Partners in UK offshore wind

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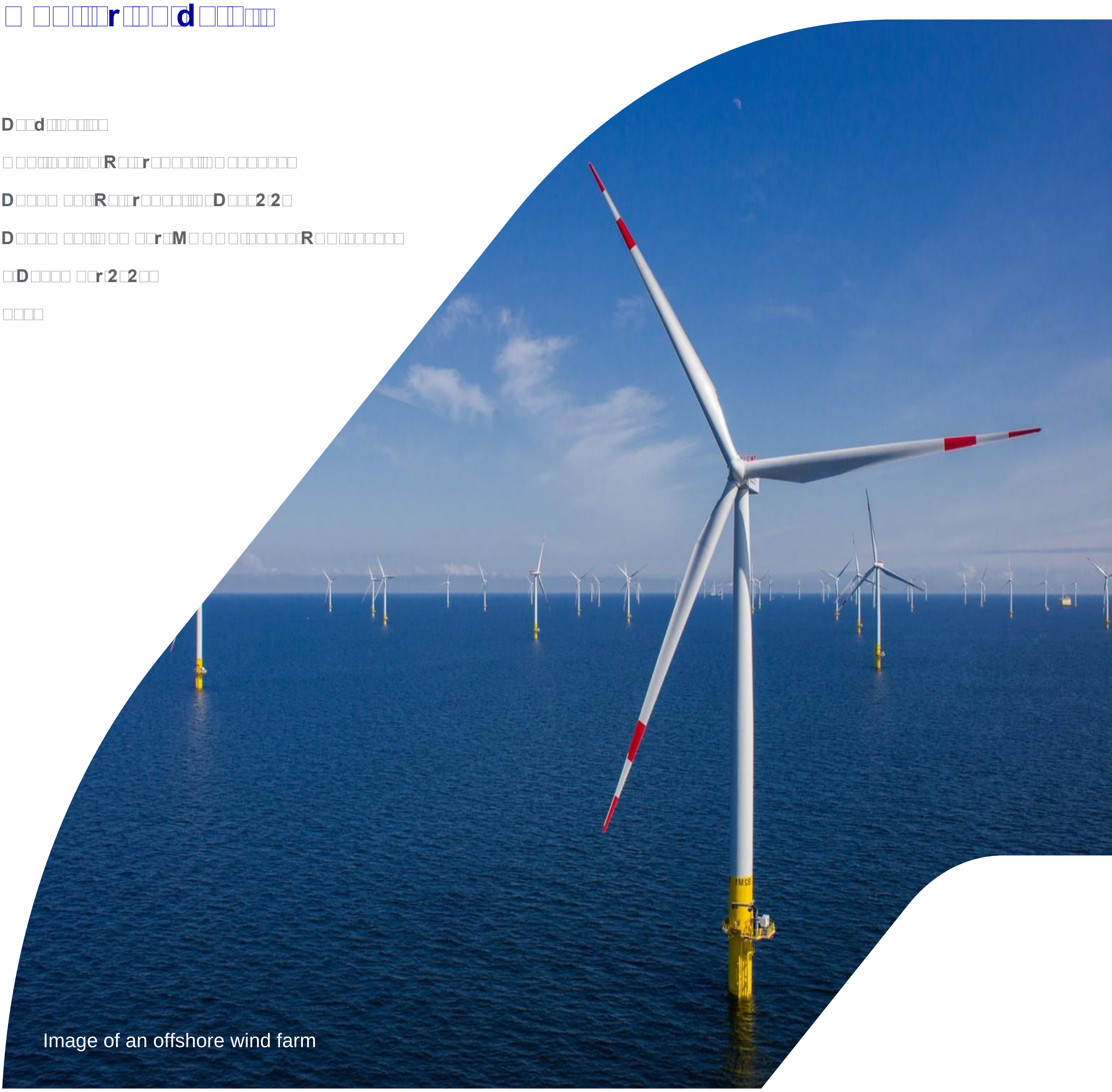

Image of an offshore wind farm

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F01	Submission at D5	RPS	Mona Offshore Wind Ltd	Mona Offshore Wind Ltd	3 Dec 2024

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□r□□□□□□□d□d□□□: Defra and The Marine Management Organisation

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R□□□r□□□r□□□r□d□□□: Fugro EMU with support from British Trust for Ornithology (BTO), National Physical Laboratory (NPL) and SMRU Marine.

Disclaimer

This report contributes to the Marine Management Organisation (MMO) evidence base which is a resource developed through a large range of research activity and methods carried out by both the MMO and external experts.

The opinions expressed in this report do not necessarily reflect the views of the MMO nor are they intended to indicate how the MMO will act on a given set of facts or signify any preference for one research activity or method over another. The MMO is not liable for the accuracy or completeness of the information contained nor is it responsible for any use of the content.

Report to be cited as

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First published April 2014.

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□D□□□	Acoustic Doppler Current Profilers
□DD□	Acoustic Deterrent Device
□□D□□	Acoustic Ground Discrimination Systems
□□□□□	Before And After Control Impact
□□□□	Before-After Gradient
□□□□	Federal Maritime And Hydrographic Agency (Germany)
□□□□	Civil Aviation Authority
□□□ □	Countryside Council For Wales
□□□□□□	Centre For Environment, Fisheries & Aquaculture Science
□□□□□	Catch Per Unit Effort
□R□□M□	Centre For Research Into Ecological And Environmental Modelling
D□M□	Digital Terrain Maps
□□□	Environment Agency
□□□	European Commission
□M□□	Electromagnetic Fields
□M□□	Environmental Management Plan (also referred to as the MMP)
□□□□	English Nature (now Natural England)
□□□	Environmental Statement
□□D□	Fish Attraction Devices
□□□□□	Food And Environment Protection Act, 1985
□□□□	Formazine Turbidity Unit
□□M□□	Generalised Additive Models
□R□□	Habitats Regulations Assessment
□□□□M□□	International Advisory Panel Of Expert On Marine Ecology
□□□□	International Organization For Standardization
□□□□	Invitation To Tender
□D□	Lynn And Inner Dowsing
M□□□□	Marine And Coastal Access Act, 2009
M□□□□	Multibeam Echosounder
M□□□	Monitoring And Evaluation Programme
MM□□	Marine Management Organisation
MM□□□□	Marine Mammal Observer
MMM□□	Marine Mammal Mitigation Plan Document
MM□□□	Marine Monitoring Plan
M□□	Marine Scotland
M□□D□	Marine Strategy Framework Directive
□□□□	Non-Indigenous Species
□□□ □	Near Shore Wind Farm
□□□□	Nephelometric Turbidity Units
□□□□	Optical Backscatter Sensors
□R□□□□	Offshore Renewables Joint Industry Programme
□□ □□□	Eegmond Aan Zee

□□ □□	Offshore Wind Farm
□□	Pathways, i.e. The Route Or Medium That Changes The Environment Of A Receptor
□□**M**□	Passive Acoustic Monitoring
□□□**D**□	Population Consequences Of Disturbance
□□□□	Particle Size Analysis
□□□□	Permanent Threshold Shift
R□	Environmental Receptors, I.E. Something That Is Sensitive To A Specified Change
□□	Source, I.E. The Origin
□□**M**□	Static Acoustic Monitoring
□□□	Sub-Committee
□□□□	Sound Exposure Level
□□□□□	Statutory Nature Conservation Body
□□□□□	Special Protection Areas
□□□□	Sound Pressure Level
□□□□	Suspended Sediment Concentrations
□□□□□	Site Of Special Scientific Interest
□□□	Technical Committee
□□□□	Temporary Threshold Shift
□□ □□□	Underwater Television
□ □□	Working Group
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Foreword

The Marine Management Organisation (MMO) is responsible for most marine licensing in English inshore and offshore waters and for Welsh and Northern Ireland offshore waters. The licensing process involves a thorough assessment of the likely effects of any proposal on the marine environment; identification of measures required to mitigate impacts; and includes provisions for marine environmental monitoring once consent is granted.

Post-consent monitoring requirements can be incorporated into licence conditions, and are included in order to:

a. Validate, or reduce uncertainty in predictions on environmental impacts recorded in supporting Environment Impact Assessments (EIA) and Habitats Regulation Assessments (HRA).
b. Provide evidence on the effectiveness of mitigation measures.
c. Allow identification of any unforeseen impacts.

Post-consent monitoring is also important because the information attained can contribute to the evidence base, which can then influence future licensing conditions.

In 2010, The Marine and Fisheries Agency (which preceded the MMO) commissioned Cefas, Fera and SMRU Ltd to undertake a strategic review of offshore wind farm (OWF) monitoring conditions associated with FEPA Licences (Cefas 2010). The project reviewed monitoring reports from ten wind farms, which were operational or under construction in English and Welsh waters at that time. The aim of this project was to summarise the monitoring undertaken at each site and compare the monitoring and licence conditions between sites to distinguish between generic and site specific issues. In addition, the project sought to identify comparability of datasets; assess which conditions could be removed or require amendment; and where possible, forecast implications of identified effects for future Rounds of OWF development. The Cefas report produced a number of recommendations, but identified few conditions that could be either amended or removed from licences, which was in part a consequence of the limited number of cases and hence evidence from which to draw on.

In 2011, Renewable UK (the trade and professional body for the UK wind and marine renewable industries) produced a report on Consenting Lessons Learned - An offshore wind industry review of past concerns, lessons learned and future challenges (Renewable UK 2011). This report sought to reflect on the key challenges identified through OWF Rounds 1 and 2 development, and provide recommendations to facilitate improvements in understanding and processes for applications associated with future Rounds. A key issue highlighted in this report was the need to review and understand the evidence gained from data collection associated with licence conditions, and to refine and improve data collection strategies. This report (along with the Cefas 2010 report) also highlights the need for further guidance on data acquisition to help facilitate comparability and assessment of evidence between developers. This latter need has been addressed through the development of guidance produced by Cefas, and approved by the Offshore Renewable Energy Licensing Group (Cefas (2011).

In November 2011, the Government announced a review of the Habitats and Wild Birds Directives, as currently implemented in England, with a view to reducing burdens on business while maintaining the integrity of the purpose of the Directives. The review (HM Government 2012) contains a number of measures which include:

> (15) Establish a Habitats and Wild Birds Directives Marine Evidence Group to address marine data sharing, research gaps, and post-construction monitoring
>
> (18) New rolling programme of post construction monitoring reviews on priority marine sectors, which is to be undertaken by Cefas and the MMO.

A key priority identified for the Marine Evidence Group was to develop a more strategic approach to post construction monitoring of marine developments so that monitoring is better designed and targeted to inform future development proposals, mitigation measures and conditions of licence. This could also include development of post construction monitoring protocols specific to individual sectors, including OWF.

In response to the Cefas, Renewable UK, and the Habitats and Wild Birds Directives reviews, Defra, the MMO and Cefas commissioned an updated review of OWF monitoring data, to inform recommendations on improving future license-related monitoring strategies. This report is the independent review prepared by Fugro-Emu in partnership with others.

The work described in this report was overseen by an expert steering group throughout the duration of the project. The members of the steering group included staff from Cefas, the Crown Estate, The Department of Energy & Climate Change, Defra, MMO, Marine Scotland, Natural England, Natural Resources Wales, and representatives from industry. We would like to thank the steering group for their contributions during the delivery of this work.

The recommendations contained within this report will be considered by the MMO, Cefas and the Marine Evidence Group, in consultation with relevant stakeholders in order to determine whether they will be taken forward into decision making processes.

Executive Summary

This report examines outcomes and conclusions from monitoring regimes undertaken as a result of statutory requirements imposed on developers of OWFs in UK waters through consent conditions.

Consent conditions are typically developed between the regulator (advisors and stakeholders) and developer as a project evolves. The terms of the consent conditions are translated into monitoring specifications which are required to be undertaken for defined durations. The consent conditions require that the outcomes of these monitoring programmes are subsequently reported to the regulator.

The monitoring requirements are largely driven to:

- validate predictions made in an EIA or HRA
- detect any unforeseen impacts
- ensure compliance with measures identified in assessments to mitigate significant impacts.

Two important considerations for monitoring are:

i) **Uncertainty** – the extent of error or assumptions that were made in calculating the impact. The higher the degree of uncertainty, the greater the need to monitor
ii) **Significance** – the extent to which the identified impact is deemed significant.

The aims of this report are to:

- Provide a review of the extent to which data collected through post-consent monitoring has enhanced the evidence base on direct and indirect impacts of OWFs both at the site, and generic level
- Explore whether the rationale and objectives of the post-consent monitoring conditions are appropriate, proportionate and achievable, and whether monitoring strategies and licence conditions are presently fit for purpose or require amendment
- Produce a list of recommendations to improve monitoring in the future and ensure that data collection is targeted at areas where the largest risks and uncertainties remain.

To achieve these aims the study has been undertaken in three tasks listed below:

- Task 1: Site-specific review
- Task 2: Synthesis review of evidence gathered from all Offshore Wind projects (i.e. as documented through Task 1)
- Task 3: Recommendations on a framework for identifying and implementing future post-consent monitoring.

This report describes the outputs from Tasks 2 and 3. More detailed results from Task 1 will be published separately.

[illegible]

For each OWF site a set of generic questions was asked within each applicable topic. For some topics not all of these questions are relevant, or an alternate set of questions was also necessary. Where this was the case these variations are further specified within the text, under topic specific variations. For each topic a Pro Forma was developed for these questions with further technically appropriate sub-questions, in order that a consistent approach was taken across all wind farms.

Site-specific questions:

1. Is the rationale for the monitoring activity clearly defined? Are stated objectives or hypotheses defined and are they cross referenced to consent conditions or, where applicable, the level of predicted impact for that receptor within the corresponding ES and/or HRA?
2. Are data gathered appropriate to the defined rationale/objective/hypothesis/licence condition? For example, do the data reduce uncertainty in the impact described in the ES or HRA for a defined receptor?
3. Are data collected of sufficient statistical power and have suitable statistical analysis been used to validate the findings of the monitoring report? Have data been collected over the appropriate temporal and spatial scale in order to be able to successfully detect change?
4. Where industry standard methodologies and equipment are available for data collection and interpretation, have these standards been followed i.e. in line with Cefas (2012) or previous (JNCC 2001) best practice guidelines. Is there evidence of adherence to national or international quality procedures?
5. Have any unforeseen impacts been identified? If not, has any consideration in the monitoring report been given to the possibility of impacts outside of those described in the ES and HRA occurring?
6. Where applicable to the type of monitoring, assess whether current monitoring conditions are appropriate, proportionate and achievable. Will a continuation of data collection increase understanding of impacts?

[illegible]

The review is split by topic areas identified above. For each topic area the review points below are considered, citing results from the site-specific review of OWF monitoring reports including any notable exceptions. Additional information from case studies abroad has also been used to address the synthesis questions outlined below where appropriate.

Synthesis questions:

1. Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?
2. What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data

acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403

3. Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?
4. Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs?
5. Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

[illegible]

The third phase provides recommendations through a framework to identify and implement future post-consent monitoring. These were derived from a workshop with key industry stakeholders in which the results of Task 1 and Task 2 were reviewed.

1. [illegible]

1.1 There is currently a large variation in approaches to data collection and assessment methodologies between sites and across the UK Devolved Administrations. An inter-agency specialist team of technical experts (topic/taxa specific teams) who work across all regions and all topics could be established to facilitate the development and adoption of best practice. These could either be specialist virtual teams set up as part of existing government and advisory departments or a new independently employed team. In effect this would be a restructuring of the current situation where case officers from the MMO, Cefas, SNCBs, developers and consultants work formally together on specific applications, complemented by a core team who have an oversight of licensing and monitoring issues across sites and the Devolved Administrations. This will improve consistency between sites/projects/regions and provide the remote overview required to ensure that maximum learning is gained from each site.

2. [illegible]

Historically there has been no single set of agreed standards for the following elements necessary to fully utilise previous reports:

2.1 One central statutory/government organisation to compile, hold, organise and provide access to all relevant communication, reports, ESs, licences and subsequent changes to monitoring within a centralised and accessible database with a common structure across all projects. All signed-off monitoring plans, monitoring reports, agreed amendments (with explanations for any changes) to licence conditions and monitoring scopes should be available online. A good example of a valuable collation and presentation of such kind of documents and communication tracing is the Planning Infrastructure Portal found under (http://infrastructure.planningportal.gov.uk/) which is well organised, accessible and easily searchable. A similar approach could be extended to cover the post consent phases of projects.

2.2 All raw monitoring data and outputs derived should have a consistent naming convention reflective of the content of the document as described by an agreed data management protocol. This should improve the functionality of metadata repositories, e.g. The Crown Estate and MEDIN as searching for information should be easier. The issue of storing large scale, geophysical datasets is recognised and the best means of holding these data, potentially including a requirement for the site owners to hold this data, will need to be agreed.

2.3 Some summary reports/post construction monitoring reports are available on the website of the developer. This is commended and to be encouraged although should not detract from efforts to establish the central data/report repository.

Reporting

2.4 Agreement over standard approaches to reporting – e.g. annual updates with a final report drawing everything together

2.5 All reports should be subject to a single and consistent naming convention

2.6 All relevant reports should be supported by source or raw data

2.7 All reports should have a mandatory metadata section up front identifying the report purpose (i.e. post construction Year 2 monitoring), date, author, relevant licence requirement etc.)

2.8 Regular reviews of previous monitoring results would provide a good general indication of monitoring results. For instance, Substantive Reviews, which are currently required for the aggregate industry every 5 years, summarise previous annual or bi-annual monitoring results. These reports and monitoring results provide a clear understanding of environmental change associated with a development over time and are summarised in one easily accessible report covering all topics. These review reports should be compiled by, or the compilation should be supervised by, the specialist technical expert groups mentioned in recommendation item 1.1.

Standard[illegible] Data [illegible]

2.9 A data management protocol should be written (ownership of which lies with the central government organisation charged with holding and disseminating reports).This should cover those elements listed in recommendation item 2 above (main report Section 6.2) for example, data standards, file naming, metadata etc. Topic specialists will need to input into these

2.10 The reporting of metadata is required for all studies. Guidance for recording of metadata is provided by organisations such as MEDIN and should be pre-agreed through the data management protocol

2.11 Consenting process should ensure data must be collected in formats that are compatible for use in other PCM and/or cumulative studies (subject to agreement of data owners). The use of templates with topic/receptor specific minimum requirements and guidelines for the developers should be established. This should be specified in the data management protocol

2.12 The formats and metadata for raw and derived data in particular, need to be clearly captured by the data management protocol

2.13 All data (raw and derived) needs to be supported with information on methodology/protocols used in their collection/analysis.

[illegible]

2.14 All changes to a licence should be captured in the licence document such that it is clear what revisions/changes occurred and when they were made.

2.15 The licence is recommended to have a cover page which lists the revision history.

[illegible]

2.16 Historically changes to monitoring requirements are far from transparent which can inhibit the use of the monitoring outputs in contributing to the consent process for other sites. It is recommended that a system be put in place to capture changes transparently and allow for a clear audit trail with respect to those changes.

[illegible]

Recommendations on management of data such that they can be made compatible between different studies will fall out of the comparative studies and data management protocol. Development of regional environmental assessments, with respect to certain receptors, and regional monitoring (building on concepts employed by the aggregate industry) should be considered and discussions opened with both developers and owners to determine the practical application of this type of approach. Such discussions with developers are beyond the scope of this review, however may be achievable though input from the Project Steering Group.

[illegible]

By defining the minimum appropriate scales (temporal and spatial) over which PCM can occur, the potential for co-ordination with other developers (offshore wind, tidal and wave energy, aggregate extraction etc.) can be identified and integrated into monitoring efforts.

Cross topic recommendations are:

4.1 Round 3 sites will be a region themselves and so it may not be beneficial to use other Round 3 site reports, although it is important to acknowledge that the extent of the region is dependent on the effects and distribution of receptors. However, if they are close to R1/R2 sites or aggregate licence areas, the use of earlier relevant reports would (in most cases) help inform monitoring

4.2 Future offshore renewable energy projects (e.g. wave and tidal) would benefit from the bank of knowledge gained from the wind industry. As a whole this should help bring down industry costs

4.3 The practical constraints that arise during this process could be resolved to some extent by the establishment of the group in recommendation item 2.1, which would manage all data and, in the process get all parties involved to agree to the contribution of data. This would be an important precursor to initiating collaborative data collection where clear intra and inter-industry cost savings could be envisaged.

[illegible]

The cross topic recommendations for a suitable model for formal review of the monitoring data are:

5.1 Topic specialists/consultants and regulatory authorities need to come together to form relevant, site-specific conditions for each process where a sensitive receptor has been outlined as being potentially impacted in the ES

5.2 Topic specialists/consultants should be involved in review stages of technical reports, to ensure best practice is being adhered to and the results presented are relevant to monitoring sensitive receptors that have been identified in the ES

5.3 If monitoring plans are changed, these should be recorded in a monitoring appendix to the licence, the Marine Monitoring Plan (MMP) also referred to as the Environmental Management Plan (EMP) in some cases – this review has highlighted the discrepancy between required licence monitoring conditions and actual monitoring that is undertaken by the developer.

5.4 Unforeseen consequences of building an OWF should have new monitoring applied through a variation made to the licence, which should be added as a separate condition for clarity (where this is agreed to be necessary i.e. a potentially significant impact is predicted) – as above, this could be included in a monitoring appendix linked to the original licence

5.5 Conditions need to be site-specific, fit-for-purpose and driven by sensitive receptors. A new condition for one site should not be applied to all subsequent licences unless similar sensitive receptors and impact pathways have been identified

5.6 Sharing of knowledge/experiences should reduce the likelihood of any unforeseen circumstances/impacts

5.7 Final monitoring reports should be reviewed to ensure that the necessary analyses have been undertaken satisfactorily and to evaluate how well the predictions from the EIA have been borne out and whether significant uncertainties have been reduced and thus monitoring programmes adaptively changed.

The review process of licences and monitoring conditions should be adaptive to capture changes in:

- Development approaches for OWFs (multiple/parallel projects in a given zone for example)
- The physical environment in which OWFs are planned (deeper water for example, with respect to sound propagation)
- The ecosystem in which OWFs are planned (with respect to potential impact on marine fauna)
- Available technology (for example different construction methods, mechanical mitigation or larger capacity turbine)
- Scientific approach/best practice (the availability of international standards for example).

[illegible]

6.1 Particular emphasis in the formatting of the conditions will be placed on defining achievable objectives, which will be mirrored in the reports, including well defined hypotheses. An option for achieving this without over-complicating the licences is to introduce greater standardisation to the Marine Monitoring Plan (MMP) as currently employed to include the detailed rationale and hypotheses for evaluation in the PCM. The MMP should be included, as an annex, in all new licences, and can then be referred to rather than having to include the details within the licence itself, as in many earlier licences. It will be essential for the version number of the MMP to be documented in the licence, with the version number updated and the licence varied to reflect any changes to the MMP. The same principles to drafting licence conditions (i.e. ensuring that they are proportionate, achievable and enforceable) should be applied to formulating the MMP. As the MMP is annexed to the licence it still represents a legal document.

In addition to the above on formatting consent conditions and the MMP, the recommendations below are required for the formatting of reports:

6.2 Critical environmental metadata should be reported to allow interpretation of the measured data

6.3 A clear statement should be provided on which units, procedures and guidelines have been used within the report

6.4 Reporting of data should be consistent where possible with international standards, although the metrics and format in which the data is reported will be dependent on the type of data being measured

6.5 All source or reference data should be detailed and fully referenced

6.6 The report should include a clear and unambiguous section describing the aims of the report including what it intends to achieve, which must be directly linked to the conditions of the monitoring

6.7 Significant impacts for key receptors, as defined in the HRA and ES, in combination with the monitoring methods used to investigate the impacts, as defined in the MMP, should be presented, preferably as a table in the introduction of the report

6.8 Clear hypotheses should be presented for each of the sensitive receptors identified, followed by a detailed description of post consent monitoring methodologies

6.9 In all cases the full spectrum of metadata, raw data, analysed data (which must include a clear identification of changes made to the raw data) and data analysis methods, used to draw the conclusions (including detailed statistical methods in appendices if necessary), should be presented or made available to allow third party, independent evaluation

6.10 Conclusions should be drawn with respect to exceedance or compliance with identified threshold levels and/or hypotheses. Cross references to the predictions presented in the EIA should be made indicating whether the predictions were correct and the consequences if they were not

6.11 Feedback from the MMO or appropriate regulator should form an integral part of a final signed off report, using a tabulated format corresponding to compliance with the conditions, acceptance of the conclusions of the hypotheses and consequences of these, e.g. no action or action should be continuation of monitoring, further scour protection recommended, etc.

[illegible]

7.1 Generally, environmental monitoring needs to be focused on areas identified in the ES (and agreed by the regulatory authorities) to be most likely to result in potential impacts on a sensitive receptor(s)

7.2 Guiding principles for this would require the application of risk-based criteria e.g. establishing the likelihood of effects through standard Source-Pathway-Receptor relationships.

[illegible]

8.1 Where possible, recommendations on what periodicity of sampling and what spatial scales will be most appropriate for a range of categorised wind farms will be given. The guiding principles will be built upon the basis of temporal and spatial extent of required monitoring, to be confident that conclusions drawn from monitoring data are correct, i.e. for how long and over what time scale do you have to collect monitoring data to be confident in the findings? Where not possible or appropriate to do so, current knowledge gaps will be identified.

8.2 Across all topics monitoring should be receptor driven using EIA and HRA impact statements as a hypothesis for investigation. Monitoring should be used where there is uncertainty in the significance of an impact which could lead to a potentially significant impact on a sensitive receptor. Surveys should be designed so that data collected can reduce uncertainty in impact significance statements.

8.3 Hypotheses to be tested in monitoring should be clearly stated in monitoring plans and monitoring reports so that the objectives are not lost.

8.4 Monitoring should not be required for impacts where there is already high certainty. For impacts where there is a significant impact with a high degree of certainty, mitigation should be used to protect the environment and other uses of the sea. There may, however, be circumstances where uncertainty remains in the effectiveness of mitigation proposed. In these instances monitoring should be used to reduce uncertainty, testing the hypothesis questioning the effectiveness of mitigation.

[illegible]

Fugro EMU has been contracted to undertake a review of post-consent monitoring data and reports collected from UK OWF developments to investigate the evidence associated with environmental impacts and from this, to make recommendations to maximise the effectiveness of future monitoring programmes

This report examines outcomes and conclusions from monitoring regimes undertaken as a result of statutory requirements imposed on developers as a result of consent conditions. Section 2 provides a detailed introduction to the study and current OWF renewable energy projects in the UK. Section 3 examines the theory behind consent conditions and why they are necessary and Section 4 defines the methodology and approach taken in this study. Section 5 presents the findings of the synthesis review with Section 6 onwards making recommendations with respect to ongoing and future monitoring.

[illegible]

The aims of this report are to:

- Provide a review of the extent to which data collected through post-consent monitoring has enhanced the evidence base on direct and indirect impacts of offshore wind both at the site, and generic level
- Explore whether the rationale and objectives of the post-consent monitoring conditions are appropriate, proportionate and achievable, and whether monitoring strategies and licence conditions are presently fit for purpose or require amendment
- Produce a list of recommendations to improve monitoring in the future and ensure that data collection is targeted at areas where the largest risks and uncertainties remain.

With the objective of contributing to the consenting process, this project has reviewed the supplied post-consent OWF data and reports which have been conducted over approximately the past decade and under various regulatory and consenting regimes.

2 [illegible]

The UK has ambitious targets for the deployment of offshore renewable energy. The UK is legally committed to delivering 15% of its energy from renewable sources by 2020 and offshore wind is seen as playing a key role in meeting renewable energy targets and the offshore wind energy programme has gathered apace over the past decade and the UK is now the world leader in offshore wind with more installed capacity than any other nation. Figure 1 displays current and proposed UK OWF.

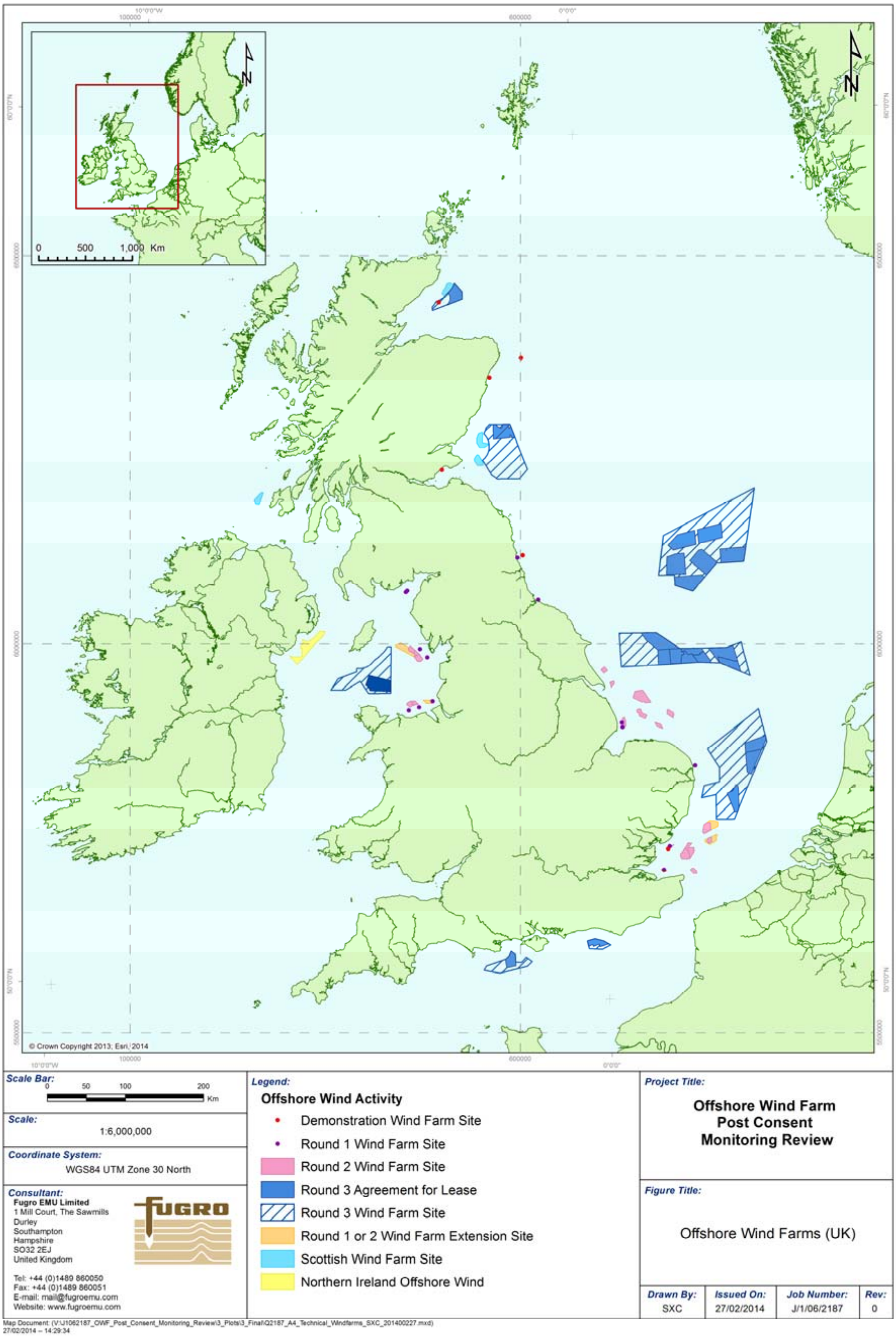
These targets are being achieved through the leasing of the seabed by The Crown Estate (TCE) to wind farm developers in competitive bidding rounds of which there have been six so far (Rounds 1, 2, 2.5, Scottish territorial waters sites, Round 3 and Northern Ireland). There has been a significant increase in scale from Round 1 to Round 3, with Round 1 consisting of 13 relatively nearshore wind farms, with each site typically having a maximum capacity of 0.1 GW. Round 2 sites are larger (with each site being on average 0.42 GW).

The Round 3 developments will have the potential to contribute up to 33 GW of energy due to their increased size and scale. The eight remaining Round 3 development zones are situated variously near shore to hundreds of kilometres offshore. The considerable increase of the expected capacity of Round 3 is demonstrated in Table 1. It should be noted that some Round 3 zones will yield multiple development applications due to their size, which necessitates a phased approach to development. The Scottish territorial waters sites add a further 4.8 GW of potential capacity.

[illegible]

[illegible]	[illegible]	[illegible]
1	1.16	13
2	7.2	17
2.5 (extensions to R1 and R2)	1.5	6
3	31.7	8 (zones)
Scottish territorial waters	2.9	4
[illegible]	[illegible]	[illegible]

[illegible]



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Coordinate System:
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Consultant:
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Offshore Wind Activity
Demonstration Wind Farm Site
Round 1 Wind Farm Site
Round 2 Wind Farm Site
Round 3 Agreement for Lease
Round 3 Wind Farm Site
Round 1 or 2 Wind Farm Extension Site
Scottish Wind Farm Site
Northern Ireland Offshore Wind
Project Title:
Offshore Wind Farm Post Consent Monitoring Review
Figure Title:
Offshore Wind Farms (UK)
Drawn By: SXC
Issued On: 27/02/2014
Job Number: J/1/06/2187
Rev: 0
0 500 1,000 Km

[illegible]

The most significant piece of legislation for marine licensing in the UK is the Marine and Coastal Access Act 2009 (MCAA), which received Royal Assent on 12 November 2009. The MCAA created a new marine planning system designed to bring together the conservation, social and economic importance of our seas.

The Act also includes new approaches for managing and protecting coastal and marine waters through:

- The establishment of the Marine Management Organisation (MMO) in England
- A new UK system for marine planning, taking account of all activities and resources and encompassing issues related to the land-sea interface
- Streamlining the UK Government's regulatory regimes for considering and licensing certain types of marine development, simplifying the process at the same time as delivering objectives to ensure sustainable development
- New mechanisms for the conservation of marine ecosystems and biodiversity, including the designation of a network of Marine Conservation Zones (MCZs) / Marine Protected Areas (MPAs), both for protection of individual habitats and species.

As a licensing authority, the MMO determines applications for marine electricity generating installations of 100MW and below under the MCAA. The MMO also has powers to issue section 36 consent under the Electricity Act 1989 for relevant electricity generating installations in both the MMO marine area and also in Wales. The MMO when considering an application for a marine licence, can grant the licence unconditionally, refuse the application or grant the licence subject to such conditions the licensing authority thinks fit.

In England, the MMO has a dual role as both a Licensing Authority and a Consultee (Interested Party) under the Planning Act 2008 (as amended). The Planning Act 2008 does not apply to Scotland or Northern Ireland. The MMO provides advice to the Planning Inspectorate (PINS) for electricity generating installations including OWFs over 100MW (offshore energy generating stations with a capacity more than 100MW are designated as Nationally Significant Infrastructure Project and require consent through the Planning Act 2008). PINS makes a recommendation to the relevant Secretary of State who can grant a Development Consent Order (DCO) for OWFs with a capacity of >100MW and the DCO can include a deemed marine licence. The MMO is responsible for the enforcement of the deemed marine licence conditions. As the majority of offshore renewable energy applications are now >100MW and hence Nationally Significant Infrastructure Projects under the Planning Act 2008, the MMO has an advisory role to PINS with an enforcement function and powers to vary, suspend, revoke deemed marine licences.

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The EIA Directive and associated Marine Works and Electricity Works EIA Regulations have been the largest driver for post construction monitoring in the UK.

However, the regulator has to consider a range of supporting legislation which provides further regulatory drivers. These include:

- Habitats and Birds Directives (which can lead to the requirement for a Habitats Regulations Assessment)
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention)
- Marine Conservation Zones under the Marine and Coastal Access Act 2009
- Marine Policy Statement
- Relevant National Policy Statement(s)
- OSPAR Convention
- Planning Act 2008
- Ramsar Convention
- Water Framework Directive
- Waste Framework Directive
- Wildlife and Countryside Act 1981.

Each piece of legislation must be considered by the regulator during consent decision process. If there is concern or uncertainty over a project's suitability or potential impacts then conditions can be attached to the Marine Licence. These conditions may include pre-construction, construction or post construction monitoring.

It is worth noting the majority of OWFs reviewed , i.e. Round 1 and Round 2, were permitted under the Food and Environment Protection Act 1985 (FEPA) and Section 34 of the Coast Protection Act 1949 (CPA). Under the MCAA, developers no longer need to apply for both a FEPA licence and CPA consents and developers now apply for a single marine licence. No distinction was made between FEPA and CPA consents during this review and only FEPA licences were reviewed as the CPA consent was granted for reasons of safety of navigation rather than environmental receptors *per se*. For this reason the present review makes reference to FEPA licences and not CPA or Marine Licences now issued under the MCAA.

The limitations of this earlier legislation had definite impacts on the monitoring conditions which were applied, for example FEPA capped monitoring conditions to a maximum of three years post-construction. Further, regulators were constrained in their approach by the requirement of these acts to assess specific project details in combination with set parameters (Cefas, 2004). As the Cefas guidance note on EIAs goes on to observe the high degree of uncertainty often still present in OWF designs still present at application stage made 'a robust scientific assessment of the environmental impacts very difficult' and led to delays in consent and the use of a pragmatic precautionary approach to the issuing of licences. This design uncertainty, captured by the Rochdale or Design Envelope approach, can also be seen as a contributing explanation as to why monitoring conditions often change post consent to account for changes to the OWF design.

[illegible]2 D [illegible] d [illegible]

Consent conditions are generally agreed between the regulator and developer through iterative drafts of the licence or through the ensuing negotiations between the developers and designated authority. The consent terms are translated into monitoring specifications which are required to be undertaken at key intervals or other defined durations. The outcomes of these monitoring programmes are subsequently reported to the regulator by the technical specialists procured by the developer to undertake the monitoring. The entire process can involve many different parties and chains of communication and therefore careful documentation of any licence changes, meetings and decisions is required in order to understand how a given monitoring requirement may have evolved. The monitoring requirements are largely driven to ensure compliance with measures identified in assessments to mitigate significant impacts, detect any unforeseen impacts and validate predictions made in an EIA or HRA. Two important considerations for monitoring are:

i) [illegible] – the extent of error or assumptions that were made in calculating the impact. The higher the degree of uncertainty, the greater the need to monitor
ii) [illegible] – the extent to which the identified impact is deemed significant.

Where the EIA process has assessed an impact as being significant (or where a sensitive receptor is identified), monitoring can be useful in validating the individual ES conclusions. Ideally the monitoring and subsequent reporting will contribute to a better understanding of the assessment; monitoring and mitigation thereby influencing future mitigation measures and monitoring requirements. In some cases this may result in a change to a specific project’s on-going monitoring requirements.

To this end monitoring should have clear aims, a clear hypothesis and a strategy for consequence should the monitoring regime determine the original conclusions are incorrect (see also the discussion on establishing environmental risks in Section 3.3). For comparison between, before, and after construction, the monitoring regime should consider either changes to the given receptor or a key variable in the pathway between the source and receptor, i.e. where a change in the environmental conditions as a result of the development has had an effect (positive or negative) on the existing environmental conditions. Subsequent monitoring reports should highlight the perceived reasons for the impact and draw conclusions based on comparisons with the original assessments. The case for monitoring should be a clear distillation of the impact assessment and not just monitoring for the sake of monitoring and conditions that relate to informing research should never be attached as a licence condition.

In turn this should contribute to the evolving cycle of EIAs and subsequent licensing and monitoring conditions for future developments – it is crucial that outcomes from ongoing monitoring regimes are drawn on to aid future decisions and to shape future monitoring regimes.

The subsequent monitoring data should ideally be readily available and comparable across all sites and can thus contribute to the collective knowledge database which then informs the EIA/HRA process of future developments.

Building on this, there is a clear need for regulators and developers to work together to drive down the size and complexity of the ESs. However, the net impact of increased volumes of applications and currently increasing size of the ESs compound the pressures on those bodies involved in assessing the applications and granting consents.

Whilst the rate of application is increasing rapidly, so are the difficulties with respect to EIA and HRA with complex issues of cumulative and trans-boundary impacts becoming significantly more relevant due to the greatly increased scale of the developments.

[illegible]

Defra (2011) presents a generic framework for environmental risk assessment with four main components:

- Formulating the problem
- Carrying out an assessment of the risk
- Identifying and appraising the management options available
- Addressing the risk with the chosen management strategy.

The MMO is developing these concepts (with Cefas, Fera and Cranfield University), to apply to their decision-making to ensure that the acceptability of environmental risks is considered across a range of diverse activities. Applying risk assessment principles in determinations on the need and scope for post-consent monitoring is important to ensure that these are proportionate, consistent, and appropriately targeted. This involves the systematic and explicit evaluation of a series of information layers from the pre-consent, ES determination and decision-making process to ensure that:

- The underlying problem (i.e. the trigger determining the need to monitor) is clearly defined. In monitoring parlance this could relate to defining a hypothesis
- There is a clear understanding of the hazard(s) associated with this problem (hypothesis) and the mechanism(s) through which receptors may be exposed / affected by the hazard(s)
- This understanding is used to establish the risk(s) which in turn guides the determination on the type, extent, frequency and duration of monitoring required to address the problem (hypothesis). This includes consideration of the degree of uncertainty (e.g. in the data, in the predictions (power); in the strength of conclusions)
- The development of a clearly defined monitoring procedure, with clear objectives and deliverables
- An active evaluation of the monitoring outputs and a direct utilisation of these outputs in the need and design of future monitoring (including termination if appropriate), i.e. has the problem identified at the outset been addressed? If not, what, if anything, can be done to address it?
- Each step defines what is / is not being done and why. NB. Each of these steps may also provide the justification for why monitoring is not required and if so the later steps are not required.

[illegible]

The study has been undertaken in three tasks listed below and outlined in the subsequent sections:

- Task 1: Site-specific review
- Task 2: Synthesis review of evidence gathered from all Offshore Wind projects
- Task 3: Recommendations on a framework for identifying and implementing future post-consent monitoring.

[illegible]

The site-specific review has been organised by site with sub-sections answering key questions for each topic area as follows:

- Physical processes
- Underwater noise
- Benthic ecology
- Fish and shellfish
- Marine mammals
- Birds.

For each OWF site a set of generic questions was asked within each applicable topic. For some topics not all of these questions are relevant, or an alternate set of questions was also necessary. Where this was the case these variations are further specified within the text, under topic specific variations. For each topic a Pro Forma was developed for these questions with further technically appropriate sub-questions, in order that a consistent approach was taken across all wind farms.

[illegible]

- Is the rationale for the monitoring activity clearly defined? Are stated objectives or hypotheses defined and are they cross referenced to consent conditions or, where applicable, the level of predicted impact for that receptor within the corresponding ES and/or HRA?
- Are data gathered appropriate to the defined rationale/objective/hypothesis/licence condition? For example, do the data reduce uncertainty in the impact described in the ES or HRA for a defined receptor?
- Are data collected of sufficient statistical power and have suitable statistical analysis been used to validate the findings of the monitoring report? Have data been collected over the appropriate temporal and spatial scale in order to be able to successfully detect change?
- Where industry standard methodologies and equipment are available for data collection and interpretation, have these standards been followed i.e. in line with Cefas (2012) or previous (JNCC 2001) best practice guidelines. Is there evidence of adherence to national or international quality procedures?

- Have any unforeseen impacts been identified? If not, has any consideration in the monitoring report been given to the possibility of impacts outside of those described in the ES and HRA occurring?
- Where applicable to the type of monitoring, assess whether current monitoring conditions are appropriate, proportionate and achievable. Will a continuation of data collection increase understanding of impacts?

