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Inclusion of natural disturbance in fisheries management advice for UK mobile sediment MPAs

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Department for Environment Food and Rural Affairs (Defra)
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Executive Summary

The overall aim of this project was to produce a guidance document, incorporating relevant published literature, to assist the SNCBs in providing fisheries management advice for MPAs with mobile sediment features exposed to demersal fishing.

The project was commissioned by Defra's Marine Biodiversity Impacts Evidence Group (IEG), and funded by Defra. The direction of the work was informed by a project steering group comprising Defra, JNCC and NE. The project scope was limited to demersal fishing where trawls and dredges are in seabed contact, and where fishing gear is used to fish areas of seabed characterised by mobile sediments. The project scope was also limited to SNCB advice for MPAs in English waters only (inshore and offshore), however the final recommendations could be equally applicable to other UK waters.

Following designation, in English waters, responsibility for assessing, managing and monitoring MPAs currently passes to one of three organisations:

- Inshore Fisheries and Conservation Authorities (IFCAs): inshore 0 to 6nm;
- Marine Management Organisation (MMO): inshore 6 to 12nm; and
- Defra: offshore 12 to 200nm (depending on feature location can be 6-200nm).

JNCC and/or NE may then provide advice to the authority based on the MPA designated features, details of what fishing activity takes places within the area, and the potential impact of this activity on the site features.

The processes that JNCC and NE use to issue MPA fisheries management and fisheries impact advice for offshore and inshore MPAs respectively are captured in this report and graphically summarised.

Previous work funded by the Marine Biodiversity Impacts Evidence Group is summarised (Goodchild *et al*., 2015; Johnson *et al*., 2017) and put into context of relevant research publications. In addition, recent related academic studies published since Goodchild *et al*. (2015) and Johnson *et al*. (2017) are summarised in relation to their applicability and application to issuing fisheries management advice.

Using the recent relevant literature and previous Impacts Evidence Group work, guidance is provided to allow consideration of natural change when delivering fisheries management advice for mobile sediment MPA features in English waters. In particular, types of evidence (empirical, expert judgement, and statistical models) are discussed in terms of confidence and cost-effectiveness.

The outcomes of this study are intended to support development of effective, evidence-based management measures for fishing activities within UK MPAs.

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1 Introduction

1.1 Background

There are over 250 marine protected areas (MPAs) designated in English waters including special areas of conservation (SACs[1]) with marine components, special protection areas (SPAs[2]) with marine components, and marine conservation zones (MCZs). Every MPA has conservation objectives associated with it, describing the desired state of designated features in relation to the extent, quality, and supporting processes and associated diversity, community structure, and typical species. The conservation objectives explicitly state whether a feature should be maintained or restored to favourable condition. A designated feature is considered to be in favourable condition when it is being adequately conserved and all the site-specific monitoring targets are being met.

For MPAs in English waters, conservation objectives are set subject to natural change/processes. This means that components of natural change (natural variability and natural shifts), can be incorporated into MPA management and provide context for managing anthropogenic activities, such as demersal fishing.

Demersal fishing with beam trawls, otter trawls and toothed dredges occurs in marine areas that are designated MPAs. Many of the MPAs are designated for mobile sediment features such as subtidal sandbanks. Using the definition from Johnson *et al*. (2017), mobile sediments are: "*non-cohesive fine to coarse sands, gravels and mixed sediments which are subject to disturbance from tides, waves or currents; where we consider disturbance events over shorter time scales and not at a scale where infrequent extreme events may lead to the erosion of cohesive sediments*". This included, but was not limited to, Annex I subtidal sandbanks, mudflats and sandflats, estuaries, and large shallow inlets and bays, and broadscale habitats BSH A5.1 Subtidal coarse sediment, A5.2 Subtidal sand, A5.3 Subtidal mud, and A5.4 Subtidal mixed sediment.

All fisheries regulators are required by Defra to assess the impacts of fisheries on designated features of SACs, SPAs and MCZs and put in place any required management to achieve favourable condition. The statutory nature conservation bodies (SNCBs) advise fishery regulators on whether a fishing activity is acceptable or may cause deterioration of the MPA features. An understanding of fishing activity, natural disturbance and natural variability is essential to advising on appropriate management measures.

In dynamic marine environments, it can be difficult to decouple natural change from anthropogenic change, and so this introduces a challenge to developing appropriate management. There is a body of published literature on the interactions between natural disturbance / natural variability and demersal fishing in mobile sediments. This forms an important part of the evidence base

[1] In this instance, SAC refers to cSAC, SCI and SAC stages in order to differentiate between different designations.
[2] Not including pSPAs

underpinning SNCB advice and management; therefore, it is advantageous to be able to easily refer to and incorporate published literature into the MPA management process.

For the purposes of this project, the SNCBs were the Joint Nature Conservation Committee (JNCC) and Natural England (NE). JNCC is responsible for identifying and providing conservation advice for managing MPAs in UK offshore waters (beyond 12 nautical miles). NE is responsible for identifying and providing conservation advice for the management of MPAs in English inshore waters (0-12 nautical miles). JNCC and NE have adopted different approaches in how they provide advice on fisheries management in MPAs. This is the result of different legislation governing inshore and offshore fisheries as well as different organisational processes. Chapter 2 provides a summary of the different processes used in the development of proposals for management.

1.2 Project Aims and Objectives

This project followed on from project phases I and II commissioned by Defra and the Marine Biodiversity Impacts Evidence Group. The project was commissioned by JNCC and NE and is funded by Defra. The project aim was to produce useable guidance, incorporating relevant published literature, to assist the SNCBs in providing management advice for MPAs with mobile sediment features exposed to demersal fishing.

The direction of the work was informed by a project steering group (PSG) comprising Defra, JNCC and NE.

The project was split into the following objectives from the project specification:

1) Provide an overview of the process used to deliver MPA management advice by JNCC and NE (Chapter 2);
2) Provide a synopsis of the conclusions, limitations and caveats of reports from the Natural Variability Project Phase I (Goodchild *et al*., 2015) and Phase II (Johnson *et al*., 2017), including literature in the respective project reports (Chapter 3);
3) Provide a synopsis of relevant academic literature published since the Phase I and II reports and applicability of these reports in assessing impacts of trawling on sediment features of MPAs (Chapter 4); and
4) Utilising published literature and the Phase I and II reports, provide guidance that will allow consideration of natural change when delivering fisheries management advice for mobile sediment MPA features in English waters (Chapter 5).

The project scope was limited to demersal fishing where trawls and dredges are in seabed contact, and where fishing gear is used to fish areas of seabed characterised by mobile sediments. The project scope was also limited to SNCB advice for MPAs in English waters only (inshore and offshore), however the final recommendations could be equally applicable to other UK waters.

2 The Process of Delivering MPA Fisheries Management Advice

2.1 JNCC and NE

An MPA is designated by the Secretary of State for environment, food and rural affairs. Sites are designated following a public consultation and consideration of the consultation responses by JNCC and NE. NE is responsible for identifying and providing conservation advice on MPAs in English inshore waters (out to 12 nautical miles) and JNCC is responsible for identifying and providing conservation advice on MPAs in UK offshore waters (beyond 12 nm). For sites that cross the 12 nm boundary, advice on management is provided jointly by JNCC and NE.

MPAs in English waters predominately comprise Special Areas of Conservation (SACs) with marine components, Special Protection Areas (SPAs) with marine components, and Marine Conservation Zones (MCZs).

2.2 Fisheries advice

Following designation, responsibility for assessing, managing and monitoring of management measures pass to three organisations:

- Inshore Fisheries and Conservation Authorities: inshore 0 to 6nm;
- Marine Management Organisation: inshore 6 to 12nm; and
- Defra: offshore 12 to 200nm (depending on feature location can be 6-200nm).

Monitoring MPA and feature condition is a responsibility of the relevant SNCB.

JNCC and/or NE may then provide advice to the authority based on the MPA designated features, details of what fishing activity takes places within the area, and the potential impact of this activity on the site features.

For each site, there is a detailed data-gathering exercise on historic and current levels of fishing, evidence on fishing interactions with this habitat type in the scientific literature and stakeholder engagement. Where fishing activities are assessed as posing a risk offshore, management options papers are drafted. A management options paper informs the choice of management approach. From 0-6nm, the Inshore Fisheries and Conservation Authorities undertake an assessment and consult with NE to determine whether management measures are necessary or not. Where fisheries management measures are deemed appropriate, proposals for such measures are drafted in consultation with relevant stakeholders.

Inshore, management measures to reduce the impact of fishing activities are introduced through a byelaw. The byelaw sets out the affected area within the MPA and the fishing activity restrictions. All permanent byelaws are subject to public consultation before they are introduced.

Offshore, fisheries management is implemented through the European Common Fisheries Policy. Where sites straddle the Exclusive Economic Zone of the UK and EU Member States, joint proposals and recommendations are submitted to the European Commission. JNCC advises throughout the management cycle.

