larvae) into the pelagic may alter the structure and function of the plankton community and the pelagic food web on a wider scale. In addition, man-made islands may attract or repel predators such as fish, mammals and seabirds and thereby alter their overall distribution in and influence on the NS. All of these mechanisms have been addressed in the Phase 1 projects.

INSITE has provided field (SHADOW) and model (UNDINE) evidence that the presence of MMS and their epigrowth affects the surrounding soft bottom community, but only locally, i.e. at most within some few hundreds of meters. The described alterations span from chemical composition of suspended particulate matter, sediment physical and chemical composition, relative abundance of species, sediment production, to organic turnover (sediment respiration). The results also suggest that MMS may affect sediment species composition and biological trait composition locally. The effects are subtle, but mostly regarded as negative. Validation of model results by observations have only to any extent been done in SHADOW, showing modelled influence area to be smaller (<100 m distance) than what was found in the measurements. It is important to note that these results so far are only valid for the southern, shallow region of the NS (the water depth at the SHADOW measurement site is 40 m). There have been no attempt to compare with, or extrapolate to, conditions around deeper installations more common to the greater NS, and there is no basis for assessing the validity of such extrapolation.

The long-term and seasonal dynamics of NS phyto- and zooplankton, including pelagic larvae of benthic fauna, over the last 45 years correlate most of the time with changes in sea surface temperature and wind (SIGNAL). The impact of oil and gas installations is at most marginal on the selected spatial (local to regional) and temporal (month to decade) scales, even in areas densely populated with MMS. No clear link between the presence or quantity of MMS and the plankton dynamics could be detected. As the commercial sampling vessels applied tend to avoid close encounter with the MMS, the database used in SIGNAL may not be suitable to assess local effects on plankton dynamics.

The results from modelling of MMS connectivity (UNDINE, ANChor, EcoConnect) clearly indicate that dispersion of pelagic larva from species living on MMS has the potential to influence species composition both on other MMS, and at distant natural habitats. MMS may feed natural hard bottom biotopes with settling larvae that may sustain/support populations of species already present or introduce new (including possibly unwanted) species. This has been exemplified by the modelled connectivity pattern for the deep water coral *Lophelia pertusa* (ANChor). The connectivity also has the potential to modify community structure e.g. in Marine Protected Areas, or could do so in the future.

There appears to be a positive but weak association between harbour porpoise distribution in the NS and presence of MMS and a weak negative association between MMS and grey seal and fulmar distribution (MAPS). The distribution of these species is probably regulated mainly by environmental factors, but for harbour porpoise the influence of MMS seems at level with other environmental factors. On a population level, proximity to structures was not associated with increased foraging in any of the seabird species. Whether the same holds for seals is at present uncertain. Overall, the results suggest that MMS presence is not a key driver of the distribution of apex predators, or the behaviour of seabirds.

4.2 Objective 2

To what extent, if any, do the man-made structures in the North Sea represent a large inter-connected hard substrate system?

Interconnectivity may be separated into three questions. Do the MMS represent an interconnected hard bottom ecosystem across the whole of the NS? Are there only regional or local clusters of interconnected MMS with no connection in between? Or are interconnections non-existent? Objective 2 is covered by RECON, UNDINE, MAPS, ANChor, and EcoConnect, of which, ANChor, and EcoConnect cover the whole of the NS, MAPS only the British sector (the whole NS for cetaceans and seabirds), and RECON and UNDINE only the southern, shallower NS region. All projects base their connectivity studies on the biological traits of selected model species.

Basically, there are three main mechanisms of species connectivity between the MMS: dispersion by drifting pelagic larvae, spores and other propagules, adults migrating from one MMS to another across less favourable environments, and pipelines forming corridors of hard substrates facilitating dispersal of hard bottom species. Except for MAPS the projects focussed on larval dispersion only, using biological traits of selected "model" species as input to dispersal and connectivity modelling,. In some instances recorded distribution of the species has been used to validate the model results.

In spite of different modelling approaches UNDINE, ANChor, and EcoConnect clearly indicate that several common hard bottom species form interconnected networks of MMS through larval dispersion. Clusters of connected installations are found across the NS and there seems also to be connection between several such clusters. The pattern and degree of interconnection are species specific and seem primarily dependent on spawning season and duration of the pelagic larval stage (ANChor, EcoConnect). The number of species-specific clusters correlated negatively with pelagic stage duration (ANChor), i.e. a long pelagic stage resulted in fewer, but larger clusters of interconnected MMS. The connectivity pattern also seem to vary between years driven by oceanographic conditions, mainly changes in current pattern and intensity (UNDINE, ANChor, EcoConnect). Amongst the selected model species, only the blue mussel *Mytilus edulis* seemed to be highly connected over most of the NS (ANChor). For other species, such as the soft coral *Alcyonium digitatum* and the anemone *Metridium senile*, the the modelling suggested a general disconnection into northern, central and southern NS clusters of MMS.