[illegible]

The review is split by topic areas identified above. For each topic area the review points below are considered, citing results from the site-specific review of OWF monitoring reports including any notable exceptions. Additional information from case studies abroad has also been used to address the synthesis questions outlined below where appropriate.

[illegible]

Initial consideration was given to incorporating some example non-UK wind farms into the site-specific review, however, many of the early European OWFs for which there are data, were not a product of the same developer and regulatory process that UK sites have seen. These initial OWFs were built and consented by the State for the purpose of providing an evidence base on which to evolve the consenting process. Since the rationale behind the monitoring is quite different from that seen in English, Scottish and Welsh wind farms there was little to be gained by carrying out a review of the site-specific consent conditions and subsequent monitoring. A review of the monitoring data and consenting practices was, therefore, incorporated at the synthesis stage.

[illegible]

- Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?
- What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403
- Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?
- Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs?
- Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

[illegible]

The third phase provides recommendations through a framework to identify and implement future post-consent monitoring. These were derived from a workshop with key industry stakeholders in which the results of Task 1 and Task 2 were reviewed. The framework was specified with the following steers on where recommendations could be made (as specified in the Initial Invitation to Tender (ITT)):

- Recommendations for better knowledge exchange (e.g. cascading relevant information).
- Recommendations for better integration and co-ordination of monitoring, assessment, and reporting of individual developers working in the same regions/zones. This includes making recommendations on the need and scope for comparability in datasets.
- Potential for developers to link up with other sectors or other organisations undertaking environmental monitoring/surveys to deliver objectives jointly.
- Recommendations for a suitable model (including timing and arrangements) for formal review of the monitoring data, in order to understand critical issues; ensure monitoring is appropriate; and results are incorporated into adaptive management approaches.
- Recommendations for formatting conditions (including clear objectives and cross referencing with EIAs) and reporting from developers.
- Recommendations on what should, and can, be achieved through post-consent monitoring programmes associated with each receptor, i.e. the realistic level of ambition.
- Recommendations on the guiding principles associated with the spatial and temporal scale of monitoring.

Recommendations are made for a suitable model (including timing and arrangements) for formal review of the monitoring data, in order to understand critical issues; ensure monitoring is appropriate; and ensure results are incorporated into adaptive management approaches. Figure 2 illustrates the work flow of the above tasks. The following sections provide the results for Task 2: Synthesis.

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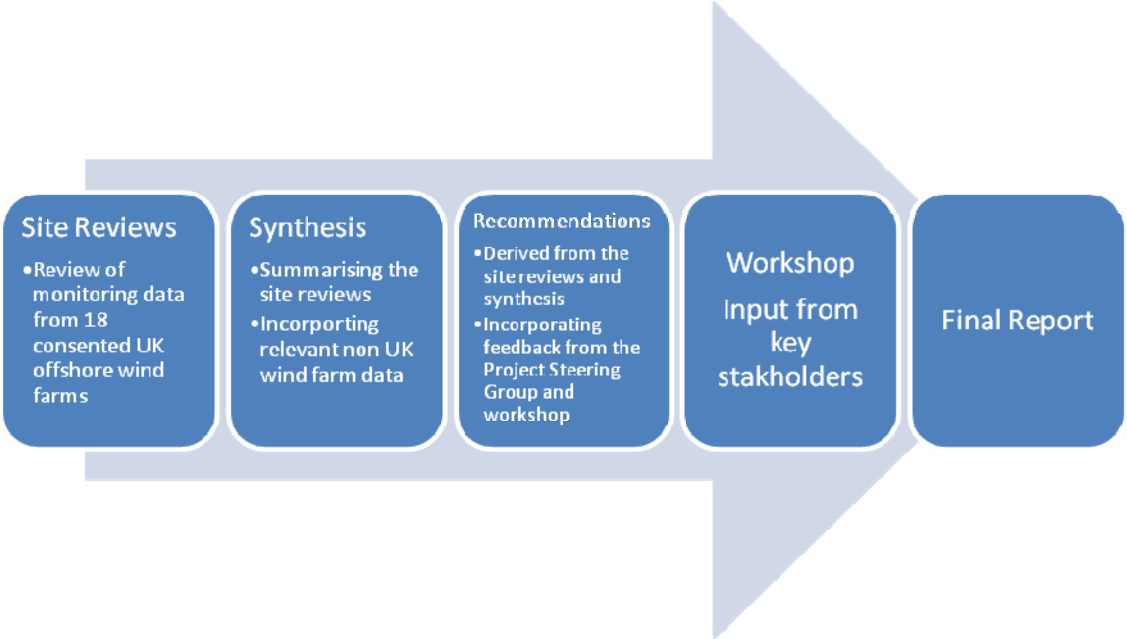

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Whilst this review is limited by the scope of the available material, all efforts have been made to gather as comprehensive an information base as is feasibly possible. This review is based on the documents made available by the Marine Management Organisation (MMO), Centre for Environment, Fisheries & Aquaculture Science (Cefas), Countryside Council for Wales (CCW) and Marine Scotland (MS), plus other publicly available information. RenewableUK were also contacted to co-ordinate provision of additional materials from industry. The sites reviewed are summarised in Table 2. The authors and the PSG therefore consider that the reports reviewed in this project are as comprehensive a body of evidence that could feasibly be collated. That said, it is acknowledged that the licences reviewed here may not always have been the most recent licence agreed between the Licence Holder and Licensing Authority, e.g. in some cases:

- The available documentation makes reference to reports and licences that were not available at the time of the review
- The lack of a monitoring report may indicate that monitoring has not taken place, but this cannot be confirmed with the available information.

In addition it should be noted that only reports submitted prior to 30th January 2013 are considered for this review and the submission of environmental monitoring is an ongoing process and there has been a lot of information submitted since this date. However the reports reviewed are wholly representative of the issues being investigated and the approaches applied to monitoring and thus provide a sound basis for this review to reach robust and defendable conclusions and recommendations.

[illegible] 2 [illegible]

Wind farm	Generating year[1]	Location	Round
North Hoyle	2003	Irish Sea - off Welsh coast/Liverpool Bay	1
Scroby Sands	2004	East Anglia	1
Kentish Flats	2005	Thames Estuary	1
Barrow	2006	Irish Sea - off Lancashire coast/ Morecambe Bay	1
Burbo Bank	2007	Irish Sea - off Welsh coast/Liverpool Bay	1
Lynn and Inner Dowsing (LID)	2008	Humber	1
Gunfleet Sands I	2009	Thames Estuary	1
Rhyl Flats	2009	Irish Sea - off Welsh coast/Liverpool Bay	1
Robin Rigg E	2009	Solway Firth	1
Robin Rigg W	2009	Solway Firth	1
Gunfleet Sands II	2009	Thames Estuary	2
Greater Gabbard	2010	East Anglia	2
Thanet	2010	Thames Estuary	2
Ormonde	2011	Irish Sea - off Lancashire coast/ Morecambe Bay	1
Sheringham Shoal	2011	East Anglia	2
Walney 1	2011	Irish Sea - off Lancashire coast/ Morecambe Bay	2
Walney 2	2011	Irish Sea - off Lancashire coast/ Morecambe Bay	2
Teesside	2012	North Sea	1
London Array	2012	Thames Estuary	2
Gwynt y Môr	2013	Irish Sea - off Welsh coast/Liverpool Bay	2
Lincs	2013	Humber	2
West of Duddon Sands	2013	Irish Sea - off Lancashire coast/ Morecambe Bay	2

[1] Construction may continue beyond the generating year and as such there may be examples where there is a delay between generating year and the beginning of post-construction monitoring.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1	1	1	1	1	1	1	2	1	1	2	2	1	2	2	2	2	1	2	2	2
[illegible]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	Y	Y
[illegible]	P	P	P	P	P	P	Y	P	P	P	Y	P	Y	P	P	P	Y	P	P	Y	P
[illegible]	Y	Y	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y
[illegible]																					
Benthic	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	UN	N	N	P	Y	Y	P	N	N	N	O
Fish	P	NR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	P	N	Y	Y	N	N	N	N	O
UWN	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Physical Processes	P	NR	Y	Y	Y	Y	Y	Y	Y	UN	P	Y	Y	N	Y	N	N	N	N	N	O
Marine Mammals	Y	Y	NR	NR	NR	Y	NR	NR	NR	NR	Y	Y	NR	NR	Y	Y	O	O	Y	O	O
Birds	Y	Y	Y	Y	Y	Y	Y	Y	Y	y	P	N	Y	N	Y	Y	N	N	Y	N	O
[illegible]																					
Benthic	Y	NR	N	Y	Y	NR	NR	NR	Y	N	NR	NR	NR	NR	Y	Y	NR	NR	NR	NR	O
Fish	NR	NR	NR	NR	NR	NR	Y	Y	Y	y	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	O
UWN	NR	NR	NR	NR	NR	NR	NR	Y	NR	P	Y	Y	Y	N	P	P	N	Y	UN	Y	O
Physical Processes	P	UN	Y	NR	Y	Y	Y	Y	Y	UN	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	O
Marine	NR	Y	NR	Y	NR	Y	NR	NR	Y	P	N	NR	Y	NR	Y	Y	NR	NR	O	O	O

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mammals																					
Birds	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	P	N	Y	N	Y	Y	N	O	UN	O	O
[illegible]																					
Benthic	Y	Y	Y	Y	Y	N	N	N	UN	Y	O	O	O	P	O	O	O	O	O	O	O
Fish	Y	NR	P	Y	Y	Y	Y	Y	Y	Y	O	O	O	O	O	O	O	O	O	O	O
UWN	DY	DY	DY	Y	P	DY	Y	O	P	O	O	O	O	O	O	O	O	O	O	O	
Physical Processes	P	P	Y	Y	Y	Y	Y	Y	P	Y	O	O	O	O	Y	O	O	O	O	O	O
Marine Mammals	Y	Y	NR	NR	NR	NR	NR	NR	O	Y	O	O	NR	O	O	O	O	O	O	O	O
Birds	Y	Y	Y	Y	Y	Y	y	Y	Y	Y	O	O	O	O	O	O	O	O	O	O	O
[illegible] 2																					
Benthic	Y	NR	Y	Y	N	Y	Y	Y	UN	Y	O	O	O	O	O	O	O	O	O	O	O
Fish	Y	NR	P	Y	N	Y	Y	Y	UN	UN	O	O	O	O	O	O	O	O	O	O	O
UWN	DY	DY	DY	DY	DY	Y	DY	Y	O	DY	O	O	O	O	O	O	O	O	O	O	O
Physical Processes	P	Y	Y	Y	Y	Y	Y	Y	UN	UN	O	O	O	O	O	O	O	O	O	O	O
Marine Mammals	Y	Y	NR	NR	NR	NR	NR	NR	O	O	O	O	O	O	O	O	O	O	O	O	O
Birds	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	O	O	O	O	O	O	O	O	O	O	O
[illegible]																					
Benthic	Y	NR	NR	Y	Y	O	UN	UN	UN	Y	O	O	O	O	O	O	O	O	O	O	O
Fish	P	NR	Y	P	P	P	UN	UN	UN	UN	O	O	O	O	O	O	O	O	O	O	O

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
UWN	Y	Y	Y	DY	DY	DY	DY	Y	O	DY	O	O	O	O	O	O	O	O	O	O	O
Physical Processes	Y	N	Y	UN	P	Y	Y	Y	UN	UN	O	O	O	O	O	O	O	O	O	O	O
Marine Mammals	Y	NR	NR	NR	NR	NR	NR	NR	O	O	O	O	O	O	O	O	O	O	O	O	O
Birds	Y	NR	Y	Y	NR	Y	O	O	UN	N	O	O	O	O	O	O	O	O	O	O	O

Y	Report available. Report provided and reviewed.
P	Partial information available. Full report not present but information in summary text or cited in other reports.
NR	Report not required. No specific requirement in licence conditions for monitoring report.
O	Monitoring report understood to be not yet completed and therefore not included for review (30/01/2013).
UN	Not present, but not clear from the supporting information (i.e. licence) which of the not present categories (O,N, NR), the report falls under.
N	Report exists, not present.
DY	Report exists for a different (earlier/later) year of operation.

[illegible]

The following section provides an amalgamated overview of post consent monitoring distilled from the systematic individual site reviews that were undertaken for the first stage of this project (see Section 4.1.1 for a list of the questions and methodology employed at the first stage). As such the conclusions are based on historic consenting and monitoring data and reports reviewed rather than a consideration of current practice. It should be noted that when the monitoring was consented:

- It was intended to address site-specific issues
- Had been agreed with regulators and advisors as adequate, at the time of consent, to address the site-specific issues.

The questions are listed in Section 4.1.2. Where appropriate a further section covering non-UK practice is also provided.

Whilst many of the sections lend themselves to concluding recommendations the reader is reminded that recommendations are covered in Sections 6 to 12 of this report (with some outline recommendations, based on initial findings of the review, presented in section 5).

[illegible]

In the UK, the monitoring of physical processes has been undertaken through the monitoring of four parameters:

- Scour monitoring
- Suspended sediment concentrations (SSC) monitoring
- Current/wake monitoring
- Coastal monitoring.

The following section provides answers to the questions posed of the UK sites split into sub-sections for each of the above process. Where relevant a further section provides further non-UK derived answers.

[illegible]

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

[illegible]

In terms of the conditions applied across reviewed sites, all licence conditions stated a requirement for scour monitoring. All but four licence conditions had requirements for suspended sediment concentration (SSC) monitoring. Only five OWF conditions stated a requirement for current/wake monitoring – generally these were later Round 1/early Round 2 sites. Only five OWF conditions stated a requirement for coastal monitoring, of any kind. This information is summarised by Table 4.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Barrow	Morecambe Bay	2003-06	1	Scour protection /Cable Integrity	Validation of predictions	Monitor predictions	N/A
Burbo Bank	Liverpool Bay	2003-07	1	Scour protection /Cable Integrity	Validation of predictions	Monitor predictions	N/A
Greater Gabbard	Thames Estuary	2007-02	2	Scour protection /Storm	Herring	N/A	N/A
Gunfleet Sands	Thames Estuary	2004-06	2	Scour protection /Cable Integrity/Storm	Validation of predictions	N/A	N/A
Gwynt y Môr	Liverpool Bay	2008-12	2	Scour protection /Cable Integrity	During jetting/ No reason	N/A	N/A
Kentish Flats	Thames Estuary	2003-03	1	Scour protection /Cable Integrity	Oysters	N/A	N/A
Lincs	Humber	2003-07	2	Scour protection n/Cable Integrity	Fish and Shellfish/Chalks	N/A	N/A
London Array	Thames Estuary	2008-10	2	Scour protection /Storm	During jetting/ No reason	N/A	N/A
Lynn & Inner Dowsing	Humber	2006-12	1	Scour protection /Storm	Validation of predictions	Monitor predictions	N/A
North Hoyle	Liverpool Bay	2002-07	1	Scour protection	Validation of predictions	N/A	N/A
Ormonde	Morecambe Bay	2007-02	1	Storm	Validation of predictions/ during jetting	N/A	N/A
Rhyl Flats	Liverpool Bay	2002-12	1	Scour protection	Validation of predictions	Monitor predictions	N/A

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Robin Rigg	Solway Firth	2006-12	1	Scour[2]	N/A	N/A	N/A
Scroby Sands	East Anglia	2002-04	1	Scour protection	Validation of predictions/ modelling	N/A	Protection of SSSI
Sheringham Shoal	Humber	2008-11	2	Scour protection /Storm	Crabs and lobsters/ during jetting	N/A	Cable burial at landfall
Teesside	Teesside	2007-09	1	Scour protection /Storm	During jetting/No reason	N/A	Erosion
Thanet	Thames Estuary	2006-12	2	Scour protection /Storm	During jetting/ Sabellaria spinulosa	N/A	N/A
Walney	Morecambe Bay	2007-10	2	Scour protection /Storm	During jetting/No reason	N/A	N/A
West of Duddon Sands	Morecambe Bay	2008-09	2	Scour protection /Storm	During jetting/No reason	N/A	N/A

[illegible]

Licence conditions specifically required scour monitoring around foundations or cable routes. The rationale for monitoring was usually provided as one of the following:

- To ensure the structural integrity of the wind farm and intra-array/export cable routes
- To assess the requirement for scour protection.

The rationale for scour monitoring is not specifically linked to a sensitive environmental receptor and therefore does not inform the environmental receptor impacts. Instead, the scour monitoring rationale is typically linked to structural/engineering integrity.

Assessing the need for scour protection was included in 17 (of 19) licence conditions reviewed. The only two sites where this was not applicable were Robin Rigg, a Scottish OWF with different licence conditions, and Ormonde, the only OWF to use jacket foundations.

[2] Licence conditions were unspecified and stated that monitoring should address “Scour, sedimentary, erosional, hydrological processes and their impact on marine benthos and ecosystem function.”

The specific requirement to assess the integrity of intra-array and/or export cables was included in only 6 (of 19) licence conditions. Four of these (Kentish Flats, Barrow, Burbo Bank and Lynn & Inner Dowsing) are Round 1 OWFs – the remaining two are Round 2 OWFs (Gunfleet Sands and Gwynt y Môr). It is not clear why some wind farms have this requirement as geological conditions across all sites are different, that is to say scour monitoring conditions do not appear to be targeted to OWFs with particular risk of scour/cable exposure.

Scour monitoring requirements following a storm event (ranging from 1 in 10 to 1 in 50 year events) are a common feature of late Round 1 and all Round 2 OWF licences. However, no rationale for monitoring post-storm events is provided and there is no available evidence of any monitoring having taken place to see if this condition has been complied with. Whilst the logic of monitoring for scour after extreme weather events is sound for a few select sites, the definition of those events (in terms of what threshold would be appropriate to trigger a survey and how soon following such an event a survey should be carried out) and the practicality of deploying a survey in the timeframe necessary is problematic and probably explains the lack of evidence of these conditions having been met.

Scour Summary
In summary, the licence requirements to monitor scour are similar across sites, with a consistent rationale driven by engineering concerns, rather than impacts identified through the EIA process. It is therefore recommended that scour monitoring, in terms of physical processes, is not necessary for post consent licensing conditions, especially since the review of post-consent scour monitoring reports did not identify any significant impacts on sensitive physical receptors. However, scour monitoring may form part of ecological monitoring in the future (further information on ecological monitoring is discussed from Section 5.3 to 5.6).

The requirement to monitor ‘post extreme weather events’ as a licence condition should also be reconsidered on the grounds of impracticality and rationale.

[illegible]
Of the 19 OWFs reviewed, SSC monitoring was a requirement for all but four, three of which had a requirement for SSC monitoring only if jetting was undertaken as a method for cable installation. The remaining site, Robin Rigg, had no specific requirement at all for SSC monitoring (this is because the wind farm and the export cable were consented separately and there was no mechanism to include licence conditions on the consent for the cable). Four (of the 19) licence conditions for OWFs specified sensitive receptors in the region as the rationale for monitoring. The sensitive receptors included:

- Oysters at Kentish Flats
- Crabs & lobsters at Sheringham Shoal
- “Fish and shellfish” at Lincs
- Herring spawning grounds at Greater Gabbard.

Early OWFs (consented before 2005) stated “validation of predictions” as the rationale for SSC monitoring. The only exception to this was Kentish Flats, which identified oysters as a specific receptor and the main rationale for SSC monitoring.

Later OWFs (consented from 2006 onwards), excluding those which identified a sensitive receptor (see above) or stated “validation of predictions” as rationale for SSC monitoring, did not state any specific rationale for SSC monitoring.

Jetting during construction and cable installation
SSC monitoring is required as stated in nine licences from 2006 onwards if jetting is undertaken as a method for cable installation. For five of these licences, there is no specific rationale provided for monitoring. For the remaining four, the rationale for SSC monitoring during jetting includes sensitive receptors (crabs and lobsters, Sheringham Shoal, fish, and shellfish at Lincs and Sabellaria spinulosa at Thanet) and the validation of predictions (at Ormonde).

SSC summary
In summary, at some OWFs, SSC monitoring licence conditions are receptor driven, however for the majority monitoring has been used to minimise uncertainty relating to modelling predictions. The conditions included in the licences reviewed do not provide instructions which would prevent impact to a sensitive receptor as results from deployed instruments are not available in near real time. SSC monitoring should be tailored to record impacts on identified sensitive biological receptors. A recent Cefas (2010) review of OWFs concluded that SSC monitoring would not normally be a requirement - and is now not routinely included in Marine Licences. Post-consent monitoring programmes which require SSC monitoring in future licence conditions will use adaptive management to mitigate any impacts identified, e.g. providing a trigger for action.

Current and wake monitoring
Five (of 19) licence conditions required current/wake monitoring to be undertaken. The requirement for current modelling commenced in licence conditions in 2002 as part of the Rhyl Flats OWF. The requirement for current and wake monitoring was no longer in licence conditions after Gunfleet Sands in 2004, following advice from Statutory Nature Conservation Bodies (SNCBs) (Defra, 2005). The rationale for current monitoring was always “monitoring predictions made in the ES”. Only at Rhyl Flats was it specifically mentioned that the rationale/purpose was to validate predictions made in numerical models. There were no instances where the rationale was specifically linked to a particularly sensitive receptor, or based on predictions or uncertainty discussed in the ES.

Current and wake monitoring summary
Current and wake monitoring was included in early conditions but has been removed in later licences following a shift in advice following initial results.

Coastal monitoring
Only five (of 19) OWFs had licence conditions requiring coastal monitoring. One of these (Gunfleet Sands) required pre-construction shoreline mobility studies to be undertaken, in order to better understand the processes at work adjacent to the OWF. For the remaining four OWFs, monitoring requirements were for post-construction surveys. The rationale for monitoring was always related to erosion, usually focusing on i) coastal erosion adjacent to the wind farm, ii) the erosion of a Site of Special Scientific Interest (SSSI) and iii) ensuring the export cable at landfall

remained buried. Three of these four OWFs refer to a sensitive receptor as the rationale for monitoring (the coast) – the fourth, looking at cable burial, is an engineering consideration unrelated to a specific receptor.

Coastal monitoring summary
Coastal monitoring is generally required for nearshore sites located in relatively shallow waters, or sites located on nearshore banks which might act as coastal protection features. In some cases (e.g. Scroby Sands), coastal monitoring was also required for wind farms located adjacent to coastal areas with designated features of conservation interest, such as SSSIs.

Consenting rationale summary

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

In the UK, the rationale of post-consent monitoring conditions is consistent in terms of uniform or almost identical monitoring requirements across the majority of OWF sites, regardless of site-specific geological and metocean characteristics. However, it is important to point out that the rationale for post-consent monitoring, based specifically on significant impacts or uncertainty identified in the ES, is not captured in monitoring conditions.

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What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects.

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Of the 19 licences, all except Ormonde required regular post-construction scour monitoring using bathymetry surveys. Ormonde, which had a jacket foundation type only required scour monitoring following a major storm event.

Of the 18 licences requiring regular monitoring, ten of these did not specify a method for survey, stating only that bathymetry was required every six months for three years post-construction (or six monthly during construction, annually post-construction, in the case of Robin Rigg).

Post-construction monitoring reports from eight sites were reviewed (mostly these are from Round 1 OWFs). All of these were for wind farms with the licence conditions requiring post-construction bathymetry surveys to be undertaken (as discussed previously). This condition does not state a specific requirement for multibeam bathymetry to be used for data collection; however all developers and contractors used 100% coverage multibeam bathymetry in post-construction monitoring surveys (this was either within a set radius of the selected foundations chosen for survey, or full coverage of the whole site).

With only three exceptions, late Round 1 and most Round 2 licences (consented from late 2006 onwards) specified a requirement for swath (multibeam) bathymetry surveys every 6 months for 3 years post-construction. The exceptions to this are i) Ormonde, which had only a condition for scour monitoring after storms, ii) London Array, which did not specify multibeam bathymetry, and iii) Robin Rigg, which does not specify a methodology.

Across most OWFs, the frequency of scour monitoring defined in licence conditions is every 6 months for 3 years following post-construction. However, at some sites this was reduced to annual surveys following advice and discussions with the licensing authority and advisors. It is recommended that the frequency of surveys is tailored and defined based on the susceptibility of OWF foundations and/or cable infrastructure to the effects of scour – it would be advisable that scour monitoring conditions be drawn up with the developer and their installation/structural engineers. Licence conditions requiring scour monitoring following a significant storm were first included in the Gunfleet Sands licence in 2004, and were included in all subsequent licences issued for OWFs (with one exception – Gwynt y Môr). There was no recommended methodology provided in licence conditions for monitoring scour at OWFs following a significant storm. Multibeam bathymetry is clearly the most useful and accurate ‘best-practice’ survey method for quantifying scour. This is a consideration presented in other reports (Cefas, 2010; ABPmer 2010; DECC, 2008). While single beam bathymetry will provide spot-depths, multibeam bathymetry can give a full and accurate picture of scour and, as such, accurate volume of sediment removal can be calculated (or difference plots can be created). This could be an explanation why early developers elected to use this method of data collection, and why later licences specify swath bathymetry as a requirement.

Scour monitoring summary
The best practice survey method for scour monitoring is considered to be multibeam echosounder (MBES) bathymetry. This quantitative and high-resolution survey method has been used extensively in scour monitoring to date for the vast majority of OWFs. It is likely that this will continue to be the recommended best practice, where scour monitoring forms part of post-consent monitoring requirements, e.g. in support of ecological investigations.

[illegible]
Monitoring methodologies recommended in licence conditions were generally not consistent:

- Licence conditions for some of the earlier wind farms (North Hoyle, Kentish Flats and Barrow) specify that data should be collected utilising Optical Backscatter Sensors (OBS) at three separate locations (covering near-field, far-field and ‘control’ sites), for a minimum of 4 weeks covering the pre-, during and post-construction periods at each development. The only OWF developer which followed this specific method of data collection was North Hoyle (the first completed Round 1 OWF in the UK).
- The licence conditions for 6 OWFs do not specify the use of OBS, but use the term “sensors”, which could allude to the use of either optical or acoustic sensors (which are not compatible with one another).

- The licence conditions for five OWFs do not specify a methodology for collecting SSC data, merely stating that a plan for SSC monitoring should be created prior to the onset of works at the site.
- The licence conditions for Scroby Sands, the first OWF to get consent and consequently with stand-alone licence conditions which are incomparable to those from other OWFs, describe only the rationale for data collection.
- The licence conditions of the remaining four OWFs had no requirement for SSC monitoring and as such no methods were presented or discussed.

While several licences stated that SSC thresholds must not be breached, threshold values were not specified in any of the 19 licences reviewed. Those licences which state thresholds must not be breached contained the following text:

> *"…should suspended sediment levels associated with the construction works be shown to be at unacceptable levels (i.e. above threshold) works may need to be suspended while a less disruptive methodology is investigated."* – Example from Burbo Bank licence 31864/03/0

Only two of the 19 OWFs subsequently defined threshold values based on sensitive receptors, during pre-construction/baseline monitoring reports. These OWFs were Kentish Flats and Greater Gabbard.

As mentioned previously, the only wind farm to undertake the exact monitoring methods specified in the licence conditions was North Hoyle. Subsequent reports used methods ranging from twin OBS deployed at a single location, OBS sensors towed through the sediment plume during construction and the use of Acoustic Doppler Current Profilers (ADCP). The Rhyl Flats Construction Report (RWE, 2010) states that SSC monitoring methods at Rhyl Flats were changed after assessing the results from monitoring at North Hoyle, which suggested that changes in SSC were confined to the near-field.

While it would appear that all developers since North Hoyle have adopted different methodologies to measure SSCs, there was little consistency in what methodology was adopted, although towed or hull mounted sensors traversing through the plume during construction was undertaken by four developers. The specific licence monitoring requirements for SSCs did not change over time (i.e. the requirements and methods were almost identical), even though methods and subsequent results from other OWFs were on hand for review which could have led to a subsequent amendment to licensing conditions.

From approximately 2010 onwards, licence conditions did not specify the method of SSC monitoring to be undertaken – this is consistent with licences which also did not specify a rationale for monitoring.

While towed OBS through the sedimentary plume appears to be the most widely adopted method of SSC monitoring, it is difficult to comment on the most appropriate method for monitoring as none of the methods utilised to date provided real-time *in-situ* data, which would indicate when a threshold was about to be breached, potentially preventing impacts of increased SSC on a sensitive receptor(s). The standardisation of sensor (and subsequent measuring units) to be used in a survey, such as OBS sensors and reporting standard values in mg/l or NTUs, would help improve further comparability between datasets.

SSC monitoring summary
SSC monitoring best practice (as undertaken by developers) differs to what is specifically required in licences – often the same licence conditions are present as were first issued for early OWFs, but these have not been carried out by developers since North Hoyle. A recent Cefas (2010) review of OWFs concluded that SSC monitoring would not normally be a requirement - and is now not routinely included in Marine Licences unless risks to ecological receptors have been identified (e.g. herring spawning grounds).

Currents and wake monitoring
Of 19 licences reviewed, only five had a requirement to monitor currents/turbine wakes – the methodology recommended in these licences was to use ADCP. Three of the OWFs (Barrow, Burbo Bank and Lynn & Inner Dowsing) undertook monitoring using hull mounted ADCP through the turbine wake areas. Current monitoring was not undertaken at Gunfleet Sands following the removal of this condition by the MMO. As part of this review, it is not known if any specific wake and current monitoring was conducted at Rhyl Flats.

Should current or wake monitoring be a requirement (based on conclusions drawn in an ES) for future developments, it is likely that a towed or hull mounted ADCP, following transects through the wake area, would be the most standard 'best-practice' method of data collection. The use of ADCP specifically to monitor currents and wakes is a consideration presented in other reports (Cefas, 2012; DECC, 2008).

Current and wake monitoring summary
Best practice for current and wake monitoring is considered to be the use of ADCP, which was carried out by all OWFs which had this monitoring as part of their licence conditions.

Coastal monitoring
Four licence conditions required coastal monitoring to be undertaken. As previously mentioned (Section 5.1.1), Gunfleet Sands required pre-construction monitoring to be undertaken in order to better understand the shoreline mobility of the Essex coastline. The methods required for coastal monitoring at Gunfleet included laser PSA, dry sieving and modelling in order to understand the movement of sediment along the coast.

For Scroby Sands, transects across the beach between the Norfolk settlements of Great Yarmouth and California were required to be undertaken, with higher resolution (more closely spaced) transects required within conservation areas.

For Lynn & Inner Dowsing, the monitoring of beach profiles was required for the 3 years following construction but the licence suggests that the Environment Agency (EA) may already do this to a suitable resolution.

For Sheringham Shoal and Teesside (still under construction), no specification is provided, merely stating that beach profile monitoring must be undertaken for 3 years following construction and a suitable method is to be confirmed with competent authorities.

In summary, there is little consistency between methods recommended in licence conditions. As part of this review, only coastal monitoring reports relating to Lynn and Inner Dowsing OWFs are available and therefore it is not possible to discuss comparability of post-construction survey methods or results with monitoring reports from other locations. It should also be noted, based on available reports for review, it was suggested that post-construction coastal monitoring requirements associated with certain OWFs may not have been conducted but this may have been if construction has not been completed even though the OWF has begun generation.

Coastal monitoring summary
As part of this review, only Gunfleet Sands' pre-construction coastal monitoring report was available; therefore it is not possible to comment on existing best practice. However, the use of existing coastal monitoring datasets and coastal transects (for example by the Environment Agency) are considered to be best practice where potential coastal impacts attributed to a development have been identified.

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Scour monitoring
Where scour monitoring has been undertaken, multibeam bathymetry is the most widely adopted method of data collection, e.g. at Thornton Bank and Belwind OWFs (Van den Eynde *et al.*, 2010; cited in Degraer *et al.*, 2010). Multibeam bathymetry is also likely to have been undertaken at the Dutch Princess Amalia OWF in order to produce Digital Terrain Maps (DTM) (Cowrie, 2010).

At the Danish Horns Rev and Nysted OWFs, prior to installation of the turbine foundations a filter layer (consisting of stones) was placed on the seabed. Therefore no post-construction scour monitoring was undertaken.

SSC monitoring
SSC monitoring at the Belgian wind farms was undertaken using OBS at near-field and control sites, and values were reported in mg/l – in addition, an ADCP sensor was also deployed simultaneously as a backup. The use of a control site at the adjacent Goot Bank was found to be not representative of SSCs at Thornton and Bligh Bank due to the influence of coastal waters (Van den Eynde *et al.*, 2010).

Modelling studies for Horns Rev, prior to construction, looked at worst-case sediment spill scenarios having identified benthic communities as a sensitive receptor. These studies concluded that increases in SSC were likely to be localised and temporary due to the character of the seabed and natural variability in SSCs in the region, and as such no monitoring studies were recommended or carried out, even if jetting had been undertaken during installation (DONG *et al.*, 2006).

No methods for SSC monitoring at Nysted are presented (DONG *et al.*, 2006). Sensitive receptors (eelgrass, macro algae and benthic infauna) were identified along the cable route during “detailed” surveys following installation. It is not clear if these surveys included SSC monitoring.

Current and wake monitoring
Current monitoring at the Belgian wind farms was undertaken using ADCP sensors at near-field and control sites. An additional ADCP sensor was also deployed simultaneously as a backup. It was found that the use of a reference site did not add any further value to the study (Van den Eynde *et al.*, 2010). No specific turbine wake monitoring was undertaken.

Coastal monitoring
Although coastal morphology has been considered for Danish OWFs, results from these studies are not presently accessible to the review team and therefore not reviewed.

Non-UK OWF monitoring summary
Methods utilised at other European OWFs echo current best practice for UK OWFs.

Monitoring best practice summary

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

In general, best practice to monitor scour was undertaken using MBES; best practice to measure SSCs was undertaken using boat-based OBS studies and best practice to measure currents and wakes was undertaken using ADCPs.

Best practice for all physical topics in the UK indicates evolution of licensing requirements following improved understanding. The exception to this is SSC monitoring, where best practice (undertaken by developers) differs to what is required in the licence. Best practice in UK wind farms is echoed in monitoring undertaken elsewhere in Europe.

[illegible]

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

[illegible]

As a general overview, scour develops in mobile sandy sediments in areas of strong tidal currents. Scour is often limited to the thickness of mobile sediments where they occur as a veneer over a harder and less erodible substrate (e.g. chalk, tertiary clays or boulder clay/till deposits).

Sites located in areas of silty or cohesive sediments (notably in the eastern Irish Sea) also experienced lower rates of scour compared to those sites located in the

North Sea and Thames Estuary where seabed and shallow subsurface sediments tend to be sandier.

Where sandy sediments occur in greater thicknesses, these may be scoured to an equilibrium depth and width which is roughly proportional to turbine foundation diameter (on monopile foundation structures). For sites located on highly mobile sandbanks or in areas of large mobile bedforms, scour patterns may be more variable with secondary scour forming around any foundation protection and the formation of scour wakes (e.g. as occurs at Scroby Sands).

Since no specific scour monitoring was undertaken at Ormonde (the only OWF with jacket foundations forming part of this review) and no post-construction monitoring reports have yet been published, it is not possible to comment on scour associated with jacket foundations for UK sites.

It is therefore possible to derive a generic overview regarding the sedimentary response to scour around turbines, informed by the results of post-consent monitoring. The effects of scour around turbines and cables are quantifiable through the use of multibeam bathymetry data and it is possible therefore to subsequently calculate volume changes attributed to scour.

Scour lessons learned summary

Where geological, sedimentary and metocean conditions are similar, OWFs have similar responses in terms of scour. Any requirement for scour monitoring can be based on the environmental characteristics of analogous sites in terms of geology, sediments and metocean conditions. For example, sites with a thin veneer of surficial sediment overlying glacial tills are unlikely to have significant scour. The use of multibeam bathymetry for data collection provides quantifiable and comparable results. In general, the ES for each OWF over-predicted the amount of scour which would occur based on the monopile diameter. The predictions were attributed to whichever scour models were used in the calculations, often without considering the underlying substrate or thickness (or absence) of overlying mobile sediments. However, it is likely that the modelling took a ‘worst-case scenario’ of no barrier to realising potential full scour depth.

[illegible]

SSC monitoring revealed that increases in SSC were localised and temporary during construction and cable laying operations. Often, increases in SSC were within the limits of natural variation present at the site, and findings were consistent with predictions made in the ES.

SSC monitoring (if required) should be focused within areas where baseline SSCs and natural variability are low and where a sensitive receptor has been identified, which is potentially impacted by higher concentrations, especially during construction activities. Monitoring SSCs should also target areas where significant volumes of source materials are predicted to enter the receiving environment and where predictive modelling and impact assessment has identified a potentially significant effect. Locations where background SSCs are high (e.g. Liverpool Bay) should not require SSC monitoring since receptors are likely to be tolerant to these conditions.

The current methods that were employed during monitoring (notably towed OBS through the sediment plume) would likely be sufficient to capture changes to SSC during construction activities. However, the time it takes to process and review the data collected is not sufficient to capture increases in SSC above a given threshold before it becomes a more serious issue (e.g. impacting on environmental receptors). It is also important that units of measurement must be standardised for SSC monitoring.

The methods for SSC monitoring recommended in licence conditions are generally not suitable to identify potential instantaneous breaches of SSC thresholds. An instrument deployed for four weeks, or even a boat-based OBS sensor, does not collect real-time *in-situ* data which can be instantly verified. Since significant changes in SSC can occur over a tidal cycle, by the time the data have been processed and reviewed and a breach of threshold has been identified, the threshold exceedance may have occurred several weeks in the past and may no longer present an issue.

Based on methods adopted by developers to measure plumes and SSCs, it appears that boat-based OBS surveys are ‘best-practice’ due to their relative flexibility, simplicity and the ability to monitor and measure areas where elevated suspended sediments are predicted (e.g. plumes within a tidal ellipse downstream of a foundation that is being installed). This is a consideration presented in other reports (DECC, 2008).

In conclusion, it is possible to monitor changes to SSCs during construction and cable laying operations using the methods that have been employed for SSC monitoring. However, the value of these data for preventing ‘real time’ impacts to potentially sensitive receptors is questionable due to the long data processing timescales involved post-collection.

Therefore, a method of obtaining ‘real time’ boat-based turbidity measurements (in NTU (Nephelometric Turbidity Units) rather than mg/l) in areas where sensitive receptors have been identified and are at risk of impacts due to higher turbidity, would be the best method in the future. It would also be critical that threshold values in NTU units for a potential receptor are established in advance with regulatory authorities and topic specialists.

SSC lessons learned summary
It is possible to monitor changes caused during construction and cable laying operations using the methods that have been employed for SSC monitoring. However, the value of these data for preventing impacts to sensitive receptors is questionable due to the long data processing timescales involved in post-collection.

[illegible]
Where post-construction current and wake monitoring reports were available to review, it is evident that wakes form on the down-current side of a turbine. The length of the turbulent wake is directly influenced by the width of the turbine foundation and the current speed. It is concluded that, provided turbines are located at sufficient distance from one another, cumulative effects of flow separation and wake changes will not be an issue.

The method which was employed to monitor current and wake patterns from turbine foundations, using ADCPs, was sufficient to quantify the effects caused by the flow separation around the foundation.

Current and wake monitoring lessons learned summary
The turbulent wake in lee of a foundation is proportionate to the width of the structure and the current speed. The ADCPs used to collect this data were sufficient to quantify changes to water flow.

Coastal monitoring reports produced by the EA for Lynn and Inner Dowsing OWFs indicated that the scale of any changes to coastal erosion/accretion directly attributable to the construction of the wind farms would not be discernible against seasonal and annual variations in the wave regime.

No further reports were available to review in order to confirm if generic lessons regarding coastal erosion could be derived following monitoring. Small changes to coastal erosion are difficult to quantify as erosion rates can vary considerably based on the geology and wave climate of an area. As larger scale changes to the coastline happen over extended periods of time, it is not likely that the current method of monitoring over three years immediately following construction (the only timeframe enforceable under the old FEPA licences) will be sufficient to capture any changes that occur as a result of wind farm construction. It is also important to note that no clear guidance or methodology for assessing coastal change attributed to OWFs was provided within licences.

Coastal monitoring lessons learned summary
It is likely that any changes to coastal erosion/accretion directly attributable to the construction of the wind farms would not be discernible against natural variability over a relatively short-term three year post-construction monitoring period (valid for previously issued FEPA licences).

Scour monitoring
Scour monitoring of the Belgian OWFs concluded that measured scour was generally less than the predicted ‘worst-case’ scour and was linked to seabed sediment character, underlying geology and prevailing hydrodynamic conditions (Van den Eynde *et al.*, 2010). No secondary scour was identified at any location.

Scour monitoring, in terms of scour depth and extent, was not undertaken at Danish Nysted or Horns Rev OWFs because scour protection was installed prior to foundation installation.

SSC monitoring
SSC monitoring at Thornton Bank and Belwind OWFs, which was similar in approach to that undertaken at North Hoyle in the UK, concluded that the use of a control site outside of the construction site did not add value to the study due to high natural variability at the site. It also summarised that an extended duration of monitoring (spread across different seasons) would provide more meaningful baseline data.

Current and wake monitoring
Current monitoring was undertaken at the Belgian OWFs, but no specific wake monitoring downstream of turbines was undertaken. Current monitoring was part of turbidity monitoring at the sites.

Coastal monitoring
There are no reports available in order to review findings of coastal monitoring at non-UK OWFs.

Non-UK OWF lessons learned summary
Lessons learned at other European OWFs echo results from UK OWFs, where geological and metocean characteristics are similar, the effects are also likely to be comparable.

[illegible]
Generic lessons from OWF monitoring to date can be applied, especially for predicting scour. If geological, sedimentary and hydrodynamic conditions are similar, the extent of scour (depth and width) can be predicted regardless of geographical location.

With the exception of SSC monitoring, methods currently used to assess coastal and seabed changes are sufficient to detect changes and potential impacts attributed to physical processes.

OWF Environmental Impacts: lessons learnt summary

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

Yes it is possible to derive generic lessons. Areas with similar geological, sedimentary and metocean conditions respond similarly to one another following wind farm construction. The methodologies undertaken were sufficient to detect changes in the physical environment.

[illegible]

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

[illegible]
The authors of this review believe that scour is essentially an engineering issue, and therefore scour monitoring should only be conducted by developers and their engineers in order to monitor the structural stability of any foundations and other associated infrastructure over the lifetime of the project. In most cases, scour predictions made in ESs have exceeded subsequent scour measurements; scour monitoring has shown smaller impacts than predicted and has therefore reduced

uncertainty. Therefore the value of scour monitoring for environmental reasons, especially if no sensitive receptor has been identified, should be revised. The reviewers would only recommend scour monitoring where there is a potential impact on sensitive receptors. However, should scour monitoring still be required by regulators within post-construction monitoring conditions, then the following is recommended.

At development areas where a thin veneer of mobile sediment overlies a harder and less erodible substrate and where scour is less likely to cause structural issues (Section 5.1.3) it is recommended that one post-construction scour survey followed by a scour survey one year after would be appropriate to detect any *unanticipated* changes to seabed morphology. Results from these post-construction and Year 1 surveys could then be used to determine whether any further monitoring would be required. Since scour is considered to be an engineering issue, the frequency, location and coverage of all scour monitoring surveys should be based on local characteristics and in consultation with the developer and their engineers.

Following initial post-construction and Year 1 monitoring reports, the frequency of surveys at sites with silty, cohesive seabed sediments should be reviewed and adjusted accordingly, as these are also likely to experience reduced scour (Section 5.1.3).

At development locations where sandy sediments are thicker, it is likely that an annual monitoring frequency will sufficiently capture scour changes. However, at development sites located on highly mobile sandbanks or where large bedforms are present, the present monitoring frequency of every six months might be more appropriate.

Where palaeochannels have been identified within a development area, it is recommended that monitoring is also undertaken at these sites due to the unpredictable nature of the channel infill substrate and localised hydrodynamics.