2.3 Subject to natural change

Natural variability is currently considered implicitly at several stages of the MPA process:

- Site selection – the prevailing natural conditions in the site are taken into consideration in part during the search for and selection of sites. Sites have been designated by regional sea, which have been determined biogeographically using primarily the factors of temperature, depth and currents. This means that large-scale (national and global scale) natural processes have been factored into site selection. In terms of representativity, for the same feature, sites are chosen that are different from each other in order to protect the range of habitat types. This has led indirectly to selection of features that are exposed to different natural processes within a regional sea (sub-regional or site scale);
- Conservation advice – the conservation objectives of a site are set 'subject to natural change' ensuring that the targets for feature and site condition take into consideration biological processes such as population dynamics and succession and the influence of environmental processes such as temperature, rainfall, and storms (excluding anthropogenic environmental change) on any change in condition. At present, these are loose and are not precisely defined for features or sites. In terms of advice on operations, the risk to designated features is assessed in terms of the exposure to a given pressure that an activity might exert and the corresponding sensitivity of that feature to the pressure. This also indirectly considers natural disturbance, as feature sensitivity will be partly shaped by the prevalent environmental conditions (for instance, infaunal assemblages routinely moved by tidal currents will typically be more resistant to that type of physical disturbance compared to assemblages from more stable sedimentary systems); and
- Fisheries advice – consideration of feature sensitivity, indirectly considers natural disturbance, as feature sensitivity will be partly shaped by the prevalent environmental conditions.

Figure 2.1: Schematic summarising inputs and outputs of JNCC's process for offshore MPA management and fisheries impact advice (STECF = Scientific, Technical and Economic Committee for Fisheries; CFP = EU Common Fisheries Policy)

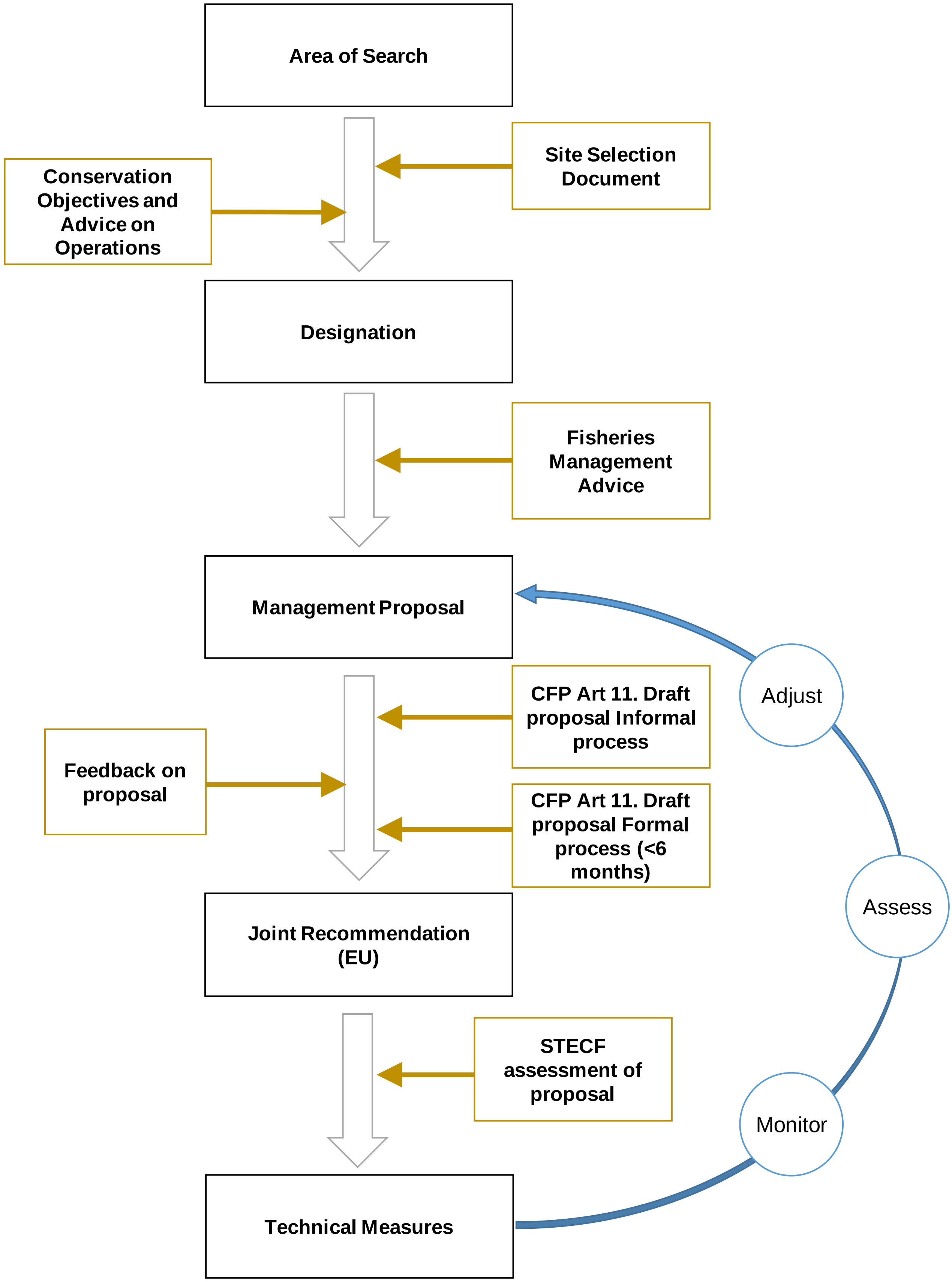
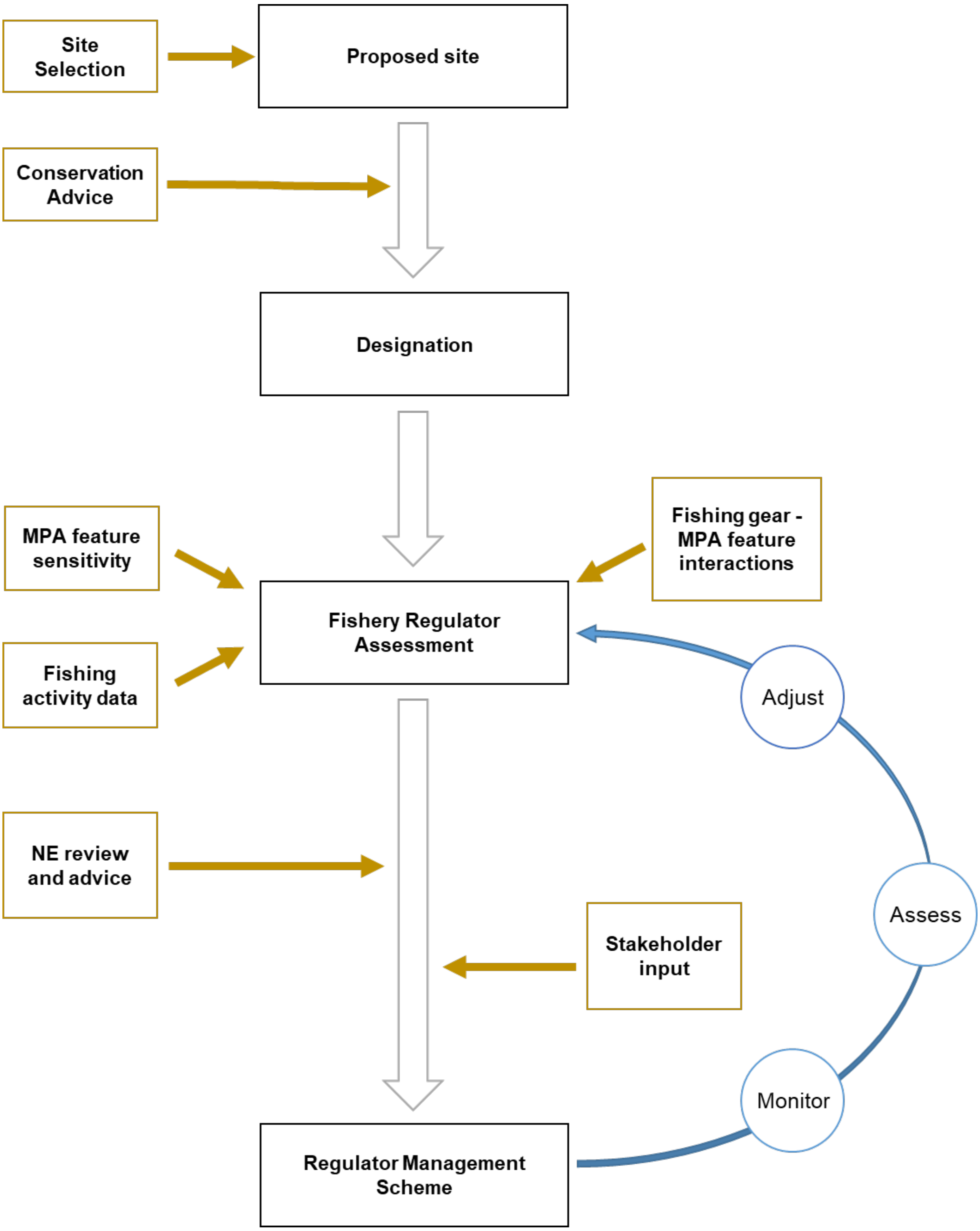


Figure 2.2: Schematic summarising inputs and outputs of NE's process for inshore MPA management and fisheries impacts (the adaptive risk management cycle is in development and may change in the future)



3 Summary of work to date and associated research

3.1 Phase I Natural Variability

3.1.1 Overview

Goodchild *et al*. (2015) conducted a feasibility study as Phase I of the Natural Variability project. Marine Recorder[3] was interrogated to determine if there were sufficient data on the distribution of benthic infauna species and environmental metrics to potentially investigate effects of towed gear on mobile sediment communities. The project involved several steps:

- Completing data-filtering exercises using data in the Marine Recorder database;
- Conducting a summary data analysis of data screened into the project;
- Reporting on the results of the analysis;
- Providing commentary on the results and limitations of data, with reference to the overarching project objectives, and;
- Identifying potential next steps towards understanding natural variability of infauna and progress towards decoupling the effects of natural variability from fishing impacts.