Both ANChor and EcoConnect recognize two well-connected networks of hard bottom organisms, one in the south region and one in the north central region of the NS. EcoConnect recognizes both networks in their network analysis, but only the southern network in the species specific modelling. UNDINE concluded that MMS in the southern NS, both O&G and offshore wind farms, were interconnected. Species are able to colonise MMS from coastal populations and then colonise other MMS from their new locations. Not surprisingly, the network spatial pattern corresponds with the geographical distribution of MMS, and the general water circulation characteristics.

There is model evidence that MMS may have different functions in a species specific network, categorized as "suppliers/sources", "conductors/bridges", and "receivers" of organisms (ANChor, EcoConnect). EcoConnect found a relatively stable overall spatial distribution of function, but still with distinct variations between species and years. The MMS along the central and northern axis of the NS seem most important as sources, whereas MMS closer to land seem mostly to be receivers. MMS in the western part of the Central Bank seemed most important as connectivity conductors.

In contrast to the other projects RECON concludes that the results on the genetic patterns and modelled particle transport give no support for ongoing connectivity for *M. edulis* among installations in the southern NS with water currents as vector. However, the two methods of analyzing correlation between modelled particle migration and genetic pattern gave opposite conclusions. As both approaches have their insufficiencies, we consider the results as inconclusive. RECON suggests that larval transport by currents probably has contributed to the initial colonization of *M. edulis* on artificial hard substrates in the region, but present-day larval exchange between MMS is low. It is however likely (as also suggested by RECON) that connectivity may be enhanced during stochastic storm events, which are not reflected in the modelling of particle transport.

The only model species with direct development included in the projects, is the amphipod *Jassa herdmani*, investigated by RECON. *J. herdmani* had clearly different genetic structure amongst 17 analysed MMS (all in the southeast region along the coast of the Netherlands and Denmark), indicating hardly any connection between locations. The proposed mechanism is that *J. herdmani* colonizes the hard substrates once and afterwards develops distinct genetic populations. This suggests that the process by which *J. herdmani* is able to migrate to and colonize new MMS occurs seldom. An assumption (not discussed by RECON) may be that this is related to episodic storm events.

The geographical pattern of suppliers, conductors and receivers of pelagic larvae seem not always to harmonize with known species distribution and major current characteristics. For instance, receiver MMS for the coral *L. perthusa* were located on the UK east coast, the southern Bight, and the German Bight (EcoConnect), where the species does not exist. Apparently, modelling predicts that *L. perthusa* larvae may be transported to installations in these regions, but the conditions are not fit for coral growth. Supplier MMS were also identified along the Norwegian coast for all the species included, but the coastal current pattern suggest that receivers from these are not offshore MMS, but biotopes along the coast. Connection among coastal hard bottom biotopes is well known, and of little relevance to Objective 2.

Connectivity modelling is based on known biological traits for the selected species. The values used are crucial for the outcome of this modelling, but are not accurately known. It is realised that at least two of the projects (ANChor and EcoConnect) apply very different reproductive trait input values for the same species even though both have generated the information from the scientific literature (Table *1*). The reason is that trait values are often given as intervals in the literature. It appears that ANChor has used the lower end of the intervals for spawning duration and duration of larval pelagic life (most conservative when modelling connectivity), whereas EcoConnect has used the upper end of these intervals. This might explain some of the differences in model results between these projects. To enable proper comparison of model results between projects covering the same geographical region, the input data on biological traits needs to be the same.

Table 1. Information on spawning time and duration of larval pelagic stage for species common to ANChor and EcoConnect. Red highlights trait values that differ considerably. Similar information for *M. edulis* used by RECON and UNDINE has not been presented.

		Spawning date	Pelagic stage (days)
Alcyonium digitatum	ANChor	Dec-Jan	18
	EcoConnect	1 Jan ± 22d	200*
Lophelia pertusa	ANChor	Jan-Feb	60
	EcoConnect	15 Feb ± 56d	50*
Mytilus edulis	ANChor	Apr-Sept	30
	EcoConnect	1 Aug ± 30d	72*
Metridium senile	ANChor	Aug-Sept	22
	EcoConnect	15 June ± 15d	181*

* Calculated from net size increment throughout the larval stage divided by growth per day.

There is observational evidence (MAPS) that MMS may affect the behaviour of top predators, and that they may act as a large interconnected system for individual seabirds and seals. It is, however, not likely that the MMS have effects at the population level of top predators.