When reports from Ormonde are available it is recommended that they are used to inform future offshore renewable energy projects using jacket foundations. This is also the case for any future offshore renewable developments using other foundation types (e.g. gravity base).

Regardless of foundation type, monitoring conditions must take into account the geological conditions at the site. Repeat surveying of a site that is not likely to experience scour issues increases costs and reduces efficiency, and does not further our understanding of scour conditions at that site.

With regard to the duration of surveys, it should be possible for regulatory bodies and developers to come to a mutual conclusion as to when to cease scour monitoring surveys at any offshore development, i.e. if further monitoring would enhance the understanding of scour processes at the site. Any changes made to monitoring requirements should be appropriately captured with the relevant regulatory authority.

Several licence conditions require scour monitoring to be undertaken following a significant storm event; however the licence conditions are vague and provide no specific rationale for the monitoring (i.e. they are not receptor driven). Unless clear rationale and guidance for this condition can be included, this condition should be removed. Although it is accepted that low-frequency/high magnitude storm events can induce significant hydrodynamic changes, if these conditions are required for all OWFs operating within a region, it will not be possible to rapidly mobilise surveyors and their equipment to target each OWF within a short period of time. However, if routine monitoring is able to capture a significant storm event, then the results should be made available for other developers within the same region.

General recommendations regarding scour monitoring are presented below. However, the reviewers would emphasise that these monitoring recommendations are only undertaken if scour monitoring continues to form part of post-consent conditions. Furthermore, any required monitoring needs to be project and receptor specific.

- For monopile foundations:
    - Monitoring where only a thin veneer of sediments is present should occur during post-construction and Year 1
    - In areas of thick sands, monitoring should occur during post-construction and every 6 months for the first year
    - Sites located on highly mobile sandbank margins or in areas of large scale mobile bedforms should occur during post-construction and at least every 6 months for the first year.
- For other foundation types, scour monitoring reports should be available to inform further developments using that type of foundation
- Scour monitoring licence conditions must be targeted based on geological and hydrodynamic conditions at a site and in consultation with the development engineers to capture engineering considerations
- For all monitoring, frequency, duration and spatial coverage of bathymetric surveys must be assessed with regulators, developers and their engineers in order to prevent unnecessary monitoring
- Any changes made to monitoring requirements should be captured and be traceable by updating the original licence.

Recommendations for ongoing scour monitoring summary

The authors of this review believe that scour is essentially an engineering issue, particularly if no sensitive receptors to scour are identified. Therefore scour monitoring should be conducted by developers and their engineers in order to monitor the structural stability of any foundations and other associated infrastructure over the lifetime of the project, and therefore should not form part of a marine licence condition.

Presuming scour monitoring continues to be required for post-construction monitoring within future Marine Licences, then the frequency of scour monitoring needs to be based on the geological and metocean characteristics. For instance, scour monitoring for areas with a thin veneer of mobile sediments should require less monitoring than locations with large mobile bedforms, palaeochannels or sandbanks.

[illegible]

It is recommended that SSC monitoring is only undertaken at future OWF projects if a receptor has been identified which may be sensitive to changes in SSCs and where there is potential for a significant impact (e.g. shellfish beds, spawning areas, bathing waters, salmon migration routes). For OWFs which do not identify sensitive receptors within an ES, it is recommended that monitoring SSCs is not necessary. This is a consideration presented in other reports (Cefas, 2010; DECC, 2008) and is the current practice as noted in the recently issued Marine Licence for the Kentish Flats OWF Extension.

Where SSC monitoring forms part of future licence conditions, a consistent approach to the reasoning, methods and objectives of the monitoring required in licence conditions would be of most benefit to data collection, including the standardisation of units to be reported.

However, the limitation with measuring SSCs (which is the specific term and measurement required within Licences) is the fact that real time measurements cannot be obtained (due to the time required to process samples). As a result, sensitivity thresholds may be exceeded in real time; this would not be captured until the samples were analysed, which unfortunately would be too late in the process. The reviewers would recommend that rather than monitoring SSCs, *turbidity* should be adopted instead to measure water clarity. Monitoring turbidity using optical sensors would permit real time and targeted monitoring. Importantly, establishing thresholds for sensitive receptors and having protocols in place should thresholds be exceeded (for example temporal or spatial restrictions during construction activities) would need to be established in advance with developers, regulators and topic specialists to ensure the monitoring was targeted.

Since boat-based OBS monitoring appears to be the method of choice for developers measuring suspended sediments, this specific survey method is arguably ‘best-practice’. Most importantly, it allows for targeted, *in-situ* and flexible monitoring as construction related plumes are generated in the water column and seabed.

Recommendations for ongoing SSC monitoring summary
SSC monitoring should only be undertaken when a sensitive receptor has been identified and is predicted to be significantly impacted by construction and installation activities. It is recommended that data collection is taken using boat based surveys utilising optical sensors and presented using NTU (units) allowing for real time monitoring which can be targeted towards sensitive receptors. All thresholds should be established early in the process with regulators, developers and topic specialists. However, fixed seabed mooring surveys should also be considered as an alternative method where targeted ‘sensitive receptor specific’ monitoring may be easier or more achievable than boat-based surveys.

[illegible]

Licence conditions requiring monitoring of currents and wakes of turbine foundations have not been included since 2009. As this condition has already been removed from more recent licences, it would appear that current and wake monitoring is no longer required to improve our understanding of downstream turbine wakes and currents, i.e. the uncertainty regarding turbine effects on currents and wake has been removed and therefore monitoring for these effects is no longer necessary.

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For future offshore renewable developments, coastal monitoring should be undertaken based on conclusions drawn in the ES, i.e. where developments are close to a particularly sensitive or erosion prone coastline and where there is uncertainty in the impact predicted. This consideration is current practice, since only wind farms close to a sensitive coastline and considered at risk of a potentially significant effect were monitored for coastal change.

Where monitoring is required, it is recommended, where possible, that Environment Agency (EA) coastal data are used for monitoring, as the EA has been collecting data from aerial photographs, topographic beach surveys, bathymetry surveys and continuous wave and tide recordings since 1991. Since natural coastal changes often happen over a range of temporal scales, it might be recommended that sensitive coastlines that are close to OWFs (or where numerical modelling has shown potential overlap with hydrodynamic effects and sensitive coastal areas) are monitored for change throughout the lifetime of the project, rather than just three years immediately following construction (which was the validity period for previous FEPA licences). Licences issued under the more recent Marine and Coastal Access Act (MCAA 2009) are for the lifetime of a project, hence extended monitoring is now feasible.

Where possible, existing coastal monitoring datasets should be utilised rather than commissioning new coastal studies, especially if no long term baseline data exist. For OWFs located significant distances from coastal areas, coastal monitoring should not be implemented as a licence condition unless validated numerical modelling identifies significant changes to coastal hydrodynamics. Monitoring is also recommended where export cables cross highly sensitive coastal areas and/or require some form of nearshore protection (e.g. rock-dumping or mattressing) potentially resulting in significant changes to coastal processes.

Recommendations for ongoing coastal monitoring summary

Coastal monitoring should, where possible, use existing datasets and should only be undertaken where a sensitive receptor has been identified (e.g. a coastal segment within a conservation area) and where significant changes in hydrodynamics reaching the coastline have been predicted in numerical models. Monitoring should be undertaken over a longer period of time than the current three years post construction, in order to attempt to capture changes that might otherwise be masked by natural variability.

OWF Environmental Impacts: recommendations for ongoing monitoring summary

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

The post consent monitoring of physical conditions should be removed where the risk of impact is low, i.e.

• Where sensitive receptor(s) are not identified in the ES; or

• Physical conditions indicate there will be no impact (e.g. no risk of changes in coastal morphology).

However, it is noted that the developer may want to undertake physical monitoring for engineering / maintenance purposes to test the integrity of the site.

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

Comparability of licence conditions

In general, licence conditions for scour, SSC, current and wake monitoring are almost identical to each other since the issue of the North Hoyle licence in 2002. Minimal changes are made to the specific licence conditions between 2002 – 2008; regardless of physical and environmental characteristics, the same licence conditions are required for OWFs.

For example, a condition might exist for early OWF licences, and then be removed from a certain date (e.g. specifically monitoring scour with regard to cable route integrity which was only required in licences issued in 2003 and 2004). Conversely, in some cases there is initially no requirement to monitor a physical effect which subsequently is specified within a licence condition at one wind farm and is a requirement in all subsequent licences (e.g. scour monitoring after a significant storm, which becomes a requirement in 2004 and is in all subsequent licences, except Gwynt y Môr, which is the most recent licence reviewed in this study). This leads to high comparability between licence conditions issued at approximately the same time, or within a couple of years of one another – however, it is important to note that in general site-specific environmental conditions are not considered when issuing the licences. It is recommended that FEPA licence conditions (now replaced by Marine Licences in 2011) are tailored to geological and hydrodynamic environments; in areas where similar effects are predicted, licence conditions and monitoring requirements should be comparable, though tailored further to specific circumstances.

The inclusion of new licence conditions over time might be linked to findings from previous post-construction monitoring reports and findings. For example, the inclusion of current monitoring conditions which were first used in the licence conditions for Rhyl Flats in 2002 were no longer required post-2004.

Comparability of monitoring reports
Where methodologies and instrumentation are similar during post-consent monitoring, monitoring reports are generally comparable. For example, the use of multibeam bathymetry for scour monitoring across most of the sites is directly comparable from one OWF to the other due to the high resolution instrumentation and quantitative values of change to depth and extent that are presented. Similarly, where boat-based OBS surveys have been conducted for SSC monitoring, presentation of methodologies (e.g. the use of mg/l as a measurement) and results have been comparable. For current and wake monitoring, all surveys where monitoring reports were available to review used similar methodologies i.e. hull-mounted ADCP, resulting in good comparability of results across OWFs.

Summary of comparability between licences and monitoring reports
Licences are generally comparable as very little has changed since the early licence conditions were issued. However, it is strongly recommended that licence conditions are tailored to each individual site in terms of monitoring and should be more receptor driven.

Monitoring reports and the results contained within are generally comparable as the same methodologies are carried out for data collection in most cases.

[illegible]
The effects of scour and suspended sediments are either highly localised (scour, current and wake) or temporary (SSC plumes) which do not extend outside of an OWF's licence boundaries. However, where significant cumulative effects to wave heights and/or wind are predicted to overlap with potentially sensitive receptors (e.g. an erosion prone coastal segment), then it is advisable to establish a coastal monitoring program to reduce the uncertainty of cumulative effects, which are typically based on outputs from numerical models.

Summary of cumulative effects
Scour, current/wake and suspended sediment plumes are either localised or temporary in nature and are therefore unlikely to overlap outside of specific OWF licence boundaries. No cumulative effects are therefore predicted for these processes.

However, significant cumulative changes to wave heights (principally identified with numerical modelling) might overlap with a sensitive receptor, such as a coast or a sandbank, and therefore it is advisable to establish a monitoring program to reduce uncertainty or prevent impacts to these environments. However, this should only be done where overlap and impact is predicted in the ES.

OWF post consent monitoring data summary

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

Licence conditions have changed very little since 2002 and as such are comparable. In addition, monitoring reports are comparable as all utilise the same methods for data collection.

Many of the physical processes which have been monitored, including suspended sediments and scour, have shown localised and often temporary effects during and after wind farm construction. Therefore cumulative effects are less likely to occur from these processes. However, although a localised effect has a small spatial area, as the number of localised effects increases with increasing number of turbines, so does the spatial extent. As a result, it may reach a point where these processes may need to be considered from a cumulative perspective.

[illegible]

This section summarises licence requirements pertaining to underwater noise monitoring for UK OWF developments.

Careful consideration was given to the best approach for the inclusion of non-UK OWFs in this review. Rather than considering individual non-UK OWFs, a more generic review of current non-UK guidance in relation to monitoring requirements was undertaken. This decision is based on the fact that, to be useful, a review of overseas wind farms would ideally require the same level of information that was considered for the UK wind farms, i.e. ES, licence and monitoring reports. Fortunately, similar reviews have already been undertaken in Germany and the Netherlands, for example, which have resulted in protocols and guidance documents. To provide the best insight into the current best-practice applied for non-UK OWFs, it is these protocols and guidance documents that have been considered as part of this review.

[illegible]

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

The reviewed licences span a number of years and include the first round of UK OWFs, when limited information existed on the underwater noise levels generated by either foundation installation or the operation of wind turbines. As such, it is understandable that the licence requirements, relating to monitoring of underwater noise, changed substantially during the time period considered in this review.

In general, the licence conditions for monitoring of underwater noise from (i) construction and (ii) the operational phase are broadly similar for different licences. All the licences reviewed had a requirement to monitor underwater noise from the operational phase. However, the requirement for monitoring of underwater noise from the construction phase was only introduced in the later licences, possibly because the early ESs had not recognised the significance of underwater noise resulting from impact piling of such large wind turbine foundations or the smaller size of the sites meant that management measures were possible. The licences for

Scroby Sands, LID, Kentish Flats, North Hoyle, Barrow, Burbo Bank, Gunfleet Sands (relates to Gunfleet Sands I, although the distinction between Gunfleet Sands I and Gunfleet Sands II was made later), and Rhyl Flats spanning years 2003 to 2007, for example, did not require that the underwater noise from wind farm construction be monitored. It is understood that part of the reason for this is the relatively short construction period for the Round 1 sites which meant that the construction schedules did not coincide with sensitive life stages of key receptors (e.g. periods of peak fish spawning). As far as can be determined, all other licences had a requirement for monitoring of underwater noise from both the construction phase and operational phase, although it is worth noting that in some cases multiple versions of the licence exist and some of the reviewed licences may not represent the final version.

None of the licences reviewed had a clearly defined requirement for pre-construction ambient noise monitoring. In general, there was no guidance provided on how the measured underwater sound data should be obtained and reported.

[illegible][3]

[illegible]	[illegible]	[illegible]	[illegible] start d[illegible]	R[illegible]d[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scroby Sands	East Anglia	2003	05/09/2003	1	No	No	Yes	No
North Hoyle	Liverpool Bay	2002-07	18/03/2005	1	No	No	Yes	No
Rhyl Flats	Liverpool Bay	2002-12	17/02/2006	1	No	No	Yes	No
Kentish Flats	Thames Estuary	2003-03	22/02/2005	1	No	No	Yes	No
Barrow	Morecambe Bay	2003-06	19/12/2005	1	No	No	Yes	No
Burbo Bank	Liverpool Bay	2003-07	21/02/2005	1	No	No	Yes	No
Lynn & Inner Dowsing (separate licences)	Humber	2003-07	30/06/2006 & 13/10/2003	1	No	No	Yes	No
Gunfleet Sands I	Thames Estuary	2004-06	28/08/2007	2	No	No	Yes	No
London Array	Thames Estuary	2006-12	20/08/2007	2	No	Yes	Yes	Yes

[3]The table reflects the contents of the licences available for this review (Task 1: Site-specific review), with additional consideration of the Sheringham Shoal and Gwynt y Môr licences. The latter two licences were obtained at a later stage of the review, and were not considered in the main body of the text.

[illegible]	[illegible]	[illegible]	[illegible] start d[illegible]	R[illegible]d[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Robin Rigg	Solway Firth	2006-12	14/03/2006	1	No	Yes	Yes	No
Thanet	Thames Estuary	2006-12	07/11/2007	2	No	Yes	Yes	Yes
Greater Gabbard	Thames Estuary	2007-02	19/02/2008	2	No	Yes	Yes	No
Ormonde	Morecambe Bay	2007-02	01/09/2007	1	No	Yes	Yes	Yes
Teesside	Teesside	2007-09	29/10/2007	1	No	Yes	Yes	Yes
Walney	Morecambe Bay	2007-10	01/04/2008	2	No	Yes	Yes	Yes
West of Duddon Sands	Morecambe Bay	2008-09	01/01/2009	2	No	Yes	Yes	Yes
Lincs	Humber	2008-10	01/01/2009	2	No	Yes	Yes	Yes
Sheringham Shoal	Humber	2008-11	07/10/2010	2	No	Yes	Yes	Yes
Gwynt y Môr	Liverpool Bay	2008-12	01/01/2009	2	No	Yes	Yes	Yes

[illegible]

There was a general requirement in eight of the available licences (Greater Gabbard, Thanet, Walney, Lincs, London Array, Ormonde, Teesside and West of Duddon Sands)[4], for underwater noise monitoring during the construction phase, following an agreement on the monitoring specification with the Licensing Authority (in some cases specified that this will be in consultation with Cefas and the JNCC) at least four months before the commencement of construction work. The key requirement of these eight licences, except Greater Gabbard, was to measure, as a function of range, the underwater noise from the installation of a minimum of four foundation pieces. In all cases, the four monitored wind turbine foundations were required to be of ‘the first few foundation pieces’, except for the London Array OWF, where they were to be ‘the first foundation pieces’. The latter terminology allows no monitoring flexibility, for example due to bad weather or engineering problems. Experience has shown that it may not always be practical or efficient for the measured foundation installations to be the first few and this may not always capture the maximum hammer energy employed during the construction period. It is worth noting that the

[4] The Robin Rigg licence also had a requirement for construction noise monitoring, but included no details about this requirement. It was assumed that the draft licence made available during the review was not complete with respect to monitoring underwater noise. Similarly, Gunfleet Sand II PCM report indicates a construction monitoring requirement (Task 1: Site-specific review), although, unfortunately, the referenced licence was not available for this review together with the licence for Sheringham Shoal and Gwynt y Môr.

acoustic energy radiated by the source, into the water, scales up with the hammer energy, and the amplitude of the noise radiated into the water may depend on other factors including foundation type, underlying geology etc. The amplitude of the noise propagated through the water column would also depend on a number of factors including bathymetry and seabed type.

The origin of the requirement for a minimum of four foundation pieces cannot be determined from the licences. Whilst more measurements would be needed to provide a statistical power; the intention of collecting noise data for the first four installed turbines was to acquire an early warning that the predictions in the ES were valid (Adrian Judd *pers. comm.*). Monitoring of fewer foundation pieces may be sufficient, in many cases, to validate predictions, provided the chosen foundation location and piling parameters are representative of the higher noise levels expected.

In contrast to the above approach, the licence for the Greater Gabbard OWF did not place a requirement on the number or sequence of foundation installations to be measured, specifically whether the measurements should be undertaken at various ranges or whether the soft-start should be measured. However, the underwater monitoring carried out during the construction phase indicates a requirement for the first foundation piece to be measured, as well as any subsequent foundation which was larger in diameter. This approach ensured that the largest foundation piece was monitored, although it is uncertain where this requirement originated as it is not specified in the licence. The monitoring also used a static underwater noise recorder to monitor the soft-start although this was not a requirement of the specific licence. Such ‘range independent’ monitoring is essential for the monitoring of changes in noise output with time.

The eight licences, which required underwater noise monitoring, specified that the construction monitoring report be submitted to the Licensing Authority within 6 weeks of the installation of the first foundation piece to assess whether further noise monitoring was required. The main variation between the licences, in this respect, was that the Walney, Lincs, West of Duddon Sands and Teesside licences further stipulated that ‘should noise levels be significantly in excess of those predicted during the EIA assessment process then further pile installation will not occur without the consent of the Licensing Authority.’

The licence for the London Array OWF also had a requirement for the programme of work to validate the predictions made during the noise propagation modelling to support the EIA. This programme was linked to fish surveys and appeared to serve the purpose of validating the potential for impact on fish spawning areas to inform any restriction in the following year.

In summary, monitoring of construction noise was not a requirement of earlier licences and had generally not been considered of significance in the corresponding ES (Task 1: Site-specific review). However, measurements of construction underwater noise were obtained as part of the COWRIE study (Nedwell *et al*., 2007) at several of these wind farms (North Hoyle, Scroby Sands, Kentish Flats, Burbo Bank and Burrow). The results of the COWRIE study indicated that the noise levels were potentially of significance to marine fauna. The later OWF licences generally required measurement of underwater noise for the first few foundations installed and to do so at various distances from the pile. Monitoring of the ‘first few’ foundations may not capture the highest noise levels during construction as this depends on parameters such as hammer blow energy, pile locations etc., and the worst case (i.e. the noisiest piling event) may not occur at the first few piles. It is advisable that discussion takes place between the developer and advisors to ensure that representative noise profiles are obtained.

Monitoring of the soft-start is also commonly specified and the requirement for a static measurement (i.e. fixed position), would enable empirical quantification of the variation in the sound output during the soft-start period and help quantify the usefulness of this mitigation strategy. It is difficult to quantify the soft-start using range dependent measurements as the noise level would be expected to change with both range and the hammer blow energy.

[illegible]

Four key requirements are apparent in the supplementary licence conditions relating to underwater noise monitoring of the operational phase of the OWF:

i) the Licence Holder must make provision during the construction phase of the wind farm to install facilities to enable subsea noise and vibration from the turbines to be assessed and monitored during the operational phase of the wind farm
ii) before completion of the construction phase the Licence Holder must supply specification to the Licensing Authority of how it proposes to measure subsea noise and vibration
iii) monitoring is required at various frequencies across the sound spectrum at a selection of locations immediately adjacent to, and between turbines, within the array and outside the array at varying distances
iv) the study would need to reflect differences in foundation/tower type, water depths and sediment types within the site and would need to be supported by adequate baseline data.

These were not always requested consistently for all the OWFs reviewed as part of this study.

The first three key requirements are common across all the OWF licences reviewed, except for the Robin Rigg OWF licence which simply states ‘*The licensee shall make provision during the construction phase of the wind farm to monitor subsea noise and vibration during the construction work and for the first year of the operational phase of the wind farm’*. The Year 1 monitoring report indicates that the requirement for the monitoring of underwater noise was consistent with that stated above. The wording of the supplementary condition for the Lincs OWF is slightly different on the first requirement, stating that ‘The Licence Holder must develop plans’, rather than ‘make provision’, however, the overall requirement remains the same.

Of the three common key requirements stated above, there are also some wording variations relating to the third point, but the requirement is largely unchanged. The Greater Gabbard OWF licence is the exception, in that it does not require measurements ‘adjacent to and between turbines’. Despite the wording variations, the overall requirement of the licence (including Annexes) for measurement across various frequencies and as a function of range remains the same.

In general, the required duration of operational noise monitoring is uncertain (references to licence Annex 1 and Annex 2 may be considered to leave this ambiguous in some cases as the request for ornithological monitoring often requires three years of data collection). It appears that this has been interpreted, in some cases, to be a requirement for three years of operational underwater noise monitoring.

Also, as identified in point i) above, the licences generally require the Licence Holder to make provision during the construction phase to install facilities for the monitoring of operational underwater noise. The reason for the inclusion of this in the earlier OWF licences is acknowledged to have been reasonable given the lack of knowledge at the time. However, there is evidence of agreement between the Licence Holder and regulator at Barrow, for example, that permanent fixtures could be substituted with mobile measurements and it is presumed that this was discussed post-licence for other developments as well (although no direct evidence had been made available). It is therefore not clear, given that this requirement has been supplanted by an alternative and more appropriate solution, why this requirement was not subsequently included in more recent licences. It should be noted that none of the OWFs reviewed achieved the operational noise monitoring requirement with facilities which were preinstalled during the construction phases (Task 1: Site-specific review).

The fourth key requirement which relates to the differences in foundation/tower type, water depths, sediment types and adequate baseline data is only present in seven of the licences reviewed (Lynn, Inner Dowsing, Burbo Bank, Kentish Flats, Barrow, Rhyls Flats and Gunfleet Sands). This general point is also reiterated in Annex 1 of the licences. Chronologically, the licences in which this requirement is present generally represent the earlier, Round 1, OWFs. The Scroby Sands OWF licence is a clear exception, as it does not contain this specific requirement, nor any references to underwater noise and vibration in Annex 1. The remaining licences reviewed generally have a later issue date and do not have this specific requirement for location selection, although the requirement to obtain measurements at ’a selection of locations’ is specified. Consideration is also given to the effect of depth in Annex 1 of the licences (‘effects of distance depth’, presumed to mean distance and depth).

When reviewing the licence conditions related to operational underwater noise measurements it was not always clear how the requirement for monitoring different conditions such as sediment type, depth and turbine type specified in some licences was addressed by the Licence Holder. It is assumed that the monitoring specifications supplied to the Licensing Authority as requested in the licence, would have demonstrated how this point had been addressed. It is possible for the smaller OWF developments that sediment type and bathymetry did not vary across the site. It is also acknowledged that many of the OWFs reviewed would have employed similar foundation and turbine types within site.

In addition to the points highlighted above, Burbo Bank, Kentish Flats, North Hoyle, Barrow and Rhyl Flats OWF licences stated that, ‘collaborative studies, e.g. research funded by COWRIE in this respect, would be an acceptable means of fulfilling this condition'. Fulfilling this requirement was facilitated by a COWRIE study that was underway to establish the underwater noise levels resulting from operational wind turbines, which included measurements at a number of these OWFs.

In summary, there appears to be general consistency in the rationale behind the requirement for monitoring of underwater noise from the operational phase of an OWF. Some variability exists, possibly as a result of improved understanding with time. The removal of the following requirement in the latter licences 'the study would need to reflect differences in foundation/tower type, water depths and sediment types within the site', however, omitted an important aspect of monitoring as these parameters are likely to be very important in influencing the measured noise levels and was considered a useful requirement of the licence.

[illegible]

There was no direct requirement for pre-construction monitoring of ambient noise in any of the licences reviewed. However, licence conditions for Walney, Lincs and Teesside OWFs could be interpreted as having an indirect requirement for ambient noise monitoring during the pre-construction period. At the start of the 'Environmental Monitoring' section these licences state that *'The Licence Holder shall carry out environmental monitoring in accordance with conditions 9.29 to 9.39. Such monitoring shall include pre-construction monitoring for a minimum of one year prior to the commencement of construction, to provide a baseline for subsequent monitoring of the effects of the wind farm, construction and post-construction monitoring programme following the completion of the works.'* Whilst 'Noise and Vibration' is a clearly defined section within the licence, the two underwater noise monitoring conditions (9.35 and 9.36) are between conditions 9.29 and 9.39, indicating that there may have been an intention to monitor pre-construction noise. The two licence conditions relating to underwater noise monitoring (9.35, 9.36) do not require pre-construction levels.

Some other licences have a clear requirement for adequate baseline data to support the monitoring of operational noise (Barrow, Burbo Bank, Lynn, Inner Dowsing, Kentish Flats, Rhyl Flats, Gunfleet Sands I), however, this can be considered to be obtainable through *in-situ* measurements or from previously reported data for comparable conditions. The reference to baseline data is absent from the licence for North Hoyle, Robin Rigg, Scroby Sands, Greater Gabbard, London Array, Thanet, Walney, Lincs, Teesside, West Of Duddon Sands and Ormonde.

In summary, there was often a licence requirement for an adequate baseline against which to compare measured noise. As ambient underwater noise is subject to large variation due to environmental, seasonal and anthropogenic factors, snapshot measurements of ambient noise at the pre-construction stage may not necessarily be the best way of assessing the background noise level against which operational noise should be compared. In light of this, the licences reviewed may be considered to be ambiguous as to how an adequate baseline should be determined. This can be interpreted as measured or otherwise deemed adequate (i.e. measurement of background noise during construction or operation, or reference to other appropriate ambient noise data).

It should be noted that ambient noise is primarily relevant for assessing the significance of operational noise, which is generally of low level and has previously been demonstrated to be broadly comparable with ambient noise within a few hundred metres of the foundation (Nedwell *et al*., 2007; Nedwell *et al*., 2011, Tougaard *et al*., 2009; Wahlberg and Westerberg, 2005).

Consistency of monitoring rationale summary

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

The understanding of the potential impacts of underwater noise has changed significantly through the licensing period reviewed and is reflected in a subsequent evolution in conditions from R1 sites which generally required little by way of construction monitoring, to R2 sites for which construction monitoring is a consistent requirement. The monitoring of underwater noise is an evolving discipline and the appropriateness of the monitoring specifications for ambient, construction and operational noise requires constant evaluation against evolving techniques and technologies.

[illegible]2[illegible]2[illegible]M[illegible]r[illegible]r[illegible]

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

At the time of writing, there were no detailed guidance documents, protocols or measurement instructions for how measurement of underwater noise from the construction or operation of an OWF should be undertaken in the UK. This has been recognised as a limitation during the previous licence review (Cefas, 2010) and recent attempts have been made to provide some initial basic guidance (Cefas, 2012).

Furthermore, there are currently no international standards for the measurement of underwater noise from the construction or operation of an OWF. The International Organization for Standardization (ISO) currently has a work item under Technical Committee (TC) 43, Sub-Committee (SC) 3, Working Group (WG) 3, to produce a measurement standard for the ‘Measurement of radiated noise from pile-driving’, which should be available before 2016. TC43-SC3-WG2 is also working towards an ‘International Standard for Underwater acoustical terminology’, which will also be relevant to any underwater noise measurement. It is recommended that beyond 2016, these ISO standards documents are considered for adoption to provide a standardised measurement methodology.

Compared to the UK, Germany and the Netherlands provide more guidance on how the monitoring of underwater noise related to OWFs should be carried out. Germany has produced a measurement instruction note for the measurement of underwater noise from OWFs and the Netherlands have published a guidance document.

In Germany, the Federal Maritime and Hydrographic Agency (BSH) is responsible for the licensing of OWFs and provides comprehensive guidance on how underwater noise should be assessed and monitored. BSH specifies the requirements for underwater noise prediction, and monitoring to check compliance against the predictions, in a BSH guidance document entitled 'Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment (StUK 3)' (BSH, 2007). The measurement protocol to be followed is further specified in a BSH application instruction document entitled 'OWFs - Measuring instruction for underwater sound monitoring' (BSH, 2011). This instruction document provides all the necessary specifications for carrying out the required measurements during pre-construction, construction and operational phases of the wind farm. These include, the required frequency range, hydrophone depth, hydrophone performance and calibration requirements, measurement distances/positions, metrics to measure, analyses and reporting parameters, and metadata requirements. A key requirement during the construction phase is monitoring at distances of 750m and 5,000m, with the additional requirement that the single pulse sound exposure level (SEL) at a distance of 750m around the source should not exceed a predetermined threshold (160dB re 1 µPa·s^2). There are also a number of requirements for the measurements during the operational phase. These include a measurement at a distance of approximately 100m from a turbine in the middle of the wind farm, a measurement outside the wind farm at a distance of 1,000m, plus another measurement location at a distance of 5 km or in the nearest nature conservation area if it is less than 5km from the wind farm.

In the Netherlands, licences for the second round of wind farms required measurements during the construction and operational phases. The measurement requirement during the construction phase included the use of a 'permanent' noise measurement system, plus ship based measurements along a transect, with hydrophones at various depths (De Jong *et al*., 2011). During the operational phase, the initial monitoring requirement included use of a permanent measurement system to measure the underwater noise continuously during the first year of operation in and around the wind farm to distances where the noise was no longer distinguishable above ambient noise. These requirements were reviewed (De Jong *et al*., 2011) and current guidance in the Netherlands is based on the result of preliminary steps towards standardisation between North Sea European nations and is essentially provided through two documents; one relating to definitions of quantities and units (Ainslie, 2011) and one related to procedures for measuring underwater noise in connection with OWF licensing (De Jong *et al*., 2011). This second document provides all the necessary specifications for carrying out the required measurements during pre-construction, construction, operational and decommissioning phases of the wind farm. These include, the required frequency range, hydrophone depth, hydrophone performance and calibration requirements, instrumentation and processing, measurement distances/positions, metrics to measure, analyses and reporting parameters, uncertainties and metadata requirements. The key points are:

- Ambient noise measurements are to be carried out at a minimum of two fixed points during the pre-construction phase. One position must be inside the wind farm and a second outside the wind farm (either at a distance of 4km or at a distance where construction or operation can have a significant effect on marine species). This is required in minimum periods of 24 hours, where the periods are chosen to capture different seasons and weather conditions. These levels are required in one-third octave bands.

- Monitoring during construction must be carried out at a minimum of two fixed locations, with one of these being at a distance of 750m from the foundation piece. A second position must be either at a distance of 4km from the foundation or at a distance where construction or operation can have a significant effect on marine species. The measurements must encompass each type of foundation and installation method used across the wind farm site and must also capture the effects of any mitigation used such as soft-start, bubble screens, cofferdams, etc. The levels, at different hammer energies, are required in one-third octave bands, with additional guidance suggesting that broadband SEL and peak acoustic pressure be reported as a function of range.
- Monitoring during the operational phase must be carried out at a minimum of two fixed locations, with one of these being at a distance of 100m from the foundation piece. A second position must be either a distance of 4 km from the foundation or at a distance where construction or operation can have a significant effect on marine species, or at or close to the position where ambient noise was monitored. This is required in minimum periods of 24 hours, where the periods are chosen to capture different operational states. These levels are required in one-third octave bands, in addition to narrow band analyses to characterise tonal components.
- Monitoring during the decommissioning phase must be carried out at fixed locations to validate against predictions in the EIA or against specified thresholds. The measurements must also allow characterisation of the source (the type of source might vary substantially for decommissioning).

For other North Sea European nations, the requirement for monitoring of underwater noise during construction may be led by that member states Marine Strategy Framework Directive (MSFD) commitment to the European Commission (EC). In Belgium for example, their MSFD descriptor for underwater impulsive noise requires that the level of anthropogenic impulsive sound sources is less than 185dB re 1µPa zero-to-peak sound pressure level (SPL) at a distance of 750m from the source (Degraer *et al*., 2012).

In the United States, the approach has been very different and has historically been driven by concern of injury to fish. There is also variation, between different States, in the adoption of criteria against which the severity of underwater noise from pile-driving has been assessed. In 2009, California issued ‘Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish’ (Oestman *et al*., 2009). This document primarily deals with injury criteria and how to assess the likelihood of injury to fish from pile-driving. It does not provide the level of guidance necessary to undertake consistent measurements in the way that the German and Dutch guides do.

Despite the lack of any national or international standardisation, the monitoring reports reviewed as part of this study (Task 1: Site-specific review) undertook measurements with sufficient technical competence that the measurement equipment was of the required performance and the methodology adopted was arguably the best approach, given the requirements of the licence. The lack of guidance or standardisation has, however, led to differences in the metrics used and the way the data are reported, making comparisons potentially challenging. This has been alleviated, to some extent, by the relatively limited number of organisations that have been employed to undertake the monitoring. As has previously been recognised (e.g. Cefas, 2010 and Cefas 2012), it is important that the measurements are carried out and reported such that they are comparable across the board.

In summary, there are no national or international guidance and standards (on measurement methodology, definitions or units for example) on how underwater noise from wind farms should be monitored, which introduces the potential for inconsistency in the way the measurements are performed and reported. Until such guidance and standards are available, comparability of reported acoustic parameters could be facilitated by requesting a range of metrics to be reported for underwater noise levels resulting from piling and operational turbines such that comparison can be made with the predicted levels and future measurements. Many of the measurement data obtained so far have only been reported as peak-to-peak pressure levels stated in decibels. Similarly, for operational noise measurements, there are several ways in which the data can be analysed and reported, which cannot be easily compared. Ideally, for comparison against ambient noise it is sensible to report frequency dependent levels resulting from operational noise as power spectral density, which, has been done in most reviewed monitoring reports. It would have been very useful though had these power spectral densities also been expressed as third-octave bands, as it is quite common to see ambient noise levels reported in this way. Metrics are further discussed in Section 5.2.3 below.

Monitoring best practice summary

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

Monitoring undertaken to date has been carried out competently. Due to the evolving nature of underwater noise monitoring there is currently no guidance for best practice; however other countries provide extensive guidance which could be tailored to UK needs. International standards are being drafted and should be considered for adoption once they are available. In the meantime, good practice being developed in the UK should be followed.

[illegible]

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

Substantial underwater noise data were collected as a result of the licences requirements and the early COWRIE study (Nedwell *et al*., 2007). The collaborative approach through COWRIE allowed data to be gathered and reported consistently and coherently, providing invaluable evidence that construction noise has the potential to result in significant noise levels. Where possible this collaborative approach should be encouraged, particularly in areas where comparable developments are taking place.

Overall, post-consent monitoring to-date has considered the acoustic pressure field around; (i) pile foundations being driven into the seabed during wind farm construction; and (ii) operational wind turbines. In addition, ambient noise data have also been measured and reported. Generally, the reported methodologies and equipment employed were of sufficient quality to be able to detect and report changes (Task 1: Site-specific review).

A considerable amount of underwater noise data has been collected from the installation of foundation pieces, providing improved confidence in predictive modelling and in the potential underwater noise levels expected during impact piling of monopile foundations in shallow coastal waters, with the range of hammer energies that were available at the time (the maximum pile diameter being around 6m and the maximum hammer energy being around 1800 kJ). These have been shown to result in significant impulsive noise levels, which can propagate tens of kilometres at levels which have the potential to impact sensitive marine fauna. The underwater noise monitoring does not, however, directly monitor the environmental impact of underwater noise on marine fauna. However, correlating measured noise levels with empirical data from marine mammal and fish surveys may help address knowledge gaps regarding the potential response of marine receptors to OWF construction and operational noise.

Measurement data have also been collected of underwater noise radiated from operational modern wind turbines, and were reported to be of a relatively low level, broadly comparable to ambient noise at ranges of only a few hundred metres from the source.

Available data also indicate that sound levels realised during wind farm construction and operation do not achieve levels that would be considered lethal to sensitive marine receptors considered in the EIA.

A parameter not specifically considered in the licence and thus post-monitoring reports is particle velocity in the water column, which would require utilisation of different types of equipment to that used to measure sound pressure changes underwater (e.g. Mueller-Blenkle *et al.,* 2010). Similarly, measurement of seabed vibration, a parameter yet to be quantified in relation to OWF development, would require specifically tailored equipment. The relevance of both these parameters is further considered in Section 5.2.4.

OWF Environmental Impacts: lessons learnt summary

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring?

Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

Evidence to date demonstrates:

- ***Underwater noise from operational wind turbines is not considered significant.***
- ***Underwater noise associated with marine impact piling can result in significant impulsive noise levels with the potential to impact marine fauna.***

Measurement data obtained to-date, as a result of post consent monitoring and other studies, particularly relating to underwater noise resulting from piling, has led to improved confidence in understanding and thus predicting the likely noise levels expected from OWFs and therefore, to some extent, the potential for impact. There still remains some uncertainty regarding future developments employing technology which has yet to be measured (e.g. new hammer technology, mechanical mitigation measures).

Better correlation of measured noise levels with marine mammal and fish surveys is required to obtain a better understanding of the noise levels that result in observable behavioural changes and to allow better validation of predictions made during the environmental impact assessment phase.

[illegible]

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

[illegible]

The monitoring reports, reviewed as part of this study (Task 1: Site-specific review), show that the underwater noise levels resulting from the pile-driving of monopile foundation pieces are significant, and assessing these levels accurately in any pre-consent predictions is important, as is validation during post-consent monitoring. However, it should be noted that the previous measurement data provide valuable information on the noise levels resulting from a range of wind farm construction projects, in shallow coastal water (i.e. generally less than 25 m), which installed monopile foundation using pile-driving. For future wind farms which fall within the construction envelope of the existing UK wind farms (i.e. foundation type and size, foundation penetration depth, hammer size (hammer blow energy), water depths and seabed/geology types) the value of the monitoring activity should be assessed. It is expected that there will be a number of future wind farms employing different foundation types, with larger hammers (or indeed smaller) and in deeper water when compared to the already constructed OWFs. If such future wind farms are employing pile-driving then monitoring of underwater noise levels would be beneficial and would allow validation of propagation modelling within the scope of these different conditions. This requirement should also remain if mechanical mitigation methods are used, to ensure they are achieving the level of reduction required.

The use of foundation types which do not require pile-driving is anticipated to be more widely used in the future. If the method used is not expected to result in a significant increase in local noise levels then the requirement for monitoring of the underwater noise would naturally be reviewed.

From a more holistic perspective, facilitating comparison with measurements of underwater noise from pile-driving in other European countries could be advantageous. The supplementary licence condition relating to the monitoring of underwater noise during construction of an OWF already includes a requirement for measurements at various distances from the source and could include the requirement for one of the measurement positions to be at a distance of 750m from the foundation piece, or as close as is practically possible. This would enable comparison with measurements made in other European countries, particularly Germany, the Netherlands and Belgium. Specifying a distance at or near 750m from the pile also ensures that at least some of the measurements are obtained in the vicinity of the pile, which would also be useful for validation of the likely efficacy of the mitigation zone employed during the pre-piling watch[5]. These close-in measurements can provide some of the most valuable data when attempting to estimate the sound source level by back propagating received levels measured at various ranges back to the source.

Due to the lack of standards or guidance documents on how the underwater noise from marine pile-driving should be measured and reported, it is recommended that the licence conditions stipulate reporting of the noise levels in a range of metrics, which will aid in comparison of collected data. These should at least include:

- Peak-to-peak
- Zero-to-peak
- Pulse SEL
- The root mean square over the duration of the pulse.

At present, the underwater sound levels predicted in support of the environmental impact assessments and measured during the monitoring programme are in terms of acoustic pressure. For marine mammals, this is likely to be the parameter of importance when assessing impact. However, for many fish species, particle velocity will also be important and is further discussed below (section ‘General’).

Pile-driving will result in vibration of the seabed. At present, there is very limited understanding of the characteristics of this vibration and how efficiently it travels along the seabed for different seabed types. As discussed below (section ‘General) there is also very little understanding of the effect this may have on seabed dwelling marine fauna and further understanding of this would be required to establish if this should form a requirement of future licences.

[5] Ideally, the measurement procedure should provide an increase in the confidence that the noise level at the onset of piling (i.e. during the first few minutes of the soft-start) is such that it does not exceed the threshold believed to have the potential to cause instantaneous injury to marine mammals beyond the range of the required mitigation zone.

M[illegible]
Available data on the operational turbine noise, from the UK and abroad, in general show that noise levels radiated from operational wind turbines are low (e.g. Betke *et al*., 2004; Tougaard *et al*., 2005; Nedwell *et al*., 2007; Edwards *et al*., 2007; Nedwell *et al*., 2011) and the spatial extent of the potential impact of the operational wind turbine noise on marine receptors is generally estimated to be small, with behavioural response only likely at ranges close to the turbine (e.g., Madsen *et al*., 2006; Wahlberg and Westerberg, 2005 and Tougaard *et al*., 2009). Although the early measured data were mainly for smaller capacity wind turbines ranging from about 0.2 to 2.0MW (largely summarised in Wahlberg and Weston, 2005; Madsen *et al*., 2006), more recently reported measured operational noise data (Nedwell *et al*., 2011) from larger capacity wind turbines had noise levels and characteristics comparable with previous wind farms reported in Wahlberg and Westerberg (2005) and Madsen *et al*. (2006).

In light of the published data, and following a review of the available monitoring reports on the monitoring of operational noise (Task 1: Site-specific review), it is suggested that operational noise monitoring of individual wind farms may be of limited value in relation to the potential impact of acoustic pressure on sensitive marine receptors, unless there is a specific concern relating to the effect on a local habitat; the development is planned in an unusually 'quiet' area; or there are any reasons why a particular OWF may result in underwater noise levels which are substantially different to those already measured for other OWFs. Parameters for consideration when deciding if a particular wind farm requires monitoring of underwater noise during the operational phase should include at least:

- The type of turbine being used
- The type of foundation being used
- The underlying geology for the wind farm
- The water depth
- Turbine separation distance
- The total number of turbines
- The local ambient noise
- The presence of sensitive receptors.