3.1.2 Conclusions and Recommendations

Key conclusions and recommendations from the Phase I report were as follows:

- Consistent, standardised monitoring techniques should be used to remove sources of confounding variables and thus enable robust statistical analysis;
- Any investigation and analysis into the effect of towed fishing gears on benthic infauna should acknowledge caveats and limitations of fishing data layers;
- Different methods to standardising datasets from Marine Recorder could be trialled;
- Analyses should be conducted at smaller spatial scales;
- The temporal resolution of datasets could be enhanced through a data mining exercise in which industry data is gathered;
- Functional groups with known sensitivity to fishing disturbance should be studied; and
- There is potential to compare infauna data from areas of the sea with low and high fishing intensity to better understand natural variability and fishing impacts.

3.1.3 Limitations

The study identified limitations specific to data extracted from the Marine Recorder database:

- Limited temporal replication of sampling sites within surveys;

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[3] Marine Recorder is the database application used by JNCC, the Statutory Nature Conservation Bodies and organisations such as DASSH, SeaSearch, and the Wildlife Trusts to store marine benthic data such as species, physical attributes and biotopes. It is compatible with the NBN data model, enabling data to be contributed to the NBN Atlas.

- Potential redundancy of pre-2006 benthic data due to absence of Vessel Monitoring Systems (VMS) data; and
- Limited number of offshore benthic samples.

3.2 Phase II Natural Variability

3.2.1 Overview

Johnson *et al*. (2017) completed Phase II of the Natural Variability project, which analysed monitoring data from three MPAs to test methods and metrics of assessing fishing impacts and natural disturbance. Drawing on recommendations from the Phase I report, the Phase II study aimed to:

- Identify and recommend benthic infauna metrics and analytical methods to test for effects of natural disturbance and demersal fishing activity in UK mobile sediment habitats at local scales; and
- Assess and qualify effects of natural disturbance with respect to demersal fishing activity in a number of UK MPAs in order to identify natural changes and those that may have resulted from fishing activity, or both.

The project involved several steps:

I. A literature review to identify which metrics and methods would be the most appropriate and sensitive to detect variation in benthic macrofaunal data from natural and anthropogenic impacts;
II. Completion of a geospatial assessment and mapping exercise of existing benthic macrofaunal datasets;
III. Development of data analysis methods tested during Phase I and statistical analyses of datasets within case study MPAs; and
IV. Review outputs of the literature review and data analysis to discuss implications for management measure development, and provide recommendations for next steps in order to better target management measures for MPAs designated for mobile sedimentary habitats.

The project scope was limited to mobile sediments including: Annex I subtidal sandbanks, mudflats and sandflats, estuaries, and large shallow inlets and bays, and broad-scale habitats of A5.1 Subtidal coarse sediment, A5.2 Subtidal sand, A5.3 Subtidal mud, and A5.4 Subtidal mixed sediment. As the study focused on potential physical effects of fishing on the seabed, only demersal fishing gear types were included: beam trawls, otter trawls and toothed dredges.

Metric and case study identification

Following a selection process, Johnson *et al*. selected four metrics to test: species richness, average taxonomic distinctness (Δ+), multivariate AMBI (M-AMBI), and biological traits linked to infauna intolerance of physical disturbance (size range, morphology, living habit, sediment position, and mobility).

Through consultation with the PSG, three MPA case studies were selected that had different monitoring designs and sufficient data for reanalysis: Dogger Bank Site of Community Importance (SCI) which is an offshore MPA in English waters; The Wash and North Norfolk Coast Special Area of Conservation (SAC), which is an inshore MPA in English waters; and Cardigan Bay SAC which is an inshore MPA in Welsh waters.

Modelling

Metrics were tested using a process of model selection on benthic grab data from site monitoring surveys. Of a range of environmental factors and fishing activity estimates, the terms that explained the most deviance in each benthic metric indicated where the strongest relationships might exist.

Estimates of fishing activity were made using raw VMS and inshore fishing data layers provided by Cefas. For VMS data, the Euclidean distance between a benthic grab station and the nearest VMS ping was used as a proxy measure of demersal fishing activity for each sample and which has been shown to perform as well as more complicated models (see Lambert *et al*., 2013).

Environmental parameters that were included to capture direct and indirect aspects of natural disturbance included depth, wave-induced bed shear stress, bed shear stress, wave-induced kinetic energy, tidal current-induced kinetic energy, latitude and longitude of sampling stations, and substrate.

Models of natural seabed disturbance developed by Cefas were included in the analysis for Dogger Bank SCI (see Diesing *et al*., 2013) and models produced by ABPmer for the NFFO for The Wash and North Norfolk Coast SCI (ABPmer and Ichthys Marine, 2015b). These models are discussed further in Sections 3.3 and 3.4 respectively.

3.2.2 Conclusions

For each MPA, the fitted models that best explained deviance in the response metrics contained similar model terms in a broadly comparable order in terms of their contribution to model fit. The model terms for each MPA are summarised in

Figure 3.1 by rank order.

Figure 3.1: Summary of model terms for the best fitting models in each MPA case study. Model terms are in rank order according to the terms contribution to model fit.

Rank model terms	Dogger Bank SCI	The Wash and North Norfolk Coast SAC	Cardigan Bay SAC
1	Region (biogeographic)	Year	Survey period (time)
2	Sand and silt content (or substrate)	Region (Wash/N Norfolk)	Effort: Survey (Sept)
3	Natural disturbance	Sand and silt content (substrate)	Shear stress (wave)
4	Shear stress (wave and tide)	VMS distance	Current energy
5	VMS distance (traits only with poor fit)	Current energy	

General conclusions for selected metrics

Species richness (S), average taxonomic distinctness based on presence/absence information (Δ+), multivariate AMBI (M-AMBI), and selected biological traits, all varied in a comparable way with parameters associated with natural disturbance and demersal fishing activity.

Taxonomic distinctness measures should not be considered any more sensitive to effects of physical disturbance, compared to other diversity indices. M-AMBI responded in a similar way to species richness likely because the component sensitivity assessments need to be adapted to better reflect physical disturbance. M-AMBI could be a useful indicator for observing fishing over longer timescales, as it has been shown to be relatively insensitive to episodic natural disturbance.

Specific biological traits that had a relationship with fishing activity varied markedly between MPA case studies. This could have been due to site-specific differences in community composition and response to demersal fishing activity, or due to effects of the different gear types used at the three sites. Johnson *et al*. (2017) emphasised that it may not be appropriate to consider the same suite of biological traits for the same MPA feature in different sites. Also, that regional and site-specific variation in species composition and response should determine the most appropriate traits.

Natural change and case study MPAs

Natural change was divided into two components: natural variability and natural shifts. Natural variability was defined as changes, due to abiotic and biotic factors, which are of a magnitude that the system could recover to its natural range. Natural shifts are defined as gradual changes to an alternate stable state and range shifts. Levels of natural variability and disturbance in the MPA case studies varied in existing time-series data, with persistent natural disturbance e.g. from waves or currents, or episodic weather events e.g. driven by the North Atlantic Oscillation.

3.2.3 Recommendations

Due to differences in the sensitivity of the metrics to natural variability, it was recommended that a range of indicator types (based on indicator species, ecological strategies, and diversity, and multi-metric indices) are included in any long-term assessment of fishing impacts. This is to ensure that natural change can be detected and considered.

Natural processes should inform relative resistance and resilience when considering natural disturbance against demersal fishing disturbance within an MPA.

Modelled layers of natural disturbance were not used to define absolute thresholds of fishing activity. However, the modelled layers were a useful evidence source to help understand relative resistance and resilience of benthic communities to physical effects of demersal fishing.

MPA condition assessments should include persistent disturbances and extreme weather events, and should identify the general levels of disturbance underlying rare natural events.

Findings are summarised in Table 3.1.

Table 3.1: Summary of findings from Phase II natural variability contract

Result
Dogger Bank SCI The benthic metrics related in a similar way to environmental factors. Broad biogeographic regions explained most of the metric variability followed by sand and silt content. The Diesing *et al*. (2013) natural disturbance models improved the model fit. Only a few biological traits showed a relationship with fishing activity and any relationship was weak. The Wash and North Norfolk Coast SAC In both the two- and 24-year datasets from The Wash and North Norfolk Coast SAC, sampling year explained the most variability in the benthic metrics. Sediment composition was also an important model term possibly due to the range of sediment types encountered in The Wash and North Norfolk Coast SAC. Long-term monitoring data showed large shifts in benthic metrics for some years, not linked to fishing activity levels and with a much larger than any observed potential effect of fishing. Cardigan Bay SAC There was no consistency in the environmental terms that related to the benthic metrics and models were a poor fit. There was an observed effect of experimental dredging and some metrics even increased to pre-fishing levels following cessation of fishing. There were strong seasonal changes in faunal composition irrespective of fishing, which may reflect the ephemeral nature of the benthos in this SAC.
Conclusion
Overall, the metrics that were tested performed in a similar way, indicating that they captured similar structural aspects of benthic assemblages. Diesing *et al*. (2013) models were useful additional parameters at Dogger Bank likely due to the scale of processes and sediment composition (no compaction due to no silt). NFFO models did not feature in any of the models for The Wash and North Norfolk Coast SAC, possibly due to data gaps and additional complexities and influences associated with a coastal site. Natural variability should be considered at the spatial scale over which natural processes operate. The long-term monitoring data from The Wash and North Norfolk Coast SAC showed large shifts in benthic metrics possibly due to episodic events such as cold winters or extremely high freshwater run-off. It is suggested that site monitoring could be adaptive and data collected after an extreme natural event e.g. storm surge, should be excluded from any assessment. In some instances, inter-annual variability in benthic metrics can be much larger than any intra-annual variability, natural or anthropogenic. Model fit was relatively poor in Cardigan Bay SAC and could be explained by several factors: data resolution in terms of natural processes; analysis was only conducted to family level; or in-combination effects from anthropogenic activities.
Advantage
Demonstrated that species richness performed as well as more complicated metrics of benthic condition tested in terms of detecting possible fishing impacts. Demonstrated that a simple univariate analysis of benthic metric against fishing activity would not allow sufficient consideration of the relative importance of environmental drivers on benthic assemblages. Johnson *et al*. (2017) emphasised the importance of considering natural disturbance in the context of proposed fishery management measures for the SCI. This is because of the large (natural) variance in metrics over time observed in site monitoring data.