In summary there seems to be two well-connected networks of larval exchange for several hard bottom species in the NS: one in the south region and one in the north, central region. For some species and under certain environmental conditions there seem to be MMS that act as bridges between these two networks. The results also suggest that there may be interconnections between these open ocean networks and coastal hard bottom biotopes, both natural and MMS. This indicates that for some species and conditions there may be a global network of hard bottom substrates across the NS, including the MMS. The connectivity pattern is species specific and varies annually with oceanographic conditions. For some species the MMS in the two main networks appear somewhat disconnected forming several clusters of MMS with less connectivity in between.

5 Is the MMS impact on the NS ecosystem sensitive to decommissioning options?

An important driver for industry engagement in INSITE has been to improve the knowledge base that can inform decommissioning strategy. Three projects have treated the issue of how decommissioning, i.e. how complete or partial removal of installations may influence the NS food web structure (COSM) and how decommissioning options may alter the hard bottom network structure and function supported by the MMS (ANChor, EcoConnect).

COSM has developed and tested model tools to simulate changes in the food web structure that may occur if installations were removed. Model testing of the present distribution of MMS against the scenario of complete removal of all oil and gas installations, identified clear winner and loser species or functional groups of organisms either directly as a result of the removal or from consequential cascading effects on other species and groups, and hence effects on the overall trophic structure.

By use of network analysis EcoConnect) simulated how the present MMS network would change from leaving all MMS *in situ* against four decommissioning scenarios. The results showed that the decommissioning options involving removal resulted in less community connectivity and reduced network resilience. Generally, scenarios that removed more oil and gas structures had a larger impact on the network. Generic derogation had little impact, probably due to the small changes in area relative to the total amount of hard substrate. Structures on the western edge of the NS Central bank (the Dogger Bank) were most important as an anchor point for connectivity. The Norfolk Banks and northwest coast of the Netherlands have many wrecks so were less sensitive to removal of oil and gas structures.

Through development of an optimization procedure balancing cost of MMS removal and ecological benefit of leaving them in, an optimal network of about 40 areas in the southern NS was shown that would keep the MMS network connected, but keep economic costs of removal down (ANChor). The next best network to keep in place included 75 areas, because the method then found the next most highly connected network, which happened to be in the northern NS.

Hence, the results from these model exercises indicate that partial or complete removal of MMS may change the present food web structure in the NS, and the interconnection between epigrowth communities on the MMS. The degree of removal and magnitude of effects seem to correlate positively, which is not too surprising. It should, however, be emphasised that the models have not been thoroughly validated by empirical data. It is also feasible that several natural and man-made factors are not included in the model simulations, which may obscure any ecological effects of MMS removal. ANChor sees a potential for developing their models into more practical tools to inform the decommission decision making process, and to maximise the ecological benefit from decommissioning.

6 Assessment of Phase 1

A major achievement in Phase 1 has been the identification, implementation, and testing of a range of numerical models to assess how MMS may affect NS food web structures and ecosystem functioning, the dispersion and exchange of hard bottom larvae, and the degree of species connectivity between MMS. These models have been developed and run separately or in concert. The impression is that the suite of models used in INSITE are state-of-the-art and fit for purpose. The main insufficiency is that they have not yet been well validated by field data. Although model validation did not have the highest priority in Phase 1, it is imperative for the reliability of the results and should be strongly encouraged in future studies. The main problem is insufficient field data for ground-truthing, partly because such data do not exist and partly due to proprietary issues not yet resolved (The Data Initiative Project, ANChor). Both of these issues are likely to be addressed in INSITE Phase 2.

An important result of Phase 1 has been to build up/compile databases regarding hard bottom community structure on MMS (RECON, ANChor, EcoConnect), sediment community features around and remote from the MMS (UNDINE), and on size, age, nature, location, etc. of MMS. This part of the work has been facilitated by the INSITE Data Initiative Project. These databases and extensions thereof, in particular the addition of data present within oil companies, are crucial for the next phase of INSITE. It is unfortunate that almost no Norwegian data have yet been compiled and applied, since the Norwegian sector covers a major part of the NS. Long term data series on sediment community structure near and remote from oil and gas installations exist and are freely available from DNV. One can also assume that ROV generated and other useful data on epigrowth communities on MMS are in the Norwegian operators' domain, as is the case for other regions of the NS.