All the measurements undertaken to-date indicate that the broadband turbine noise is generally comparable with ambient noise at distances of a few hundred metres, however, tonal components have been shown to be detectable at greater distances from the OWF. If the monitoring of underwater noise from operational wind turbines is indeed required, there should be a requirement to report the noise data as a function of frequency using both narrow (e.g. a resolution of 1 Hz to adequately capture the tonal components) and third-octave band spectra to allow comparison with other noise measurement data, and include a comparison with background noise measurements near the site under comparable conditions.

Whilst the broadband underwater noise resulting from the operation of an OWF has been shown to be of a relatively low level, the level of seabed vibration resulting from an operational wind turbine is still unknown. Similarly, whilst there is understanding of the likely sound pressure level in the water resulting from operational wind turbines, the resulting particle motion in the water column as a function of depth and range is not known, although it is generally possible to derive this from hydrophone measurements for a propagating wave. Particle velocity measurements near an operational wind turbine have also been undertaken by Sigray and Andersson (2011). Both, particle velocity and seabed vibration are further discussed below (section ‘General’).

General

All FEPA licences reviewed used the term ‘noise and vibration’ which is not specifically defined in the licence, however, it can be inferred from the post-consent monitoring reports reviewed (Task 1: Site-specific review) that the term ‘noise and vibration’ was interpreted to mean acoustic pressure. It is further understood that the original intention of including ‘vibration’ in the licence conditions was to understand the effects that ‘mechanical vibration’ caused by the rotating blades had on epifauna colonising the surface of the turbine structures (Adrian Judd *pers. comm*). In line with the post-consent monitoring reports, this review adopts ‘noise and vibration’ to mean acoustic pressure and a clear distinction is made with regard to seabed vibration and particle motion in the water column (i.e. displacement, velocity or acceleration).

For all underwater noise monitoring, the specification of a minimum requirement for reporting metadata parameters, perhaps similar to the requirements specified in Germany and the Netherlands, could prove beneficial. The MEDIN data guideline for the recording of underwater ambient noise data, published in 2011, should be used where applicable.[6]

In general, there are a number of unknowns relating to the underwater noise and vibration resulting from wind farm construction and operation and further understanding of the significance of these is required before deciding if they warrant inclusion in future licences. These are:

i) The underwater acoustic particle velocity as function of depth and range from both a piling event and an operational wind turbine. In some cases, the plane-wave approximation for converting acoustic pressure to acoustic particle velocity will not be true due to the interaction of the sound wave with the surface and seabed.
ii) The seabed vibration as a function of range from a piling event and an operational wind turbine. This understanding would expand the current knowledge base and should perhaps be investigated generally, rather than through specific licence conditions. Its relevance within the EIA and whether it should be included as a requirement in future licences can then be established subsequently. Further to highlighting the data gaps in relation to the level of seabed vibration that may result from wind farm developments, it should also be noted that the effect of seabed vibration on seabed dwelling marine fauna is also unknown. As such, understanding the absolute level of vibration may be of limited value without improved understanding of its effect on the relevant marine receptors.
iii) The effect of multiple, large scale, operational wind farms on regional ambient noise levels.

[6] http://www.oceannet.org/library/key_documents/Index.html

The measurement of noise levels should not be considered a measure of the impact as it is a cause and not an effect. To measure the impact, receptor monitoring is essential and correlation of measured noise levels with marine mammal and fish surveys are required to obtain a better understanding of the noise levels that result in observable behavioural changes and to allow better validation of predictions made during the environmental impact assessment phase.

Recommendations

Further work is required, beyond the scope of post consent monitoring, to understand the significance of seabed vibration before considering whether this should be included as a requirement for noise and vibration monitoring for either the construction or operational phase.

Similarly, work beyond the scope of post consent monitoring is needed to establish the requirements for acoustic particle velocity measurements alongside acoustic pressure measurements when undertaking underwater noise monitoring during either the construction or operational phase.

The requirement for monitoring of underwater noise during the operational phase should be considered on a case-by-case basis and need not be included unless there is a specific concern relating to the impact on a local habitat; or the presence of sensitive receptors; or the noise levels are expected to be significantly higher than local ambient noise; or there are any reasons why it may result in underwater noise levels which are substantially different to those already measured for other OWFs. Parameters to consider when reviewing this decision should include at least; the type of turbine being used, the type of foundation being used, underlying geology into which the foundation is installed, water depth, turbine separation distance, total number of turbines, local ambient noise and presence of sensitive receptors.

The requirement for monitoring of underwater noise during the construction phase should remain if the foundations are installed using the pile-driving method. However, the inclusion of this requirement should be reassessed if an OWF construction project is considerably similar to previous wind farms for which reliable measurement data exist. The inclusion of this requirement should also be reassessed if an OWF construction project is employing an installation method other than pile-driving. However, this requirement should remain if there is uncertainty regarding the radiated noise levels, such as for example when mechanical mitigation methods are used, and there is uncertainty regarding their efficacy under specific operating/environmental conditions, to ensure that the required level of reduction has been achieved. Any reassessment of this requirement should consider the potential presence of receptors which may be impacted and whether noise measurements are required for this impact to be tested.

The existing requirement should stipulate a range of metrics for which the underwater sound levels should be reported and should require one of the measurement position to be at a distance of 750m from the foundation piece, or as close as practically possible, to allow comparisons with other European countries. Additionally, the requirement for which foundation pieces should be monitored should be based on the specifics of a given development and take into account varying foundation types, hammer energies, geology etc. It is advisable that discussion takes place between the developer and advisors to ensure that representative noise profiles are obtained. The monitoring should look to demonstrate the validity of any marine mammal mitigation zone (e.g. following the JNCC guidance; JNCC, 2010) and soft-start, i.e. that the noise level at the onset of piling (during the first few minutes of the soft-start) is such that it does not exceed the threshold believed to cause instantaneous injury to marine mammals at distances greater than the required mitigation zone.

Licences reviewed in this study do not specifically require ambient noise monitoring, although many specify the request for adequate baseline data to enable comparison with the monitored wind farm noise. This could be obtained through dedicated measurements or from previously measured data. However, existing data for the UK waters are sparse and as ambient underwater noise is subject to large variation due to environmental, seasonal and anthropogenic factors, snapshot measurements of ambient noise at the pre-construction stage may not necessarily be the best way of assessing the background noise level. Because anthropogenic contributors to ambient noise include a wide range of industries besides the OWF industry, ambient noise level for UK waters might be best realised through collaboration between the relevant offshore industries and government, in parallel with the requirements of the MSFD Descriptor 11, Indicator 11.2.1 relating to ambient noise. It is recommended that, during the underwater noise monitoring of the construction phase, background or ambient noise measurements are undertaken as a matter of course when pile driving is not underway.

The licence conditions relating to underwater noise should, where possible, look to explore options for strategic studies, with the COWRIE study (Nedwell *et al*., 2007) being an example of where this was successful. This would provide more coordinated studies with the potential to increase knowledge output whilst potentially reducing the overall cost.

OWF Environmental Impacts: recommendations for ongoing monitoring summary

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

[illegible]

- [illegible]
- [illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

The monitoring reports which have been reviewed as part of this study are broadly consistent with respect to the methodology adopted (Task 1: Site-specific review). Most inconsistencies occur in the reporting of the data, but in most instances common metrics have been reported. However, for the future, the definitions which are currently being defined within the International Organization for Standardization (ISO) should be considered alongside previously employed parameters. This would facilitate comparisons with future measurements whilst preserving a level of comparability. Although, as many of the OWFs are constructed in shallow water, the tidal state can have a significant influence on the noise levels at a range from the source, particularly for pile-driving. Also in shallow water, the measurement hydrophones are sometimes necessarily closer to the surface than would be desired. Without accounting for these factors, it may be difficult to make relative comparisons between wind farms. Despite this, the measurement data have established that pile-driving from wind turbine foundation installation generates significant noise levels, whilst noise from operational turbines is relatively low.

There are instances where previous measurement data for underwater noise could be applied more broadly to inform the likely significance of the noise for other sites, if the relevant conditions are comparable. This might particularly be the case for operational noise monitoring, or when wind farm expansion is considered, where similar turbines and foundations are being used in similar environments.

Although the measurement of underwater noise does not directly inform the actual impact on marine fauna, the underwater noise monitoring reports can be used to inform cumulative impacts, such as for example wind farm construction on a region-wide scale. In combination with marine mammal observations, knowledge of the noise levels can be useful in understanding the impact on a broader scale. Underwater noise radiated during the construction activities could be correlated with animal density information and specific habitats, for example, to help estimate the overall potential impact and inform cumulative impacts on a population level. Such a survey may also wish to consider seismic surveying which results in high source levels, is widespread in the North Sea region and would help demonstrate a more historic trend if one existed.

OWF post consent monitoring data summary

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

Yes, the monitoring reports and data therein do allow for comparison and could be used to determine cumulative impacts. However, guidance documents or national/international standards should be adopted, if appropriate and where possible, to ensure consistency in the future.

[illegible]

[illegible]

Benthic ecology has been considered based on several sub-components that have been employed to assess this aspect of the post-consent monitoring. These are specifically; benthic grab surveys, 2m beam trawling, intertidal surveys and monopile colonisation studies. The greatest level of effort in the UK has been directed towards the benthic grabbing studies and this is the focus of the observations made below with additional, technique specific, comments provided for each of the questions.

[illegible]

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

[illegible]

Post-consent monitoring conditions of the OWFs in the UK, reviewed as part of this exercise, account for a pre-construction, a construction and up to three years of post-construction monitoring studies aimed at assessing and understanding the potential impacts of the developments onto benthic habitats and associated faunal communities. There is consistency of requirements across most licences, as summarised in Table 4 but these are generic and lack reference to site-specific impacts predicted in the ES.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scroby Sands	East Anglia	2003	1	Rees *et al*. 1990; details of sampling and laboratory analyses	Day Grab; Dredge; 2m Beam trawl	No	No
North Hoyle	Liverpool Bay	2002-07	1	Indicative sample locations and no. of replicates	Grab	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
Rhyl Flats	Liverpool Bay	2002-12	1	Indicative sample locations and no. of replicates	Grab	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
Kentish Flats	Thames Estuary	2003-03	1	Indicative sample locations and no. of replicates	Grab	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
Barrow	Morecambe Bay	2003-06	1	Indicative sample locations and no. of replicates	Grab	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
Burbo Bank	Liverpool Bay	2003-07	1	Cefas, 2002	No	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
Lynn & Inner Dowsing	Humber	2003-07	1	DTLR (Cefas) 2002; EN Research project 543 (*Sabellaria* assessment)	AGDS, grab and video to assess *Sabellaria*	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
Gunfleet Sands	Thames Estuary	2004-06	2	DTLR (Cefas) 2002;	AGDS, grab and video to assess *Sabellaria*	Yes (sampling upper, mid & lower shore, 3 transects)	Yes (diver operated video and sampling)
London Array	Thames Estuary	2006-12	2	None; indicative no. of replicates	No	No	Yes (video observations and sampling)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Robin Rigg	Solway Firth	2006-12	1	No	No	No	No
Thanet	Thames Estuary	2006-12	2	None; indicative no. of replicates	No	No	Yes (video observations and sampling)
Greater Gabbard	Thames Estuary	2007-02	2	None; indicative no. of replicates	No	No	Yes (video observations and sampling)
Ormond e	Morecamb e Bay	2007-02	1	None; indicative no. of replicates	No	No	Yes (diver operated video and sampling)
Teesside	Teesside	2007-09	1	DTLR (Cefas) 2002;	No	Yes (sampling upper, mid & lower shore, 3 transects)	No
Walney	Morecamb e Bay	2007-10	2	None; indicative no. of replicates	No	No	Yes (video observations and sampling)
West of Duddon Sands	Morecamb e Bay	2008-09	2	None; indicative no. of replicates	No	No	Yes (diver operated video and sampling)
Lincs	Humber	2008-10	2	None; indicative no. of replicates	No	No	No
Sheringh am Shoal	Humber	2008-11	2	None; indicative no. of replicates	No	No	No
Gwynt y Môr	Liverpool Bay	2008-12	2	None; indicative no. of replicates	Beam trawl for epifauna.	Yes (no type of survey specified)	Yes (diver operated video and sampling)

A general requirement within the licence, common to physical and biological monitoring, is that the interpretation and reporting need to capture all interrelationships. However, no details of such relationships are given, which, specifically to benthos, include relationships with the physical environment, habitat and food supply to fish, shellfish, seabirds and marine mammals populations, as well as effects associated with the exclusion of trawling activities.

The licences' rationale for the design of benthic surveys is limited to advice on the choice of sampling stations based on the foundation locations and cables, taking into account coastal modelling outputs and geophysical surveys. Some licences refer to guidance to be followed (e.g. Cefas, 2002; Rees *et al.*,1990); others require agreement of site-specific survey design with the relevant advisors and regulatory authorities (e.g. Cefas, Natural England, CCW).

The number of replicate samples at each benthic grab station is established at three and based on the results of the characterisation survey. The majority of licences require a suitable baseline dataset and adequate control sites, in fewer cases the number and location of survey stations are specified in relation to the area of potential impact, e.g. development site, secondary impact, scour assessment, cable corridor and reference areas. A common requirement across all licences is that sedimentary and benthic datasets need to be closely related, but no further specification or guidance for e.g. subsampling for sediment particle size and/or chemistry, are provided.

Requirements for the type of sampling gear are not specified within the majority of the licences reviewed and the few that do make recommendations propose the Day Grab ($0.1m^2$) and dredge for infaunal communities and 2m beam trawl for epifaunal and fish communities.

Specifications for the identification of areas likely to support features of conservation importance, such as Sabellaria spinulosa reef, are consistent across the licences and include acoustic ground discrimination systems (AGDS) ground-truthing using grab and dropdown video observations, with areas of potential reef, as identified by the AGDS, to be surveyed at a fine scale using video observations to confirm the presence, or otherwise, of reef in line with the Sabellaria monitoring guidelines outlined in English Nature Research Report 543. Similar bespoke techniques have been proposed for geogenic reef features, primarily based on geophysical methods supported by video.

In terms of outputs, licences' requirements include provision of data, interpretation, assessment, and conclusions with full datasets (processed and unprocessed) submitted within the reports.

Review of studies on the potential ecological effects of the OWFs outside the UK was undertaken as part of this exercise with a view to comparing approaches to post-consent monitoring programmes. The points deemed pertinent to this study are summarised below.

Danish environmental monitoring programmes adhere, where possible, to the Before and After Control Impact (BACI) design. With regard to benthos, the studies are focused on the assessment of the consequences of the introduction of a hard-bottom habitat and a survey of the infauna community in the wind farm (DONG, 2006). Monitoring of the environmental-biological condition *during the construction phase* of Horns Rev were not deemed necessary on the basis of three factors to include a) the very limited and temporary impact associated with construction of the wind farm and the cable route; b) the total reclaimed area being minor (0.1%) in relation to the total area; and c) the fact that in the area affected by the development there are no species or habitat types that require special protection.

Similarly, a special programme for monitoring and control of the benthic fauna during the *operational phase* was not considered necessary on account of 1) the predicted impacts being only localised and resulting in marginal changes, 2) the absence of species or habitats specially requiring protection, 3) the predicted impacts on water exchange, current, sediment and wave regime of the area, assessed to be localised

(ELSAM Horns Rev OWF EIA). The monitoring programme however, did focus on assessing the establishment and succession of turbine foundation epifauna through qualitative and quantitative studies of the course of succession, community stability and sensitivity to extreme weather conditions. The results of the monitoring were required to be assessed in relation to enhancement of the existing fish and bird fauna or that which is expected to develop. Monitoring was required on a representative sample of the wind farm turbine foundations and scour protection reef and used a combination of quantitative sampling and video documentation. The sampling area and the stations were selected using a statistical sampling design, programmed to cover the depth range and the prevailing currents in the wind farm area (ELSAM Horns Rev OWF EIA). The key difference with respect to UK conditions is in relation to items 1 and 2, where a more precautionary approach has been adopted, primarily due to lack of certainty over outcomes. The UK assumption is that impacts will be broad-scale, whereas those in Denmark have been that impacts will be small scale and will have wider impacts through interactions with other trophic groups. Although a stated requirement of UK conditions, the importance of trophic interactions has been largely ignored in UK studies.

The Belgian programme for monitoring the environmental permit includes a monitoring programme to ensure 1) the ability to mitigate or even halt the activities in case of extreme damage to the marine ecosystem and 2) an understanding of the environmental impact of OWFs to support policy, management and design of future OWFs. The former objective is achieved through the baseline monitoring, focusing on the *a posteriori*, resultant impact quantification, while the latter monitoring objective is covered by the targeted or process monitoring focusing on the cause-effect relationships of *a priori* selected impacts. Through a combination of large and small scale studies, Belgian monitoring of OWF indicates that major effects onto the benthos component of the marine ecosystem become more pronounced as the wind farms ‘grow older and bigger’. In this context, the effects can be linked (mainly) via the food chain from hard substrate “epifouling” organisms to the natural soft bottom macrobenthic and epibenthic communities and subsequently to demersal and bentho-pelagic fish (Degraer, Brabant and Rumes, 2012).

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Epibenthic survey methods do not easily fit within the post-consent monitoring programmes due to a lack of clarity with respect to their intended use. In some cases they have been included to support fisheries studies (juvenile and small fish populations) whereas in others they support the benthic grab studies (epibenthic invertebrates). In many cases (50%) 2m beam trawling, as a method, was not included in either benthic requirements or fisheries requirements. Where it was included, in only one instance was it linked to the ES impacts. In a further recent instance at Sheringham Shoal, although not included via the licence, a requirement was negotiated through Cefas and included in an Environmental Management Plan (EMP).

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With respect to intertidal monitoring, in all cases no rationale for the monitoring (sediment coring for invertebrates) has been provided in the licence conditions. Many of the licence conditions (50% approximately) make no mention of an intertidal requirement, regardless of predictions in the ES. These predictions are primarily related to disturbance to intertidal sediment habitats and communities, through the laying of cables, with potential consequential effects on the intertidal bird species. However, when a requirement is indicated it is consistent across the licence conditions. Unfortunately, the requirement has been presented as a formulaic description of a survey array, which is unrelated to specific issues within the ESs. The subsequent application of the survey array, as described, has led to inappropriate and ineffective monitoring activity. However, one area of a consistent and effective approach has been with respect to exclusion for the need to monitor if directional drilling has been employed, although no alternative monitoring to identify effects of breakout disturbance (where the laterally drilled cable route emerges at the seabed surface to join the offshore cable) has been indicated. In those instances where monitoring has been for a specific issue e.g. *Sabellaria* reef, then reference back to the ES predicted impacts has been made, although sequential and traceable reference, including discussions with regulators and or advisors through the licence process, lacks transparency.

[illegible]

In all cases no rationale for the survey and analysis of the monopile colonisation has been presented other than to identify what has colonised the turbine and scour protection. Several of the licences (26%) make no reference to the need to monitor colonisation. Those that did refer to the need to study the colonisation make reference to diving or dropdown video surveys, supported by sampling. No greater definition has been provided. As indicated above, the focus on several of the European studies has been to determine the colonisation of the turbines and then identify the consequential effects of the turbines on the benthos.

Consistency of monitoring rationale summary

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

With regard to infaunal grab sampling, there is consistency of requirements across the majority of the licences reviewed, these being generic and, in most cases, lacking reference to site-specific impacts predicted in the ES. With regard to intertidal and turbine foundation colonisation, limited or no rationale for the monitoring programme has been provided in the licence conditions; similarly, there is lack of clarity with respect to the intended use of epibenthic 2m beam trawl monitoring surveys.

[illegible]

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

[illegible]

Methods of survey and selection of sampling stations for the post-consent monitoring studies were based on the baseline and characterisation studies, which provided coverage of the main site-specific habitats, a broad assessment of their distribution and extent within the study area, and aided the selection of reference areas. Particularly good examples of monitoring have been based on a before and after impact survey design, with selected reference sites, well defined impact areas, including those within the boundary of the development site comprising stations selected for scour assessment, sites within the cable corridor and the secondary impact areas (outside the development site and either side of the cable corridor). These methodologies, although not stated as such, are consistent with the current Cefas (2012) guidelines.

These survey designs allowed comparison of temporal changes in benthic communities in each impact area and in relation to the reference areas. However, none of the monitoring programmes has to date been able to validate the highly localised, ecological effects of scour, predicted to occur in close proximity to the turbines (<50m). Some information has been acquired through diving studies (see below) and indirectly through geophysical surveys of scour pits, the latter of which have confirmed predictions of physical impacts made in the ESs.
Community interactions, when explored, have been discussed in relation to changes in the overall benthic faunal communities, within and between impact areas and reference sites, as a likely consequence of fluctuations in the abundance/biomass of selected species. However, these interactions have not been extended to consider fish and shellfish population and/or birds and marine mammals.

Good examples of data analyses have employed tests aimed at detecting the statistical significance of the observed changes and these have been subsequently discussed in ecological terms in relation to potential impacts and natural variability. These tests have been substantially multivariate in nature and as such have not employed Power Analysis.

Guidelines for monitoring assessment were not always specified in the licences, and when they were, they included Cefas (2002) in all cases but one (Scroby Sands), where Rees *et al*. (1990) was recommended. The most recently developed and currently available guidelines are provided by Cefas (2012): ‘Guidelines for data acquisition to support marine environmental assessments for offshore renewable energy projects’. These in turn refer to Ware and Kenny, (2011) with respect to benthic grabbing, which provides guidance in relation to monitoring at marine aggregate extraction sites. In terms of specific sample analysis, NMBAQC (2011) ‘Best Practice Guidance Particle Size Analysis (PSA) for Supporting Biological Analysis Standard’ provides guidance on procedures for sampling and sediment particle size analysis. Adherence to recommended procedures promotes standardisation of data acquisition, processing and analysis, ultimately allowing meaningful comparison of results across similar projects and use of existing datasets for cumulative impacts thus reducing the need for repetitive surveys.

The Belgian monitoring programme is of particular interest with regard to a spatially, small scale study, conducted on the soft-sediment macrobenthos. In this case the study was in close vicinity to substantial gravity base foundations with scour protection, on the Thornton Bank (Degraer *et al*., 2012), to investigate if the sediment and the soft sediment macrobenthic communities were affected by organic enrichment and changing hydrodynamic conditions around the turbines. The aim of the small scale study was provision of data from which to extrapolate information to investigate possible future large scale and more global impacts. Sediment samples were taken along four gradients around selected turbines (at 15, 20, 50, 100 and 200m from scour protection boulders) sampled by means of van Veen grab. Benthic core samples at 1m and 7m distance from the scour protection were taken by divers by means of an airlift suction device. It is acknowledged that extrapolation of the localised effects to a wider area needs to be considered with a degree of caution and may not, in any event, result in a change in the significance of the impact predicted in the ES. The relevance of the Belgian study to the current report is that it has highlighted a potential lack of certainty with respect to UK data in relation to localised effects of turbines and potentially the consequential effects on fauna in a wider area.

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Field aspects of 2m beam trawling, as a monitoring tool, are well established through Cefas based methods (Cefas, 2002 and, more recently, Ware and Kenny, 2011). However, the data generated by the technique are used in a variety of ways, which differ considerably, for example; fish community composition, individual species abundances, fish population structure (weight/length measurements), epifaunal speciation, epifaunal biomass, etc. The data also suffer from a semi-quantitative character, due to variable efficiencies of the survey equipment in relation to weather, tidal conditions, length and direction of tow and time of day. The methodologies related to this technique, therefore, need to be reconciled and focused to those that are most quantifiable and targeted in relation to the relevant receptor.

Non-UK monitoring practises, including methodologies, are broadly in line with those in the UK in terms of the gear type and field data collection (see for example BSH, 2007). However, for the wind farms in the Belgium part of the North Sea (Degraer *et al.,* 2012) an alternative method employing an 8m shrimp net was used. The main differences, however, relate to the management and application of the data, including division of the data into trophic groups, a close focus on individual species abundance, biomass and population structure. Emphasis has also been placed on the requirements for species level biomass.

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No best practice with respect to intertidal monitoring currently exists that applies to cable landfalls, however, appropriate methodologies are available in the JNCC Marine Monitoring Handbook (Davies *et al*., 2001), PG 3.1 and PG 3.6: biotope mapping and core sampling respectively. These need to be placed into the context of the type of impact and receptors anticipated, including disturbance to habitats or species of conservation importance both within the habitat, such as *Sabellaria* but also other species at a higher trophic level. Several levels of detection are possible, with PG 3.1 providing methods for a broad-scale indication of impacts on biotopes, supported by photographic records as well as generic data provided from core sampling (PG 3.6). More detailed, quantitative methods are those included in PG 3.6, which, if adapted using a well-structured BACI design (missing from all of the current studies), would be appropriate for identification of statistically valid differences, either within a multivariate approach, or a potentially more intensive, univariate approach employing Power Analysis to identify minimum sample numbers. No Non-UK methods have been evident in the reports reviewed.

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This section considers both the effects on the turbine directly, as well as the localised and consequential effects on the seabed. No best practice with respect to turbine colonisation and its consequential effects exists in the UK, however several appropriate field methodologies are included in the JNCC Marine Monitoring Handbook (Davies *et al*, 2001) PG. 3.3, 3.5 and 3.7 referring to subtidal biotope identification, dropdown video and subtidal quadrat sampling respectively. No consideration of BACI design is required as the turbines and scour protection are newly placed habitats and, in general, are fundamentally different from the habitats into which the turbines are placed (i.e. new hard substrata within a particulate substrata). Recommendations for data analysis methods that could be specified need to be placed into an appropriate definition of the requirement, which should be receptor/hypothesis based.

The field methodologies included in the JNCC procedural guidelines are based on expert activities by marine biologists, which present practical, although not insurmountable, barriers to their application in the offshore diving environment, primarily due to health and safety concerns. Some of these field methods may be employed by non-marine ecologist divers but the level of training needed to apply them would have to be increased and new, cross-over, best practice and guidelines introduced. Specific guidance related to sample and data analysis needs to be established such that a degree of compatibility with datasets derived from other methods (benthic grab and 2m beam trawl) would be possible. Employment of ROV survey has been suggested but this remains a relatively costly methodology of limited application.

Non-UK studies are broadly in line with those in the UK. The method employed at Barrow, which included collecting seabed samples within the scour pit (EMU, 2008), which could produce data compatible with the benthic grab data, was also used in the studies of the Belgian part of the North Sea (Degraer *et al*, 2012) and formed an integral part of their overall assessment of the impact of the turbine and scour protection on the seabed. A study at Egmond aan Zee (2012) successfully employed a commercial diving team supported by surface based marine ecologists, including sampling in the scour pit. An existing JNCC method exists for seabed coring as well (Davies *et al,* 2001), which could be applied to scoured sediment conditions. Analogous methods for detecting impacts, although not of a biological nature are available through geophysical surveys, which have effectively defined the limits of the physical effects of scour as predicted in the ES.

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No guidelines on data analyses were provided in the studies reviewed. Statistical analyses were not always focused on the detection of change due to impacts, rather on descriptive account of benthic communities based on degree of similarity/dissimilarity and temporal trends. These analyses, while still required to characterise the benthos, do not provide statistically significant evidence of change and would, therefore, benefit from the use of additional tests capable of detecting statistical significance. Once assessed, the statistical significance would need to be put into the site-specific ecological context to assess this significance in relation to potential impact or natural variability (e.g. are differences in faunal communities due to abundance of species or to the introduction/loss of species?; can higher values of abundance in the impact areas than the control area be a sign of recovery of local benthos?; what other human induced impact is known to occur in the control areas (e.g. fishing)?; do signs of recovery link with the recovery time predicted in the ES?).

Assessment of the power of the data to detect change through Power Analysis is not appropriate to the techniques employed, which were based substantially on multivariate (most frequently PRIMER) methods, rather than univariate tests. In most cases data outputs were either missing or limited, in that they did not include full (raw) results of the statistical analyses, including any graphic representation and assumptions upon which the test was based (e.g. graphs of ANOSIM and BIOENV together with number of permutations), thus preventing an independent assessment of the robustness (power) of the analyses and hence the conclusions drawn by the study. Best practice for the future should include provision of raw statistical results such that the ability of the data to detect change may be independently assessed.

Monitoring best practice summary

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

Guidelines for monitoring assessment were not always specified in the licences, along with limited justifiable rationale, objectives and criteria. Guidelines when they were included, comprised of Cefas (2002) in all cases but one, where Rees et al. (1990) was recommended. The current Cefas (2012) guidelines were built upon these previous methodologies and hence are the most appropriate for future benthic surveys. Cefas (2002 and 2012) also provides guidelines on field aspects of 2m beam trawling monitoring. No best practice specific to intertidal and turbine foundation colonisation monitoring are currently available, although reference to existing published methodologies has been made. Consideration of new guidance for non-marine biologist divers needs to be considered to achieve appropriate levels of data quality. Best practice with respect to statistical analyses are currently poorly defined in relation to desired outcomes. Multivariate data analysis packages which include potential to test the robustness of the outcomes (not necessarily Power Analysis) are commercially available but best practice will require recommendations on which sub-routines will be needed to draw statistically valid conclusions.

[illegible]

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

[illegible]

The post-monitoring reports reviewed during this study concluded that to date OWFs have not had significant impacts on the benthic habitats and associated faunal communities, as the observed differences within the impact areas were also recorded within the reference area and, therefore, could be attributed to natural variability. The review indicates that in the majority of cases the monitoring programmes have fulfilled the aim of verifying the ES predictions of non-significant impacts of the OWF on the benthic habitats and associated faunal communities, albeit within relatively well defined limits of the, generally, infaunal benthic communities studied. The focus has been on survey designs that allow major changes in the infaunal community to be demonstrated, which, given the overall weight of evidence presented, has been successful in identifying no impact. It should be noted, in particular, that the current studies have been successful in identifying lack of ecological impact due to cable laying. In these circumstances an initial disturbance to the seabed is followed by a period of recovery, unlike conditions created by the installation of the turbine.

This review has, however, highlighted several flaws with regard to data analysis and interpretation in some monitoring programmes, making the final assessment of non-significant impacts on benthos at those sites uncertain. In addition, the studies fall short of fully assessing the changes in benthic communities in relation to associated trophic groups including mobile epibenthos and fish species, which may not be evident until the turbine bases, and any associated scour protection, have developed a mature associated community.

Notwithstanding the overall lack of impact over the periods of study (three years maximum to date), there is some evidence from the Belgian study on Thornton Bank that localised scour pit effects and decreased local current flow creates an ideal situation for the settlement of macrobenthic larvae and organic material from the hard substrate onto the seabed. This in turn may result in changes in infaunal community structure and composition, which in time (e.g. >5 years) may propagate across the wider wind farm site, resulting in detectable changes by means of the current benthic grabbing methods. It is acknowledged that the hypothesis on which this is based employed data from a small-scale study conducted on the soft sediment macrobenthos in 2011 (after two years of commercial operation) in close proximity to a gravity base foundation at Thornton Bank. An apparent enrichment and change in community composition was first observed in comparison to previous studies after one year of commercial operation. A clear observation was of a changing macrobenthic community extending up to 50m from the scour protection boulders, indicating the possibility of a long term shift in community composition, which may become spatially extended as well as resulting in longer term consequences to fish, shellfish, seabirds and marine mammals population (Degraer *et al*., 2012). This stresses the importance of longer term monitoring of OWF, as already highlighted by the International Advisory Panel of Expert on Marine Ecology (IAPEME) during an independent review of the Danish OWF. The authors stated that only long term monitoring could provide appropriate datasets with information of how the communities associated with the new habitats will develop and contribute to the ecology of the area (DONG, 2006).

[illegible]

The nature of the 2m beam trawl technique has enabled descriptions to be made of overall epibenthic communities and smaller fish species present over certain seabed types, within each wind farm area. Changes due to impacts have not been detected, although in some cases temporal and spatial variability was noted, which has been attributed to natural conditions. In many cases however it was not possible to differentiate between natural variability and impact effects, primarily due to the limitations created by inappropriate and ineffective survey arrays (e.g. lack of reference data, no sites in operational area post-construction) linked with unfocused data analysis. The method is capable of being employed in the detection of impacts and or natural change, with the proviso that the structure of the survey is rigid (temporally and spatially), is focused on particular species groups and spatial areas, measures are made in a quantifiable manner (accounting for tow length/seabed cover) and data are analysed using repeatable methods. To date this has rarely been the case.

Non-UK sites have in some instances detected changes in the wind farm operational area, both at species level and community level. The employment of more detailed sample and data analysis has aided the process of detection of impacts, most noticeably in the Belgian part of the North Sea studies.

It should also be noted that methods from the aggregate industry employed to investigate epibenthic communities (Fugro EMU, 2013) make extensive use of dropdown video to identify both sessile encrusting communities, but also mobile epibenthos, which although generally collected in the 2m beam trawls, have not been sufficiently well monitored for the reasons indicated above. It is suggested that these mobile epibenthic species may be those that are most influenced through prey availability within the mature encrusting epifaunal communities on the turbines. Dropdown video is now used routinely in parallel with grab sampling in the aggregate industry studies, such that combined datasets are available. Similar procedures have also been developed for several of the Round 3 characterisation studies.

[illegible]

The post-consent monitoring of the intertidal areas affected by cable laying has been able to demonstrate a range of effects. These have been detected at a variety of levels ranging from simple, observable sediment disruption on sandy beaches, to changes in individual species populations, changes in the invertebrate communities and changes in habitat and biotope. The generic lessons are that one of the principal habitat types (mobile sands and gravels), that has been impacted by this cable laying activity is quick to physically recover with, in most cases, commensurate recovery of associated faunal communities and consequentially the biotopes present. However, failings in the structure of the intertidal coring surveys (lack of reference areas) have led to the identification of community structure and composition change, generally over a short term (<1 year), which could not be placed into a wider area context. Therefore, the monitoring has been able to detect differences but these cannot, in most cases, be specifically related to the impacts due to the cable laying. In cases where impacts due to cable laying have been identified these have been in relation to highly sensitive and specific biotopes, for example the *Sabellaria* reef areas. On this basis the range of activities employed in monitoring have been sufficient to detect change, although they have not always been correctly applied.

[illegible]

The current type of survey (video/photography and or sample collection) is able to detect self-evident changes due to the introduction of hard substrata, whereas the requirement of the studies should be to identify “what consequence to the environment does this have?” This in turn needs to be linked to a wider range of potential impacts and their consequences. Stated requirements have been to identify occurrence of non-indigenous species, which the few studies that have been completed have successfully demonstrated the absence of. They have also been able to identify the nature and occurrence of a range of fouling species that would not normally be found over the otherwise particulate based habitats. Other observations have related to calculation of total biomass provided by the epibenthic species and observations on mobile epibenthic species attracted to the turbines. However, the major drawback of the studies has been the limited number completed and their extent both spatially and temporally. Of the reports reviewed only three sites undertook studies on turbine colonisation and at only one site was the study completed in more than one year. No consideration of the impact of the turbine epifaunal development on the surrounding areas has been considered, although this may be an area of concern as indicated in non-UK studies. One observation that is indicative of wider change and which warrants further investigation has been the increase in numbers of common starfish *Asteria rubens*, which was noted in two areas and may have consequences in terms of predator prey interaction away from the turbine location.

Impacts of scour on benthic communities have also not been considered although data were collected at least at one site. Physical recording of this process has been successfully achieved through geophysical surveys, which are able to identify the physical limits of the effect, but no close focus on the predicted effects of turbine installation on benthic habitats has been attempted in these areas, where it is most likely to take place and could be easily quantified. Notwithstanding this statement it is probable that effects will still remain negligible in the overall wind farm, although this is clearly an area of uncertainty.

The non-UK sites have adopted the target issues considered in the UK, i.e. occurrence of non-indigenous species; occurrence and composition of fouling communities and assessments of the biomass. They have also considered impacts potentially related to the peripheral and consequential effects of the turbine colonisation. In the instance of the Belgium part of the North Sea study, apparently clear consequential effects of the colonisation have occurred in the peripheral areas around each turbine, in excess of 50 metres (radius) from the edge of the scour protection system. The Danish studies (Dong, 2006) have identified only small effects around the turbines but have hypothesised the development of a “feeding halo” around the turbines, predicted to occur after the development of a mature biofouling community, which is likely to take in excess of five years. Increased biomass values and their potential exploitation by a range of fish species has been demonstrated in Egmond aan Zee (Bouma and Lengkeek, 2012) and the introduction of non-indigenous species has been clearly demonstrated by several studies (see review by Wilhemsson and Malm, 2008). Those impacts that have been observed were achieved through combining diving techniques with those used for benthic grab studies.

OWF environmental impacts: lessons learnt summary

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

Results of this review exercise indicate that to date OWFs in the UK have not had significant impacts on the benthos (primarily the infauna). However, flaws with regard to survey design, data analysis and interpretation (subtidal and intertidal) have been highlighted in many of the cases reviewed, which make a universal conclusion of no significant impact uncertain. This relates primarily to the epifaunal components of the benthos, rather than the infauna, the latter of which have been relatively uniformly investigated. An area of shortfall has been identified with respect to potential long-term consequences of the turbine colonisation on the wider communities particularly via food web interactions. In small-scale studies in overseas projects, results have demonstrated significant localised changes, with the potential for propagation across the wind farm area and farther afield, as the developments begin to support mature communities on the turbines. This represents an area of uncertainty in the UK studies to date.

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Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

[illegible]

The licences reviewed as part of this exercise made little reference to the ES, with no details of the site-specific predicted impacts, their environmental relevance and the degree of certainty of the prediction. Consequently, all monitoring programmes involved baseline, pre-construction, construction and up to three years' post-construction monitoring studies, regardless of the type and significance of the predicted impacts. The Danish approach to environmental monitoring of OWFs is deemed a good example of monitoring tailored to detecting impacts predicted in the ES. Essentially, the monitoring may not be deemed necessary if the area does not support features of conservation importance and the predicted impacts on benthos as well as hydrodynamic conditions and coastal processes are temporary (e.g. during the construction phase), assessed to be of no environmental importance, and the assessment is made with a high degree of certainty based on evidence of previous or similar studies. The emphasis here is in relation to "a high degree of certainty based on previous evidence", which is currently the case for short term (three years or less) benthic grab data, but less so for longer term, trophic interaction effects arising from establishment of mature epibenthic communities on turbines and scour protection.

The UK approach to monitoring, based on the current review, involves monitoring of benthic communities on a large scale, i.e. within and outside the wind farm, with little focus on the multiple, small-scale effects, which may occur in close proximity to the turbine foundation. Evidence for small spatial extent of epifaunal growth on turbines exists, however, these studies have not been extended to consider wider area impacts associated with potential cumulative (within wind farm) and long-term effects of the development of epifaunal communities on the wider benthos and ecosystem as a whole. Hence further monitoring is required to reduce uncertainty and fill knowledge gaps. In this regard, the Belgian approach of monitoring (detailed in previous sections) provides a good example of how small-scale monitoring can provide valuable information, which has been hypothesised can have long term effects (>5 years) on a wider scale, and which, as the current UK studies have shown, are not detected in the relatively short term (three years) post construction benthic monitoring studies.

[illegible] Conditions with respect to benthic grab monitoring should not, therefore, be removed but should be restructured to establish a closer focus on the evident areas of impact in close proximity to the turbines, set within wider operational area studies, the later within a longer time frame, including alternative but compatible monitoring methods (see below). The pre-construction benthic survey array at London Array, including sites anticipated to be in close proximity to turbines, is a potentially good model (EMU, 2010). The temporal scale over which the benthic grab studies are employed should be modified to take account of the longer time periods over which effects may occur, or for which less certainty exists, hence comprising sampling at a reduced frequency.

[illegible]

This method in its current format should be considerably modified with respect to epibenthic species. The technique of surveying epibenthic fauna needs to be retained within the benthic ecology studies, including a consideration of small fish species, but with the main emphasis on mobile epibenthic invertebrates. The objective for future monitoring (based on a consideration of the current UK and non-UK studies) should be to sample, using epibenthic trawls/dredges, for epibenthic and selected fish species that may have their populations modified by the development of the epifaunal populations on the turbine monopiles or on the scour protection. Particular examples of this would be echinoderms, including *Asterias rubens*, scavenging molluscs, such as *Buccinum undatum* and mobile crab populations. The importance of this is that these populations may be modified by the monopile/scour communities, with a potentially wider area influence on prey species (including infauna) and species at a higher trophic level, including fish species. The potential drawbacks of this approach relate to the practical employment of epibenthic sampling in close proximity to turbines, due to the potential to foul cables and turbine related installations. Data from close to the turbine would need to be included in a wider consideration of overall populations and alternative techniques to quantify epibenthic species in close proximity to the turbine will need to be considered, including towed or dropdown video for the most evident and easily identified epifaunal species. The wider area impacts, potentially due to exclusion of fishing activities in the operational area could equally be picked up in the process of this monitoring.

[illegible]

Post-consent monitoring conditions with respect to the intertidal elements of work continue to be needed, specifically with highly sensitive habitats and species, such as the *Sabellaria* reef areas. However, the current generic methodology clearly needs to be adapted on a site-specific basis, taking account of installation techniques, sensitivity and consequentially the EIA predictions.

[illegible]

The post-consent monitoring of turbine and scour protection should be continued but initial consideration should be given to undertaking example studies to observe location specific effects in differing regions around the UK. The nature of these studies should be focused on consequential effects and should include collection of benthic data from scour areas which would be compatible with the wider area benthic grab and video surveys. Studies to investigate colonisation of the turbines and scour protection should be related to predicted impacts, rather than to address the generic impact of “colonisation will occur”. Examples of predicted impacts are, non-indigenous species vectors (survey for introduced species and or potentially damaging fouling species), wider influence of epifaunal communities on mobile, epibenthic, predatory species (survey for population changes in predators such as *Asterias rubens*), which may have an influence outside of the turbine area and effects of deposition of organic debris in proximity to the turbine and further afield. A comparison of biomass values between the fauna on the monopiles and that within the infauna of the surrounding sites has been provided using Kentish Flats data. In this instance the total ash free dry weight biomass for the operational site (10km^2) has been calculated as 15 tonnes (based on values in EMU, 2007), while the biomass contributed by the turbine epifauna has been calculated at approximately 11.5 tonnes for the 30 turbines in the area (EMU, 2008a and Ricciardi and Bourget, 1998, for biomass conversions). A similar total monopile biomass estimate was noted at Barrow (EMU, 2008b). Clearly values of this scale have the potential to modify the overall trophic interaction in these areas, which are not currently monitored for.

Non-UK studies completed in Egmond aan Zee (Bouma and Lengkeek, 2012) have indicated similar biomass values to those in the UK, with an average of 7.5 tonnes for 36 turbines and have also suggested wider scale effects on fish species as a consequence. A recent study by Krone, Gutowa, Breya, Dannheim and Schröder (2013) in the German Bight, reports specifically on the potential consequences of epifaunal growth on the turbines on mobile demersal megafauna (such as crabs and echinoderms), including estimates of the area wide increase in carrying capacity for certain of these species, using existing wreck fauna for comparison. Analogous studies have also been completed on artificial reefs (see OSPAR, 2009) which provide conflicting evidence with respect to wider scale impacts, perceived to be both positive and negative. Similarly growth on offshore oil installations have been studied, generally focused on fouling growth, see for example Whormesley and Picken, (2003), although an earlier paper by Wolfson, Van Blaricom, Davis and Lewbel (1979) has described localised impacts extending to at least 100m from a ten year old oil platform.

The integration of the monopile and scour protection data into an overall consideration of the impacts of the wind farm operation has been demonstrated in non-UK sites and this needs to be adopted here. In several cases the studies have indicated that effects from the monopile colonisation have taken many years to develop, hence more appropriate temporal sampling periods need to be adopted. The scale of future, area-wide benthic grab and 2m beam trawl surveys is highly likely to be contingent on the outcomes of studies in close proximity to the turbines and should lead to a considerable reduction in both the scale and periodicity of the grab and 2m beam trawl surveys.