Time-series data is essential to consider the relative scale of fishing impacts relative to natural temporal as well as spatial variability in benthic communities. The study validated the Diesing *et al*. (2013) model using site monitoring data from Dogger Bank SCI. The model was produced on a 12x12km grid. The authors suggested that the model was a good representation at Dogger Bank because of the large scale of the site and environmental processes that structure the benthic communities on it. The validation showed that the model added to the explained deviance in the benthic metrics, but not that it could be used as a threshold for when fishing activity should be managed.
Limitation
Lack of reference conditions for The Wash and North Norfolk Coast and Dogger Bank SCI made it difficult to conclude whether there was a small effect of demersal fishing or whether the site was already modified due to historical activity. The relationship of natural disturbance and fishing disturbance can only be inferred from generic monitoring data, and confounding variables can make it challenging to interpret any results. A lack of accurate fishing activity data for <15 m vessels. The definition of the term ‘subject to natural change’ needs to be improved with regards to processes that apply and the spatial and temporal scales over which change may occur.
Future use
Recommend using a simple metric or mix of different metrics to monitor fishing effects on soft sediments. Monitor a few sites frequently that are representative of regional features; data could be collected to provide regional context of natural temporal variability. The report recommends developing a typology of natural disturbance and lists of natural variability drivers at different spatial and temporal scales for each regional sea. Measures were highlighted that could help meet site conservation objectives. For example, spatial closures over representative areas of the seabed to monitor the response of benthic communities and ascertain what reference conditions look like, in the absence of reference conditions.

3.3 Assessing seabed disturbance from demersal fishing and natural disturbance

Diesing *et al*. (2013) developed a method to directly compare physical seabed disturbance, from demersal fishing gear, with natural disturbance from waves and tides. The method was tested for demersal fishing in the English sector of the Greater North Sea, where there were four different substrate types and three biological zones (expressed as depth). VMS data were used to estimate the area of seabed impacted by a number of demersal gear types (beam trawls, otter trawls, dredges). Probabilities of disturbance by waves and tides were modelled at two sediment depths (1 and 4cm) for frequencies of >1, >10 and >17 days per annum. The authors tested the method by determining the probability of natural disturbance frequency exceeding demersal fishing frequency across the Greater North Sea (Table 3.2).

Table 3.2: Summary of findings of Diesing *et al*. (2013)

Result
Natural disturbance levels (frequency) were predicted to exceed fishing disturbance for 45.1% of the study area seabed. Whereas levels of fishing disturbance exceeded natural disturbance over a total of 54.9% of the study area seabed. Fishing disturbance varied with substrate type. Fishing disturbance typically exceeded natural disturbance for cohesive muddy sediments, while natural disturbance exceeded fishing disturbance for some seabed areas with coarse sediment.
Conclusion
Fishing disturbance was greater than levels of natural disturbance in deep circalittoral habitats compared with shallow circalittoral or infralittoral habitats The model is a repeatable and quantitative way in which to determine the probability of natural vs fishing disturbance, at a common scale. Several assumptions had to be made when developing the methodology. Those assumptions relating to the impact of the different fishing gears on the seabed were associated with the largest uncertainties.
Advantage
The disturbance models are a useful tool for looking at frequency of disturbance events from waves and currents compared to demersal fishing. The study produced a number of models for different disturbance frequencies and depths, which can be tailored to individual requirements. Models were produced on a regional sea scale to allow comparison of relative effects of natural disturbance between sites.
Limitation
EUNIS substrate types were too coarse to assess feature sensitivity accurately. The model assumed that VMS data provided an adequate representation of fishing effort, and assumed set dimensions for demersal fishing gears. Both assumptions underestimate fishing footprints. Little information was accessible from published literature to ascertain different gear penetration depths in different substrata.

Assumptions were made about natural disturbance, such as disturbance depth in sand equates to the height of small-scale ripples. Assumptions were made about the distribution of trawling effort with penetration depth and in the case of mud and gravel, penetration depth from fishing disturbance was assumed equal to natural disturbance. Assumed comparison of frequency of fishing and natural disturbance events could be used to identify when fishing starts to have an effect above natural disturbance. Doesn't account for seasonality of events or possibility of additive effects. <u>The study cautioned against describing sediment mobilisation from demersal fishing to be the same as natural disturbance.</u>
Future use
Very useful platform to predict relative sensitivity of sites to general physical disturbances and inform site assessments at larger scales and for offshore sites where there are fewer influences. Models are already available to add to SNCB toolkit to inform fisheries management advice. Requires empirical validation to show that assumptions about effects of natural disturbance and fishing pressures hold.

3.4 NFFO shadow assessments

The National Federation of Fishermen's Organisations (NFFO) commissioned a project in 2015, in which shadow assessments of demersal trawling were completed for three European Marine Sites:

- The Wash and North Norfolk Coast SAC (ABPmer and Ichthys Marine, 2015a);
- North Norfolk Sandbanks and Saturn Reef SCI (ABPmer and Ichthys Marine, 2015b); and
- Margate and Long Sands SCI (ABPmer and Ichthys Marine, 2015c).

The project aimed to support evidence-based, risk-based assessments of fishing. For each site, existing evidence, biological traits and work completed by ABPmer (2013) were used to determine the sensitivity of the site features to pressures from demersal trawling. Sensitivity was based on tolerance and recoverability. Pressures to site features were determined at the level of individual fishing gear components, using information from fishers and modelling. Exposure was calculated for fishing gear components of relevance in each site.

Exposure of biotopes/habitats of designated features, was determined separately for ≥15 m vessels and <15 m vessels in each site. VMS-based fishing ‘footprints’ were calculated for vessels ≥15 m. Swept area footprints were calculated for vessels <15 m, based upon a range such as information from fishers and consideration of sightings, landings and fish plotter data. Vulnerability of the biotopes/habitats of the designated site features, was ascertained by combining feature sensitivity and level of fishing exposure. Vulnerability assessments were considered in relation to site conservation objectives.

Natural disturbance modelling was carried out for each site. Natural disturbance was inferred from the proportion of time, and the number of days in a year, that sediments are mobile, and that mobile ripple bedforms of 2.5 cm height are present in each site. Fishing disturbance in each site was then considered in the context of natural disturbance.

The Wash and North Norfolk Coast SAC

Pressures exerted by shrimp beam trawling on features of shallow inlets and bays and subtidal sandbanks were assessed (ABPmer and Ichthys Marine 2015a). Pressures considered for shrimp beam trawling were:

- Physical damage resulting from abrasion and/or selective extraction; and
- Biological disturbance through the selective extraction of species.

Natural disturbance modelling predicted that within the deeper (>15 m below chart datum) parts of The Wash, sediments are mobile and active bedforms are present for around 30-40 % of the time. Generally, in shallower areas of the site i.e. shallower than 15 m bCD, sediments are mobile and active bedforms are present 60-85% of the time.

North Norfolk Sandbanks and Saturn Reef SCI

Pressures exerted by beam trawling and electric pulse trawling on subtidal sandbanks, were assessed (ABPmer and Ichthys Marine 2015b). Pressures considered for beam trawling and electric pulse trawling were:

- Physical damage and disturbance through changes in suspended sediment concentration;
- Physical damage and disturbance through abrasion; and
- Biological disturbance through the selective extraction of species.

The report highlights that in the North Norfolk Sandbanks and Saturn Reef SCI, current-induced disturbance is generally more frequent and persistent, but of a relatively lower magnitude than wave-induced. Wave-induced disturbance tends to be episodic, seasonal and with short-term fluctuations in magnitude and direction (ABPmer and Ichthys Marine, 2015b).

Margate and Long Sands SCI (ABPmer & Ichthys Marine, 2015c)

Pressures exerted by otter trawling on subtidal sandbanks were assessed (ABPmer and Ichthys Marine 2015c). Pressures considered for otter trawling were:

- Physical damage and disturbance through abrasion (surface abrasion, shallow disturbance and deep disturbance);
- Changes in siltation rate; and
- Biological disturbance through the selective extraction of species.

Natural disturbance modelling indicated that in the northern part of the Margate and Long Sands SCI, active bedforms are present around 60% of the time. In the south-west part of the site, active bedforms are only present around 10–30% of the time. In areas of muddier sediments in the troughs in the southern part of the site, mobile bedforms of 2.5 cm height may not form, but surface sediments are mobile 50–70% of the time (Table 3.3).