INSITE has provided the first scaling in terms of trophic levels and overall area of the ecological influence of MMS on plankton communities (SIGNAL). One may argue that the data available in the SAHFOS database may not be very suitable for assessing near-zone effects on plankton, e.g. a seasonal large supply of pelagic larvae of several epigrowth species. From the connectivity perspective one may, however, question if near zone effects are significant as long as the spatial and temporal distribution of the NS phyto- and zooplankton seems only marginally, if at all, influenced by the presence of MMS.

INSITE has also generated insight into the potential effects of MMS on top predator behavior and distribution (MAPS, EcoConnect, COSM). For seabirds and marine mammals, observations from MAPS show that the presence of MMS has an influence on the behavior of single individuals, but also that effects on the population level are unlikely. It is, however, notoriously difficult to measure whether population effects are present.

A general observation is that fish may aggregate around MMS as artificial reefs, and it has been suggested that these may function as a sort of refuge from fishing, but it is still an open question if the presence of MMS has changed the overall standing stock of NS fish species or only caused a redistribution. INSITE model evidence (COSM) suggests that removal of installations may have a measurable effect on overall fish biomass, and that this may go either way depending on species.

Although in its infancy and although there is still very little empirical evidence, INSITE has demonstrated the potential of using population genetic fingerprinting in studies on community structure and species connectivity patterns (RECON, SHADOW). Pilot analysis of genetic variability in bulk samples from salvaged fish nets (RECON) showed clear differences in overall genetic diversity, but less than 10 % of the gene sequences could be assigned to a species or genus. SHADOW demonstrated a better species genetic resolution in sediment macro- and meiofauna samples. These results were also ground-truthed by traditional species identification. The RECON results on genetic characteristics in *M. edulis* and *J. herdmani* from several MMS indicate that genetic fingerprinting may also be a valuable tool for ground-truthing results from the connectivity network modelling.

The phase 1 studies are geographically somewhat unbalanced. Five of the projects (SIGNAL, ANChor, EcoConnect, COSM, and MAPS for cetaceans and seabirds) appear to have covered the whole of the NS, whereas the others have only dealt with the southern region (RECON, UNDINE, and SHADOW) or the British offshore zone (MAPS for seals). The validity of extrapolation from smaller regions to the greater NS has not been tested. Oceanographic conditions, water depth, epifauna community structure and vertical zonation, bottom sediments, and sources of migrants and pelagic larvae are clearly different in the southern, middle, and northern NS. It is therefore not possible to assess whether the observations and conclusions from the studies confined to the southern NS are valid for the regions further north. In particular this concerns epigrowth community structure and function, and effects of MMS presence on the surrounding benthos.

Phase 1 has improved our knowledge with respect to INSITE Objective 1 (*Investigate the magnitude of the effects of man-made structures compared to the spatial and temporal variability of the North Sea ecosystem, considered on different time and space scales*). There is empirical and model evidence that MMS have an influence on the surrounding benthic community structure and function, but only on a scale in the range of some few hundred meters. Model evidence also suggests that the presence of MMS have generated a fish distribution pattern which would change if the installations are removed, and that removal may have an impact even on overall fish biomass. The Phase 1 results further suggest that the presence of MMS has had little or no effect on plankton distribution in the NS and on behavior and distribution of seabirds and mammals at the population level. For these elements natural factors such as weather and oceanographic conditions are dominant.

Phase 1 has also generated new knowledge pertaining to INSITE Objective 2 (*To what extent, if any, do the man-made structures in the North Sea represent a large inter-connected hard substrate system?*). There is compelling evidence from independent network modelling studies that MMS form interconnected “islands” for hard bottom organisms. For species with a long-lasting pelagic larval stage the connectivity may span most of the NS, for others there are clusters of MMS that are interconnected. The size and spatial distribution of such clusters, and whether installations are suppliers or receivers of propagules vary with species reproductive traits, and may change annually due to oceanographic conditions. Also the possibility that rare or episodic storm events, not included in the models) may enhance larval migration and hence connectivity should not be ignored. There seems however to be certain common patterns in the INSITE results. Two main networks of connectivity were identified, one in the southern NS and one in the central region further north. These may be further divided into MMS clusters depending on species and natural conditions, and for some species, there are bridging MMS in between. These conclusions have, however, still to be validated by empirical data, e.g. on species composition at representative MMS, and by genetic fingerprinting. The practical significance of the levels of connectivity found has also not yet been determined, and this should be a high priority for Phase 2, even though it is challenging.

One important aspect that could not be covered within the constraints of INSITE Phase 1 is to what extent the possible impact of MMS depends on type and age of the structures. With the rapid growth in number of new windfarm installations, the shift from installation of large concrete gravity base to new and smaller steel platforms in the petroleum industry, and decommissioning of installations that also will be different for concrete and steel structures, this differentiation seems important.

7 Final project reports

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