OWF environmental impacts: recommendations for monitoring going forward summary

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

Conditions with respect to benthic monitoring should not be removed but restructured based on the likelihood that any impacts that occur will initially (<5 years) be in close proximity to the turbines. The objective, therefore, should be to establish a closer focus on the evident areas of impact in proximity to the turbines, and then set these observations within the wider operational area, as studied to date at most UK wind farm sites. These wider area studies need to be considered over longer timescales and consider overall trophic interactions. There is evidence that increased faunal biomass associated with turbine foundation colonisation has the long-term potential to modify overall trophic interaction, as demonstrated in some non-UK OWFs and other data from similar offshore structures. Outcomes from studies on the turbines and areas in their close proximity will influence both the scale and periodicity of the wider scale studies, if subsequently undertaken, using benthic grab and 2m beam trawl.

[illegible]

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

[illegible]

Benthic grab

This review exercise has highlighted several differences between studies in terms of sample acquisition, processing and analyses, with discrepancies occurring even within the same site-specific monitoring programme, due to different sampling gear, number of replicates and subsampling techniques. Consequently, the datasets to date, acquired through the monitoring programme are not sufficiently compatible to be used across studies on a regional, national or international basis, without the risk of introducing artefacts which may mask true change or highlight potential, but untrue changes. Compatibility could be achieved to some extent through what would undoubtedly be a lengthy data reconciliation process. For the future a degree of standardisation of survey and analysis protocols and monitoring studies would ensure that studies are designed to provide comparable and meaningful results with appropriate level of confidence, although clearly consideration of local conditions will necessitate difference in methods that should not be modified just to achieve a wider compatibility.

An example of non-UK practice aimed at ensuring compatibility of monitoring conditions can be seen in the Netherlands, where an extensive Monitoring and Evaluation Programme (MEP) has been linked to a demonstration wind farm project, known as the Near Shore Wind Farm (NSW). The programme requires that other monitoring programmes conducted in the Netherlands and further afield, are accounted for to avoid duplication of work, and the results of all studies made available for use in similar projects (NSW-MEP, 2001). The difference between the UK system and Netherlands model is that the government is responsible for a limited number of studies including a survey of benthos and fish before construction. The operator is responsible for the other studies that are within the mandatory monitoring programme, and this includes survey of benthos and fish and changes in current patterns after construction. The operator also has the option to undertake other studies outside of the terms of the licence (i.e. assessment of exotic species, changes in erosion and sedimentation and electromagnetic fields). This model establishes the compatibility of the data from the mandatory monitoring programme studies through the early intervention of the government into the survey process. Whilst not envisaging the same system in the UK the potential for an earlier, regulatory intervention into data management would be appropriate.

Epibenthic 2m trawl
Currently no synoptic approach could be adopted due to the variable nature of the surveys and employment of data.

Intertidal
Data from the reports are scientifically comparable in many cases. A synoptic approach could therefore be derived related to habitat type. The synoptic approach would be more related to minimising effort at sites with known responses to cable laying, rather than completely removing the need to monitor.

Turbine foundation epifauna
Very few of the colonisation studies have been completed and the level of detail is currently variable. However, an extensive data source is available through other industries (oil industry in particular) and non-UK sites, which would be able to inform or contribute to a synoptic approach. Equally, if all UK sites, where monopile colonisation studies were included in the licences, had undertaken them, or are due to undertake them, then a synoptic approach may be possible.

[illegible]

Benthic grab
The currently available data on benthos in relation to OWF development are not considered sufficient to assess cumulative effects on benthic communities. In addition, a standard, coherent approach to cumulative impact assessment on

benthos has not yet been developed. Major focus is currently placed on loss of seabed habitat, which can be quantified and has to date been reported to be of negligible significance, based on the very small percentage of the wind farm area(s) affected, even for cumulative impacts. However, there are no guidelines for how much of a change should be considered negligible. Of particular concern are the ecological consequences of the newly introduced habitats by means of turbine bases and scour protection. The studies available provide information on the type, rate and pattern of succession of the epifauna, but there is lack of studies that have looked at the new habitats in terms of their sustainability, energy flow, species interaction and an understanding of how individual foundations interact with each other and with the surrounding natural community, which is particularly important where new developments are at short distance from existing ones.

Epibenthic 2m trawl
Current data variability would not make cumulative impact assessment possible; however, if uniform monitoring and data analysis methods are adopted then cumulative impacts could be monitored. Similarly, if existing data were reviewed with respect to compatible components, then cumulative impacts could, in spatially discrete areas (e.g. outer Thames), become possible.

Intertidal
Cumulative impacts from cable laying are unlikely to be an issue, given the spatially discrete nature of the activity. Where multiple cable landfalls exist in close proximity they should be considered within one overall study.

Turbine foundation epifauna
This is one of the areas where cumulative impact is most likely to be relevant, in relation to the facilitating of introduced and fouling species vectors. To achieve this aim a good degree of conformity in the methodologies, analysis and reporting will be required, which is not presently the case.

OWF post-consent monitoring data summary

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

The datasets to date acquired through the post consent monitoring studies are not deemed sufficiently compatible to contribute to a synoptic approach, due to differences in sampling techniques and data analyses methods. Consequently, existing datasets may similarly not be sufficient to determine cumulative impacts. Retrospective reconciliation of benthic data may enable a synoptic approach but efforts would be better put into standardising sampling arrays and data analysis methods for the future, clearly without trading off standardisation for relevant site-specific detail.

[illegible]

A total of 17 OWF licences from the UK were reviewed with respect to requirements for the monitoring of fish and shellfish. Please refer to Task 1 for further details. A review of non-UK OWF monitoring reports has also been undertaken and where appropriate, best practice described.

Juvenile fish are most frequently sampled in conjunction with the epibenthic surveys using a 2m scientific beam trawl. As such, please refer to Section 4, Benthic Ecology, as no reference to 2m beam trawling is made below unless specifically mentioned under the fish and shellfish ecology sections of the licence, ES or post-consent monitoring reports

[illegible]

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

The majority of licences reviewed had a requirement to monitor populations of fish and shellfish in the area of the wind farm by post-construction survey(s). The aim of post-consent monitoring is to assess and understand the potential impacts as predicted in the ES and to reduce uncertainty concerning the responses of sensitive fish and shellfish receptors. A summary of the licensing conditions is provided in Table 7.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scroby Sands	East Anglia	2003	1	None	No	No	No	No
North Hoyle	Liverpool Bay	2002-07	1	EMF, FAD, operational noise	No	No	No	No
Rhyl Flats	Liverpool Bay	2002-12	1	Piling noise on spawning fish, EMF, FAD and operational noise.	No	No	No	Yes
Kentish Flats	Thames Estuary	2003-03	1	EMF, FAD, operational noise, disturbance of sediment - oysters	No	No	Yes	Yes*
Barrow	Morecambe Bay	2003-06	1	EMF, FAD	No	Yes	No	No

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Burbo Bank	Liverpool Bay	2003-07	1	EMF, FAD	No	Yes	No	No
Lynn & Inner Dowsing	Humber	2003-07	1	EMF, FAD	No	Yes	No	No
Gunfleet Sands	Thames Estuary	2004-06	2	Flatfish and herring spawning, EMF, FAD	No	Yes	No	Yes
London Array	Thames Estuary	2006-12	2	EMF, FAD	Yes	No	No	No
Robin Rigg	Solway Firth	2006-12	1	No licence conditions or ES reports were available at time of review. Only the year one post consent monitoring report was reviewed.				
Thanet	Thames Estuary	2006-12	2	EMF, FAD	Yes	No	No	No
Greater Gabbard	Thames Estuary	2007-02	2	EMF, FAD	Yes	No	No	Yes
Ormonde	Morecambe Bay	2007-02	1	Addition of new hard substrate on flatfish populations	No licence conditions, ES or PCM reports available at time of review. Only construction report reviewed.			
Teesside	Teesside	2007-09	1	EMF, FAD	Yes	No	No	No
Walney	Morecambe Bay	2007-10	2	Demersal fish of commercial importance and EMF sensitive species, FAD	Yes	No	Yes	Yes
West of Duddon Sands	Morecambe Bay	2008-09	2	EMF, FAD, Proximity to Ormonde, changes in fish community after construction	Yes	No	Yes	Yes
Lincs	Humber	2008-10	2	SSC on fish and shellfish, EMF, FAD	Yes	Yes	No	No
Sheringham Shoal	Humber	2008-11	2	SSC shellfish, EMF, FAD	Yes	No	No	No

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gwynt y Môr	Liverpool Bay	2008-12	2	EMF, FAD	Yes	No	No	Yes

The licence for Scroby Sands OWF, the earliest of the licences reviewed in this report (April 2002), made no specific reference to fish and shellfish or to the impacts predicted upon them. As such, no monitoring specifically targeted fish and commercially important shellfish at Scroby Sands but fish were caught and reported upon during the benthic surveys (2m beam trawls) at this site. The remaining licences for the other OWFs were issued between September 2002 and May 2010 and were broadly similar in terms of the stated requirements for the monitoring of fish and shellfish populations. These included:

- The importance of canvassing the views of local fishermen, regardless of predictions made in the ES
- Post-consent monitoring to reduce uncertainty with regards to enhancement and aggregation of fish populations
- The effects of operational noise on fish enhancement and aggregation, regardless of predictions made in the ES
- The effects of Electromagnetic Fields (EMF) on electro-sensitive species, although conditions on different licences varied as to their specificity.

All of the licences (excluding Scroby Sands) reviewed referred to monitoring of fish and shellfish populations during the operational phase of the wind farm. However, the requirement for monitoring of populations during the pre-construction and construction phase was only present in seven of the seventeen licences. The requirement for pre-construction monitoring surveys to provide adequate baseline characterisation is seemingly dependent of the licence chronology. Six Round 1 wind farms issued after 2003 (with the exception of Teesside) have this requirement in their licence. As with the Round 2 wind farms the absence of this pre-construction monitoring requirement in Teesside's licence conditions may be linked to the presumption that pre-construction monitoring would occur anyway as the bench mark had been set by the earlier Round 1 sites. All monitoring programmes reviewed involved baseline, pre-construction, construction and up to three years' post-construction monitoring studies, despite there being no mention of the necessity to do this in the licence conditions.

Sampling methodologies are not specified in any of the licence conditions reviewed. Techniques for the monitoring of adult fish and shellfish are therefore site-specific and involve locally chartered commercial fishing vessels and gear types which are representative of the region, in line with best practice guidance. In all cases, onus is placed upon the developer to detail proposals for any fish and shellfish monitoring required and to agree these with the Licensing Authority (and their advisors) prior to monitoring surveys commencing. The submission date of the proposals to the licence authority varied considerably, from three months after the completion of the construction work (for North Hoyle) to at least four months prior to the commencement of any construction work (for Teesside and all Round 2 wind farms except Gunfleet Sands). As a general rule, the more recently the licence was issued, the earlier the proposals were requested by the Licensing Authority.

Only five of the licences reviewed referred directly to impacts predicted in the ES. However, there was no mention of their significance and the degree of certainty of the impacts made. Four of these (Barrow, Burbo Bank, Lynn & Inner Dowsing, and Gunfleet Sands) made reference to uncertainty with regards to EMF effects on local elasmobranch populations of commercial and/or conservation importance. Each of these wind farms was granted consent between 2003 and 2004. The fifth (Lincs) referred to SSCs and the need to monitor this aspect to address the concerns of local fishermen. The remaining licences did not relate to any specific EIA predictions but requested monitoring nonetheless in relation to potential interactions with EMF emissions and operational noise "*to elucidate any interactions between noise generation and the provision of new habitat and fish aggregation effects of the turbine support structures*". The licences required the technical specifications of the cables used in the development to be discussed in terms of EMF emissions and the probable effects on electro-sensitive fish.

Five licences had timing restrictions on pile-driving activity during the construction phase of the development because of concern about the effects of noise on the spawning grounds of commercially important fish species including herring and sole. Three of the restrictions put in place were for developments in the Thames Estuary, with a fourth restriction there removed for Thanet. Restrictions to piling activity ranged from a minimum of six weeks duration at Rhyl Flats in Liverpool Bay to a maximum of three and a half months at Greater Gabbard in the Thames estuary. The temporal restrictions on piling activity were generally longer in the earlier licence conditions and became less precautionary in the later licence conditions reviewed.

Likewise, three of the earlier licences (Burbo, LID and Gunfleet Sands) issued between 2003-2004 made specific mention of the use of soft-start in relation to Basking Sharks stating "*During construction the Licence Holder must ensure that disturbance to basking sharks is minimised by operating 'soft-start'* procedures for all drilling and/or driving operations. Soft-start later became embedded mitigation and is now standard procedure during pile-driving operations. This may explain the absence of this condition in areas where Basking Shark are known to occur, in the later licences reviewed.

Rhyl flats and Burbo Bank licence conditions, both issued in 2002, made reference to the use of non-destructive methods for monitoring fish and shellfish populations. However, both sites used 2m beam trawling as their primary method of sampling. More suitable non-destructive methods include fish traps or baited underwater video systems.

Emphasis in all the licences reviewed (excluding Scroby Sands) was placed upon increasing knowledge about the potential effect of wind farms in terms of enhancing or aggregating fish populations during the operational phase of the wind farm. This requirement was often linked to the post-construction data collection of underwater noise. Licences for Scroby Sands, LID, Kentish Flats, North Hoyle, Barrow, Burbo Bank, Gunfleet Sands I+II, and Rhyl Flats spanning years 2003 to 2006, for example, required that the underwater noise from the operational phase be monitored but made no mention of the monitoring of construction noise. The monitoring of reef effects / Fish Attraction Devices (FAD) requires monitoring inside and outside of the development to assess distribution and abundance.

The licence conditions concentrated on areas where there was uncertainty on the effects of the wind farm and where those effects may cause impacts on the fish and shellfish populations. Impacts with regards to construction activities such as pile-driving noise and habitat disturbance were generally given less attention than the long lasting impacts associated with the operational phase of the project (EMF, FAD / reef effects and operational noise). This is likely to be as a result of the emphasis placed upon these impacts in the licence conditions and that timing restrictions were imposed to protect the most sensitive life-cycle stages (e.g. spawning). The monitoring of construction noise specifically linked to effects on fish and shellfish was not clear in earlier licences and had generally not been considered of significance in the corresponding ESs. Only three sites, Greater Gabbard, Thanet and London Array had the specific requirement for the monitoring of pile-driving noise during construction with regards to fish and shellfish (although a further five sites; Walney, Lincs, Ormonde, Teesside and West of Duddon Sands agreed specification on the monitoring of underwater noise during the construction period with the Licensing Authority). The licence for the London Array OWF had a requirement to validate the predictions made during the noise propagation modelling to support the EIA to validate the potential impacts on fish spawning areas. Each of the three sites with specific licence conditions relating to construction impacts on fish are situated in the Thames estuary and these licences were issued in 2007 and 2008.

The impact of wind farm construction on fish and shellfish populations was assessed as negligible to minor for most of the impacts in the ESs reviewed, mainly as a result of a combination of the following factors:

- The sites were generally only considered to be important if utilised by commercially important fish species for spawning activity
- Construction impacts were considered to be generally low and temporary in nature
- Fish were regarded as highly mobile and likely to avoid the construction area temporarily without any long term effects at the population level. If population effects were considered likely to occur, timing restrictions were placed upon construction activities.

Moderate effects were predicted for construction noise at Gunfleet Sands and Gwynt y Môr (minor to moderate), for habitat loss at West of Duddon Sands, and for habitat disturbance at Gunfleet Sands (minor to moderate). The operational impacts that were of greatest concern in the ESs reviewed were EMF and the introduction of new habitat/reef effect/FAD, and at a single site (Burbo Bank), changes to the hydrodynamic regime. Moderate effects were predicted for the introduction of new habitat at Gunfleet Sands (minor to moderate), Walney and West of Duddon Sands, for changes to the hydrodynamic regime at Burbo Bank and for EMF at Burbo Bank, Walney and Lincs. A single major effect was predicted for the introduction of new habitat at Teesside. The majority of both construction and operational impacts were assessed qualitatively rather than quantitatively and as such the severity of some impacts may have been underestimated.

In terms of non-UK approaches, the Danish monitoring of Horns Rev focused upon long term changes to the fish community and species diversity due to the presence of the wind farm. Baseline conditions were before construction in 2001-2002 and post-consent monitoring seven years later in 2009. The impacts during the construction phase of the project were not monitored due to the temporary nature of the construction period, the small spatial extent of the project (relatively) and because no species of conservation concern were known to be present at the development site. The monitoring programme focused upon the long term changes associated with the operational phase of the wind farm including; the introduction of new hard substrate, changes to hydrological conditions and changes to fishing activities. The German standards BSH (2007) set out similar guidance to UK licence conditions with regards to the selection of suitable reference areas. However, it is stipulated that if no such area can be found representing conditions at the development site, then the reference area may comprise a number of smaller areas located in the vicinity of the project area but they should be largely free of any impacts from construction. The guidance recommends that the reference area should be a minimum distance of 1km from the wind farm with regards to fish populations and epifauna.

The Dutch wind farms had more rigorous conditions set for the selection of reference areas with the suitability of the sites statistically tested so that the no significant difference in fish populations exists between the reference and development sites. Monitoring of wind farms in the Netherlands placed considerably more emphasis upon early life stages of fish, distinguishing eggs and larvae from juveniles and adults as the former were considered to be passive and as such unable to avoid wind farm developments and so may be subject to effects in contrast to older, mobile fish (Deltares, 2010). However, only the pre- and post-construction period was subject to the investigations at wind farm sites with no monitoring of the construction phase of the development.

Consistency of monitoring rationale summary

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

Fish and shellfish post consent monitoring at UK OWF projects has been largely generic and lacking reference to site-specific impacts predicted in the ES. At certain non-UK sites a more refined approach to monitoring is evident; however the focus of this monitoring has been centred on long term operational effects. Less emphasis was placed upon construction effects such as pile-driving noise, sediment plumes and deposition at non-UK sites due to the temporary nature of construction activities. However seasonal pile-driving restrictions were imposed during the construction of wind farms in the Netherlands and Belgium (as they were in the UK) to limit the impact upon fish spawning grounds and fish larvae, whilst German wind farms had noise limitations imposed during construction activities to lessen the effects of noise on fish and marine mammal populations. There is now a general consensus that pile-driving noise at OWFs poses the greatest threat to fish

populations. Licence conditions need to specify that this and other significant impacts and uncertainties as highlighted in the ES are specifically targeted by pre-construction, construction and post construction monitoring to enable the collection of finer scale distribution and abundance data necessary to determine impact significance.

[illegible]2 M[illegible]r[illegible]r[illegible]

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

With respect to fish and shellfish, best practice is currently considered to be the most recently developed and current Cefas Guidance (Cefas, 2012). To evaluate the ecological impacts of wind farms on fish and shellfish populations, a BACI (Before After Control Impact) strategy was proposed and agreed in all cases, based on repeated samplings (annually and at some sites seasonally, before and after impact) in impact areas and reference areas. The selection of sampling stations for the post-consent monitoring studies was based upon baseline characterisation surveys wherever possible, and provided a broad spatial coverage of the development site with reference areas and impact areas targeted.

The majority of monitoring reports used a 2m scientific beam trawl as part of the benthic monitoring strategy to report on the distribution of fish and commercially important shellfish populations. Nine sites used 2m beam trawls only. This technique is used to sample epibenthos and is generally considered to be inadequate at sampling adult populations of fish and as such is not considered to be suitable for site characterisation. Where other techniques were employed those included in the JNCC Marine Monitoring Handbook were largely ignored. The handbook sets out standard monitoring techniques for the sampling of fish and shellfish populations, e.g. PG 4.1, 4.2 and PG 4.3, sampling demersal fish populations on subtidal rock, vegetative cover and on sediments, respectively. These techniques however, were replaced in favour of the commercial fishing utilised in the vicinity of the wind farm according to guidance from Cefas (2012). The commercial methods were often adapted by the inclusion of undersized meshes, etc., so as to retain undersized fish (for which dispensation is required). These techniques provided a broad-scale indication of the fish and shellfish species present, their abundance, distribution and size. These semi-quantitative methods, if adapted using a well-structured BACI design (missing from all of the current studies), may be appropriate for identification of statistically valid differences. However, fish populations show high inter-annual variability and this must be considered before drawing conclusions regarding cause and effect. No significant changes were observed and where change did occur, in all cases it was linked to inter-annual variability rather than impact predictions made within the ESs.

The marine monitoring handbook (Davies *et al*., 2001) states "*High natural variability within fish populations and the problems of observation and capture efficiency mean that standardisation of techniques used to assess a fish population is essential if* *other sources of variation are to be minimised. Quality assurance depends on the technique chosen. However, in general terms, apparent changes in abundance may simply be caused by a change in catchability (Beja 1995; Costello et al., 1995; Sayer et al., 1994; Sayer et al., 1996) or by movements into or out of the sampling area (Allen et al., 1992; Claridge et al., 1986; Gibson et al., 1993; Ross et al.,1987). It is, therefore, difficult to link cause and effect unless extensive background data on the behaviour of the fish species of interest are available or intensive surveys with control sites and sufficient replication can be carried out (Barber et al., 1995)"*.

As extensive background data did not exist with regard to fish populations in UK waters with regards to their behaviour with respect to impacts from pile-driving noise, EMF, FADs etc. and other significant impacts as presented in ESs, the better use of long term monitoring projects and landings data is recommended.

The monitoring reports reviewed as part of this study undertook monitoring using appropriate commercial fishing techniques as agreed in consultation with local fisherman, and recommended by Cefas 2002, 2004 and 2012. These gears, be they trawls, pots, static nets etc. are deployed by local fishermen, using local fishing gear, techniques and knowledge. Observed changes in fish and shellfish communities and abundance are assumed to reflect actual changes to the populations, rather than survey error. Sufficient technical competence during survey design ensures an appropriate layout and suitable reference/control sites. However, in all cases of monitoring reports reviewed, the reference areas were located in an area likely to be affected by disturbance from the development, i.e. pile-driving noise.

The adoption of agreed site-specific methodologies appears a suitable strategy for addressing local concerns but gives rise to differences in the data collected making comparisons of fish and shellfish populations between wind farm sites difficult. Even at the site-specific level the monitoring results were rarely adequate to show change over the duration of the development because of the broad scale approach taken by the monitoring, as well as the patchiness and variability of the mobile populations.

No robust conclusions have been drawn as a result of the monitoring of fish populations, showing a change to fish numbers, distribution or species composition. Changes observed during the monitoring of a wind farm over the duration of a project are invariably reported as being the result of high inter-annual variability of the species concerned. As such, it is important that the data generated as a result of fish and shellfish population monitoring surveys are presented and reported such that they are comparable across the board.

Data produced from the monitoring surveys should be standardised. All fish should be identified, measured (total length) and weighed (wet weight) and Catch Per Unit Effort (CPUE) calculated for each species and for each sampling day e.g. fish per 1000m tow, or fish per 24 hour soak time so as to allow comparison between sites and specific mesh sizes stated for the gears used depending on the populations of interest. Whilst monitoring should be site-specific as a result of variation in the fish and shellfish communities, commercial fishing pressures, habitat and environmental variables at each site, etc., better use of regional and longer term datasets is recommended to better characterise baseline conditions, as well as the presence of other existing influences upon the fish and shellfish populations.

This review exercise has highlighted the general lack of targeted approaches to the sampling of fish and shellfish populations in relation to the development of OWFs in the UK. Current PCM will likely detect major impacts on fish and shellfish populations. However, it is not refined enough to detect lesser impacts as predicted in ESs. The result is post consent monitoring that is unable to distinguish between impacts and natural variation of the fish and shellfish populations. As such, it has not been possible to draw meaningful conclusions from the post consent monitoring works conducted to date. The inclusion of licence specific requirements targeting impacts and uncertainties as highlighted in the ES would likely result in collection of the finer scale distribution and abundance data necessary to determine impact significance.

Germany goes some way towards standardising fish monitoring methodologies in its guidance standard, providing gear specifications for both active and passive fishing gears (BSH, 2007). German guidance recommends that measurements of depth, salinity, temperature and oxygen are taken at sites where fish monitoring occurs. These data would further support the seasonal monitoring efforts helping to explain inter-annual variations in fish and shellfish populations. The BSH guidance also requires targeted installation-based monitoring at two installations during the operational phase of the project for about six days per annum.

Good examples of data analyses have employed tests aimed at detecting the statistical significance of the observed changes and subsequently discussed in ecological terms in relation to potential impacts and natural variability. However, whilst it is interesting to report on changes to the fish and shellfish communities, none of the observed changes has been linked to impacts other than the introduction of hard substrate and/or reef effects.

Guidelines for monitoring assessment were not specified in the licences, however in every licence reviewed, there was the requirement to canvas the views of local fishermen. The most recently developed and currently available guidelines are provided by Cefas (2012): '*Guidelines for data acquisition to support marine environmental assessments for offshore renewable energy projects*'. Adherence to recommended guidance promotes standardisation of data acquisition, processing and analysis, ultimately allowing meaningful comparison of results across similar projects and use of existing datasets e.g. for cumulative impacts thus reducing the need for repetitive surveys.

Non-UK studies from within the EU are broadly similar to those in the UK; however, greater emphasis is placed upon passive stages of monitoring fish and shellfish life histories (Netherlands) and to the operational impacts. Impacts related to construction activity are considered to be of lesser importance than operational effects.

An assessment of cumulative impacts using the current available data would not be possible due to the variability in the reporting of the data. If the existing data were reviewed and presented in a comparable form then it is possible that cumulative impacts could be identified at least in discrete areas such as Liverpool Bay or The

Wash. If a more uniform approach to monitoring and data analysis methods were adopted then cumulative impacts could be more realistically monitored.

Monitoring best practice summary

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

No best practice specific to fish and shellfish monitoring are currently available. However lessons could be learned from non-UK sites where more emphasis is placed upon oceanographic conditions (salinity, temperature, depth etc.) as well as larval stages of fish and shellfish and operational impacts. By monitoring and reporting physical changes in the environment, it may be possible to rationalise natural variability in fish and shellfish populations and highlight natural cycles (e.g. the importance of temperature with respect to sole, herring and cod etc., Hutchings, 1994, Winters and Wheeler, 1996, Fincham et al., 2012). This information could then be used in future analyses to explain inter-annual variation and separate potential impacts from natural variability.

[illegible]

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

In all cases the requirements prescribed in the licence were fulfilled; however, there are not necessarily clear lessons to be learned. Post-consent monitoring has identified changes but has not attributed these to impacts due to the wind farm development. Accordingly, the post-consent monitoring reports indicate that to date, OWFs have not had significant impacts on fish and shellfish populations, as observed differences within predicted impact areas were also recorded within reference areas and so were attributed to high natural variability. An increase in fish abundance has been reported from Kentish Flats in the UK and numerous international sites including Horns Rev, Nysted and Bligh Bank.

Several inaccuracies with regard to data analyses and interpretation in some monitoring programmes have been identified in this review making the final assessment of non-significant impacts on fish and shellfish populations uncertain. This is particularly the case for the nine sites that used the 2m beam trawl as the only methodology for sampling the fish and shellfish communities as well as for the development (North Hoyle) that relied upon using Cefas ground fish data from a site some distance away from the wind farm.

On this basis the range of activities employed in monitoring have been sufficient to detect change to species composition, abundance and distribution, but generally insufficient to relate this to specific impacts as predicted in the ESs. It is likely that no moderate or major impacts to fish populations have occurred at the sites reviewed here. It is less clear if there have been minor changes to the fish populations due to impacts resulting from the developments and that these have gone undetected by the standard monitoring methods used as a result of the naturally occurring high variability inherent in fish and shellfish populations. Minor changes have been detected as a result of reef effects/FAD and changes in fish communities due to the addition of hard substrate at sites including North Hoyle and Kentish Flats. However, this effect has not been reported at most sites in this review. This is either because the post-consent monitoring occurs too early in the operational phase of the development, the post-consent monitoring is incomplete or the survey design is inadequate. Correctly applied survey design with choice of suitable reference and control areas and more rigorous statistical analysis of the monitoring data may allow for a better detection of impacts, as would the direct monitoring of predicted impacts i.e. the monitoring of fish in the presence of pile-driving noise.

Apart from licence specific requirements, methodologies need to be site-specific targeting the sensitive receptors predicted to be impacted in the ES, as well as the key uncertainties identified at the EIA and HRA stage at each site. Methodologies should, at a minimum, adequately sample current fish and shellfish assemblages and should not rely solely on epibenthic 2m beam trawling sampling techniques. Preferably, methodologies and gear should be consistent for pre, during and post construction. This is particularly important given the scale and location of many of the Round 3 developments in relation to critical habitat (spawning, nursery, over wintering grounds, feeding and migration) for fish and shellfish.

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

No significant impacts to fish and shellfish have been identified as a result of PCM in the UK, and it is likely that this is because no moderate or major impacts to fish populations have occurred at the sites reviewed here.

Impacts most readily observed are an increase in the abundance and diversity of fish and or shellfish populations within the turbine array (see Steinber et al., 2011). This effect at UK wind farms has been relatively minor but more pronounced changes have been observed at some non UK sites. This may be because this change develops as projects mature and that the full effect may not be fully understood until after the three year post-construction monitoring stipulated by the FEPA licences. However, the Marine and Coastal Access Act, 2009 (MCAA) has the potential to provide much greater flexibility to PCM allowing temporal extensions (if required). The greatest challenge is for survey design that can describe change (if any) on fish populations attributable to OWF development and the consequences of any such change on other

parameters (e.g. fish as a food supply for marine mammals and birds). We acknowledge that this may be beyond the scope of what can be achieved in site-based monitoring, so an industry / government collaborative approach may be the best way to address this.

[illegible]

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs?

Post-consent monitoring reports reviewed investigating the impacts detailed above reach the general conclusion that the significance of wind farm developments on fish and shellfish populations is negligible or minor overall. However; the sites reviewed here are almost all in shallow water (<20m) and on soft sediments, and studies have shown that fish and shellfish populations recover quickly after the construction phase (e.g. Walls *et al*., 2013). Whether this will be the case for the larger Round 2.5 and Round 3 sites still under development is unknown as extrapolating effects to larger, offshore areas is uncertain. The main potential impact at these larger sites will be noise, as the strength and duration of the pile-driving activity for these sites is predicted to be greater than anything undertaken in this review with respect to likely pile diameters, hammer energy and number of piles per development. The underwater noise monitoring does not, currently, directly monitor the environmental impact of underwater noise on fish and shellfish. However, correlating measured noise levels with fish surveys may help address knowledge gaps regarding their responses to OWF construction and operational noise.

The post-consent monitoring of fish and shellfish populations should be standardised and then reviewed on an impact by impact basis, specific to the site in question. If species of commercial, ecological or conservation importance are of concern at a development site and the ES identifies likely significant impacts on these populations, then targeted monitoring should be focused upon the specific receptor and the impact or uncertainty in question. The need for generic monitoring of fish and shellfish populations conditions could be removed and a licence requirement prescribed for specific monitoring impacts on fish and shellfish as highlighted in the ES. For instance, if the effects of construction noise from pile-driving operations are highlighted to be of concern for a population of conservation and recreationally important salmon, then behavioural data on this species should be collected in the area of impact before, during, and after, construction. This could include for instance, tagging, Underwater Television (UWTV), hydro-acoustic techniques or a before after gradient (BAG) design. The results of this monitoring could be used as evidence to address regional concerns with regards to displacement effects and barriers to migration for other migratory fish species of concern.

From the results of post-consent monitoring conducted to date, there is no evidence to suggest that EMFs pose a significant threat to elasmobranchs at the site or population level, and little uncertainty remains. Targeted research using high tech equipment and experimental precision has been unable to ascertain information beyond that of fish being able to detect EMFs and at what levels they become attracted or abhorrent to them. EMFs emitted from standard industry cables for OWFs are unlikely to be repellent to elasmobranchs beyond a few metres from the cable if buried to sufficient depth. It is likely that the more subtle effects of EMF, including attraction of elasmobranchs, inquisitiveness and feeding response to low level EMFs, may occur. The Burbo Bank OWF post-consent monitoring undertook EMF specific surveys including stomach analysis of common elasmobranch species. Fish caught at the cable site (and hence subject to EMFs) were well fed. No deleterious effects were recorded to fish populations, at least when this effect occurs in association with the probable increased feeding opportunities reported as a result of increased habitat heterogeneity.

The effects of EMFs upon migratory and diadromous species is less well researched and needs to be better understood. Likewise, operational noise seems to have had little significant effect on fish populations, or if it does, they are willing to tolerate the disturbance for other benefits provided by the reef like effects of the wind farm (potentially including greater feeding opportunities, shelter etc.) The requirement for monitoring of underwater noise during the operational phase should be considered on a case-by-case basis and need not be included unless there is a specific concern relating to the effect on sensitive receptors, such as haddock or other commercially important fish that vocalise to attract mates. Targeted research of these species in relation to operational noise should occur until the effects of masking of biologically important sounds is better understood. The post-consent monitoring of new hard substrate has demonstrated a seasonal change in the abundance, distribution and species diversity close to the development (see Horns Rev, Netherlands and Bligh bank Belgium). These localised effects are better understood over a larger timescale as applied on continental Europe as opposed to post-construction monitoring during years 1, 2 and 3.

The main impacts to fish populations from OWFs identified in EIAs to date are displacement and injury as a result of pile-driving noise (noting the uncertainty surrounding these impacts). It follows that PCM monitoring should focus on these behavioural and physiological effects. The monitoring of fish and shellfish populations during pile-driving operations can probably realistically determine a change in abundance of some fish and shellfish species for pre, during and post construction monitoring, reduce uncertainty on the spatial and temporal magnitude of the impact thus evaluating the predictions made in sight specific ESs.

OWF environmental impacts: recommendations for monitoring going forward summary

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs?

Generic fish monitoring conditions as previously seen in licences should be removed and replaced with targeted monitoring of significant impacts and or uncertainties as suggested by the EIA. This targeted monitoring would be used where licence specific monitoring could provide adequate data necessary for the determination of impacts i.e. for displacement of fish and shellfish as a result of pile-driving noise. For other site-specific impacts a more strategic or research based approach may be most appropriate e.g. the effects of operational noise on spawning vocalisations of cod and haddock.

[illegible]

> *Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?*

The monitoring reports which have been reviewed as part of this study are broadly consistent with respect to the methodology adopted. However, several differences between studies in terms of sample acquisition, processing and analyses have been identified, with discrepancies occurring even within site-specific monitoring over the duration of the programme. Sampling gear, the number of replicates and subsampling techniques have been inconsistent, as have the quality and experience of the surveyors. This is largely an artefact of the use of commercial fishing gears local to the site at which the data were collected. Consequently, the datasets acquired to date are not deemed sufficiently comparable to be used across studies of a regional, national or international basis.

Further inconsistencies occur in the reporting of the data, some gears present catch reported to a standardised time (for static gears) or distance/area (for active gears), whilst some sites presented raw data only. All too often, no reference is made to weather conditions, state and direction of the tide, time of day, etc. Without accounting for these factors, it is difficult to make relative comparisons between wind farms. Mesh sizes, soak times, vessel power all introduce further variables to the equation. If the licence specified metrics for reporting of catch, in most instances this would facilitate comparability.

There are instances where previous measurement data could be applied more broadly to inform the likely significance of the impacts for other sites. This is most likely when monitoring has been targeted towards a specific species or impact.

[illegible]

None of the monitoring or mitigation required at any UK or EU sites was sufficient to contribute to a synoptic approach or determine any cumulative impact.

> ***OWF post-consent monitoring data summary***
> *Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?*
>
> [illegible]

[illegible]

[illegible]

Licensing conditions for marine mammals were mostly related to mitigation measures required to reduce the risk of physical injury and auditory injury as a result of pile-driving noise, rather than any specific impact monitoring investigating the impact of the construction or operation of the wind farm on marine mammals in the area. Therefore the review for marine mammals also covers the mitigation measures required by licences. The questions below are addressed separately in turn with regards to both impact monitoring and mitigation.

[illegible]

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

[illegible]

Where monitoring was prescribed by licence conditions there was little consistency between sites. There were few examples of post-consent monitoring conditions for marine mammals. Impact monitoring was prescribed in detail on the licence for only one site; Scroby Sands, where a monitoring programme was prescribed for identifying any impacts on the nearby seal haul out site. The condition stipulated that surveys should take place pre, during and post-construction and the methods and survey design were detailed in the licence condition. The rationale for this monitoring was not provided explicitly in the licence but the monitoring reports expressed the rationale as "*To determine the impact of the wind farm on the seal populations".*

Most of the licences consented from 2007 onwards included a condition that stated "*post-construction monitoring to be determined in consultation with Natural England and the Licensing Authority*" (Table 8); however, the monitoring reports for these sites were either not yet completed by the time of the review, or agreement had been reached in consultations that site-specific monitoring was not required for that site. The authors are aware of data presented in the marine mammal assessment ES for the Galloper wind farm (GWFL, 2011) which appears to be from monitoring for harbour porpoise density pre, during and post-construction at the Greater Gabbard OWF, however reports detailing this work specifically were not available to the review team.

At the Rhyl Flats OWF, the licence conditions contained a requirement to assess whether a 'sterile area' was created during the operation of the wind turbines. It is unclear where the rationale to focus monitoring on the operational phase of the wind farm came from, given that in the ES, the operational phase was predicted to have only a minor impact on marine mammals.

None of the licences included any specific requirement for impact monitoring of cetaceans at any of the sites. However, specific impact monitoring for marine mammals was carried out at Robin Rigg in the Solway Firth. For this site the requirement for monitoring came from the consent granted under Section 36 of the

Electricity Act (1989). The Section 36 consent included a requirement for a Robin Rigg Management Group to be created to develop and oversee the Marine Environmental Monitoring Programme (MEMP) to identify and detect any changes to the physical and ecological environment that may be caused by the construction and operation of the wind farm. The programme concentrated on areas where there was uncertainty about the effects of the wind farm and where those effects may cause impacts to the marine ecology.

A detailed review of why few monitoring conditions for marine mammals was included in licences is outside the scope of this report, however as predictions of impact and uncertainties presented in the EIA provide the basis of the rationale for monitoring conditions, this review did evaluate the ESs (and the corresponding technical appendices) for all sites, as a basis for the rationale of the licence conditions.

The impacts of wind farm construction on marine mammals were assessed as ‘negligible to minor’ in most of the ESs reviewed, mainly as a result of a combination of factors:

- The site was thought to be of low importance for marine mammals
- Any impacts were considered to be generally low and temporary and the adoption of standard mitigation would reduce any risk to negligible
- Marine mammals were regarded as highly mobile and likely to avoid the construction area temporarily without any long term effects at the population level, particularly because construction periods were relatively short.

This review has identified a few general issues with these assessments. There was generally a lack of site-specific baseline data to inform the potential for risk or to confidently characterise the importance of the site for marine mammals. Site-specific surveys designed specifically for marine mammals were not always conducted, and many assessments were often informed by literature review and incidental sightings of marine mammals collected during ornithological surveys. These sources may not allow a robust assessment of the potential for impact, for example bird observers may not be trained for detecting and/or identifying marine mammal species, high bird densities can hamper the detection of mammals, and bird survey effort may not be adequate or sufficient for calculating mammal densities. However, it is important to appreciate that there has been a growing awareness of these issues and many of the pre-consent survey designs for Round 2.5 and Round 3 wind farm sites have included dedicated marine mammal surveys and in a few cases, dedicated acoustic monitoring programmes to fully characterise the site.

Most impacts, notably underwater noise as a result of pile-driving, were assessed in a qualitative manner and the severity of underwater noise was often underestimated, particularly in early assessments. However, it is important to note that, as standards for predicting the effect of underwater noise have progressed and as data have been gathered on the magnitude of noise produced by pile-driving, there has been a corresponding increase in the level of attention given to the assessment of the impact of noise on marine mammals, an increasing awareness of the potential severity of underwater noise and an increasing quantitative element to noise impact assessment. This has led to a large variety in the modelling and assessment approaches used in impact assessments, and can often lead to a variety of metrics, thresholds and methodologies being adopted between different projects. See Section 11.3 for recommendations for thresholds for noise impact assessment.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
Scroby Sands	1	2003	Seal haul out surveys pre, during and post-construction.
Inner Dowsing	1	2003	Lynn 2008 / Inner Dowsing 2010: merges bird and mammal behavioural observations General note on During Construction monitoring. During construction, surveys will comprise the presence of an independent ornithologist on site during those operations, with significant noise generation to assess the impacts. The ornithologist will observe changes in bird/mammal behaviour on site and, where discretion is available within the terms and conditions of the contract, influence proceedings.
North Hoyle	1	2005	None.
Kentish Flats	1	2005	None.
Barrow	1	2005	None.
Burbo Bank	1	2005	None.
Robin Rigg	1	2005	None.
Lynn	1	2006	None.
Rhyl Flats	1	2006	"*The number of cetacean sightings around Great Ormes Head necessitates further monitoring with regards to potential impacts by the Rhyl Flats OWF. The specification for this monitoring should be agreed with CCW and Cefas at least one month prior to the proposed commencement of the monitoring work. The monitoring must be based on the use of sightings and hydrophones to record the presence of cetaceans on, or close to, the site and should ensure the collection of adequate baseline data. There is scope to link this monitoring with the noise and vibration and bird studies. These data are required to assess whether a sterile area is created whilst the turbines are in operation (down-time would be used as a control).*"
Gunfleet Sands I	1	2007	None
Greater Gabbard	1	2007	All sites contain a very similarly worded generic condition:

[illegible]	[illegible]	[illegible]	[illegible]
Ormonde	1	2007	*"As a number of cetaceans and pinnipeds are found in the general area of the wind farm site there is a requirement to conduct monitoring during the construction[7]. The need for additional post-construction marine mammal monitoring, over an initial three year period and ongoing during the lifetime of the wind farm's operation, will be determined, in consultation with JNCC, Natural England and the Licensing Authority and reviewed at agreed periods."*
Teesside	1	2007	
Thanet	2	2007	
London Array	2	2007	
Lincs	2	2008	
Sheringam Shoal	2	2008	
Walney	2	2008	
West of Duddon Sands	2	2008	
Gunfleet Sands II	2	2009	
Gwynt y Môr	2	2010	

[illegible]

Mitigation measures were specified in licences for all but three of the earliest wind farm sites to minimize the impact of the construction on marine mammals. The rationale given was generally to *"ensure that disturbance to cetaceans, seals and basking sharks is minimised"*. A clear progression in the mitigation requirements is noticeable in the licensing conditions (Table 8), likely connected to an increasing awareness of the severity of the possible impact of construction noise on marine mammals. The three licences with no requirements for marine mammal mitigation were from Round 1 (Kentish Flats, North Hoyle and Scroby Sands); later licences detailed prescribed mitigation measures by requiring soft-starts and/or a temporary suspension of pile-driving when marine mammals were sighted close to the construction site.

From 2007 onwards, detailed mitigation measures were prescribed in licences, measures included soft-starts, monitoring of a mitigation zone with dedicated Marine Mammal Observer (MMOb) and Passive Acoustic Monitoring (PAM), and enhanced PAM during pile-driving at times with low visibility (e.g. at night time, bad weather conditions). The compilation of a protocol presenting a detailed description of the mitigation measures (Marine Mammal Mitigation Plan or similar) was also required for the majority of these sites. Though acoustic deterrent devices (ADDs) such as pingers or seal scarers were not a condition in any of the licences, they were used at three sites, Barrow, Walney and Robin Rigg, to displace marine mammals from the construction site. At Walney, the use of pingers was restricted to the first three night-time piling events of Walney phase 1 as according to the construction monitoring report: "*The use of the ADDs was challenging due to intense boat traffic, making it*

[7] This requirement was common although it is important to note that this monitoring related only to recording the presence of marine mammals in a monitored 'mitigation' zone around the piling operation and not any wider survey to determine changes in marine mammal use of the site during construction.

difficult to deploy the equipment safely. The use of ADDs was abandoned (after consultation with Natural England) after the initial three night-time piling events."