Table 3.3: Summary of NFFO shadow assessments (ABPmer & Ichthys Marine, 2015a-d)

Result
North Norfolk Sandbanks and Saturn Reef SCI - Shallow and deep disturbance on all habitats: low vulnerability, except for deep disturbance on deep circalittoral sand (moderate); - Biological disturbance through removal of target and non-target species: low. The Wash and North Norfolk Coast SAC - Surface abrasion for sublittoral biogenic reefs: moderate vulnerability; - Removal of target and non-target species for: • *N. cirrosa* and *Bathyporeia* in infralittoral fine sand: low vulnerability; • *E. cordatum* and *Ensis* spp. in lower shore and shallow sublittoral slightly muddy fine sand: low; • *A. alba* and *N. nitidosa* in circalittoral muddy sand or slightly mixed sediment: low; • *M. bidentata* and *Abra* spp. in infralittoral sandy mud: low; • Sublittoral mixed: low; • *M. bidentata* and *Thyasira* spp. in circalittoral muddy mixed: low; - Shallow disturbance for sublittoral mud and biogenic reefs: low; and - Surface abrasion, shallow disturbance and removal of target and non-target species for *F. foliacea* and *H. falcata* on tide-swept circalittoral mixed sediment: low Margate and Long Sands SCI - *F. fabula* and *M. mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand: moderate; - Dense *L. conchilega* and other polychaetes in tide-swept infralittoral sand and mixed gravelly sand: low - *A. alba* and *N. nitidosa* in circalittoral muddy sand or slightly mixed sediment: low - Polychaete worm reefs on subtidal sediment: low vulnerability to surface and to shallow and deep disturbance.
Conclusion
Recommends that assessments of fishing in MPAs be based on impacts and exposure at the level of individual gear components. This is because there are different impacts caused by different gear components and the area over which the impacts is exerted also differs between gear components. Natural disturbance should always be accounted for when assessing the significance of demersal fishing impacts in a site. The significance of fishing should be considered in relation to the site conservation objectives. It should be clear what baseline has been used to determine the site conservation objectives and whether this included fishing activity at the time of designation.
Advantage
Applied natural disturbance models to MPA management advice in English SACs. Detailed consideration of different gear types and modification. Acknowledgement that fishing gears are mechanistically different to effects of natural disturbance and need to be considered in addition to these models.

Used different types of evidence in coming up with management advice: expert judgement; empirical observations; and statistical models. Consideration of site conservation objectives. Stakeholder involvement and expert judgement to fill data gaps.
Limitation
Calculations of fishing activity extent and intensity. For vessels <15 m, the study relied on data gathered from a sub-set of interviewed fishers then scaled up for the whole fleet. This process may have resulted in under or over-estimated values. Calculations of swept area may not have fully reflected the actual fished area of biotopes. For vessels ≥15m, VMS pings may have been misclassified and underestimated activity, especially where fishing gear was not specified. Limitations were highlighted for biotope extent derived from feature data layers. Also, that there was a limited availability of studies into long-term effects of fishing and habitat interactions for a range of habitat types. For the natural variability modelling, limitations were identified in model source data. Limitations included the chosen bathymetric data not potentially being suitable for shallow, nearshore areas; relying on a single grain size in areas of mixed grain size; and the coarse resolution of tidal current and wave data, relative to the scale of the three MPAs. The significance of beam and pulse trawling effects will also depend, to some extent, on the baseline against which achievement of the conservation objectives is assessed, particularly whether this baseline includes existing levels of fishing activity. Assumed comparison or frequency of fishing and natural disturbance events could be used to identify when fishing starts to have an effect above natural disturbance. Doesn’t account for seasonality of events or possibility of additive effects. No model validation.
Future use
Estimates of swept area have been improved through the use of information on towing speed (from VMS), gear type and gear configuration (from skippers) Interviews with skippers of under-15m vessels explored gear configurations, fishing behaviour (tow speed, number of tows per day, pattern of fishing throughout the year) and spatial mapping of fishing areas. This allowed estimates of swept area of different habitats and biotopes to be developed for the <15m vessels. Validation of the natural disturbance models is required to show that they are reliable.

3.5 Impact of scallop dredging on benthic communities and habitat features in Cardigan Bay SAC

Lambert *et al*. (2015a; 2015b) and Murray *et al*. (2015) investigated the impacts of experimental scallop dredging on benthic communities and habitat features in the Cardigan Bay SAC following a 5-year fishing closure. The study aimed to identify fishing disturbance thresholds relative to the site's natural capacity. A BACI experimental design was applied using a gradient of scalloping dredging intensities, from none in control areas to fished more than six times. Seventeen experimental plots were dredged at differing intensities and then surveyed four months after dredging. Plots were spread across inshore (3-6 nm) and offshore (6-12 nm) sections of the SAC that had been closed to scallop dredging since 2009. Responses of infauna, epifauna and seabed geology were quantified and related to the study objectives. Evidence was intended to inform the development of a fishery management regime that would take account of the SAC conservation objectives (Table 3.4).

Table 3.4:Summary of findings of Lambert *et al*. (2015a,b) and Murray *et al*. (2015)

Result
Infaunal and epifaunal biomass and abundance decreased in sand after dredging and with a steeper decline with increasing effort. This was primarily caused by the response of organisms attached to the substrate. Infaunal and epifaunal richness did not change along the dredging gradient. Four months after dredging, there were increases in abundance and biomass of infauna and epifauna and sometimes to levels higher than those pre-dredge. Relative abundance and biomass decreased in gravel and four months later, some recovery was evident. However, recovery had not occurred in plots fished most heavily (>3.5-4.0 times). Plots fished <4.0 times had generally recovered four months later. Recovery in the summer months coincided with recruitment and growth. No significant change in sediment composition was observed. In sand, dredge tracks were not visible, whereas in coarser sediment, dredge tracks persisted for up to 10 months after dredging.
Conclusion
The authors derived conservative estimates of scallop dredging intensity thresholds. These are considered to be thresholds of scallop dredging intensity that could be tolerated by benthic communities and the seabed. A fishing intensity <3.45 times swept per year could potentially be tolerated in inshore waters (3-6 nm) and in gravel. A fishing intensity <6.2 times swept per year, could potentially be tolerated in offshore waters (6-12 nm) and in sand. It was concluded that, in offshore parts of the experiment, recovery was still occurring four months after dredging and reformed within 10 months of dredging due to natural processes. Some parts of the seabed inshore (3-6 nm) of the SAC, were considered to require up to 12 months for recover. Recovery was likely to have been facilitated by immigration and settlement of infauna and epifauna from adjacent areas of the site still closed to fishing.
Advantage

The experimental design allowed effects of fishing activity at different levels to be quantified in an MPA relative to conditions at the start of the study. A period of recovery during the 5-year fishing closure allowed the experiment to be conducted on a partially or fully-recovered benthic community. Experimental trawling using a commercial vessel allowed a reliable measure of fishing activity. By using only one gear type, specific effects could be isolated and quantified.
Limitation
Taxa were only identified to family level due to budget constraints and this may have impacted data analyses for infauna and epifauna. Increases in abundance and biomass of infauna/epifauna in sand were partly explained by very high abundances of mysid shrimps. However, mysid shrimp are not the most suitable indicator of fishing pressure and the authors excluded them from analyses to determine the difference. Decreases in biomass of dead man's fingers *Alcyonium digitatum,* and sponge *Dysidea fragilis* and poor cod *Trisopterus minutus* were associated with decreases in epifauna biomass. However, fish are not the most suitable indicator of localised effects of scallop dredging. Seabed in the study plots, including impact and control plots, may not necessarily have been fully recovered from historic scallop dredging impacts. No monitoring data were available for the period during the 5-year fishing closure to track recovery and an assumption had to be made that the site was in favourable condition at the start of the study (based on evidence from similar habitats).
Future use
Specifically of use to Cardigan Bay SAC, but valuable lessons to be learned in terms of experimental closures and subsequent fishing trials. In the absence of a reference area, a long-term closure followed by a robust fishing impact study and gathering of empirical data allowed evidence to be generated on sustainable levels of fishing for this site.

4 Synopsis of recent reports

There have been a number of recent studies published after or during Phase 2 of the project (Johnson *et al*., 2017) that have sought to further our understanding of how to decouple effects of fishing on benthic communities from those effects caused by natural processes such as waves and currents. Here we provide a brief synopsis of the most relevant to support fisheries management advice in these habitats and discuss the advantages and limitations of each.

Table 4.1: Summary of new literature reviewed

Name	Year	Title	Approach	Stage in process
van Denderen *et al*	2015	Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats	BTA VMS Bed Shear Stress	NE and JNCC: site information (shear stress) and sensitivity assessment for conservation advice and fisheries advice
Rijnsdorp *et al*	2016	Towards a framework for the quantitative assessment of trawling impact on the seabed and benthic ecosystem	BTA Gear interactions Swept area	Fisheries advice and adaptive risk management
Depestele *et al*	2015	Measuring and assessing the physical impact of beam trawling	Gear comparison	Fisheries advice
Szostek *et al*	2016	Natural vs. fishing disturbance: drivers of community composition on traditional king scallop, *Pecten maximus*, fishing grounds	BTA VMS Environmental gradient	Conservation advice; fisheries advice; and adaptive risk management

4.1 Comparison of trawling and natural disturbance benthic effects

van Denderen *et al*. (2015) assessed commercial trawling and natural disturbance effects on soft sediment benthos, focusing on community composition and function. The study tested the hypothesis that bottom trawling and natural disturbance (tidal bed shear stress) have comparable effects on benthic communities. Tidal-bed shear stress was estimated using a 2-dimensional hydrographic model. This model predicts shear stress (the force per unit area exerted on the seabed by the tidal currents: N m^{-2}) per sampled station on a 1/8° longitude by 1/12° latitude spatial scale (see Hiddink *et al*., 2006 for more detail). A total of eight study areas were included in the study; seven study areas were located in the North Sea and one in the Irish Sea. During the study, benthic communities were sampled across a gradient in trawling disturbance, with data from comparable studies supplementing the dataset for the North Sea. Tidal bed shear stress was used to predict natural disturbance frequency. A biological traits approach was used to describe changes in benthic community function and resilience. VMS data were used to quantify trawling disturbance, expressed as the ratio between the area of the site and area of the site trawled annually (Table 4.2).

Table 4.2: Summary of findings of van Denderen *et al*. (2015)

Result
No effects of trawling (at high or low intensity) on benthic communities at locations with high natural disturbance (tidal-bed shear stress 0.3 to 1.4 N/m^2). The community composition was comparable with areas exposed to high natural disturbance but with no trawling. In general, there were declines in long-living, hard-bodied and suspension-feeding organisms. Conversely, shifts in trait composition from trawling were evident in the majority of sites with lower bed shear stress (0.1 to 0.3 N/m^2). Trawling and natural disturbance were associated with declines in long-lived, hard-bodied (exoskeleton) and suspension-feeding animals, with potential to subsequently affect community function.
Conclusion
van Denderen *et al*. (2015) concluded that trawling and natural disturbance (tidal bed shear) affect benthic communities in similar ways. The authors highlighted that trawling can affect different components of the benthos in different ways, with impacts potentially overlooked unless several sampling gears and community indicators are used. Trawling had most adverse effects on infaunal organisms positioned between 0 and 5 cm in the seabed. Surface-dwellers were less affected in this study possibly because they were able to quickly repopulate trawled grounds. In this study, most surface-living animals were mobile swimmers or crawlers.
Advantage
Demonstrates that benthic community composition and function at sites with high shear stress are likely to be relatively more resilient to the effects of trawling than those where tidal shear stress is low. Provides partial validation of a tidal shear stress model developed by HIddink *et al*. (2006). Broadly confirmed the applicability of the Diesing *et al*. (2013) approach, though acknowledge that there will be some complexity of response that reflects local site characteristics.

Provided further evidence of biological traits of infauna most likely to be negatively impacted: exoskeleton, sessile, suspension-feeder, planktotrophic larval development, pelagic egg development, burrow-dwelling, positioned 0−5 cm in the sediment, surface-deposition activity and a maximum longevity of 3−10 or >10 yr. These were characterised by abundant bivalves such as *Dosinia*, *Spisula*, *Acanthocardia*, *Ensis*, *Phaxas* and *Abra*.
Limitation
The study model only considered one metric (bed shear stress) of natural disturbance. Trawling disturbance impacts were limited to beam and otter trawls. For two sample areas in the North Sea, aerial surveillance data dating back to 2001 was the basis for estimating trawling disturbance. The sampling dates for each sample area were different and spanned dates from 2002 to 2009. The number of benthic sampling sites ranged substantially, from 6 to 230 among areas. While the number of samples taken at each site ranged from 1 to 5. The effects of trawling were examined over a gradient of commercial bottom trawling intensity. Any observed effects of fishing pressure could be a result of the fishery selecting areas with a particular community composition where they catch the most fish. Where there were no detectable effects of trawling, it was impossible to tell whether the areas had not recovered from historic trawl disturbance or whether the effects of trawling were relatively low in relation to natural disturbance.
Future use
The study compared the similarity of natural disturbance and demersal trawling, relative to community composition and function. Combined traits analysis with use of a model of natural disturbance (tidal bed shear). Would benefit from addition of empirical data from specific MPA and expert judgement to fill data gaps and provide context (e.g. historic fishing levels). The survey areas in the study spanned a broad geographic extent with different habitats and trawling intensities. The geographic scope of the study is useful for perhaps informing the regional context of MPA assessments, particularly larger, offshore MPAs, but is probably too broad for site-specific MPA assessments especially in dynamic inshore locations.

4.2 Framework for trawling and natural disturbance assessments

Rijnsdorp *et al*. (2016) developed a framework to assess the benthic impacts of bottom trawling. The framework incorporated an understanding of benthic ecosystem processes and the mechanisms of trawling gear interactions with benthic ecosystems. The study distinguished between the physical effects of the gear on the seabed (gear penetration, collision, and sediment mobilisation) and effects of the gear on marine fauna and the functioning of the benthic ecosystem (Table 4.3). Biological trait analysis was used as a proxy to examine changes in ecological function. Three indicators of trawling pressures were considered; the proportion of habitat that is not trawled during a year; the proportion of habitat that was trawled less than once a year; and estimates of the surface area of the most intensively trawled grid cells. Trawling frequency, derived from VMS data, was linked with benthic community recovery, specifically taxa longevity.

The framework was applied in an assessment of trawling in the North Sea to three seabed habitats; A5.1 Sublittoral coarse sediment, A5.2 Sublittoral sand, and A5.3 Sublittoral mud.

Table 4.3: Summary of findings of Rijnsdorp *et al*. (2016)

Result
The framework was explored through a preliminary assessment of three seabed habitats in the North Sea: EUNIS habitats A5.1 Sublittoral coarse sediment, A5.2 Sublittoral sand, and A5.3 Sublittoral mud. The average annual trawling intensities recorded in the period 2010-12 substantially reduce the area of seabed where the benthos is in their reference state. Trawling had the greatest impact on total benthic community in sublittoral mud (A5.3) and comparatively less impact on sublittoral sand (A5.2) and on sublittoral coarse sediment (A5.1). Surface trawling impacts were greatest for surface deposit feeders in sublittoral mud and lowest for deposit feeders in sublittoral coarse sediment. Sub-surface impacts were greatest for suspension feeders in sublittoral sand lowest for deposit feeders in sublittoral coarse sediment and sublittoral mud.
Conclusion
The framework provides a habitat-seabed risk assessment method that allows quantification of (i) the pressure of bottom trawling on different ecosystem components, (ii) the ecological impact of bottom trawling, and (iii) evaluate the effect of alternative management scenarios Longevity differed in functional groups assessed and that this may reflect trawling-induced changes in ecological communities.
Advantage
The proposed impact assessment framework is applicable to all benthic habitats and trawl fisheries and can be applied at different spatial scales (local, regional, management areas). The proposed framework can be applied widely because the data required is generally available. The three requirements of the assessment framework are: (i) high-resolution data on the frequency of bottom trawling by fishing gear; (ii) information on the distribution of seabed habitats; and (iii) information on the composition of the benthic community with regard to biological traits related to their sensitivity and resilience to bottom trawling impacts.

Has an advantage over other more sophisticated models as only has a modest data requirement.
Limitation
All gear types were assumed to exert the same impacts. It was assumed that all benthos would be in the reach of and, therefore, impacted by a trawl. This is an unrealistic assumption given the variation in living habitat, mobility, and burial depth of different infaunal species. The study relied on a relatively limited duration of fishing activity (two years), which may account for interannual variability in fishing effort. In the absence of data, trait longevity had to be estimated from related taxa and trait longevity was not distinguished for taxa with longevity exceeding 10 years. Biomass data and resulting biomass distributions, may not provide an accurate picture of seabed habitats considered in the study, because of the limited number of sampling stations where biomass was recorded. May be less accurate than more sophisticated studies such as Hiddink *et al*. (2006) that extended the model to include spatial differences in habitat. The framework does not account for different types of natural disturbance such as persistent versus episodic events.
Future use
Provides a framework that incorporates ecological function and processes. The framework specifically considers gear interactions with the seabed. This is a useful approach because it accounts for gear components exerting different types of pressures. Also, pressures used in MPA assessments can be correlated with pressures exerted by gear components, thereby aiding with assessment of the trawling against MPA conservation advice. At present, it is quite general and would need modification to be specific enough for individual MPAs. At present, it is more applicable to offshore MPA, because of the relatively limited number of influencing factors, availability of VMS data and availability of modelled, natural disturbance layers at the scales of some offshore MPA. However, the availability of suitable benthic faunal data might be a limitation. The accessibility of monitoring data for inshore MPA means that the framework could potentially be used in inshore sites, although is currently limited by the suitability and availability of accurate trawling activity data.

4.3 Assessing the physical impacts of beam trawling

Depestele *et al*. (2015) compared the physical impacts of a 4 m tickler-chain beam trawl and a "Delmeco" electric pulse beam trawl. The physical impacts studied were changes in seabed bathymetry and sediment mobilisation (Table 4.4). Sediment mobilisation was modelled and validated with field data. Gear element penetration was empirically modelled. The study took place in a shallow coastal area (15-22 m depth) of the Southern North Sea, in soft sediment. Experimental trawling was completed with a single pass of both trawls and multiple passes with the tickler chain beam trawl. Experimental data were compared with predictive model estimates by the authors and from comparable studies.

Table 4.4: Summary of findings of Depestele *et al*. (2015)

Result
Alterations to seabed bathymetry were statistically different for all investigated combinations of gear, but highest for multiple passes of a tickler-chain trawl, which were up to 40-60 mm deeper. The tickler chain altered bathymetry more than the pulse trawl. The difference in seabed bathymetry after a single beam trawl passage was 8.8 mm with a maximum depth difference of 28.5 mm between the inside and outside of the trawl track. The measurements of sediment mobilization suggested that ~2.7 mm of the depth difference could be due to sediment being put into the water column; however, some of this will have resettled in the trawl path. Sediment compaction would have also occurred. The average penetration depth across the full swept area of the gear was predicted to be 9 mm, although this was not directly comparable as the MBES measurements are taken after the passage of the trawl.
Conclusion
Gear configuration and trawling intensity cause differences in seabed bathymetry. Repeated passes of the beam trawl within a certain area increased the bathymetrical differences. Electrodes from pulse trawls were predicted to penetrate about half as deep as tickler chains, but the trawl shoes of the pulse trawler penetrated much deeper than those of the tickler-chain trawl. This indicates that the configuration of the gear is also an important factor to consider. Though bathymetric changes could have been caused by sediment mobilisation and/or displacement of sediment, the authors suggest that it is caused by compaction due to other studies reporting increasing sediment hardness following trawling. Good agreement between numerical predictions and experimental observations. Caution is needed when extrapolating results up to the whole fleet.
Advantage
Provides experimental data on the physical impact of a conventional 4 m tickler-chain beam trawl and a "Delmeco" electric pulse beam trawl. Adds to the relatively limited evidence base on the effects of pulse trawling though the trade-off in impacts between abrasion and electrocution hasn't been addressed. The results imply that fishing gear type (e.g. relatively heavy versus light gear) has a greater effect on seabed bathymetry than repeated trawling (e.g. by a light gear). This is important when considering simple swept area models without consideration of gear weight or vessel power.