Most of the detailed mitigation measures prescribed in licences in recent years conform to current JNCC guidance (JNCC, 2010). A detailed report on the mitigation measures undertaken during construction was not specifically required by the licence. However, records of all sightings of marine mammals within the mammal monitoring zone had to be kept by the observer.

The extent of the required mitigation zone was not specified in any of the licences but where Marine Mammal Mitigation Plan documents (MMObs) were available; the extent of the zone was generally detailed therein. For seven of the reviewed sites, the monitoring radius was described in either the mitigation protocol documents or the construction reports. At all of these sites a mitigation monitoring zone of 500m radius was used. The rationale for this distance is not clear although it is likely that this requirement was adapted from the JNCC guidelines for mitigation during seismic surveys which were first developed in 1995. When comparing the predicted impact radii in the ESs with the extent of the mitigation zone adopted, for four sites, no impact radius calculations were given, two further sites predicted 500m for physical injury/TTS, and one site (Walney) predicted a radius of up to 1km for a 'physiological' impact.

The predicted impact radii for the various impacts (injury, auditory injury and behavioural reactions), where mentioned in the ESs, ranged from 5m up to 15km. The derivation of the thresholds, at which death, Permanent Threshold Shift (PTS), Temporary Threshold Shift (TTS) or behavioural responses may occur, as well as the calculation of the resulting impact radii, were often not clearly described. In most cases where they were calculated, clearly defined units of sound pressure levels for pile-driving were lacking (also see Section 6.2.2). For five sites, the SPL for piling predicted in the ES or noise modelling reports was compared with that measured during construction and the noise predicted was an underestimate in three cases examined, while it was overestimated in one case (London Array), and marginally overestimated in another case (Lincs). However, in the London Array ES, despite an overestimated SPL, a much smaller PTS impact radius was estimated (30 to 60m for harbour porpoises) compared to that calculated in the corresponding construction noise report, which predicted a PTS impact range up to 530m for porpoises. This discrepancy is due to the different analyses adopting different PTS thresholds (the ES used a threshold of 155dB_{ht}[8] to predict the onset of PTS whereas the construction monitoring report used 130dB_{ht}). None of the ES studies included an analysis of the impact of cumulative sound exposure over multiple strikes, taking into account animal responsive movement and distance from the sound source to predict the extent of the potential PTS zone over whole piling events (as has been done in more recent R3 assessments). This is likely to be because the awareness of the potential effect of cumulative sound exposure had not arisen at the time that most of the ESs were published. The pre-consent noise modelling report for Lincs and the construction noise monitoring report for Greater Gabbard did calculate the likely impact ranges for stationary and animals moving away from the sound source with

[8] dB_{ht} is a weighted noise metric that considers the level of noise above the hearing threshold for the species in consideration

defined swimming speeds. The resulting calculated impact radii ranged from 10m up to 12km for ≥ 6.3m diameter piles. Therefore, despite the consistency in approach to the requirement for mitigation, the blanket application of a standard mitigation zone of 500mis likely to have varying amounts of effectiveness in terms of reducing the risk of auditory injury across all projects and for all species.

Use of Passive Acoustic Monitoring (PAM) during construction to enhance the monitoring of the mitigation zone was detailed in 13 licences (Table 9). From the sites where PAM was required, four of the reports (Lynn & Inner Dowsing, Ormonde, Rhyl Flats and Walney) reviewed detailed the marine mammal mitigation measures. Very few instances of detections were reported. Across these sites, only one acoustic detection (of a harbour porpoise) led to a delay in a piling event (at Ormonde). This detection was not matched with a visual sighting. In comparison, only one visual sighting (at Rhyl Flat) caused a delay in piling and this was not matched with an acoustic detection.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Scroby Sands	1	2003	None.	No	NA
Inner Dowsing	1	2003	Ensure that disturbance to cetaceans, pinnipeds (seals) and basking sharks is minimised by operating 'soft-start' procedures for all drilling and/or driving operations.	Yes	Yes
North Hoyle	1	2005	None.	No	NA
Kentish Flats	1	2005	None.	No	NA
Barrow	1	2005	Ensure that disturbance to cetaceans is minimised, including temporary suspension of piling operations if cetaceans are sighted in the area.	Yes	Yes none seen
Burbo Bank	1	2005	Ensure that disturbance to cetaceans, pinnipeds (seals) and basking sharks is minimised by operating 'soft-start' procedures for all drilling and/or driving operations.	No	NA
Robin Rigg	1	2005	Ensure that during the construction phase all reasonable steps should be taken to minimise any disturbance to cetaceans. This should include temporary suspension of piling operations if cetaceans are sighted in close proximity to the works. Such 'best practice' guidance and mitigation measures as are identified in any report and/or study shall be incorporated into a working Method Statement.	Yes	Yes (observer logs)
Lynn	1	2006	Ensure that disturbance to cetaceans, pinnipeds (seals) and basking sharks is minimised by operating 'soft-start' procedures for all drilling	Yes	Yes

[illegible]	[illegible]	[illegible]	[illegible]	[illegible] MM[illegible] M[illegible]	[illegible]
			and/or driving operations.		
Rhyl Flats	1	2006	Ensure that disturbance to cetaceans is minimised including temporary suspension of piling operations if cetaceans are sighted in the area.	Yes	Yes
Gunfleet Sands I	1	2007	Ensure that disturbance to cetaceans, pinnipeds (seals) and basking sharks is minimised by operating 'soft-start' procedures for all drilling and/or driving operations.	No	NA
Greater Gabbard	1	2007	Six ‘standard’ conditions: The Licence Holder must ensure that, where driven or drilled pile foundations are to be installed, no construction activities commence until the Licence Holder has agreed with the Licensing Authority, Natural England and JNCC a scheme for the mitigation of potential impacts on marine mammals. The scheme must be submitted to the Licensing Authority by the date specified in the timetable required under condition 9.2. The Licence Holder must ensure that suitably qualified and experienced Marine Mammal Monitors (MMOb) are appointed and Natural England and the JNCC notified of their identity and credentials before any construction work commences. The MMOb must maintain a record of any sightings of marine mammals within the mammal monitoring zone and action taken to avoid any disturbance being caused to them. The Licence Holder must ensure that piling activities do not commence until half an hour has elapsed during which marine mammals have not been detected in or around the site. The monitoring should be undertaken both visually (by MMObs) and acoustically appropriate passive acoustic monitoring equipment. Both the observers and equipment must be deployed at a reasonable time before piling is due to commence. The Licence Holder must ensure that at times of poor visibility (e.g. night-time, foggy conditions, sea state greater than that associated with force 4 winds) enhanced acoustic monitoring of the zone is carried out prior to commencement of relevant construction activity.	Not known	No
Ormonde	1	2007		Yes	Yes
Thanet	2	2007		Not known	No
Teesside	1	2007		Not known	No
London Array	2	2007		Not known	No
Lincs	2	2008		Not known (generating year: 2013)	No
Lynn	1	2008		Yes	Yes
Sheringham Shoals	2	2008		Not known	No
Walney	2	2008		Yes	Yes
West of Duddon Sands	2	2008		Not known (generating year: 2013)	No
Gunfleet Sands II	2	2009		not known	No

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gwynt y Môr	2	2010	The Licence Holder must ensure that once the half hour non detection period has past, piling only commences using an agreed soft-start procedure. The duration and nature of this procedure must be discussed and agreed prior to commencement of operations with the MMOb following consultation with JNCC and Natural England. The Licence Holder must make provision for a reporting methodology to be in place before works commence to enable efficient communication between the MMObs and the skipper of the piling vessel.	Not known (generating year: 2013)	No
Inner Dowsing	1	2010		Yes	Yes

[illegible]

Consistency of the impact monitoring rationale outside the UK

In several European countries, a variety of impact monitoring studies have been conducted to investigate the impact of wind farm construction on marine mammals (see Table 10 for an overview of the various studies and their respective references). In Belgium, Denmark, and Germany impact monitoring was required as an obligatory condition with regards to the construction permission (BSH, 2007; DEA, 2013; Degraer *et al*., 2012). It was unclear from the documents available to review whether impact monitoring was carried out as part of the consenting regime in The Netherlands or whether the monitoring was as a result of more strategic research efforts.

In [illegible], the environmental permit for constructing OWFs includes a requirement for a monitoring programme. The baseline data obtained within this programme should be obtained to allow for mitigation or, in the case of extreme damage to the marine ecosystem, to halt the activities. The continuation of the monitoring during construction and operation should focus on a cause-effect relationship and ensure the understanding of the environmental impact of OWFs to support policy, management and design of OWFs (Degraer *et al*., 2012).

In [illegible], an environmental monitoring programme was launched following the completion of the prescribed ESs for the Horns Rev and Nysted wind farms, and carried out from 2000 to 2006 (DEA, 2013). This programme was an obligatory part of the planning permission. The objectives of the programme were to investigate the environmental issues of relevance to offshore wind development for clarifying environmental impacts and explore possibilities to overcome these. On the basis of the results of this programme, a follow-up programme was established, covering the years 2009-2012. The follow-up programme focused on the exploration and conclusions of the longer term effects on fish, harbour porpoises and birds. The objectives of this follow up were to further support the conclusions of the first programme and to address key issues for the planning efforts of future OWFs in Danish waters (DEA, 2013). These key issues were tackled within three projects, which were partly co-financed by the German Government. One project surveyed the effects of pile-driving (monopiles) on porpoises in the area between Horns Rev and the German border, as construction work was carried out on two installations simultaneously, Horns Rev II in Denmark and the FINO 3 platform in Germany (Brandt *et al*., 2009; 2011). A second project tested the effectiveness of seal scarers in deterring harbour porpoises, and was therefore related to mitigation, not impact monitoring (Brandt *et al*., 2013). The third project was to assess the cumulative effects of wind farms and other anthropogenic factors on the behaviour of harbour porpoises and its population dynamics (Nabe-Nielsen *et al*., 2011).

In □□r□ □□□, each wind farm developer has to follow a standard investigation programme *'Standards for the Environmental Impact Assessment'* (StUK 3) (BSH, 2007), which includes detailed technical instructions for conducting an environmental monitoring programme. These investigations shall allow an assessment of potential adverse impacts of the planned facilities on the marine environment. The second update of this booklet is currently available at http://www.bsh.de/en/Products/Books/Standard/index.jsp. On the basis of the experiences collected in the course of currently under construction, and existing operating wind farms, especially the test field 'alpha ventus', StUK 3 is currently under review and will be available in a fourth updated version in due time. At the test field alpha ventus, monitoring is conducted following the StUK 3 instruction, in close consultation with the German licensing agency, the German Federal Maritime and BSH. In parallel to the StUK 3 monitoring, an enhanced monitoring programme is conducted, funded by the German Ministry, to evaluate the quality of the StUK 3 monitoring and to help improve it.

In all four countries, impact studies focused on the harbour porpoise as the most common cetacean species in the North and Baltic Sea. Most studies were conducted in a BACI-design, in which data are collected during a sufficient time period before and after the impact, within the wind farm impact area as well as in a control area (Table 10). However, in addition to data acquisition in the pre- and post-construction period, data were also (for one site solely) collected during the impact period, i.e. during construction of the wind farms in Belgium, Denmark and Germany, allowing the determination of the impact radius of pile-driving (Brandt *et al*., 2009; 2011; Dähne *et al*., 2013, DEA, 2013; Haelters *et al*., 2012, Tougaard *et al*., 2009). In The Netherlands, only the pre- and post-construction period was subject to the investigations at the wind farm site Eegmond aan Zee (OWEZ) (Scheidat *et al*., 2012). At the wind farm site Prinzess Amalia, only those reports including the second year of operation into the investigations (van Polanen Petel *et al*., 2012) of the potential effect of the wind farm on the local harbour porpoise population were available. The most common practice was to use static acoustic monitoring (SAM) to investigate potential changes in porpoise presence caused by any impact using archival cetacean detectors (T-PODs, C-PODs from Chelonia Ltd) moored across the predicted area of impact and the control site. These devices are a stand-alone, archival data logger that detect and log sound and store certain parameters of odontocete echolocation clicks. In Belgium, Denmark and Germany, aerial and boat-based line transect surveys have also been conducted (Table 10). At the Dutch OWEZ, additional monitoring of strandings and post mortem investigations on the inner ear were carried out (Leopold and Camphuysen, 2008).

The second most abundant group of marine mammals in the North and Baltic Sea are seals (harbour and grey seals). The aforementioned wind farm sites in Germany and Belgium were assessed to be of minor importance for these species, and were therefore not considered in the studies. Seals were the focus of impact monitoring in Denmark and The Netherlands. At seal haul out and/or foraging sites close to, or within, the wind farm sites, seals were equipped with satellite transmitters to track the animals' movements and routes taken, or their abundance was monitored with aerial surveys or video and visual monitoring at the haul out site (Table 10).

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
Belgium	C-Power, Thornton Bank	SAM (C-PODs), line transect surveys (aerial), BACI-design (Haelters *et al*., 2012)	
Denmark	Horns Rev I	SAM (T-PODs), line transect surveys (aerial, boat), BACI-design (DEA, 2006; Tougaard *et al*., 2006; 2009)	Satellite tracking of harbour seals (DEA, 2006; Tougaard *et al*., 2006)
	Horns Rev II	SAM (C-PODs), Construction phase (Brandt *et al*., 2009; 2011; DEA, 2013)	
	Nysted	SAM (T-PODs), BACI-design (Carstensen *et al*., 2006 ; DEA, 2006; Teilmann and Carstensen, 2012; Tougaard *et al*., 2006)	Line transect surveys (aerial) harbour + grey seals, video and visual monitoring of haul out site, satellite tracking of harbour seals (DEA, 2006; Edrén *et al*., 2010; Teilmann *et al*., 2006)
	Sprogø	SAM (T-PODs), BACI-design (Tougaard and Carstensen, 2011)	
Germany	Alpha Ventus	SAM (C-PODs, T-PODs), line transect surveys (aerial), BACI-design (Dähne *et al*., 2013), Diederichs *et al*., 2009; 2010; Höschle, 2011)	
The Netherlands	Eegmond aan Zee	SAM (T-PODs), BACI-design (Scheidat e*t al*. 2011; 2012) Strandings and post mortem investigations on inner ear (Leopold and Camphuysen, 2008)	Satellite tracking of harbour seals, aerial surveys (Brasseur *et al.,* 2008 ; Brasseur *et al*., 2012)
	Prinzess Amalia	SAM (C-PODs), 2nd year of operation compared to reference site (van Polanen Petel *et al*., 2012)	

Consistency of the mitigation rationale outside the UK

While the monitoring techniques are quite comparable throughout the European countries mentioned above, their mitigation measures are rather diverse. The mitigation measures used in the projects mentioned above are given in Table 11 which summarises details of the steps taken during the construction at various wind farm sites in Belgium, Denmark, Germany and The Netherlands. (Note this is not an exhaustive review and was compiled using the documents publicly available and accessible). ICES (2010) summarised mitigation measures as conducted in the respective EU-countries in the framework of OWF construction (Table 12). The UK is the only country which prescribes a MMOb scheme to enable the suspension of pile-driving when marine mammals are within the vicinity of the pile-driving site. The other countries use acoustic deterrent devices such as pingers and seal scarers in order to deter harbour porpoises and seals out of the area of impact to avoid physical injury. Denmark investigated the effectiveness of seal scarers in the framework of its follow-up environmental monitoring (DEA, 2013).

Seasonal restrictions for pile-driving have been applied in Belgium and The Netherlands to protect sensitive periods for key species such as harbour porpoise and seals. Germany and Belgium (through the MSFD) limit the amount of noise permitted to be transmitted into the sea. The Belgian indicator of the Marine Strategy Framework Directive descriptor 11 for impulsive noise requires anthropogenic impulsive sound levels to be less than 185dB re 1µPa zero-peak at 750m from the source. Exceeding this level will lead to the requirement for noise reduction mitigation measures (Degraer *et al*., 2012). The German thresholds were established in 2010 and are based on values that caused temporary shift in the hearing threshold of a harbour porpoise in a study by Lucke *et al*. (2009). Emitted sounds are not to exceed sound exposure levels (SEL) of 160dB re 1µPa²s or SPL of 190dB re 1µPap-p at 750m from the piling site (van Leusen, 2012). There is also the requirement for acoustic deterrent devices, surveys or soft-start procedures to ensure the absence of marine mammals within close range prior to any piling (Verfuß *et al*., 2012). In addition to this, the German Government is funding strategic research on the development and testing of noise mitigation measures during pile-driving (e.g. Pehlke *et al*., 2013; Wilke *et al*., 2012). For meeting the required noise thresholds, noise mitigation measures such as bubble curtains (Pehlke *et al*., 2013; Wilke *et al*., 2012), Hydro Sound Damper and other systems have been investigated (Wilke *et al*., 2012) and applied. The extent to which developers have met these requirements is outside the scope of the current review, but the ability for the thresholds to be met under UK construction conditions and the barriers to the adoption of these measures should be fully assessed.

Consenting rationale summary

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

The mitigation measures prescribed to reduce impacts on marine mammals by the countries covered in this review primarily concern pile-driving activity (soft-start, MMOb[9]/PAM[10] monitoring of mitigation zones, seasonal restriction for pile-driving, acoustic deterrents), which suggests that there is a general consensus throughout that pile-driving noise is the most potentially harmful

[9] Marine Mammal Observer
[10] Passive Acoustic Monitoring

impact in OWF projects to marine mammals, causing lethality, auditory injury or behavioural disturbance and displacement. The awareness of this impact was low in the early years of the UK-OWF development, nevertheless it has grown throughout the years, leading mainly to mitigation related conditions rather than impact monitoring. On the few occasions where impact monitoring has been carried out, site-specific variation in marine mammal species and issues of concern has led to a varied, bespoke approach at each site.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
Belgium	C-Power Thornton Bank	Seal scarer (Lofitech), SL = 189dB re 1 µPa, main energy at 14 kHz (Haelters *et al*., 2012)	Piling of 196 jacket foundation pinpiles, diameter 1.83m. (Haelters *et al*., 2012), 178-195dB re 1 µPap-p @ 750m (Norro *et al*., 2012)
Denmark	Horns Rev I	Ramp-up procedure (first few piles), replaced by acoustic deterrent devices: Aquamark100 porpoise pinger and Lofitek seal scarer (Tougaard *et al*., 2006)	Piling of 80 steel monopile foundations, diameter 4m, 190dB re 1 µPap-p @ several 100m from piling (Tougaard *et al*., 2006)
	Horns Rev II	Seal scarer (Lofitech), pinger (Aquamark 100) (Brandt *et al*., 2009)	Piling of 95 monopile foundations, diameter 3.9m (Brandt *et al*., 2009)
	Nysted	Seal scarer and pinger before and during piling and vibration of steel sheet piles around one wind turbine (Carstensen *et al*., 2006	72 wind turbines, gravitational foundations. Piling and vibration of steel sheet piles around one of the 72 turbines for stabilising seabed (Carstensen *et al*., 2006)
	Sprogø	Not stated	7 turbines on concrete gravitational foundations, held in place by ballast rocks (Tougaard and Carstensen, 2011)
Germany	Alpha Ventus	Seal scarer, pinger (Dähne *et al*. (2013))	Vibrating and piling of 12 4 legged-jacket and tripod foundations, diameters 2.4-2.6m (Dähne *et al*. (2013)), SEL = 154-175dB re 1 µPa²s @ 750m (Betke and Matuschek, 2011).
The Netherlands	Eegmond aan Zee	Ramp-up procedure, a pinger	Piling of 36 monopiles
	Prinzess Amalia	Not stated	Not stated

[illegible]

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Belgium	Yes, taken up in the permit	No	Yes, but only in the advice: no piling between 1 January and 30 April	Yes, taken up in the permit, and not standardised	Not *a priori* forbidden, but currently no NATURA 2000 areas are considered for wind energy production	Noise limitation from 750m from the sound source: 185dB re 1 µPa (zero to peak SPL)[11]
Denmark	Yes	No	Currently not	Yes, but not standardised	Yes, conditions apply	
Germany	Yes	No	Currently not	Yes	No, since the establishment of marine spatial planning regulations	Noise limitation from 750m from the piling onwards: 160dB SEL and 190dB SPL[12]
The Netherlands	Yes, general guideline	No	Yes, no piling between 1 January and 1 July		Not *a priori* forbidden	There cannot be more than one construction activity in which piles are driven ongoing at any time
United Kingdom	Case by case basis as a condition of the consent	Yes, and/or real-time acoustic monitoring	Yes, in relation to spawning fish (some of which are prey items)	Yes	Not *a priori* forbidden[13]	Depending on work being undertaken, requirement for a monitoring zone prior to piling. The size of which is defined by the area over which injury may occur

[11] The Belgian indicator of the MSFD descriptor 11 for impulsive noise requires anthropogenic impulsive sound levels to be less than 185dB re 1µPa (zero to peak SPL at 750m from the source. Exceeding this level will lead to the need of undertaking noise mitigating measures (Degraer *et al.*, 2012).

[12] The German Federal Environment Agency (UBA) has defined `injury` as Temporal Threshold Shift (TTS) based on data provided by Lucke *et al*. (2009). A threshold consisting of a dual criterion of 160dB re 1mPa²·s SEL (Sound Exposure Level) and 190dB re 1µPa SPL (Sound Peak Pressure Level) should not be exceeded at a distance of 750m around the piling site. The threshold is based on a TTS found in a harbour porpoise at 164dB re 1mPa2 s SEL and 199dB re 1µPa SPL. Thus the chosen values include some safety adjustment. This threshold is part of the licence, and therefore legally binding.

[13] For protected areas, an Appropriate Assessment may be requested under The Conservation (Natural Habitats, &c.) Regulations 1994, which may require further work over and above that provided in an EIA for Offshore wind farms.

[illegible]

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

[illegible]

The best practice for monitoring and assessment methodologies depends very much on the underlying rationale for the monitoring, and the questions that require addressing for a particular site (which should be drawn from the conclusions of the ES and related to site-specific uncertainties). At the two UK sites for which impact monitoring reports were reviewed, the objectives were very different and therefore the methods employed were very different. It is difficult to define and apply standards to marine mammal post consent impact monitoring in licence conditions given the variety of conditions under which one might want to design a monitoring study and the temporal and spatial variation in marine mammal abundance and species-specific differences. However, the precise nature of such monitoring will depend upon circumstances and it is beyond the scope of this report to provide a best practice approach for each circumstance. Specific impact monitoring designs will be required for each development and site, taking into account best practice principles.

Line transect surveys, over an appropriate area, allow for surface density fitting approaches such as the approach employed at Robin Rigg. These density-surface modelling approaches take into account environmental correlates in order to better evaluate changes in densities that might be a result of the construction or operation of the wind farm. This approach builds on that used at Danish sites for birds (e.g. Petersen *et al.,* 2011) developed in conjunction with the Centre for Research into Ecological and Environmental Modelling (CREEM), St. Andrews, and allows the significance of changes in densities across the survey grid to be evaluated in relation to covariates such as distance from the wind farm, time since construction and other environmental covariates, thereby providing a better understanding of changes in distribution. This approach would be considered best practice as long as issues of imperfect detection, local surface features and autocorrelation are taken into account. Recently commissioned Marine Scotland work being carried out by researchers at CREEM aims to develop standard approaches to the statistical modelling of primarily bird but also cetacean distributions in offshore renewable development areas. The eventual aim of this project is to produce a software package and guidance in its use for assessing the impact of offshore renewable developments. As well as allowing robust assessment of displacement of marine mammals as a result of offshore developments, distribution maps can provide a reliable baseline for site characterisation thus improving EIAs.

Traditionally, line transect surveys of wind farm sites have been carried out using visual observers on boat surveys, however more recently many surveys have been carried out using digital aerial surveys. This is likely to be the case in the future, given the drive for combining survey platforms for marine mammals and birds, because for birds digital aerial techniques have, to a large extent, superseded visual aerial surveys, in the UK at least and are also beginning to be used elsewhere (e.g. in the U.S.A. and in Germany). The advantages of digital aerial surveys for carrying out bird surveys are discussed in Section 6.6.2. A detailed review of digital aerial techniques and protocols with respect to marine mammals covering potential analysis issues (e.g. correcting for 'availability') is required to inform developers and Regulators about the benefits and potential limitations and uncertainties surrounding the use of digital aerial surveys for marine mammal monitoring. A Marine Scotland commissioned study currently being carried out by researchers at the University of Aberdeen is assessing and comparing the cost effectiveness of various survey techniques and may provide some of this guidance, however at the time of writing a report was not available.

Macleod *et al*. (2010) and Cefas (2012) provide details of the general issues that need to be addressed when considering impact monitoring for marine mammals at OWF sites. Whilst there is value in industry best practice guidance on the principles underlying good monitoring design, being too prescriptive can act as a barrier to the development of better methods. The following principles are likely to be universal:

- The scale of the monitoring needs to be appropriate for the temporal and spatial variability in the metric under investigation
- Power analyses should be carried out in order to determine the minimum effort for sampling that is required in order to be able to detect change
- Monitoring must be designed such that any responses can be tied to specific causes and that the contribution of alternative drivers for change is accounted for as much as possible.

It would be very difficult to determine impacts at population level for most marine mammal species at individual OWF sites and therefore efforts should focus on key uncertainties on a site-specific basis, particularly relating to responses during the construction period and the nature and the timeframe of recovery afterwards.

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Mitigation measures so far used in the UK are mainly based on, and described in, the JNCC guidance for minimising injury (2010). These measures include monitoring for the presence of marine mammals during construction, with a pre-piling watch of at least 30 minutes. Monitoring is restricted to a defined mitigation zone and is conducted visually and with PAM equipment. Sightings of animals or acoustic detections within this zone lead to the delay of the start of piling. At times with reduced visibility (e.g. at night, with fog, high sea state), preferably no piling should be commenced; unless the developer can demonstrate that such piling is essential for commercial viability. In these cases, 'enhanced' PAM should be used (e. g. an increased number of PAM systems and PAM operators). To ensure that animals are displaced from the area of impact to avoid exposure leading to auditory impacts, a soft-start is always recommended, i.e. the gradual increase of power used by the hammer for piling. The use of soft-starts is not backed up by any empirical scientific evidence of its effectiveness but is based on the common sense assumption that marine mammals will move away from the onset of piling noise. The temporary use of deterrent devices such as pingers or seal scarers is discussed in JNCC (2010) and the guidance states that more evidence relating to the efficacy of acoustic deterrents is required to determine their applicability as suitable mitigation measures. The guidance also states that these devices should always be used in such a way as to prevent the exposure of animals to disturbance that would constitute a disturbance offence under EPS legislation. While the visual and acoustic pre-piling monitoring and commencing of soft-starts became standard in the more recent licences, the temporary use of deterrent devices has not been prescribed in any UK licence condition (see Table 9). An ORJIP (Offshore Renewables Joint Industry Project) is due to report soon on a review and assessment of the use of acoustic deterrents as standard mitigation at OWFs.

In a German governmental funded project, a sound mitigation system “Hydro Sound Damper“ (HSD) was tested at the London Array OWF under offshore conditions (Remmers and Bellmann, 2013). The HSD consisted of a net of four different sized foam elements encasing a pile. The main focus of this trial was to improve the manageability during mobilisation and demobilisation rather than the damping effect per se. Installation and recovery around a monopile was successful, i.e. the HSD was reusable, with a maximum mobilisation and demobilisation time of 1.5h in total. The noise reduction reached was 7-13dB SEL and 7-15dB SPLpeak.

The mitigation measures proposed and conducted up to now have been based on the avoidance of instantaneous auditory injury rather than preventing behavioural disturbance and displacement, or preventing auditory injury as a result of cumulative noise exposure. They rely on either the absence of animals from the zone of impact (MMOb and PAM) or the behavioural response of animals to these stimuli to displace the animals from the zone of impact (ADD use, piling soft starts) in order to protect them from physical injury. A concern here is that the mitigation zones that would result from calculations of cumulative exposure would potentially be too large to be effectively monitored without increasing the cost and effort required substantially. Given current thresholds for auditory injury to seals as a result of cumulative exposure to sound (Southall *et al*., 2007) over the duration of a typical piling event for example, the estimated impact radius could be tens of kilometres. Therefore, under these circumstances, it would be practically impossible to implement effective mitigation over the area of potential risk, although it must be noted that currently there are many uncertainties involved in the prediction of cumulative noise exposure over whole pile-driving events. Furthermore, mitigation measures undertaken, at times with low visibility, are only effective for vocalising mammals, therefore will not be appropriate for baleen whales or seals. However, the length of the construction periods required for development of the Round 3 sites means that restricting construction activity to periods of good visibility for these species will potentially render projects commercially unviable.

Deterring animals from the potential area of impact will reduce the risk of injury, although the same issues of scale are apparent as described above for monitoring a mitigation zone effectively; the large impact zones predicted for some species when considering cumulative sound exposure using current thresholds would be very large and deploying deterrent devices over such areas would be practically difficult and very expensive and would result in the potential for displacement over large areas (for seals and low frequency cetaceans in particular). Although it is unlikely that this would result in greater displacement than would result from the piling itself. Given the timescales required for construction of the Round 3 developments this would have the potential to result in displacing animals from large areas over long periods (many months to years).

The prevention of auditory injury relies on an aversive behavioural response to the pile-driving noise itself (or to the acoustic deterrent applied before piling). However, at the scale of the larger Round 3 projects, a sustained aversive behavioural response over the whole period of time it takes to construct a wind farm could potentially become an impact in itself, if the development is in an area considered to be important for marine mammals. For example, sustained displacement from preferred foraging grounds may reduce foraging efficiency and thus impact upon the energetic balance of individuals, affecting both survival and reproduction. It should be considered that such displacement may have a negative effect on individuals and possibly at a population level depending on the population status and the relative importance of the area for foraging or other functions for the species concerned. However, although there are several studies documenting temporary displacement of marine mammals during wind farm construction, there are very few data on the population level consequences of such displacement over longer timeframes.

It is currently uncertain which impacts have more severe consequence for individuals and ultimately populations (auditory injury or displacement/disturbance) and it is likely that the balance will differ between species and sites. There are several planned initiatives aimed at reducing this uncertainty over the coming years (e.g. ORJIP projects[14]) but these will rely on empirical data being collected during future construction and therefore it is imperative that mitigation and particularly monitoring at a site-specific level is geared towards gaining an understanding of these issues. Marine planning and licensing decisions still need to be made on the basis of best available evidence and decisions on consent applications cannot be delayed to wait for new evidence to become available. An interim approach has been developed for assessing the population level impacts of pile-driving on marine mammals (interim PCoD (Population Consequences of Disturbance) framework) which used expert elicitation to parameterise several aspects of population level responses in the absence of empirical data, but this approach is a temporary measure and should not be adopted without regard to the large uncertainties inherent in such an approach, or as an alternative to progressing empirical understanding of marine mammal responses to piling noise.

Rather than relying on standard mitigation preventing impacts at future developments the opportunities presented by the Scottish Territorial Waters, Round 2 and Round 2.5 sites could be used to learn about, and understand, these impacts. At the very least the likely effectiveness of the standard mitigation should be assessed before adoption on a site-specific basis, and any mitigation should be designed appropriately based on an understanding of the potential scale of impacts,

[14] *Marine Scotland (MS), The Department of Energy and Climate Change (DECC) and The Crown Estate (TCE) and the offshore wind Development community have worked together to develop an Offshore Renewables Joint Industry Programme (ORJIP) which aims to deliver strategic research projects to reduce consenting risk for offshore wind projects in UK waters. The programme is now being run by The Carbon Trust. Addressing strategic evidence gaps is a high priority for the offshore wind sector as much of the potential pipeline of offshore wind projects is at risk. Offshore wind developments in UK waters are progressing rapidly and the outputs of this proposed programme are required to inform consent and licence applications and advice and decisions by the UK regulatory authorities. The first ORJIP projects will focus on strategic data collection and technology research to develop solutions on behalf of offshore wind developers to two priority consent (planning) risks – uncertainty about potential impacts on bird species from collision, and potential effects of underwater noise on marine mammals.*

the species of concern, the importance of the area and the availability of alternative areas.

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Monitoring best practice outside the UK

The impact monitoring studies conducted in the above mentioned EU-countries used a variety of methods tailored to the specific sites and target species. Each method has its strengths and weaknesses. Main results obtained in the referenced EU-studies are given in Table 9.

For harbour porpoises, the most frequently used and most powerful method for resolving impacts at a fine temporal resolution was static passive acoustic monitoring (SAM). With this method, potential changes in porpoise detection, indicating changes in porpoise density (Siebert and Rye, 2008), can be monitored in relation to the different phases during the construction of an OWF and responses can be tied to specific piling events. Furthermore, by deploying units over the appropriate spatial area, the impact radius of pile-driving events can be investigated, although these cannot be determined independently of the effects of any mitigation measures such as the use of pingers and seal scarers. These, on the other hand, will likely only be responsible for initial escape responses, while the pile-driving - as a much louder sound source, and operating over a longer period, will inevitably have a longer lasting impact than the deterrent devices themselves. However, SAM can only be used for frequently vocalizing mammal species, and species identification is only possible for animals with a unique pattern of vocalisation, such as the harbour porpoise. Dolphins and porpoises can be distinguished from each other but dolphins cannot always be identified to species (depending on the devices used). As is true of all monitoring methodologies, SAM devices have to be applied in an appropriate and sensible way to ensure the retrieval of meaningful data. For example, varying the settings of a T-POD influences the detection range of the device (Elliot *et al., 2012*, Verfuß *et al., accepted*). General guidelines for conducting SAM are given in Verfuß *et al*., 2010).

Line-transect surveys, on the other hand, allow for the estimation of species specific marine mammal abundance over an area and may be appropriate to cover larger areas than can reasonably be covered by static passive acoustic monitoring, and can assess a wider variety of species. These kinds of surveys are based on visual sightings from boats or planes, and are therefore highly dependent on weather conditions. The robustness of the statistics to detect changes is highly dependent on the level of survey effort, the animal abundance (sample size) and the magnitude of the change. The temporal resolution of the survey design relies on the frequency of surveys. The impact of piling events can be investigated using visual surveys, as long as they are conducted close in time to the piling (as happened coincidentally in the study by Dähne *et al*. (2013)). However, constructed wind turbines will be obstacles that increase the risk of collision for the research vessel or plane and therefore survey design will need to take this into account. Due to this risk, the BSH in Germany has recently adopted the method of digital aerial surveys with video/photo-cameras in their standard monitoring programme which is currently under revision. The spatial resolution of the survey design has to be carefully planned, incorporating the size of the wind farm, the potential area of impact and the likely natural variation in animal abundance and distribution. With line-transect surveys, differences in animal abundance can be detected between project phases (before, during and after the construction), however, it may be hard to distinguish if changes are due to natural variation rather than due to the impact. Monitoring of a reference area (BACI) or over a Before-After Gradient design (BAG) is therefore recommended to assist in attributing measured changes to particular causes, however, difficulties in identifying an appropriate control reference area often means that a BAG design is preferred. As discussed in Section 5.5.2 approaches which allow surface density modelling can be used to determine changes between project phases.

For seals, a variety of additional methods proved to be valuable, such as video and/or visual monitoring of changes in animal density at their haul out site in relation to the different phases of wind farm construction. Satellite tracking of these animals may give information about the potential use of wind farm sites as foraging grounds pre-construction but unless sample sizes are large, individual variability is low or activity is very localised in the wind farm area, the potential for seal telemetry to detect changes between project phases can be limited.

Mitigation best practice outside the UK
The effectiveness of mitigation is difficult to investigate in conjunction with the construction of wind farms, unless it concerns noise reduction methods. Brandt *et al*. (2013) showed that the deployment of a Lofitech seal scarer does have a deterrent effect on harbour porpoises, and can therefore greatly reduce the risk of physical injury for porpoises during offshore piling. Nevertheless, one has to be aware of habituation resulting in a decrease of the effectiveness of such devices. Furthermore, not all animals may be scared away, especially if other factors, such as food availability, may motivate the animals to stay within the impact zone. Similar to pingers and seal scarers, soft-starts, also known as ramp-up procedures, when employed as a mitigation measure, rely on the evocation of strong behavioural reactions, namely flight behaviour and an accompanied temporary habitat loss.

Therefore, the seasonal restrictions of pile-driving activities, at times with high animal densities or at sensitive times for specific species, is one potential solution as has been applied in Belgium and The Netherlands. It is unlikely that seasonal restrictions could be applied wholesale in the UK but they may provide a solution on a site-specific basis where otherwise the project would not go ahead because of potential negative impacts on protected species. There is also, where appropriate, the potential for the use of low noise foundations such as gravity based designs or floating turbines, which basically do not require piling. However, these foundations have to be assessed in light of all other potential environmental impacts and may not prove the optimal solution when impacts on other receptors are considered. Gravity based foundations were used at the Danish wind farm sites Sprogø and Nysted.

Noise reduction mitigation has been shown to be effective in German projects (Pehlke *et al*., 2013; Verfuß 2012; Wilke *et al*., 2012). Pehlke *et al.* (2013) successfully deployed and tested a so called Big Bubble Curtain (BBC) at the wind farm Borkum West II in water depths of 26-33m. A BBC consists of a perforated pipe ring laid onto the sea floor around the sound source. Compressing air through this pipe will provide an air bubble curtain encasing the source, thereby acting as a barrier for the sound waves generated during piling activities. Applying this noise mitigation measure, Pehlke *et al*. (2013) reported a noise reduction of 9 to 13dB in SEL and 10 to 17dB SPLpeak. The system was able to reduce ramming noise to down below the German noise threshold of 160dB SEL and 190dB SPLpeak. In the same project, the effectiveness of reducing the impact on harbour porpoises was investigated with SAM using C-PODs. The results showed that the median SEL evoking a disturbance reaction was 144dB, translating in an impact radius of 15 km when ramming without a BBC and 4.8km with BBC. The noise mitigation measure therefore reduced the impact area (and likely number of animals) by 90%. Wilke *et al*. (2012) tested five different noise mitigation systems in the Lübeck bay at a water depth of 8-9m. All noise mitigation system tests yielded significant reduction effects. Verfuß (2012) presented preliminary results of different German governmental funded projects, in which noise mitigation measures were successfully tested in water depths up to 40m. Such technologies are of international interest (BOEM, 2013). Noise mitigation techniques have yet to be proven effective in water deeper than 40m and in areas with strong currents. With regards to effectiveness, the impact area has a squared relationship with the impact radius, i.e. with each halving of the impact radius the impact area will be reduced by three quarters. Nevertheless, noise mitigation has the potential to reduce the impact zone but will not completely eliminate it.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
Belgium	C-Power, Thornton Bank	Harbour porpoise	Changes in spatial distribution suggest disturbance, apparent impact around 22km (aerial surveys). Clear fine-scale match between porpoise detections and piling activities, first detections after piling took hours to days (SAM). (Haelters *et al*., 2012)
Denmark	Horns Rev I	Harbour porpoise	No significant change in abundance as a whole during construction, but during semi-operation (i.e. operation with intensive maintenance work) compared to operation. No porpoises during pile-driving, first porpoise detections after 6-8 hours (SAM). Weak negative and local effect during construction (ship surveys). On average 23 sightings per survey, with a total of three sightings within wind farm area, too little to justify statistical testing (aerial surveys) (Tougaard *et al*., 2006).
		Harbour seal	Wind farm site part of foraging area. Accuracy of obtained positions insufficient for certain results with regards to potential impact of OWF (satellite tags and data loggers). Seals observed inside wind farm area as well as outside, but only few during construction within wind farm area (boat surveys for harbour porpoises) (Tougaard *et al*., 2006).
	Horns Rev II	Harbour porpoise	No detection within 1 hour after piling and below average up to 72 hours at 2.6km from piling site. This recovery time decreases with increasing distance, detectable out to 17.8km in mean. At 22km there was an increase in porpoise detections. Up to 4.7km recovery time longer than time between most pilings, resulting in a porpoise reduction in that area for the whole construction period (SAM) (Brandt

[illegible]	[illegible]	[illegible]	[illegible]
			et al., 2011).
	Nysted	Harbour porpoise	Piling/vibration of steel sheet piles had a temporal effect on the porpoise density extending beyond 15km from the piling location (Carstensen *et al*., 2006). Slow recovery of porpoise density after construction, not yet at baseline level even after four years of operation (SAM) (Teilmann and Carstensen, 2012).
		Harbour + Grey seals	Wind farm site part of foraging area (satellite tracking). Reduction in seals resting on land during pile-driving (video and visual monitoring of haul out site) (Edrén *et al*., 2010, Teilmann *et al*., 2006). GPS/GSM tracking of both species of seal during operational phase indicated no significant effect of the wind farm on seal behaviour. This also applies to Rødsand 2 wind farm. (McConnell *et al*., 2011).
	Sprogø	Harbour porpoise	No significant effects found (SAM) (Tougaard and Carstensen, 2011).
Germany	Alpha Ventus	Harbour porpoise	Avoidance response within 20 km distance to piling site (one aerial survey during piling activity). Negative impact of piling below 10.8 km, higher detection rates at 25 and 50km (SAM). Dähne *et al*. (2013).
The Netherlands	Eegmond aan Zee	Harbour porpoise	Strong seasonal pattern, overall increase in detections from baseline to operation, in line with general increase in porpoise abundance in Dutch waters. Detection rate significantly higher inside wind farm than in reference area, possibly due to increased food availability and/or absence of vessels in otherwise heavily trafficked area (SAM) (Scheidat *et al,*. 2011; 2012). No unusual/unexpected strandings pattern (stranding scheme), collected samples were not suitable for examining ear damage using inner ear morphology investigations (animals were frozen before examinations) (Leopold and Camphuysen, 2008).
		Harbour seal	Original design not specifically suited to study effect of OWF, as haul out site was over 40km away. Seals were on average less abundant in direct proximity of large shipping routes. Seals did not visit OWF area during construction, but before and after construction their distribution extended towards OWF (satellite tracking) (Brasseur *et al*., 2012).
	Prinzess Amalia	Harbour porpoise	No difference in detection rate between wind farm site and reference site (SAM) during 2nd year of operation (van Polanen Petel *et al*., 2012).

Monitoring best practice summary

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

The best practice for any impact monitoring methodology depends on the species concerned, their abundance, the baseline spatial and temporal variability and the scale and nature of the impact of concern, as well as the site-specific circumstances. Passive acoustic monitoring for example turned out to be a valuable tool to investigate changes in presence / abundance of harbour porpoises in relation to OWF-construction, but is not applicable for monitoring impacts on seals or baleen whales. Best practice for monitoring marine mammals should take into account guidance presented in Macleod et al. (2010) and Cefas (2012). Guidance on specific methodologies is evolving.

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

As discussed above, very few instances of impact monitoring for marine mammals have been conducted on the reviewed UK wind farm sites. Only two examples were available for this review. These were seal haul out monitoring at Scroby Sands (Skeate and Perrow, 2008), and boat-based surveys for harbour porpoises at Robin Rigg (Walls *et al.,* 2013).