Limitation
Focused on a single pass of a tickler-chain beam trawl. Trawling with the tickler chain beam trawl and electric pulse trawl did not occur at the same time. The authors were not able to conclude if bathymetric changes levelled off at higher trawling intensities, and what role gear weight played in bathymetric changes. The study does not give details of the sediment types in the study area. Alterations in seabed bathymetry cannot be considered to be measurements of the gear's penetration into the sediment, as they will also comprise changes in seabed bathymetry due to backfilling of sediment behind the chains and the groundgear and to sediment mobilization and resettlement.
Future use
This study generated some useful empirical evidence that improves the evidence base of specific gear interactions with the seabed. Consideration of electric pulse trawls is useful as this type of gear could, potentially, be more widely used in the future. However, applicability of the study conclusions is limited for mobile sediment features in inshore or offshore MPAs. Data can be used to link to other benthic impact studies, like that of van Denderen *et al*. (2015) who showed effects to be greatest for organisms that dwell 0-5cm below the seabed surface.

4.4 Comparison of natural versus fishing disturbance in scallop fishing grounds in the English Channel

Szostek *et al*. (2016) related environmental drivers to epifaunal community change, along a gradient of scallop dredging in the English Channel. The study aimed to identify regions across the English Channel with distinct environmental characteristics, in areas of key importance to the scallop fishery (Table 4.5).

Environmental drivers included in the study were depth, mean seabed temperature and range, interannual temperature variation, bed shear stress, and substrate characteristics. Scallop dredging intensity was derived from a three-year VMS dataset. Eight study areas were surveyed across a broad area ranging from the Central English Channel to Western Approaches of the Channel. The study was conducted on moderately dynamic, temperate sand and gravel habitats, beyond the 12 nm limit. Biological Traits Analysis (BTA) was used as a measure of functional diversity for comparison with environmental drivers.

Table 4.5: Summary of findings of Szostek *et al*. (2016)

Result
No significant relationship was identified between dredge fishing intensity over a 3-year period, and measures of community change, including total number of species, species richness, Shannon diversity index, Pielou's evenness index, and Simpson's index. Increasing tidal bed shear stress had a significant negative correlation with species richness and diversity. There was no relationship between recent fishing intensity, or bed shear stress, and the functional composition of the communities present
Conclusion
The authors proposed several reasons for the absence of significant relationships: natural disturbance levels may exceed those of scallop dredging, community recovery could be inhibited by the frequency of scallop dredging, or epifauna communities could be already modified because of historic scallop dredging. Szostek *et al*. considered that the epifauna communities sampled in the study, may be tolerant of fishing disturbance due to historic exposure to scallop dredging and trawling. Species richness and community composition may be more heavily influenced by physical disturbance than fishing disturbance. The present study has not identified any effect of scallop fishing intensity on the habitats and communities present. All grounds surveyed had been fished at least once in the previous 3 years. Therefore, long-term (>5–8 years) or permanent closures may be more beneficial than the current cyclical regime of harvesting if an improved status of the seabed is a desirable outcome.
Advantage
Adds to the evidence base on the interrelatedness of natural disturbance (bed shear stress) and fishing impacts on a different habitat type and for a specific gear type. Conducts experiment at the scale of the English Channel king scallop fishery.

Limitation
Catch efficiency of beam trawls for sampling epifauna may have varied due to particle size in the areas sampled. Confounding variables in the study including particle size and bed-shear stress Use of aggregated VMS data meant there was a chance of over or under-estimating fishing activity depending on the scale of aggregation, however any bias would be consistent and relative rather than absolute fishing effort was considered for this study. Samples for particle size analysis were not taken and instead, particle size was derived from video image analysis. The study areas were distributed across a broad geographic area, hence smaller, more localised disturbance events may have not be adequately considered.
Future use
The study demonstrates the complexity of decoupling fishing disturbance from natural disturbance impacts for epifauna in relatively mobile, coarse sediments in offshore environments. No significant relationships were observed between dredge intensity and community measures, but the area has been fished heavily previously. As Johnson *et al*. (2017) suggested with Dogger Bank SCI, the absence of a significant relationship now does not necessarily mean that fisheries management is not required and, for MPAs that may have already been modified, consideration must be given to the conservation objectives and aspirations for site condition. For MPA assessments, particularly offshore MPAs, it may have limited applicability because it does not consider habitats at a biotope level to enable comparisons with MPA features.

5 Discussion

5.1 Introduction

In a recent research prioritisation exercise to identify the top 25 priority knowledge needs necessary to inform the development of best practices for bottom-trawl fisheries, the issue of natural disturbance ranked number 8 (Kaiser *et al*., 2016):

- *How does the disturbance by towed gear and subsequent recovery rate of habitats and biological communities differ from the frequency, timing and magnitude of natural perturbations experienced by seabed habitats?*

The question fell under the knowledge need category; ‘Ecosystem and production: Wider ecosystem effects of disturbance of the seabed that occurs as a result of bottom trawling, consequences for fisheries production’. This demonstrates that the evidence gap identified by the UK Government echoes the evidence gap perceived by the wider seafood stakeholder community. As such, there is clear need for science to address this issue in a way that addresses the policy needs of the Government and wider stakeholder community.

5.2 Types of evidence

There is already a large body of scientific research concerning the impacts that demersal fishing may have on the seabed and associated fauna (see Kaiser *et al*., 2016; Hiddink *et al*., 2017). Whilst there is general agreement that the effects of fishing on the most vulnerable species, including long-lived, slow-growing habitat-forming species, are profound and long-lasting (e.g. Hall-Spencer & Moore 2000; Cook *et al*., 2013; Clark *et al*., 2016), the response of animal communities that live in more mobile sediments is more subtle with faster recovery times (Hiddink *et al*., 2006; Lambert *et al*., 2017). While the response of a wide range of different benthic communities and habitats to fishing is well understood, there has been little consideration given to defining objective thresholds for sustainable levels of disturbance by fishing gear. Overall, effects of different fishing gear types vary considerably and with environmental context (reviews in Collie *et al*., 2000; NRC 2002; Løkkeborg 2005; Kaiser *et al*., 2006; Grabowski *et al*., 2014). What makes the issue particularly challenging in the UK is that, due to the unknown distribution of historic bottom fishing, we often lack reliable reference or baseline conditions for every habitat from which to make a comparison. That said, an increasing number of marine protected areas (many of which have existed >10 y) do provide a useful reference point against which the effects of fishing can be assessed.

Broadly, the evidence that can be used to assess fishing impacts can be grouped into five general themes:

- Empirical data – derived from control – impact studies, e.g. when an area has been closed (or opened) to fishing allowing a comparison of community responses at a larger scale than experimental studies (e.g. Depestele *et al*., 2015, Lambert *et al*., 2015a,b and Murray *et al*., 2015);

- Empirical data – derived from comparative assessment of benthic community status across a known gradient of fishing intensity derived from e.g. vessel monitoring system data;
- Statistical models – use of modelled (predictive) habitat maps and information on biological life studies combined with proxies of fishing activity to predict fishing impacts on large scales (e.g. Diesing *et al*., 2013, van Denderen *et al*., 2015, and Rijnsdorp *et al*., 2016); and
- Expert judgement – tacit knowledge of fishers, benthic ecologists, and/or MPA site or regional advisers on likely impacts of fishing based upon experience.

These approaches are not discrete and are often interrelated; for example, both statistical models and expert judgement require calibration and validation through empirical data to be robust (Cooke *et al*., 1988). Managing different evidence types is often essential in conservation decision-making in general due to a scarcity in directly applicable data (Cook *et al*., 2010). The relative advantages and limitations associated with different evidence types is summarised in Table 5.1.

Table 5.1: Benefits and limitations of different types of evidence used to inform fisheries management

Approach	Benefits	Limitations
Empirical data (observation and experiment)	Can test a specific hypothesis Real observations Can control for undesirable variables Identifies precisely the direct response to a single physical impact	Expensive Issues with upscaling – requires repeated studies to test how representative small-scale observations are on a larger scale Often does not address recovery
Empirical data (control-impact)	Can test a specific hypothesis Real observations Usually larger-scale and more realistic measure of recovery	Ad-hoc May apply to only one location May apply to only one gear type
Empirical studies – comparative studies	Identifies large scale disturbances created by the fishing fleet Allows high level of replication Identifies dose-response relationship needed to parameterise models	May be habitat and gear specific Requires access to VMS or similar data in unaggregated format
Statistical model	Cost-effective Can be used to extrapolate from empirical data to fill data gaps Can be used to forecast future scenarios	Requires validation Limitations and caveats often get overlooked when the outputs are used more widely Can be based upon other models with their own limitations and accuracy Multiple models are often produced, but then one may get chosen for decision-making purposes

		Dependent upon reliability of input data
Expert judgement	Can develop hypotheses and interpret results with data gaps Can provide information about model parameters Can ensure stakeholder involvement and support for management Can characterise uncertainty in models	Biased Poorly calibrated Self-serving Needs to be collected in a structured way if it is to be robust Requires calibration and validation May lack buy-in from stakeholders

Although the use of expert judgement in decision-making has been much criticised (e.g. Tversky *et al*., 1990), its usefulness has generally been accepted and acknowledged in the process of conservation science if it is acquired with appropriate rigour with its limitations acknowledged (Kynn, 2008; Martin *et al*., 2012). For instance, the inclusion of expert information in some models has been shown to improve the power to detect significant changes (Martin *et al*., 2005; Kuhnert *et al*., 2005).

Models are a useful tool in the context of decision-making in management, but they should be used with consideration of their limitations. It has been suggested that models can only achieve two of three desirable model attributes: realism, precision, and generality (Levin 1966; Dickey-Collas 2014). Increasingly, models of fishing impacts or natural disturbance have been produced at a large sea scale and have then been applied at a smaller MPA or feature-scale without empirical validation. If Levin was correct, then broadscale models need to be recalibrated to site scales, perhaps through expert judgement and empirical evidence, to give appropriate context of issues such as data gaps, historical fishing levels, and in-combination with the cumulative effects from other activities. Interestingly, Natural Variability Phase II found that natural disturbance models were useful at Dogger Bank SCI which is a large MPA with a wide range of external pressures, but not at The Wash and North Norfolk Coast SCI which is smaller, coastal and more complicated in terms of their external pressures (Johnson *et al*., 2017). All of these factors together mean that there is a requirement for greater spatial resolution of input layers compared to some offshore sites.

Where there are data gaps or uncertainty in terms of application, modellers often produce several different models to ensure that the approximation of reality is captured in the range of models (e.g. ABPmer and Ichthys Marine, 2015a-d; Diesing *et al*., 2013). However, this can be overlooked when decision-makers get use of the model as a tool without the accompanying information on caveats and limitations.

It is important not to lose the caveats associated with many of the modelling studies. Whilst relating the frequency of natural disturbance events to the frequency of trawling will give a relative indication of the resilience of an area (e.g. sediments that are disturbed six times a year by waves and currents may contain infauna communities that are relatively more resilient to the physical effects of fishing than those that are disturbed once a year by waves and currents), the actual events are not analogous and are mechanistically different (see Diesing *et al*., 2013). Though recent studies have looked at quantifying the magnitude of effects of physical disturbance and bottom trawling, they are still limited by collinearity and the unknown contribution of historic fishing (van Denderen *et al*., 2015). Nevertheless, the communities found across gradients of physical disturbance do seem to fit the general ecological theory on the composition and body-size structure of communities in relation to disturbance (e.g. Connell, 1978).

In a number of empirical studies, a threshold has been set where the number of trawling events exceeds the number of natural disturbance events to determine when fishing effects start to exceed natural change (e.g. ABPmer and Ichthys Marine, 2015a-d; Diesing *et al*., 2013). This assumes that the natural disturbance events set an envelope within which fishing would have a negligible effect on benthic communities. The problem is that at present there is limited empirical evidence of how these two drivers interact spatially and temporally on benthic systems. For some sensitive habitats, they could have an additive effect whereby the impact to benthic communities is greater when both natural changes and fishing are co-occurring.

Furthermore, storms tend to occur in winter months and fishing activity can be spread more evenly throughout the year. Thus, three storm events and three fishing events spread evenly across the year could result in a potential reduction in the recovery time between events from 4 months to 2 months. If the effects were additive, this could result in the communities being maintained in a modified state without sufficient time to recover. However, this does not mean that benthic communities from naturally mobile sediments are not relatively more resilient to anthropogenic sources of physical disturbance than communities from more stable conditions, just that demersal fishing can still have an effect and the size of this effect is likely to be dependent on the seasonality of fisheries. An alternative way of looking at the issue is to adopt a more fisheries based concept of sustainability, in that the frequency of disturbance (assuming that disturbance is the source of mortality) must not exceed the rate at which the affected population can restore itself through recruitment and growth.

5.3 Pressure pathways

It is important to note that this project has briefly reviewed specific recent literature in relation to the physical impacts of demersal fishing on benthic habitats and associated species. Scientific understanding in this area is advanced and at a stage where models of fishing impact and recovery, underpinned with direct empirical data, can be applied to different marine habitats across the globe (see https://trawlingpractices.wordpress.com).

Direct physical damage to the seabed is not the only pressure that trawling can exert on the seabed. Others include removal of target and non-target species (Collie *et al*., 2016) and interactions with other mobile species such as seabirds and cetaceans. This will be a particularly important consideration when these species are typical or characteristic of a designated site and support higher trophic levels (e.g. sandeel). For some empirical studies, the net effect of fishing is observed, whereas other modelling studies only try and predict specific physical impacts on the seabed.

5.4 Cost versus benefits

In a time when scientific funding is reduced, it is imperative that we make best use of the evidence that already exists in terms of fishing impacts and ensure any research is as cost-effective as possible.

It could be argued that specific experimental impact studies at every MPA would be the most robust way to inform fisheries management, but this would be prohibitively expensive. Models offer a more cost-effective option by utilising the empirical data we do have and extrapolating to fill the gaps. However, many of these models are broadscale, which is a factor of the spatial resolution of the input data layers, be they broadscale habitat maps or aggregated VMS geodata layers. Though useful to compare between sites and regions, due to the complexity of influences at each site and for each designated feature (gear modifications, in-combination effects, important local environmental variables), the broadscale maps do not accurately represent the situation at finer scales. This was evident in the work of Johnson *et al*. (2017), where natural disturbance models performed better in terms of explaining deviance in benthic metrics at Dogger Bank SCI compared to the Wash and North Norfolk Coast SAC. Thus, broadscale statistical models need calibrating to specific site requirements using empirical data and expert judgement. The current confidentiality issues associated with the use of VMS data by the scientific community are a major impediment to enable science providers to generate spatial and fishing-gear specific advice on potential impacts and thresholds of sustainable levels of disturbance (Hinz *et al.*, 2013).

5.5 Recommendations

MPA fisheries management advice currently is given by the UK statutory nature conservation bodies to the relevant fisheries management bodies (IFCAs, MMO and Defra) who are responsible for the design, implementation and enforcement of fisheries management measures (where they are required) to ensure that the conservation objectives for MPA features are met.

Several different evidence sources and types are utilised to provide this advice and the purpose of this review was, in part, to see how new research on natural change/variability could be incorporated into SNCB advice in order to contextualise the likelihood of impacts from fishing activities. Below is a summary of existing evidence sources used at different stages of the MPA designation and management process and suggestions for supporting evidence and data gaps.

Table 5.2: Integration of new tools into existing evidence base and MPA process

Stage of MPA process	Existing evidence	Supporting
Site Selection	Existing survey data and commissioned site characterisation and monitoring survey data	Supplementary information on natural processes at the site. Hydro- and sediment dynamics. Dominant processes such as susceptibility to freshwater inputs or cold winters.
Conservation Objectives and Advice on Operations	Existing survey data and commissioned site characterisation and monitoring survey data; comparison with relevant similar habitats in other regions; information on levels of historic fishing activity (JNCC only); habitat sensitivity information from the Marine Evidence based Sensitivity Assessment (MarESA) and previous Defra MB0102 outputs assessed against pressure benchmarks and based on empirical data.	Models of natural disturbance (e.g. Diesing *et al*., 2013; Hiddink *et al.*, 2006) could be used as a platform to compare to sensitivity assessments. Evidence suggests these tools are most useful for large offshore sites that are dominated by hydrodynamic processes. Expert judgment may be required to adapt them to the spatial scale of an individual MPA and consider factors including historic fishing impacts and in-combination effects.
Fisheries management advice	A risk matrix is used help regulators identify which activities required priority management measures to be introduced to protect a feature without further site level assessment or where further assessment may be required. Relevant literature on impacts of specific gear types and configurations on a feature-by-feature basis. Stakeholder engagement to fill evidence gaps and agree on an approach for the site based on local context.	Proposed framework for the quantitative assessment of trawling (Rijnsdorp *et al.*, 2016). New information on specific gear types and gear configuration (e.g. Depestele *et al.*, 2015) Initiatives such as iVMS to improve estimates of fishing activity for the <12m fleets. Reactive management, where sensitive habitats may be protected following periods of strong natural disturbance to allow a period of recovery (Johnson *et al*., 2017).
Monitoring and assessment	Indicators and methods are under development, but monitoring surveys are at present based around condition monitoring of each feature and correlative pressure-state designs.	Experimental closures and empirical BACI-type studies can be used to determine levels of sustainable fishing for specific sites (see Lambert *et al.,* 2015a; 2015b)

SNCB fisheries advisers endeavour to make their assessments as evidence-based and fit for purpose as possible. Where possible, they make their assessment based on evidence from peer-reviewed scientific journals, although in the absence of these, they also use grey literature (such as Government agency reports), expert judgement and the use of proxies for habitats, species and gears to inform assessments. As such, they are used to utilising different types of evidence or varying evidence quality and recognise the limitations associated with each.

What was evident during this review was that the evidence base is heterogeneous; some research groups focus on statistical models, others use trait-based empirical impact studies, and some look at the physical effects of very specific arrangements of fishing gear. When considering fisheries management, all of these evidence sources are required to form the evidence base on which advice is based. In particular, due to the high degree of variability within some habitat categories, the large numbers of fishing gear types and combinations under consideration, local variation in fishing practices, effects of historic fishing, possible in-combination effects, and the importance of local environmental factors, it is necessary to layer the different types of evidence in order to issue advice. Reactive monitoring and adaptive risk management will be required to ensure that the advice can be validated for each site.

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