A mixed haul out of harbour and grey seals is situated less than 2km from the Scroby Sands wind farm (Skeate and Perrow, 2008; Skeate *et al*., 2012). At Scroby Sands, monitoring (aerial survey haul out counts) was conducted monthly during the summer months before, during and after the construction phases. These data indicated a decline in harbour seal numbers during construction, with numbers remaining lower in the two subsequent years. However the surveys did not coincide with the period of pile-driving therefore it is difficult to assign a direct cause and effect to the changes observed in seal numbers over this period. The numbers at Scroby represent approximately 5% of the East Anglian population and the observed changes may reflect changes in the distribution of animals within the regional population. During the annual moult monitoring surveys carried out by the Sea Mammal Research Unit (SCOS Main Advice, 2011) numbers of harbour seals recorded at Scroby have increased continuously since 2003, suggesting that wind farm operation has not had a long term effect on haul out numbers. The numbers of grey seals at Scroby Sands increased year on year throughout the construction and early operational periods, it is therefore possible that changes in harbour seal numbers were in response to this rather than any effects of the OWF. In this case, although all requirements prescribed in the licence were fulfilled, there are not necessarily clear lessons to be learned.

At Robin Rigg, boat-based surveys were conducted on a monthly basis between February 2004 and January 2005 with an additional survey in July 2007, just prior to construction commencing (Walls *et al*., 2013). Construction phase surveys started in January 2008 and continued on a bi-monthly basis until the end of the phase in February 2010. Post-construction, one survey per month was completed for two years (completed in February 2012). These surveys were carried out in conjunction with bird surveys but a dedicated marine mammal surveyor was on each survey collecting dedicated marine mammal sightings. A standard line transect design was followed, the MMOb surveyed both sides of the line and recorded distances to sightings but unfortunately bearings to sightings were not recorded, meaning that a detection function could not be fitted to correct for the drop off in detectability with distance. Therefore only relative abundance could be determined (rather than absolute). The initial surveys conducted at Robin Rigg pre-dated current best practices but the same methods were purposely continued throughout the different phases of the development to ensure continuity in the data and enable consistent analysis. In addition, the main focus of the analysis was to look for changes between the different phases rather than absolute numbers and as long as factors affecting detectability remained constant throughout the monitoring, this would be adequate.

Harbour porpoise sightings data were analysed using Generalised Additive Models (GAMs) fitted across the data from each project phase separately with sea-state, depth, sediment type, month, distance to coast and xy position as explanatory variables. The resulting models were used to predict harbour porpoise distribution across the whole survey area, producing density surfaces and relative abundance estimates. Spatial and temporal autocorrelation were not dealt with in the modelling - not taking these into account can result in artificially low estimates of variance and misinterpretation of model results. It is understood that an update to this work addressing this issue is currently underway and will be available later in 2013.

Comparison of the density surfaces between the different phases suggested that harbour porpoises were displaced from the wind farm site during construction which could be considered an impact resulting in reduced foraging opportunities. However it is difficult to assess if the change was a result of the wind farm or was simply reflective of natural variation as there was only one year of pre-construction survey, and other parts of the survey area outside the wind farm site also appeared to experience significant declines in harbour porpoise density. Furthermore, an acoustic deterrent device designed to deter marine mammals prior to piling events to reduce the risk of auditory injury, was used for 30 minutes prior to each piling event and therefore it is difficult to disentangle any effects of construction with displacement caused by the acoustic deterrent. No analysis was possible for any other species of marine mammal due to low numbers of sightings.

Considering all information that was available for this review, few generic lessons have been learnt in the UK with regards to the impact of OWFs on marine mammals other than the suggestion that marine mammals may be temporarily displaced during wind farm construction however, large uncertainties remain.

ICES (2010) points out that each wind farm is unique, as the number and arrangement of turbines, as well as the physical characteristics of each site, vary considerably between projects. The foundation types are different, requiring different construction operations, which produce different types and levels of noise, turbidity or pollution. Furthermore, each site is inhabited by different densities and populations of marine mammals. All these factors have implications for the environmental impact and they underline the need for a case by case evaluation of projects until a more general understanding of the effects is available (ICES, 2010).

However, the primary generic lesson from the studies in EU-waters with regards to the impact of the construction of OWFs on marine mammals is that the construction phase can result in significant impacts to marine mammals, mainly associated with piling activity (e.g. Brandt *et al*., 2011, Carstensen *et al*., 2006, Dähne *et al*., 2013, Haelters *et al*., 2012, Tougaard *et al*., 2006), while the operational phase seems to have mostly no significant effect (e.g. Scheidat *et al*,. 2011; 2012, van Polanen Petel *et al*., 2012). The construction noise is not only capable of inducing physical damage on the hearing system of the animals (Lucke *et al*., 2009), Southall *et al.,* 2007), it also causes behavioural changes and temporary habitat loss that can last for the whole construction period (see Table 13). The effects of pile-driving can reach to distances beyond 20km from the construction site. The impact monitoring studies listed in Table 13 show that harbour porpoises use the wind farm sites again once piling ceases but it is not known if the same animals return or if they are replaced by other animals. In the latter case, the resulting impact may be more severe than in the former (Tougaard *et al*., 2006). There are limited data on the relationship between piling duration and length of displacement. It is important to note that behavioural changes are not necessarily caused by piling (alone). They can also be induced by other construction activities such as increased boat traffic or by mitigation measures like pingers and seal scarers (e.g. Dähne *et al*., 2013). Hearing impairment can be detected with pathological methods or measurements of the hearing thresholds as described by Southall *et al.* (2007) or Lucke *et al*. (2009). All other monitoring methods mentioned in this report generally demonstrate behavioural changes or changes in animal density with relation to the construction phase (see Table 13) and very little is currently known about the individual or population consequences of auditory injury or disturbance/displacement.

OWF Environmental Impacts: lessons learnt summary

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

A significant decrease in marine mammal density during construction involving pile-driving was generic to all reviewed impact monitoring studies. Another generic lesson related to the methodology is that the spatial and temporal coverage of the monitoring needs to be sufficient to detect a change over natural variation and studies need to be designed carefully to determine cause and effect. These issues and non-UK studies have informed the

evolution of best practice survey design and have led to a number of strategic research projects that will provide results applicable to other sites (e.g. DECC funded seal telemetry study in The Wash, Offshore Renewables Joint Industry Programme (ORJIP) projects).

[illegible]

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

[illegible]

It is clear that any licence requirement for marine mammal monitoring needs to be based on the uncertainties and significant impacts identified at the EIA and HRA stage at each site. Therefore this review provides little support for a generic set of monitoring conditions to be applied to all licences and there should be a requirement to develop an appropriate monitoring programme using available agreed best practice at the time which is centred on the key uncertainties identified in the ES and in consultation with technical experts, statutory advisors and the regulator. The approach developed at Robin Rigg, whereby a monitoring management group was set up to ensure the appropriate development of the monitoring programme, provides a good model to follow. The exact nature of any monitoring conditions will depend on the risks and uncertainties identified during the EIA on a case by case basis but consideration should be given to determining indirect as well as direct impacts where the potential for these have been identified in the EIA.

It is possible that as long as there are no large differences in turbine type or substrate conditions between those installed in Round 1 and Round 2 and future sites, that there is no requirement for noise monitoring in the operational phase. Data from the noise measurements made during the operation of the wind farms reviewed here suggest that operational noise levels are not of a magnitude to cause impacts to marine mammals and this is backed up by data from EU studies.

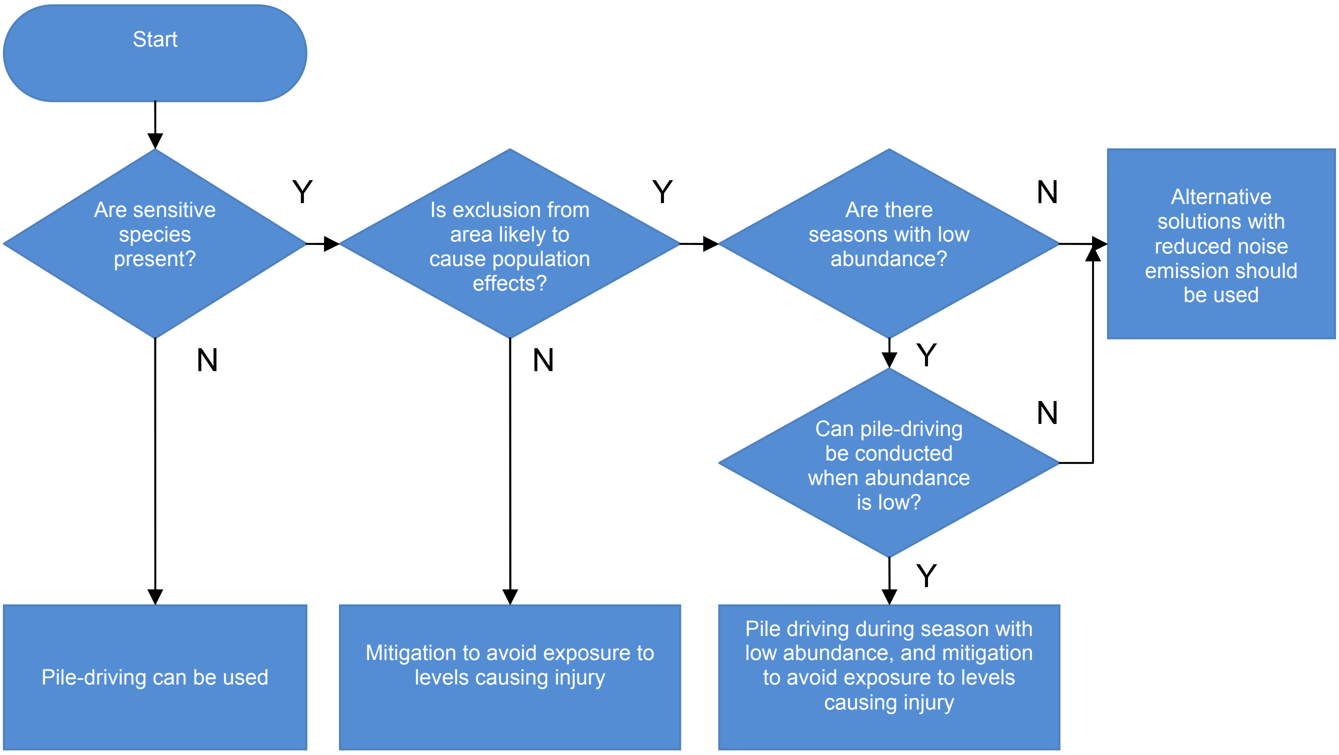
[illegible]

Similarly, the requirement for mitigation and the form it should take should be assessed on a site by site basis – and be informed by the species present and predicted impacts. The effectiveness of the standard mitigation should be clearly assessed.

Given the scale of planned future development and the (legislative) conservation importance of marine mammals (particularly where cumulative effects are likely), one solution would be if noise reduction mitigation or alternative low noise foundations were feasible. The approach taken in Germany and Belgium, (whereby noise levels are required to be below a set threshold at a set distance from the sound source), or the approach partially taken in Denmark (where alternative low noise foundations were used), have been effective in reducing the potential for negative impacts on marine mammals in other countries. The feasibility and effectiveness of these approaches needs to be fully assessed in a UK context, from both a practical and policy perspective. These approaches could be considered in sensitive areas and where piling would have to take place over long periods and where otherwise the potential for impact would result in the project not being consented under current legislation.

The application of noise reduction methods as mitigation is currently not UK policy and it is costly to adopt and may not always be feasible at UK sites. However the German example shows that the adoption of a policy of prescribing noise mitigation measures is possible. However, further work would be needed to understand how, if and under what restrictions noise mitigation measures can be applied in UK waters.

ICES (2010) proposes a decision matrix (Figure 3), for how, and which, mitigation measures would be appropriate for certain conditions: Mitigation measures should always be considered whenever low noise foundations are not feasible, and pile-driving is to be conducted where sensitive species are present in high densities. In other European countries a combination of noise mitigation, combined with either mitigation monitoring or deterrent devices, has been recommended where feasible, as neither noise mitigation alone nor mitigation monitoring or deterrent devices will prevent physical damage to the animals. Noise mitigation dampens the sound emitted into the environment, which reduces the area impacted by loud sounds. However, an area of impact will remain (with e.g. a maximum radius of 750m when following the German standards (BSH, 2007)). To avoid physical damage to marine mammals, other mitigation measures have to be taken to minimise the risk of injury on the animals. On the other hand, without noise mitigation, construction noise can have impacts up to several tens of kilometres away from the construction site (see Table 13). Mitigation measures such as seal scarers may not successfully scare all animals out of the hazardous zone (Brandt *et al*., 2013), and MMObs may not detect all animals present within the monitored zone (ICES 2010), therefore additional noise mitigation measures will reduce the risk of injury to marine mammals in the vicinity of the construction. Alternative solutions to piling with low noise emission are recommended whenever feasible, but especially when animals are present in high numbers and in areas of particular importance to marine mammals.



OWF Environmental Impacts: recommendations for ongoing monitoring summary

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

To date there have not been a significant number of large OWF developments in areas considered to be important for marine mammals in UK waters and very few examples of impact monitoring are available. However in future this will not always be the case - where developments are planned in areas with high densities of animals, specific impact monitoring will be required to address uncertainties identified in the impact assessments and to validate predictions. Conditions for monitoring the impact of the operational phase specifically and exclusively is unlikely to be necessary unless OWF-technology will be installed which may generate higher sound levels than the current ones, or as a continuation of monitoring of the impacts of construction e.g. how long after the construction period until densities return to baseline conditions. Emphasis should be on well-designed monitoring programmes that can be used to demonstrate effects at the site level. It is noted that, if possible impacts are predicted, in addition to the impact monitoring, mitigation measures will need to be in place prior to construction to comply with the Habitat Regulations.

[illegible]

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

[illegible]

Most sites did not have monitoring conditions associated with them. Reports detailing impact monitoring studies were reviewed for only two sites in the UK (Scroby Sands and Robin Rigg), both focusing on different questions, species and methodologies. In general, monitoring conditions written in the licences were mostly similar, but were quite general. From 2007 on, licence conditions relating to mitigation were comparable. The available PAM and MMOb monitoring reports (for five sites) were generally comparable. Although there are few data currently available, sighting and detection data from mitigation monitoring (pre-piling watches) could be collated and examined.

[illegible]

None of the data gathered during monitoring or mitigation required at any UK site or from the EU examples is sufficient to contribute to a synoptic approach or to determine any cumulative impact. However, the German licensing agency BSH is following a consolidating and comparative approach. With the prescription of technical standards and the collection of all data retrieved by the environmental monitoring programmes in one database (e.g. Dähne *et al*., 2011 for marine mammals), a unique dataset is being built up. This database contains the environmental monitoring datasets of all wind farm projects that are being built within the Economic Exclusive Zone of German waters, and thereby under the responsibility of the BSH. This dataset is likely to allow the analysis of cumulative effects in German waters.

As proposed in Section 5.2. the development of ISO standards for noise parameters, the development of a registry for impulsive underwater noise and the JNCC noise mapping exercise will be important in identifying potential cumulative effects.

OWF post consent monitoring data summary

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

The data available from the UK-sites will not currently contribute to a synoptic approach across sites. However, Germany is following a consolidating and comparative approach by prescribing technical standards and collecting all data retrieved by the environmental monitoring programmes in one common data base. This approach allows for a comparative analysis and the investigation of cumulative effects and could be replicated in the UK.

[illegible]

[illegible]

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

In this section, we provide a summary of the consistency of the monitoring rationale for the sites reviewed, focusing on the consistency in how licence conditions were derived, whether there has been consistency in the objectives specified in the licence conditions over time and between sites. Comparison is also made with the monitoring specifications available for non-UK sites. It should be noted that for the non-UK sites for which information was reviewed, there was a general lack of information on the reasons for monitoring and the associated licence conditions. Thus, while information from these sites is useful in determining recommendations for monitoring programmes and survey design (see Section 6 onwards for recommendations), information on the legislative requirements for monitoring or monitoring specifications was limited.

A summary of the licensing conditions is provided in Table 14.

[illegible]

[illegible]	[illegible]	[illegible]	R[illegible]	[illegible][15]	[illegible]	[illegible]	[illegible]
Scroby Sands	East Anglia	2003	1	No objectives[16]	No	EIA not available	No
North Hoyle	Liverpool Bay	2002-07	1	Changes in bird use and passage (displacement); barrier effects; distribution of birds; survey benthos; collision risk.[17]	Yes	Yes	Yes - benthic
Rhyl Flats	Liverpool Bay	2002-12	1	Changes in bird use and passage (displacement); barrier effects; distribution of birds; survey benthos; collision risk.	Yes	Yes	Yes - benthic
Kentish Flats	Thames Estuary	2003-03	1	Changes in bird use and passage (displacement); disruption to flight	Yes	Yes	No

[15] Objectives in [illegible] were those which were predicted to be of [illegible] by the EIS and those objectives in *italics* are *conditional*

[16] Four key areas identified: feeding studies, breeding colony studies, prey studies, and collision mortality

[17] Impacts of effects were assessed collectively for each species – medium significance impacts were predicted for red-throated diver

[illegible]	[illegible]	[illegible]	R[illegible]d	[illegible]	[illegible] dr[illegible]	[illegible]	[illegible]
				lines (barrier); distribution of birds; collision risk modelling; determine effectiveness of mitigation measures.			
Barrow	Morecambe Bay	2003-06	1	Changes in bird use and passage (displacement); barrier effects; distribution of birds; collision risk modelling.	Yes	Yes	No
Burbo Bank	Liverpool Bay	2003-07	1	No objectives	No	No	No
Lynn & Inner Dowsing	Humber	2003-07	1	Changes in use by feeding and passage birds (displacement)[18], collision risk; survey benthos.	Yes	Partly	Yes - benthic
Gunfleet Sands	Thames Estuary	2004-06	2	Confirm predictions in EIA are correct; collision risk monitoring; generic information on bird/wind farm interactions.	Partly	Partly	No
Robin Rigg	Solway Firth	2006-12	1	No objectives[19]	No	Partly	No
Greater Gabbard	Thames Estuary	2007-02	2	Changes in bird use and passage (displacement); barrier effects; distribution of birds; collision risk monitoring.	Yes	Yes	No
Ormonde	Morecambe Bay	2007-02	1	Changes in bird use and passage (displacement); collision risk modelling; barrier effects and distribution of birds.	Yes	Yes	No
Walney	Morecambe Bay	2007-10	2	Changes in bird distribution, use and passage (displacement); collision risk	Yes	Partly	No

[18] Reclassified from moderate to low significance following mitigation measures (gannets and divers)
[19] Although it can be inferred from the first year post-construction report that the key objectives were to monitor displacement effects and the potential for collision.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				modelling; changes in arrival time for migration.			

[illegible]

OWFs may affect bird populations through three main processes:

i) direct mortality due to collisions
ii) disturbance/displacement from the wind farm area leading to an effective loss of habitat
iii) barrier effects for migrating birds or those making regular movements to and from breeding colonies.

These effects were considered in the vast majority of the ESs (and supporting technical reports) for the sites covered by the review (note that the ES for Scroby Sands was not provided). Exceptions to this included Robin Rigg and Ormonde which did not formally consider barrier effects, the latter of which argued in its ES that the size of the development site was unlikely to give rise to any significant effect on species (although no evidence or data were provided to support this). Additional effects such as the direct loss of habitat associated with the construction of turbines or attraction to structures as perching/roosting sites were also assessed in a few example cases (e.g. Rhyl Flats). In some instances the predicted impacts, across all the phases of development, were considered collectively for the individual species of interest (e.g. North Hoyle and Burbo Bank). There was even an example where the impacts were considered for the taxonomic group of ‘birds’ as opposed to at the species level (e.g. Barrow). In these examples it is virtually impossible to apply post consent monitoring data to assess whether the predictions in the ESs (and supporting technical reports) were correct.

Collision risk, displacement (changes in the numbers of birds using the site of the wind farm) and barrier effects were considered, in turn, in the majority of the consent monitoring conditions detailed in the licences, or in the associated monitoring specifications that were reviewed (there were only two examples of the latter- Rhyl Flats and Walney). Exceptions included Robin Rigg and Burbo Bank because they did not provide specific objectives as part of the licence conditions. Also, although Scroby Sands highlighted four key areas to be addressed, barrier effects were not mentioned (the main focus of monitoring was on breeding little terns). The post-consent monitoring conditions applied can thus be viewed as broadly consistent across these projects in respect of the effects considered.

It should be noted that some conditions, especially for monitoring of collisions, were conditional. Hence there was a pre-requisite to demonstrate that there had been a significant change in use (the implication being an increase was observed) by birds at risk of collision using the site (see Barrow, Greater Gabbard, North Hoyle, and Rhyl Flats OWFs). Similar conditions were also applied with respect to indirect effects e.g. further benthic monitoring to be carried out if significant change in common scoter populations were observed (see North Hoyle and Rhyl Flats).

The consent conditions were less consistent as to whether they reflected the likely significance of the impact associated with an effect as described in the ESs (and supporting technical reports) e.g. in many cases monitoring was required in relation to effects that were predicted to have low or negligible impacts. However, in some cases, these conditions were included because of the need to reduce uncertainty in the predicted impacts of particular effects, e.g. those assessed more qualitatively (see below).

[illegible]

The sites for which information was reviewed were all UK Round 1 or Round 2 sites, and the objectives specified in the licence conditions broadly reflect the detail provided in the ESs (and supporting technical reports) for these sites, and showed no apparent chronological change between the different rounds of OWFs projects. With respect to the key effects outlined above, quantified predictions of collision risk (based on a modelling approach) were provided in the majority of ESs (and supporting technical reports) (with the exception of Burbo Bank and Barrow). In contrast disturbance/displacement and barrier effects were typically assessed in a more qualitative manner. The limited detail in the consent monitoring conditions in the licences, or in the few associated monitoring specifications that were reviewed, in part reflects either the qualitative nature of predictions (disturbance/displacement and barrier effects) or the difficulty of monitoring potential impacts (most notably the case for barrier effects and collision risk). This is discussed further below.

[illegible]

The ornithological monitoring conditions provided in the licences were usually detailed in a specific annex, although were usually brief and thus in some instances lacked site-specificity. In most licences, specific objectives were outlined with respect to the monitoring conditions (exceptions to this were Burbo Bank, Robin Rigg and Scroby Sands OWFs). There were also examples where very little detail was provided even when specific objectives were provided. In one instance (Gunfleet Sands, licence issued 2007), the first objective detailed in the conditions was simply "*to confirm that the predictions made in the Environmental Impact Assessment are correct*". Another example of a licence with minimal information was Robin Rigg (licence issued 2005), the only condition noted was that "the licensee shall undertake such ornithological monitoring as Scottish Executive experts advise" and provided no further details or objectives. The latter case is more consistent with the current Marine and Coastal Access Act licensing process, in that specific monitoring conditions are not provided in the licence itself, but agreed separately with relevant stakeholders (government advisors) and detailed in an associated monitoring protocol. For the sites reviewed, however, those few specific monitoring protocols that were available (i.e. for Rhyl Flats and Walney) provided little further in the way of objectives (as opposed to survey methodologies) than was detailed in the licence conditions.

There was some consistency in conditions, in particular with respect to the objectives, between sites in the same region. For example, in Liverpool Bay, the conditions provided for Rhyl Flats matched those proposed in relation to the earlier North Hoyle OWF. This reflects the point that the main species of concern (common scoter) was the same at both sites (note however, that Burbo Bank also within

Liverpool Bay did not provide specific objectives). Similarly, within the Thames estuary, the objectives for Kentish Flats and Greater Gabbard were broadly similar (although mitigation was not included in the latter). There was also some consistency in objectives for Morecambe Bay OWFs when comparing Walney with Ormonde (although the former specified only two compared with the four in the latter) but not with respect to Barrow. Some data-sharing for sites in these regions (e.g. in relation to scoters in Liverpool Bay) has also aided monitoring at individual sites.

[illegible]

In all the cases reviewed, the FEPA licences specified the legal requirement for three years of post-construction monitoring (with the exception of Scroby Sands), although in the case of Robin Rigg, there was a requirement for five years of monitoring with a review after three years to establish if further surveys were still required. Under the Marine and Coastal Access Act, licences are issued for the lifetime of the project. In comparison, at onshore sites in the UK, monitoring is typically undertaken over longer periods. For sites outside of the UK, for which reports were available, the monitoring undertaken has been less obviously limited and there have often been several different strands to the monitoring programmes. Overviews of the research programmes are available (e.g. for Germany, http://www.offshore-windenergie.net/en/research/federal-research-programme and for Belgium, http://www.mumm.ac.be/EN/Management/Sea-based/windmills.php), although these do not necessarily provide details of the legislative requirements for monitoring or monitoring specifications which would be necessary to make a reasonable comparison with our knowledge base of the UK system.

One detailed monitoring specification was available for the Near Shore Wind Farm demonstration project in the Netherlands (http://www.agentschapnl.nl/sites/default/files/bijlagen/Near%20Shore%20Wind%20Farm%20Monitoring%20and%20Evaluation%20Programme.pdfhttp://www.agentschapnl.nl/sites/default/files/bijlagen/Near%20Shore%20Wind%20Farm%20Monitoring%20and%20Evaluation%20Programme.pdf). This outlines the overall objectives of the monitoring required in relation to assessing the impacts associated with collision risk, displacement and barrier effects, and the associated functional (i.e. data and methodological) requirements, as well as more specific methodological details. These are outlined below to give an indication of the detail provided.

In relation to collision risk, four objectives were set:

i) to determine collision probabilities and to monitor the numbers and species of dead birds resulting from construction of the wind farm with a view to: (a): reducing risks of future OWFs and (b): understanding the necessity of mitigation measures, including closure
ii) to determine impacts at a population level
iii) to provide a better generic understanding of flight movements, the numbers and species of birds exposed to the effect, collision probabilities and potential mitigation measures
iv) to consequently refine the information used in EIA
v) Requirements specified to meet these objectives included: (i) quantitative data on species' occurrence, flight patterns and numbers; (ii) estimation of the

probability of collisions; and (iii) quantitative data on the mortality of birds (numbers and species) as a consequence of collisions.

In relation to displacement, four objectives were set:

i) to determine the direct and indirect impact of wind farm on the habitat, foraging area and behaviour of birds
ii) to estimate the impact of large-scale (offshore) farms
iii) to provide a better understanding of the numbers and species of birds exposed to the effect, the factors causing disturbance, habitat and foraging areas and potential mitigation measures
iv) to consequently refine the information used in EIA.

Requirements specified to meet these objectives included: (i) quantitative data on species' occurrence, flight patterns, numbers and behaviour; (ii) quantitative data on disturbance and/or changes in the foraging and resting behaviour of birds as a consequence of the construction of the wind farm; and (iii) an evaluation of whether any changes in species' occurrence, flight patterns, numbers and behaviour reflected disturbance or changes in food availability (including both broader changes or those associated with the construction of the wind farm).

In relation to barrier effects, four objectives were also set:

i) to determine the nature and scale of the barrier effect associated with the wind farm
ii) to estimate the impact of large-scale (offshore) farms
iii) to provide a better understanding of the impact of barrier effects and potential mitigation measures
iv) to consequently refine the information used in EIA. Requirements specified to meet these objectives included: (i) quantitative data on species' occurrence, numbers, flight paths, flight patterns, flight altitudes; and (ii) consequent quantitative data on the impact of the barrier effect posed by the wind farm.

These overall objectives are broadly consistent with those for UK sites, in that they consider the need to confirm predictions regarding the key effects of displacement, barrier effects and collision, or reduce the uncertainty in predictions. The level of detail provided on methodologies is also similar to that provided in the monitoring protocols that were available for UK sites. However, the data requirements outlined in the monitoring specification for the Dutch site were more specifically targeted towards the fulfilment of monitoring objectives; those for UK sites being more focused on survey methodologies.

Information on the legislative requirements for monitoring or monitoring specifications for other non-UK was limited. However, information from these sites – for example, from the extensive research-based monitoring programmes undertaken at the Danish wind farms, as well as Dutch and German sites – has been used in determining recommendations for monitoring programmes and survey design (see Sections 6 onwards, recommendations).

Consenting rationale summary

Is there a consistency in the rationale of the post-consent monitoring conditions applied to OWF projects (both UK and non-UK)?

OWFs may principally affect bird populations through three main processes: (i) collisions: (ii) disturbance/displacement; and (iii) barrier effects. The first two effects are considered in all ESs and, in turn, thus in the majority of the consent monitoring conditions. There was some also consistency in objectives between sites in the same region.

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What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

Best practice in post-consent monitoring reflects not only the survey methodologies being used, but also the clear definition of the objectives of monitoring in licence conditions and that these objectives are reflected in the survey design. In this section, we provide a summary of best practice in relation to the definition of licence conditions, survey methodologies and survey design, as observed from the review of UK sites covered in the site-specific reviews. The focus is thus specifically on the licensing and monitoring process used in the UK; comparison with survey methodologies and survey design at non-UK sites will be more fully drawn in determining recommendations in Sections 6 onwards.

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With respect to licence conditions, the best examples in the ornithological review were those that were most clearly linked to the monitoring of impacts predicted in the ESs (and supporting technical reports) or the resolution of uncertainty in these impacts. The North Hoyle and subsequent Rhyl Flats conditions (for example, while including generic consideration of displacement, barrier effects and, conditionally, collision risk), also included specific objectives to, first, better understand the distribution of the key species of concern – common scoter – and, second, if changes in bird numbers were observed at the wind farm site, to instigate a programme to monitor the benthos to determine whether changes were the result of change in food supplies. These two case studies also provided good examples of consistency in licence conditions and data-sharing.

There is also potential merit in the objectives being specific about the species of interest. In both Walney and Ormonde licences one of their objectives, which aimed to determine whether there is a change in bird distribution, use and passage, highlighted the same four species of particular interest (Manx shearwater, lesser black-backed gull, red-throated diver and common scoter). Clearly, this approach is dependent on a robust ES based on extensive baseline studies which have comprehensively described species' relative distribution and abundance. While monitoring may thus focus on key species for which key issues or uncertainty exist, data collection should typically encompass other species, otherwise the opportunity to identify unforeseen impacts will be compromised.

As described above, the detailed monitoring specification available for the Near Shore Wind Farm demonstration project in the Netherlands also provided clear objectives, although, here the data requirements also outlined were more specifically targeted towards the fulfilment of monitoring objectives.

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In practice, survey methods may develop over the periods of monitoring, Hence the primary requirement of post-consent monitoring for birds should be to ensure that data on the numbers of birds using the site (and, depending on survey design, wider areas around this or control sites) are collected in a manner that allows adequate statistical comparisons to be made between baseline, during construction and post-construction periods. This is, of course, particularly pertinent to the detection of displacement effects, but will also inform monitoring and the overall assessment of barrier effects and collision risk.

Guidance on standardised seabirds at sea census techniques for both boat and visual aerial surveys, (in relation to assessments for OWFs in the UK) was provided by a COWRIE-funded project by Camphuysen *et al.* (2004). This guidance was typically followed in the methodologies described in available monitoring protocols or monitoring reports (although for the earliest reports, methodologies described by Komdeur *et al.* (2002) and Kahlert *et al.* (2004) were referred to). The same guidance has also been used for non-UK sites. At present there is no industry standard relating to the use of radar for the renewable sector.

For all the sites reviewed in Task 1, boat and/or visual aerial surveys were used to collect data to inform the EIAs/ESs, and subsequently for post-consent monitoring. Several assessments drew from aerial surveys initiated through government-funded programmes. These determined populations of birds using proposed strategic areas for Round 2 OWF development. In some cases, these surveys were continued to inform the post-consents monitoring, although not always for all three years post-construction. Minimum flight height restrictions imposed by the Civil Aviation Authority (CAA) also limited post-construction aerial surveys (for examples see Barrow, Lynn and Inner Dowsing, and North Hoyle OWFs) meaning that boat surveys were thus the primary source of data capture throughout (for assessing displacement, collision risk and to lesser extent barrier effects). Radar surveys were deployed at several sites during the post consent monitoring phase (for the detection of the barrier effects and assessing collision risk).

The data obtained from boat and aerial surveys differ with respect to a number of attributes including: (1) temporal coverage, as aerial surveys can cover ground much more quickly and are thus less prone to the vagaries of bad weather likely to interrupt surveying over successive days; (2) spatial coverage, which is much higher for aerial surveys; (3) species-level identification, which tended to be higher for boat surveys but more limited for visual aerial surveys, although this less of an issue for digital surveys; (4) detectability of small and inconspicuous species tends to be lower for aerial surveys in particular visual; and (5) levels of disturbance caused and therefore boat surveys are not always regarded as being the best approach for species vulnerable to such effects (e.g. divers). Thus their suitability with respect to different objectives differs. In terms of best practice, a further fundamental need is to ensure consistency of the survey method within the site over different phases of the development. This was generally achieved, although issues regarding spatial and temporal coverage, and the adequacy of surveys, are considered further in Section 5.6.3 below.

The use of radar to look at the flight heights of birds in order to assess collision risk, or to determine flight paths to look for possible displacement or barrier effects is still a relatively new field. In comparison to boat surveys, radar surveys may potentially record birds at higher heights (Furness & Wade 2012). However, radar surveys require validation of records by extensive field observations in order to be able to ascertain the identification of birds to a species-level. The development of industry standards in terms of the different types of radar, detection issues and placement of platforms would be of benefit to the offshore renewable sector.

More recent surveys of OWF sites, e.g. for Round 3 zones, have primarily been undertaken using boat surveys and/or digital (camera or video) aerial surveys. The latter have, to a large extent, superseded visual aerial surveys, in the UK at least, and are also beginning to be used elsewhere (e.g. in the U.S.A.). They offer advantages in that aircraft fly higher and are therefore less likely to disturb birds (and can be used for during and post construction surveys), and that they offer a permanent record of the birds observed in the transects flown. Digital aerial surveys have also had limitations with regards to species identification, though considerable improvements are being made in this regard. A COWRIE-funded project provided a review of these techniques and initial protocols with respect to technical issues and survey design and analysis (Thaxter and Burton, 2009). Due to the developments in aerial survey methods that have taken place since the COWRIE review, further consideration of best practice in relation to use of these methods would be timely.

While methodologies to collect data using boat and aerial surveys on the numbers of birds using the site and other relevant areas – and thus potentially detect displacement – were, on the whole, reasonably described within monitoring protocols and reports, usually by reference to the use of protocols outlined in Camphuysen *et al.* (2004), the methodologies to collect information relating to barrier effects and collision were less well described and reflected the lack of standardised industry approach to data collection.

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Only limited detail was usually provided in either the monitoring protocols or reports regarding the survey designs adopted for assessing displacement and the analyses required, this in part being due to the lack, at the time the review was undertaken, of final monitoring reports for most individual studies.

Where details of the survey design adopted for assessing displacement are provided, typically a BACI approach (Stewart-Oaten *et al.,* 1986) has been followed. This was considered as best practice at the point in time that many monitoring programmes were being set-up. BACI approaches were indicated in nine cases (Barrow, Burbo Bank, Greater Gabbard, Lynn and Inner Dowsing, Kentish Flats, North Hoyle, Ormonde, Rhyl Flats, and Walney). Such an approach allows for changes in numbers at the wind farm site to be evaluated against those that occur in the wider population. In some instances, however, reference sites were situated adjacent to the wind farm (e.g. Barrow) and so provided a poor control. For Gunfleet Sands monitoring was restricted solely to the wind farm area and a defined buffer area around this, meaning that changes in numbers in these areas could not be contextualised and that movements of birds could not be detected.

In the more recent case of Robin Rigg, surveys did not include a specific control area, but covered a wider area around the wind farm such that displacement away from the site could be detected. Analyses presented in the year 1 post-construction monitoring technical report used distance sampling software and, in conjunction with this, a density-surface modelling approach that aimed to take into account environmental correlates in order to better evaluate changes in densities that might be a result of the construction or operation of the wind farm. This approach builds on that used at Danish sites (e.g. Petersen *et al.* 2011) developed in conjunction with the Centre for Research into Ecological and Environmental Modelling, St. Andrews, and allows the significance of changes in densities across the survey grid to be evaluated, thereby providing a better understanding of changes in distribution. The report also provides an indication of changes in numbers of species both within the survey are as a whole and in the area of the wind farm.

Further discussion of the adequacy of surveys and issues concerning survey design and analyses, in conjunction with consideration of the advantages of alternative approaches to BACI, notably the BAG approach (Ellis & Schneider 1997), and associated use of statistical methods such as density-surface modelling, is provided in Section 5.6.3 below. This discussion in turn informs the recommendations provided in Section 6 onwards.

Monitoring best practice summary

What is the best practice applied to monitoring and assessment methodologies? Give reference to preferable standards that could be specified in licence conditions i.e. Cefas (2012); Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects, Defra project code ME5403.

Guidance on boat and visual aerial survey methodologies is available and is generally adopted by the industry. Due to recent developments in technology relating to digital aerial surveys further consideration of best practice is now needed. There is also a need for industry guidance for the use of radar. Best practice survey design has evolved over time, with density-surface modelling approaches now being adopted over previous Before-After-Control-Impact (BACI) approaches.

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Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

Post-consent monitoring is required to confirm whether impacts predicted from ESs (and supporting technical reports) have occurred, but most particularly in those instances where there is uncertainty as to the scale of impacts. Thus the aims of ornithological monitoring often did not reflect the likely significance of the impact associated with an effect as described in the ESs (and supporting technical reports), but more the need for further information to reduce uncertainty. This section provides an overview of whether the results presented in the monitoring reports provide a basis for informing on the key effects of disturbance/displacement, barrier effects and collision and thereby might be used to reduce the uncertainty associated with these effects.

Final monitoring reports were available for only three of the 12 sites included in the ornithological review, and consequently the conclusions that can be made as to the success of monitoring and the lessons regarding the environmental impacts of OWFs are limited. The first section below provides a summary of the monitoring conclusions, as presented in reports. The following section then considers other limitations regarding methodologies.

Again, the focus here is on the lessons learnt from the review of UK sites covered in Task 1, the site-specific review. However, in the discussion of limitations regarding methodologies, key non-UK studies that are of relevance in determining recommendations in Task 3 (Section 6 onwards) are highlighted.

[illegible]

Disturbance / displacement

Disturbance/displacement was often assessed in a qualitative manner in impact assessments. Although the numbers of birds potentially exposed to this effect can be derived from survey data, there was, and still remains, considerable uncertainty as to rates of displacement and the possible impacts for the fitness, i.e. survival or reproductive success, of those birds displaced. With respect to this effect, the annual monitoring reports that were available typically provided data on the numbers of birds within the area of the wind farm and an adjacent buffer zone, some also providing data from a control or wider area. Prior to the completion of three years' of monitoring, however, few reports provided formal analyses of these data and those evaluations of changes in species abundance, between baseline periods and construction or post-construction periods, that were presented were thus often qualitative or descriptive (e.g. simple reference to changes in absolute numbers or visual inspection of maps). Furthermore, prior to final monitoring reports, little attempt was made to formally compare any changes in species abundance recorded in the area of the wind farm and buffer to those recorded in control sites or wider areas (exceptions being Barrow and Walney). Thus it is difficult to conclude whether the changes reported were associated with the construction of the wind farm or due to background year-to-year changes in local populations. The year 1 post-construction monitoring technical report for Robin Rigg provides a notable exception to this general finding and is discussed below.

Three years of post-construction monitoring reports were available for Kentish Flats, North Hoyle and Barrow, for which BACI approaches were adopted in the assessment of displacement. In the case of Kentish Flats, the 3rd year post-construction monitoring report indicated that statistical comparisons of the boat and aerial survey data did not reveal any statistically significant changes in the abundances of bird populations between the pre-construction, construction and operational periods relative to the control area. However, quantitative density comparisons between the pre-construction, construction and operational phases did suggest that red-throated diver numbers within the wind farm area were lower during the operational phase. Limitations in spatial and temporal coverage meant that the potential power to be able to detect change may have been restricted (see below). Two further years of further boat-survey monitoring, specifically focused on red-throated divers were thus undertaken. Using an alternative, but straightforward statistical approach, this work concluded that there had been a notable decline in diver numbers within the wind farm/buffer zone following construction, at a time when numbers in the limited control area, and the wider population (as determined from the aerial surveys), appear to have been relatively stable (Percival 2010). More recent density-surface modelling work concluded that boat-survey counts of red-throated divers within the wind farm footprint after construction were smaller than the counts in the same locations prior to construction, although due to the limited spatial scope of the surveys as well as data limitations, it was difficult to draw conclusions regarding displacement given the lack of similar data on larger concentrations of birds outside the surveyed region (Rexstad and Buckland, 2012).

In the final annual monitoring report for North Hoyle, it was concluded that, based on the analyses undertaken, there had been no changes in bird numbers and behaviour in the area of the wind farm site and buffer or specifically in the distribution of common scoter in the vicinity of North Hoyle. Again, limitations in spatial and temporal coverage meant that the potential power to be able to detect change may have been restricted (see below).

Limitations in spatial and temporal coverage also meant that conclusions that could be drawn regarding displacement for Barrow were also limited. In the final monitoring report, it was concluded that there was no evidence of a significant trend or pattern that indicated a change in abundance of birds due to the construction of the wind farm. Nor was there any indication that the operation and construction of the wind farm have changed the distribution and occurrence of common scoters, divers or other wildfowl.

In the case of Robin Rigg, the density-surface modelling approach presented in the year 1 post-construction monitoring technical report allowed an evaluation both of changes in densities and thus distribution across the survey grid and of overall changes in numbers in the survey area as a whole and in the area of the wind farm. The results presented provided little indication of a significant effect of the wind farm on the abundance of common scoter and red-throated diver between the three phases of the development (pre-construction, construction and post-construction). An increase in cormorant and large gull species abundance was observed in operational year one. A decrease in auks during construction was reported, although there was also some indication that the numbers were starting to recover in year one of the post construction phase but more data from subsequent years was required to confirm this.

Monitoring has the potential to be of value in informing on the rates of displacement that might occur from OWFs and hence the assessment process. However, more detailed research programmes are probably required to understand the population consequences of such displacement (through impacts on survival and breeding success).

Barrier effects
Monitoring of barrier effects was specified in nine of the licence conditions reviewed. The need for monitoring of this effect has been primarily driven by uncertainty as to predicted impacts rather than significance as determined by the impact assessment process. In the majority of cases, the data used to assess whether barrier effects may have occurred were drawn from the boat surveys undertaken to monitor changes in bird numbers on the wind farm site and thus methodologies were not specifically tailored to this effect – this, in part, also reflecting the uncertainty in how this effect might be assessed. Prior to the completion of three years of monitoring, only limited comment was provided regarding barrier effects.

In the final monitoring report for Kentish Flats, conclusions regarding barrier effects were ambiguous. Common tern flight paths observed through boat surveys in previous years were less pronounced post-construction, suggesting that the wind farm had presented an obstacle. However, there was also an indication that tern numbers in the wind farm/buffer zone had increased post-construction. It was acknowledged that the study methodology was not developed in order to assess a barrier effect on tern breeding success and that “without a dedicated, long term study on terns in the area including detailed insight in the annual and spatial food availability on potential feeding grounds, intensive flight line tracking and ongoing collision (risk) monitoring relatively little can be said about any influence the wind farm might have on tern flight lines and feeding behaviour and ultimately, mortality and breeding success of the breeding populations”. Conclusions regarding barrier effects in the final monitoring report for North Hoyle also drew from boat surveys, and here it was concluded from these data that no changes in flight paths had occurred.

More detailed study of barrier effects was undertaken at the Lynn and Inner Dowsing (LID) site. While monitoring of barrier effects was not specified in the original licence conditions for the Lynn and Inner Dowsing (LID) site, it was stipulated that if birds from Special Protection Areas (SPAs) were found to be using the sites in significant numbers, then English Nature (EN) (now Natural England) should be informed. As significant concentrations of pink-footed geese during autumn migration were reported in the baseline report and were flagged up with EN as an issue, a programme of monitoring using bird detection radar was instigated to collect information on their flight behaviour and whether they may be subject to barrier effects or not. The final post-consent monitoring report was unavailable for the purpose of this review, though recently published work summarising this work programme indicated that geese responded to OWFs by adopting strong horizontal and vertical avoidance behaviour (Plonczkier and Simms, 2012). Hence they were at limited collision risk, though conclusions as to whether the disruption of flight paths may have impacted the species energy expenditure and thus had fitness costs were not provided.

Walney OWF also had a licence requirement to conduct a radar study to validate the predicted estimates of pink-footed geese and whooper swan avoidance rates (and collision mortalities). Data derived from the post-construction monitoring phase (the most recent report available) showed that migration flights did not occur with the development site but it was not clear whether this was a result of the presence of the OWF or not. Moreover, it was not possible to distinguish between the two species using radar and there had been a lack of visual observations of whooper swan by the field observers. Ormonde also had similar requirement to conduct a radar study to validate the predicted >97% avoidance rates of the wind farm site by pink-footed geese and whooper swan but no reference to this was found in the post-consent monitoring reports provided.

Collision risk

Although collision risk was reflected in a number of the licence conditions reviewed, actual monitoring of collisions was specified for Gunfleet Sands, Kentish Flats, Lynn and Inner Dowsing, Scroby Sands and Walney OWF sites. Stakeholder comments also suggested that collision monitoring should be investigated at Robin Rigg. (Note, though, that the condition requiring a study into ‘state-of-the-art’ techniques for assessing collision risk at Gunfleet Sands was removed since it was deemed that such work would largely duplicate understanding gained from studies elsewhere, notably from a recent COWRIE study – Desholm *et al.,* 2005). Typically, monitoring of actual collisions was not carried out *per se* and the measure of risk was based on significant use of the wind farm site, by populations of conservation concern and at heights that could incur a risk of collision, being shown (as indicated by boat survey data). The need to be able to monitor collisions offshore, to inform on impacts and also to help to validate the avoidance rates used in collision risk models, has long been recognised. While progress in this regard is being made, with the development of an Offshore Renewables Joint Industry Programme project (ORJIP), limitations of technology restricted the feasibility of such studies in the monitoring programmes reviewed here. In the cases of Gunfleet Sands and Kentish Flats, monitoring was thus restricted to assessment of data on flight heights from boat surveys. In the case of Lynn and Inner Dowsing and Scroby Sands, detailed tracking of birds through radar and radio-tracking of birds helped provide a better assessment of the avoidance behaviour of birds, if not actual monitoring of collisions. Radar was also specified in the Walney licence conditions as a means of collecting data on collision mortalities (as well as looking at avoidance rates) for pink-footed goose and whooper swan (but there was a notable lack of flight lines recorded within the OWF site in the construction phase).

Three years of post-construction monitoring reports were available for Barrow, Kentish Flats, and North Hoyle. In none of the three cases was collision risk monitoring carried out, the studies concluding that the numbers of birds flying at rotor height through the wind farm were too low to warrant this. In the case of Lynn and Inner Dowsing, as indicated above, recently published work summarising the radar work programme indicated that geese responded to OWFs by adopting strong horizontal and vertical avoidance behaviour, thereby reducing collision risk (Plonczkier and Simms, 2012).

In the case of Robin Rigg, the year 1 post-construction monitoring technical report also provided information on the flight heights of key species. Detailed analysis of collision risk was not possible due to limitations in the size of the dataset, although it was thought that this may have been feasible once more data had been collected.

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The conclusions that could be made as to the success of monitoring and the lessons regarding the environmental impacts of OWFs were limited by the relatively few final monitoring reports that were available. The following section also considers the adequacy of surveys for addressing the questions presented in objectives, and whether other issues concerning survey design and analyses also limit the conclusions that might be drawn from the monitoring programmes reviewed. This discussion in turn will inform the recommendations provided in Task 3 (Section 6 onwards).

Disturbance / displacement

A number of issues concerning the monitoring undertaken to assess displacement were highlighted in the site-specific ornithological review carried out as part of Task 1 (Section 6 onwards):

i) Only limited detail was usually provided in either monitoring protocols or reports as to the survey designs adopted for assessing displacement and the analyses required. Where details of the survey design adopted for assessing displacement are provided, typically a BACI approach was followed, which provided a best practice approach at the point in time that the monitoring for the sites reviewed was being set-up.
ii) In those studies that adopted a BACI approach, the adequacy of the control sites was sometimes debatable, for example, because they were too close to the wind farm site and thus may have been used by birds displaced from the wind farm site and so not be independent.
iii) In no case did the monitoring protocols or monitoring reports provide an assessment of the power to detect changes in numbers from the surveys undertaken. Hence the adequacy of the surveys in being able to determine whether displacement had occurred and to what extent was unclear.
iv) The power to detect change from survey data alone is related to the frequency of surveys, their temporal extent and spatial coverage (see Maclean *et al.,* 2006; 2007; 2012; Pérez Lapeña *et al.,* 2010). The number of surveys carried out each winter/year is likely to have provided inadequate data to be able to statistically detect change in many instances, while gaps in temporal coverage, or differences in the timing of coverage each year, would have further limited power. The work of Maclean *et al.* (2006, 2007, 2012) also indicates that a number of years of data may be needed to be able to demonstrate statistically significant changes (due to ‘natural’ year-to-year fluctuations in populations), more than the three year programmes followed by the monitoring studies reviewed here.
v) The extent of spatial coverage varied between studies and, within studies, between boat and aerial surveys. Boat surveys were often restricted to the area of the wind farm and buffer area around it – and similar sized control areas, where specified – meaning that there was limited potential to detect movements from the wind farm. Although aerial surveys provided coverage of wider areas, minimum flight height restrictions imposed by the CAA limited post-construction surveys. Consequently, in some cases, survey methods varied through the monitoring programme further limiting the analyses that could be undertaken and conclusions drawn. In some cases, monitoring was

restricted to the wind farm area and a defined buffer area around this, meaning that changes in numbers in these areas could not be contextualised and that movements of birds could not be detected.

vi) In those cases where final reports were not available, there were also limited details regarding the analyses that would ultimately be carried out.

The points outlined above further limit the conclusions that could be drawn regarding displacement from the monitoring undertaken. However, it should nevertheless be recognised that the sites for which information was reviewed were all UK Round 1 or Round 2 sites, and that there have been a number of developments in methodologies since these programmes were instigated.

These include the development of digital aerial surveys, which offer advantages in that aircraft fly higher and are thus less likely to disturb birds and less affected by minimum flight height restrictions. Some of the issues outlined above regarding the consistency of survey methods over the different phase of the development are now being avoided. Digital aerial surveys have also had limitations with regards to species identification, though considerable improvements are being made in this regard.

There has also been further consideration given to survey design, with the development of distance sampling software (Thomas *et al.,* 2010) and, more recently in conjunction with this, density surface modelling approaches that allow consideration of environmental covariates (Rexstad, 2011). Such approaches much improve the power to detect change (Maclean *et al*., 2006, 2007, 2012) and have been used to investigate displacement at wind farms in Denmark (Petersen *et al.,* 2011) and also re-evaluate data for Kentish Flats (Rexstad and Buckland 2012).

Recently commissioned Scottish Government work being led on by the Centre for Research into Ecological and Environmental Modelling, St. Andrews, aims to develop statistical modelling of bird (and cetacean) distributions in offshore renewable development areas. The application of model-based approaches, such as density surface modelling techniques, can greatly improve the characterisation of development areas, thereby improving impact assessments. Furthermore, the distribution maps can provide a reliable foundation for post-development impact assessment and thus the better assessment of the displacement of seabirds arising from renewables developments.

While the BACI-based survey design was advocated in the COWRIE guidance for OWF bird surveys (Camphuysen, 2004), its applicability in the context of the OWF industry has recently been questioned (Harding *et al*. 2010). The basic principle underlying this survey design is that the study site and a control site are surveyed before and after the development is constructed. There are, however, notable difficulties in identifying control sites which are truly comparable in terms of their environmental conditions (e.g. oceanography, hydrography) and the animal populations which characterise them (e.g. birds, mammals, fish). Also, in order for the BACI approach to be rigorously applied, numerous controls have to be selected in order to be able to detect impacts of effects (e.g. Jackson and Whitfield 2011 advocated that the minimum number of controls should be 5-6). This problem of attempting to replicate controls is further compounded by (a) the wide ranging behaviour of seabirds, which often extend well beyond the spatial extent of current OWF study areas and (b); their colonial breeding behaviour which results in large numbers of birds at relatively localised hotspots. It has also been flagged up that where the BACI approach has been adopted for OWFs, control sites have been chosen immediately adjacent to the development which flouts the assumed independence of the study and control sites.

Consequently, a new approach to survey design has evolved known as Before-After-Gradient (BAG) and involves all areas within a given radius of the development being monitored before and after the development (Ellis and Schneider 1997) – see discussion in Jackson and Whitfield (2011). 'Gradient-style' analyses – encompassing the use of density surface modelling techniques – are applied in which the pre-post differences at a site are a taken as a function of the distance from the development. These developments have informed the survey design adopted for the monitoring undertaken at Robin Rigg, for which the year 1 post-construction monitoring report has recently been produced. Here, surveys did not include a specific control area, but did cover a wider area around the wind farm such that displacement away from the site could be detected. Use of distance sampling software, in conjunction with a density-surface modelling approach, allowed the significance of changes in densities across the survey grid to be evaluated, thereby providing a better understanding of changes in distribution. This and the relative size of the survey area have helped to provide a much improved design to examine the potential displacement of birds from wind farm sites into adjacent areas.

Barrier effects
In the majority of cases, the data used to assess whether barrier effects may have occurred were drawn from the boat surveys undertaken to monitor changes in bird numbers on the wind farm site. As methodologies were not specifically tailored to this effect, minimal description was provided as to how these data might be examined to determine whether barrier effects might have occurred.

More careful consideration of study design was provided in the case of the LID site, where detailed tracking of birds was undertaken using radar, although the primary aim of this was to better determine avoidance behaviour and thus the risk of collision.

Collision risk
Monitoring of actual collisions was typically dependent on significant use of the wind farm site, by populations of conservation concern and at heights that could incur a risk of collision, being shown. Hence, in these cases, monitoring was restricted to the recording of information on flight heights from boat surveys. In those cases where three years of post-construction monitoring reports were available, the studies concluded that the numbers of birds flying at rotor height through the wind farm were too low to warrant further study. Typically, data were provided on the proportion of birds at risk, although further details of the numbers of birds thus predicted to collide with turbines would be beneficial.

More careful consideration of study design was provided in the case of the LID and Scroby Sands sites, where detailed tracking of birds through radar and radio-tracking of birds helped provide a better assessment of the avoidance behaviour of birds, if not actual monitoring of collisions. There is a lack of a standard approach for such tracking studies, although any such guidelines would need to be flexible to the study site in question.

The need to be able to monitor collisions offshore, and thus to be able to validate the avoidance rates used in models, has long been recognised and is the subject of a developing ORJIP project. However, it should be recognised that, until technology is further developed, it is unlikely to be feasible to undertake such monitoring at all sites. Given this, one current option might be to focus monitoring at some consented sites towards the collection of information on the numbers of birds exposed to collision (i.e. on the numbers flying through a site and their flight heights) such that collision risk analysis could be undertaken informed by the results on avoidance rates from the ORJIP project or similar programmes. However, the potential for future innovation to enable collision monitoring at individual sites to become more cost effective or for strategic projects to be taken forward between developments should be noted.

Future developments should draw from experience in the Netherlands and Denmark, where radar has been intensively used to inform on the avoidance behaviour of birds approaching wind farms (macro-avoidance) and within wind farms (micro-avoidance), thereby informing both the evaluation of both collision risk and barrier effects.

Indirect effects

There was relatively little monitoring carried beyond the specific intention of being used to demonstrate indirect effects. North Hoyle and Rhyl Flats both had a conditional objective which specified that if changes in common scoter population occurred, then the benthos should be also be monitored in order to determine whether the changes were the result of changes in the availability of food rather than disturbance/displacement. At North Hoyle, there was no evidence that there was change in distribution however and further benthic monitoring in addition to what was carried out for the baseline was not deemed necessary. A similar conclusion was also reached for Rhyl Flats at the stage of the 1st year post-consent monitoring. The licence conditions for Lynn and Inner Dowsing OWFs also stated the need for benthic data to be collected but this appears to have been dropped latterly on the basis that common scoter did not occur in important numbers and the most abundant birds in the area were not primarily benthic feeders (gulls, auks and terns). Therefore, based on the sites considered in Task 1; site-specific reviews, there was little to draw upon in terms of lessons learnt.

Mitigation

Although potential mitigation measures were identified as part of the ESs, it was not clear from the post-consent monitoring reports whether they had been implemented or not. Moreover, if mitigation has been applied, there was a lack of scope within the monitoring programme to demonstrate its relative effectiveness. In order to show this, there would be a requirement to apply an experimental approach which would involve a matched site (e.g. another comparable and operational OWF) where the mitigation was not applied and the outcomes from both sites compared. Therefore this issue cannot be tackled at the level of an individual OWF site.

OWF Environmental Impacts: lessons learnt summary

Is it possible to derive generic lessons from the environmental impacts of OWFs (including non-UK sites) which have been informed by the post-consent monitoring? Where applicable to the monitoring are impacts detectable and are methodologies sufficient to detect changes?

Conclusions on the success of monitoring and lessons learnt regarding the environmental impacts of OWFs on birds were limited by the number of complete studies (and thus fully analysed results), as well as issues of survey design and analyses. These issues and non-UK studies have informed the evolution of best practice survey design and the recommendations, and a present Offshore Renewables Joint Industry Programme (ORJIP) project that will provide results applicable to other sites.

[illegible]

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

Post-consent monitoring conditions relating to birds applied to UK Round 1 and 2 projects focused on displacement, barrier and collision effects. This led directly on from either the predictions derived in the ESs (and supporting technical reports) or the need to reduce the uncertainty in the predictions. Monitoring conditions were usually provided in the form of specific objectives and often provided reference to the methodologies to be applied. Under current Marine and Coastal Access Act licensing, specific monitoring conditions are no longer provided in the licence itself, but agreed separately with relevant stakeholders (government advisors) and detailed in an associated monitoring protocol (relevant sites were not covered by Task 1 with the exception of Robin Rigg). The recommendations given below thus relate primarily to the existing conditions (and the former approach) which was the focus of this work.

[illegible]

In the first instance, it is important that objectives reflect the likely significance of the impact associated with an effect as described in the ESs or the need to reduce uncertainty in the predicted impacts of particular effects, e.g. those assessed more qualitatively.

There is a strong need to remove objectives that are ambiguous such as “to confirm that the predictions made in the EIA are correct”. Therefore specific objectives need to be captured either within the licence conditions or within future monitoring protocols.

Licence conditions should only specify a requirement for annual reports and not monthly or quarterly reports. The latter tend to only provide very basic descriptive summaries of the data collected in the short intervening period since the preceding. They provide no analyses and nor do they refer back to the licence conditions.

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While indirect effects are considered by the EIA (or HRA) process, there is typically greater uncertainty regarding the likely impacts predicted for such effects. Monitoring may play a role in reducing the uncertainty regarding the significance of the likely impacts associated with such effects. The North Hoyle and Rhyl Flats licences both included a conditional objective which specified that if changes in common scoter population occurred, then the benthos should be also be monitored in order to determine whether the changes were the result of changes in the availability of food rather than disturbance/displacement. Thus, where such a linked effect might be expected, both the ornithological and benthic monitoring should be carried out during each phase of the development. The current approach appears to be based on the principle that further benthic monitoring should only be carried after it has been demonstrated that changes in bird populations have occurred by which it may to be too late to collect the data need to show the link between the two.

Consideration should be given as to whether the scope of monitoring should also encompass intertidal areas affected by the cable route, if displacement impacts are predicted for these areas or are uncertain. Presently, the emphasis in most cases reviewed as part of Task 1 (site-specific review) is on offshore effects.

The following additions are not conditions as such but relate rather to specific detail that should be taken into consideration when designing a monitoring programme (see also further recommendations):

- Monitoring should be undertaken at the same time each year to allow comparison of results across the different phases of the development
- Power analyses should be carried out in order to determine the minimum effort for sampling that is required in order to be able to detect changes in numbers
- A requirement to stipulate the use of industry standards from the EIA, HRA and AA processes (e.g. IEEM 2006, 2010) to the deployment of post-consent monitoring methods (e.g. Camphuysen *et al*., 2004 for boat/visual aerial surveys) or at least provide justification as to why these approaches are not appropriate.

Data provided by the monitoring will need to be compatible with baseline data provided within the project's ES unless sufficient evidence can be provided to justify change of approach (e.g. development of new technologies, data from the ES indicates notable gaps in coverage).

OWF Environmental Impacts: recommendations for ongoing monitoring summary

Are there any post-consent monitoring conditions applied to UK projects which could be removed based on the lessons learnt here? Are there any conditions that could be added i.e. from approaches used in non-UK OWFs.

Ambiguous objectives should be removed and only specific objectives retained. Conditions relating to indirect effects and effects on intertidal areas should be considered where appropriate. Further specific detail is also required in monitoring plans.

[illegible]

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

[illegible]

Based on the sites reviewed as part of Task 1, there was some similarity with respect to the licence conditions for sites within the same regions but this was not consistent for all sites within the same regions. The best examples of sites which had similar licence conditions were: North Hoyle and Rhyl Flats from Liverpool Bay; Walney and Ormonde from Morecambe Bay and; Greater Gabbard and Kentish Flats from the Greater Thames Estuary. This was reflected to some extent in similar methodologies being adopted and shared use of data from the more extent aerial surveys (e.g. Liverpool Bay CCW common scoter surveys and the DTI/BERR surveys of strategic wind farm areas for Round 2). The use of standard guidelines for boat and aerial surveys reduces inherent differences in survey methodologies across different sites but there are often differences in the overall survey design in terms of spatial (e.g. some OWFs have a buffer) and temporal coverage between sites (e.g. surveys can often cover different months).

[illegible]

It is important to recognise that the data do not need to be collected using the same survey methodologies to be able to draw conclusions from different sites. There are analytical approaches which can be applied to relatively different datasets to allow comparisons to be made (e.g. meta-analysis) which would be a pre-requisite to a robust cumulative impact assessment being carried out – cumulative impacts being an important consideration in the consenting process. Therefore, the emphasis should be on a well-designed monitoring programme that can be used to demonstrate effects at the site level (i.e. one for which there is consistency in the approach through time) but has a relatively standardised survey design (which will be in turn led by the species of interest, the outcome of the EIAs/ESs and the associated licence conditions). Flexibility in approach is important in terms of survey methodologies since imposing constraints may limit the scope for technological advances.

OWF post consent monitoring data summary

Are the monitoring reports and licence conditions of sufficient similarity and scope to be comparable or contribute to a synoptic approach i.e. where monitoring from different sites is scientifically comparable? If results from monitoring reports are presented sufficiently could they be used to determine cumulative impacts?

Consent monitoring conditions were consistent in that most focused on the key effects of disturbance/displacement and collision. While conclusions regarding the environmental impacts of OWFs on birds were limited by issues of survey design and analyses, differences in approaches between sites should not in themselves prohibit future comparisons. Emphasis should be on well-designed monitoring programmes that can be used to demonstrate effects at the site level.

[illegible]

There is currently a large variation in approaches to data collection and assessment methodologies between sites and across the UK Devolved Administrations.

[illegible]

An inter-agency specialist team of technical experts (topic/taxa specific teams) who work across all regions and all topics could be set up. These could either be specialist virtual teams set up as part of existing government and advisory departments or a new independently employed team. In effect this could be a restructuring of the current situation where case officers from the MMO, Cefas, SNCBs, developers and consultants work formally together on specific applications is complemented by core team who have an oversight of licensing and monitoring issues across sites and the Devolved Administrations. Wider benefits may be gained from linking this group to international fora, e.g. establishment of a working group under OSPAR's Environmental Impacts of Human Activities Committee. This will improve consistency between sites/projects/regions and provide the remote overview required to ensure that maximum learning is gained from each site. This team could also be responsible for providing (and updating) guidance, defining standards and applying knowledge gained from individual projects to the refinement of models/approaches/guidelines (ensures efficient feedback loop). This should also ensure that appropriate and consistent quality assurance and control procedures and guidance are applied to monitoring plans across the board. The expertise and experience of the core team will be paramount to its success. It needs to be ensured that the team has access and uses current up-to-date knowledge and international expertise.

An example of non-UK practice aimed at ensuring compatibility of monitoring conditions and avoidance of data duplication is provided by The Netherlands. Here an extensive Monitoring and Evaluation Programme (MEP) has been linked to a Demonstration wind farm project, known as the Near Shore Wind Farm (NSW), in order to document potential impacts associated with an OWF development. The programme requires that other monitoring programmes conducted in the Netherlands and further afield, are accounted for to avoid duplication of work. The results of all studies will be made available for use in similar projects (NSW-MEP, 2001). Such practice would also help in identifying and standardising the most suitable design and installation of the monitoring infrastructure / instruments needed for data acquisition.

[illegible]

Recommendations for better knowledge exchange (e.g. cascading relevant information).

Access to the knowledge gained through monitoring reports is a fundamental part to the consenting process in order for public stakeholders, developers, SNCBs and consenting authorities to learn from monitoring.

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Historically there has been no single set of agreed standards for the following elements necessary to fully utilise previous reports:

- Accessibility
- Reporting
- Standardisation (reporting/data)
- Amendments to licences
- Negotiations/changes to monitoring requirements.

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- Accessibility
  - One central statutory/government organisation should compile, hold, organise and provide access to all relevant communication, reports, ESs, licences and subsequent changes to monitoring within a centralised and accessible database with a common structure across all projects. All signed-off monitoring plans, monitoring reports, agreed amendments (with explanations for any changes) to licence conditions and monitoring scopes should be available online. A good example of a valuable collation and presentation of such kind of documents and communication tracing is the Planning Infrastructure Portal found under (http://infrastructure.planningportal.gov.uk/) which is well organised, accessible and easily searchable. A similar approach could be extended to cover the post consent phases of projects.
  - All raw monitoring data and outputs derived should have a consistent naming convention reflective of the content of the document as described by an agreed data management protocol. This should improve the functionality of metadata repositories, e.g. The Crown Estate's Marine Data Exchange (http://www.marinedataexchange.co.uk/) and Marine Environmental Data and Information Network (MEDIN: http://www.oceannet.org/) as searching for information should be easier. The issue of storing large scale, geophysical datasets is recognised and the best means of holding these data, potentially including a requirement for the site owners to hold this data, will need to be agreed.
  - Some summary reports/post construction monitoring reports are available on the website of the developer. This is commended and to be encouraged although should not detract from efforts to establish the central data/report repository.
  - In addition, collation of data on impact predictions from assessments would be invaluable in informing future cumulative impact assessments.

- Reporting
  - Agreement over standard approaches to reporting – e.g. annual updates with a final report drawing everything together (see Section 10.4 on formatting of reports)
  - All reports should have a mandatory metadata section up front identifying the report purpose (i.e. post construction Year 2 monitoring), date, author, relevant licence requirement etc.)

  - Regular reviews of previous monitoring results would provide a good general indication of monitoring results. For instance, Substantive Reviews, which are currently required for the aggregate industry every five years, summarise previous annual or bi-annual monitoring results. These reports and monitoring results provide a clear understanding of environmental change associated with a development over time and are summarised in one easily accessible report covering all topics. These review reports should be compiled by, or the compilation should be supervised by the specialist technical expert groups mentioned in Section 6.1.

- Standardisation/Data management protocol
  - A data management protocol should be written (ownership of which lies with the central government organisation charged with holding and disseminating reports).This should cover those elements listed in this section (Section 6.2) for example data standards, file naming, metadata etc. Topic specialists will need to input into these
  - The reporting of metadata is required for all studies. Guidance for recording of metadata is provided by organisations such as MEDIN and should be pre-agreed through the data management protocol
  - Consenting process should ensure data must be collected in formats that are compatible for use in other PCM and/or cumulative studies (subject to agreement of data owners). The use of templates with topic/receptor specific minimum requirements and guidelines for the developers should be established. This should be specified in the data management protocol
  - The formats and metadata for raw and derived data in particular, need to be clearly captured by the data management protocol
  - All data (raw and derived) needs to be supported with information on methodology/protocols used in their collection/analysis.

- Amendments to licence
  - All changes to a licence should be captured in the licence document such that it is clear what revisions/changes occurred when they were made.
  - The licence is recommended to have a cover page which lists the revision history.

- Negotiations/changes to monitoring requirements
  - Historically changes to monitoring requirements are far from transparent which can inhibit the use of the monitoring outputs in contributing to the consent process for other sites. It is recommended that a system be put in place to capture changes transparently and allow for a clear audit trail with respect to those changes.

[illegible]

Recommendations for better integration and co-ordination of monitoring, assessment, and reporting of individual developers working in the same regions/zones. This includes making recommendations on the need and scope for comparability in datasets.

[illegible]

Monitoring may be more effective when carried out on a regional or strategic level if these scales are more appropriate. This could be where monitoring is required on a different spatial scale to a single project to test hypotheses. Or, it could be where a regional or strategic level data collection reduces costs for developers, speeds up the time for data acquisition, or limits disruption to other users (such as commercial fisheries who may be effected by the presence of survey vessels or equipment).

Development of regional environmental assessments, with respect to certain receptors, and regional monitoring (building on concepts employed by the aggregate industry) should be considered and discussions opened with both developers and owners to determine the practical application of this type of approach. Such discussions with developers are beyond the scope of this review, however may be achievable though input from the Project Steering Group.

[illegible]

- Incorporate existing data from sites nearby to inform baselines, ESs and licence conditions where appropriate. This will improve understanding of the site prior to construction – for example, if geological and metocean conditions are similar, impacts are also likely to be similar.
- Once a central location for data has been established this can be accessed by developers in the region, in order to inform their baselines/desktop studies;
- Regional monitoring studies should be encouraged where practicable (for wind farms developed in close proximity to each other).
- Regional surveys for some topics should be considered as they would help bring monitoring costs down. However this works at different scales for different topics, for example the outer Thames may be a relevant regional definition for benthic and fisheries, whilst a wider geographical area still would be more appropriate to Marine Mammals. This approach would need to be aware of the potential conflicts of interest that may arise from shared data.
- There is scope for region level monitoring for ambient noise. This could be implemented in regions where there are neighbouring wind farms. For example in The Wash area or around Liverpool Bay. Such a regional type assessment would have to consider the potential differences between projects, particularly where propagation may vary. Operational noise would have to consider potential differences between sites, and the type of turbine and foundation. If this approach were to be attempted for piling measurements then the engineering and environmental differences between projects would have to be considered, and a regional monitoring of other,

noise-sensitive receptors like fish and marine mammals could be conducted and linked with the noise monitoring outcomes.
- Potential to combine activities common to both the aggregate industry and other offshore renewables projects in the future may also help bring down the cost of surveys as combined cruises bring down mobilisation/demobilisation costs. We recognise however, the practical constraints related to cost sharing in these instances but for shared interest studies such as impacts on fisheries this would optimise data collection. See further in Section 9.

Where regional or strategic monitoring is undertaken there may be practical difficulties surrounding fair splitting of costs, timing of monitoring to align with varying project timescales and competitiveness between developers. These issues may prevent the successful co-operation of wind farm developers. These difficulties need to be recognised at the outset of planning monitoring programmes such that problems that might affect the success of programmes are minimised.

[illegible]

- Current best survey practice for scour and coastal surveys are comparable; future data will be inherently comparable if best practice (e.g. multibeam for scour surveys) continues to be carried out during surveys.
- Development of consistent guidelines will be required for certain topics in relation to data acquisition and data management to ensure data compatibility but also easy retrieval and availability for similar projects. Clear examples are mobile receptors such as fish, marine mammals and birds, where the assessment of impacts is most likely to benefit from coherent international datasets.
- Implementation of topic specific expert teams would ensure regional consistency and that conditions were aligned to industry requirements/biggest uncertainties.

Several clear practical issues have been identified in the above recommendations. There can be a fine line between which environmental issues may be appropriately addressed through PCM and those that should be addressed through research. Both categories of issues may be identified via the EIA process and regulators will need to determine which mechanism is best suited to addressing the problem (PCM or research). It is beyond the scope of this study to make this distinction at a generic level, but it is further recommended that a feasibility study on these kinds of approach is needed to investigate the following (which in turn will aid the determination of whether the issue may be addressed by PCM or research):

- What kind of approach is feasible, and how to reach it, e.g.;
    - 2.1 A species specific approach
    - 2.2 A region specific approach (e.g. Thames Estuary, Greater Wash) where developers join a group co-ordinated by the regulator and TCE.
- Financial models
    - 2.1 Cost sharing agreements between developers with collaborative working (perhaps steered by TCE or another organisation)

2.2 A higher-level fund where developers contribute on the basis of e.g. Megawatts generated or area covered and fund is administered centrally
2.3 Partial funding of the monitoring.

- (How) can international co-operations be implemented // considered to integrate cumulative cross border effects? This is particularly important for example with the more wide ranging species such as harbour porpoise in the North Sea.

[illegible]

Potential for developers to link up with other sectors or other organisations undertaking environmental monitoring/surveys to deliver objectives jointly.

[illegible]

By defining the minimum appropriate scales (temporal and spatial) over which PCM can occur, the potential for co-coordination with other developers (both offshore wind, tidal and wave energy) can be identified and integrated into monitoring efforts.

[illegible]

- Round 3 sites will be a region themselves and so it would not be beneficial to use other Round 3 site reports, although it is important to acknowledge that the extent of the region is dependent on the effects and distribution of receptors. However, if they are close to R1/R2 sites or aggregate licence areas, the use of earlier relevant reports would (in most cases) help inform monitoring
- Future offshore renewable energy projects (e.g. wave and tidal) would benefit from the bank of knowledge gained from the wind industry. As a whole this should help bring down industry costs
- The practical constraints that arise during this process could be resolved to some extent by the establishment of the group identified in Section 6, which would manage all data and, in the process, get all parties involved to agree to the contribution of data. This would be an important precursor to initiating collaborative data collection where clear intra and inter-industry cost savings could be envisaged.

[illegible]

- Round 3 sites where hydrodynamic and geological characteristics are similar to other OWFs would benefit to a degree from use of relevant Round 1 and Round 2 reports (e.g., Hornsea might experience scour similar to Lincs as geological conditions are similar)
- Using the results from physical processes monitoring will help monitor changes to biological receptors (as stated in Section 5)
- Helping the BGS (and other non-regulatory research bodies) improve its knowledge of seabed sediments and shallow geology might also be advisable. There are significant new data available to the BGS from Dogger Bank, for example, which will help improve the next iteration of geological charts for the area (see OSIG conference notes[20]).

[20] Cotterill, C., Dove, D., Long, D., James, L., Duffy, C., Mulley, S., Forsberg, C.F., and Tjelta, T.I., (2012) Dogger Bank – A Geo Challenge. Offshore Site Investigation and Geotechnics. Proceedings of the 7th International Conference 12 – 14 September 2012, Royal Geographic Spociety, London, UK

[illegible]

The particular measurement equipment, the measurement condition and the signal processing/analysis requirements relating to underwater noise measurement are often specific to the type of sound being measured, and any co-ordinated measurement effort would likely need to be focused on a particular knowledge gap. For example, equipment used to monitor marine mammal acoustic presence or indeed low noise floor recording equipment used to measure ambient noise, will generally not be suitable for measuring the impulsive noise from marine impact piling.

The COWRIE study, ‘Measurement and interpretation of underwater noise during construction and operation of OWFs in UK waters’ (Nedwell *et al*., 2007) is an excellent example of an industry wide approach to monitoring. This strategic approach should be used where possible to address specific licence requirements and could also be used to address knowledge gaps. Such strategic approaches should ideally extend beyond the OWF industry where possible. For example, if suitable ‘regional’ baselines for ambient noise were to be achieved, a co-ordinated approach could be adopted, including a range of offshore industries (oil and gas, offshore wind, shipping/marine transport, etc.). This could be achieved through either statistical analysis of snapshot data from many sources/projects, or by a co-ordinated effort to monitor ambient noise in regional areas. Determination on the scale (and therefore the responsibility) for such approaches rests with the regulators.

Additionally, it is recommended that collaborative work between disciplines is encouraged where possible. For example, co-ordinated survey effort between underwater sound measurements and marine receptor response could address knowledge gaps relating to the potential impact of underwater noise on marine fauna. Determination of the scale (and therefore the responsibility) for such approaches rests with the regulators.

[illegible]

The context for inter-industry or interdisciplinary monitoring can be provided by reviewing other sectors and other organisations undertaking monitoring but the individual sites will still require individual and bespoke monitoring packages, with the need and extent of such monitoring determined by evaluation of the conclusions in the EIA as agreed with the regulator.

Potential opportunity for sharing benthic reference areas of various types exist, but previous experience of establishing this both within industry sectors and across industry sectors has presented practical constraints. However, a study commenced in 2005, of the eastern English Channel (ECA, 2013) conducted through a collaborative approach within the aggregates industry is a good example of how this might work.

[illegible]

Where monitoring has been demonstrated to be necessary fish abundance data should be presented as CPUE per kilometre for active gears or individuals per 24 hours for static gears. Information on state of the tide (hours before or after high water), time of day (24 hour clock), cloud cover (oktas), depth (m), temperature (^{o}C), salinity (ppm) should be included with the presentation of monitoring surveys. This will help better understand inter annual variability at the regional and site-specific level.

Marine mammals

An interdisciplinary approach is especially recommended for the impact monitoring of marine mammals, as these highly mobile animals inhabit an area mostly larger than a specific development site. They will thereby likely experience the impacts of various development sites / industries in a cumulative manner. Covering a larger monitoring area achieved with an interdisciplinary co-operation will also enable a larger proportion of the population of concern, and thereby help to answer population related questions with regards to possible impacts.

Birds

With respect to birds, depending on the specified objectives of monitoring, there may be a need for links to fish or shellfish monitoring, for example, such that the reasons for any changes in numbers observed through and after construction against the baseline can be properly evaluated.

Consideration should be also given to the monitoring that is undertaken at nearby OWFs to ascertain whether the ornithological features of concern and the monitoring objectives are similar. Where possible, and subject to the appropriate minimum scale for monitoring that is determined (see Section 11), monitoring between adjacent developments should be co-ordinated.

[illegible]

Recommendations for a suitable model (including timing and arrangements) for formal review of the monitoring data, in order to understand critical issues; ensure monitoring is appropriate; and results are incorporated into adaptive management approaches.

[illegible]

Change needs to occur at an appropriate time based on sound reasoning and documented in an accessible and clear manner for environmental management to be effective.

[illegible]

- Topic specialists/consultants and regulatory authorities need to come together to form relevant, site-specific conditions for each process where a sensitive receptor has been outlined as being potentially impacted in the ES.
- Topic specialists/consultants should be involved in review stages of technical reports, to ensure best practice is being adhered to and the results presented are relevant to monitoring sensitive receptors that have been identified in the ES.
- If monitoring plans are changed, these should be recorded in a monitoring appendix to the licence – this review has highlighted the discrepancy between required licence monitoring conditions and actual monitoring that is undertaken by the developer. In many instances the rationale behind monitoring changes is not captured.
- Unforeseen consequences of building an OWF should have new monitoring applied through a variation made to the licence, which should be added as a separate condition for clarity (where this is agreed to be necessary i.e. a potentially significant impact is predicted) – as above, this could be included in a monitoring appendix linked to the original licence.
- New condition for one site should not be applied to all subsequent licences unless similar sensitive receptors and impact pathways have been identified
- Sharing of knowledge/experiences should reduce the likelihood of any unforeseen circumstances/impacts.
- Final monitoring reports should be reviewed to ensure that the necessary analyses have been undertaken satisfactorily and to evaluate how well the predictions from the EIA have been borne out and whether significant uncertainties have been reduced and thus monitoring programmes adaptively changed.

The review process of licences and monitoring conditions should be adaptive to capture changes in:

- Development approaches for OWFs (multiple/parallel projects in a given zone for example).

- The physical environment in which OWFs are planned (deeper water for example, with respect to sound propagation).
- The ecosystem in which OWFs are planned (with respect to potential impact on marine fauna).
- Available technology (for example different construction methods, mechanical mitigation or larger capacity turbine).
- Scientific approach/best practice (the availability of international standards for example).
- The use of templates with topic/receptor specific minimum requirements, monitoring rationale, hypotheses and methods should be established which should also record the monitoring answers to the questions posed once available. The template should also be used to record any changes in the monitoring specification, including dates of change, with whom they were agreed and why. Finally, the template should record if/how the monitoring outputs may be / are incorporated into adaptive management.

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Scientific research is developing rapidly with the majority of impacts and uncertainties on fish and shellfish associated with the development of OWFs being the object of current research. Within the formal reviews it is suggested that small scale yearly reviews are conducted to pick up critical issues that are novel in comparison to those contained in the three and five year reviews. These annual reports would not re-review all subjects but focus on critical information.

[illegible]M[illegible]r[illegible]

For marine mammals, reports should be reviewed at least annually but in more sensitive locations and more sensitive species this may need to be more frequently. Initial reviews should focus on power analysis conducted on the baseline data. This will then lead to recommendations about the requirement for adjustments to the methodology, increased effort or indeed whether any change is detectable given observed variation.

[illegible]

[illegible]

Clear objectives and the rational for monitoring may be missing from consent conditions, in particular with regard to site specific conditions arising as a result of potential impacts predicted through the EIA process. Further the current consenting systems in place are limited in their ability to require systematic documentation of the changes that can occur to consenting and monitoring conditions over time. Whilst the events leading to such changes are likely to have arisen from a pragmatic and logical process, without a clear auditable trail the changes may cause confusion and obfuscate monitoring objectives and the ability to enforce conditions.

[illegible]

During the formatting of conditions particular emphasis should be placed on defining achievable objectives, including well defined hypotheses. An option for achieving this without over-complicating the licences is to introduce greater standardisation to the Marine Monitoring Plan (MMP), also referred to as the Environmental Management Plan (EMP), to include the detailed rationale and hypotheses for evaluation in the PCM. The MMP should be included, as an annex, in all new licences, and can then be referred to rather than having to include the details within the licence itself, as in many earlier licences. It will be essential for the version number of the MMP to be documented in the licence, with the version number updated and the licence varied to reflect any changes to the MMP. The same principles to drafting licence conditions (i.e. ensuring that they are proportionate, achievable and enforceable) should be applied to formulating the MMP. As the MMP is annexed to the licence it still represents a legal document.

Appropriate guidance may be provided, for example a logical sequence of evidence could be presented, based on the defined objectives, this could include consideration of the anticipated impacts described within the ES. Such guidance may range from what the minimum information requirement for the report should be, i.e. what essential information is required, how the measurements should be presented, in what units, and what metadata are required, to a report template which captures all of the above. Licence conditions (and the MMP) should be formulated based on environmental risk assessment (ERA) principles (see Section 3.3).

[illegible]

In addition this review also recommends the introduction and use of templates for monitoring with topic/receptor specific minimum requirements and guidelines for the developers. The template should be updated on a regular basis at reasonable time periods. The guidelines on monitoring standards should be reviewed by an expert group on a regular basis at reasonable time periods.

- Monitoring requirements should be clear and concise. Complicated monitoring conditions should be broken down into component parts.
- Coordinates and/or maps should be provided where monitoring is required for a specific location.
- Monitoring objectives should either reflect the likely significance of the impact associated with an effect as described in the ES or the need to reduce uncertainty in the predicted impacts of particular effects, e.g. those assessed more qualitatively. Hence monitoring may also be required for effects whose impacts are not predicted to be of great significance, but for which there is a high level of uncertainty.
- Conditions should present a clear hypothesis where a sensitive receptor is identified.
- Emphasis should be placed on the ability of the PCM to reduce the uncertainty of the predictions made in the ES. The conditions should therefore make clear that the PCM should have the ability to reduce the uncertainty identified within predictions in the ES. In view of this, best practices could benefit from an extension to the EIA into a more explicit environmental risk assessment, where certainty/confidence levels with which the predictions of potential impacts are made should be justified on the basis of scientific evidence (including collective evidence from previous wind farm studies), which should be presented and fully referenced.
- The means by which the PCM reports will identify the predicted change (the hypotheses) must be included as part of the ES and the monitoring methods intended to do this must be described, such that they can form the basis of the MMP (although not the final version which can only be completed once the final form of the development is known) and so that it can be referred to in the conditions.
- Where available, representative background values or reference conditions, from outside of the development area, should be identified or referred to, for use in the PCM.
- Conditions for specific topics may have threshold values (e.g. physical processes Section 5.1, marine mammals Section 5.5 and underwater noise Section 5.2) attached to them if available and scientifically validated. These should be linked to the ES and set in conjunction with topic specialists and agreed by the MMO or appropriate regulator, as the regulator is ultimately responsible for enforcing the Marine Licence, including compliance with monitoring conditions; it is they who bring in, or refer to, specialist input, such as Cefas, SNCBs or others as the regulator sees fit to consult.
- Conditions should provide clearly outlined consequences and recommended actions to be carried out in the event of a threshold breach or hypothesis rejection.
- Conditions should continue to place an obligation on developers to provide data to a central data source.
- Engineering monitoring should NOT form part of the Marine Licence, unless a receptor is identified in the ES which is specifically sensitive to engineering processes e.g. shellfish beds from sediment re-suspension associated with scouring around foundations.

- Changes to monitoring conditions should be clearly captured through cross referenced correspondence and meeting minutes. These should be recorded as an annex in the MMP.

[illegible]

A summary of the minimum reporting requirements is presented below:

- All reports should be subject to a single and consistent naming convention
- All relevant reports should be supported by source or raw data
- Critical environmental metadata should be reported to allow interpretation of the measured data
- A clear statement should be provided on which units, procedures and guidelines have been used within the report
- Reporting of data should be consistent where possible with international standards, although the metrics and format in which the data is reported will be dependent on the type of data being measured
- All source or reference data should be detailed and fully referenced
- The report should include a clear and unambiguous section describing the aims of the report including what it intends to achieve, which must be directly linked to the conditions of the monitoring
- Significant impacts for key receptors, as defined in the HRA and ES, in combination with the monitoring methods used to investigate the impacts, as defined in the MMP, should be presented, preferably as a table in the introduction of the report
- Clear hypotheses should be presented for each of the sensitive receptors identified, followed by a detailed description of post consent monitoring methodologies
- In all cases the full spectrum of metadata, raw data, analysed data (which must include a clear identification of changes made to the raw data) and data analysis methods, used to draw the conclusions (including detailed statistical methods in appendices if necessary), should be presented or made available to allow third party, independent evaluation
- Conclusions should be drawn with respect to exceedance or compliance with identified threshold levels and or hypotheses. Cross references to the predictions presented in the EIA should be made indicating whether the predictions were correct and the consequences if they were not
- Feedback from the MMO or appropriate regulator should form an integral part of a final signed off report, using a tabulated format corresponding to compliance with the conditions, acceptance of the conclusions of the hypotheses and consequences of these, e.g. no action or action should be continuation of monitoring, further scour protection recommended, etc.

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Recommendations on what should, and can be achieved through post-consent monitoring programmes associated with each receptor, i.e. the realistic level of ambition.

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In some cases monitoring requirements may fall short of what can be achieved i.e. through the generic application of conditions to sites that would benefit from focused conditions. In other cases the monitoring conditions, or lack thereof, that arise may be as a result of nascent monitoring abilities or practical impossibilities of monitoring (i.e. effects from pile driving on harbour porpoise for long term population impacts).

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Generally, environmental monitoring needs to be focused on areas identified in the ES (and agreed by the regulatory authorities) to be most likely to result in potential impacts on a sensitive receptor(s) (refer to individual topics below).

Guiding principles for this would require the application of risk-based criteria; a recent report by the MMO on Environmental Risk Assessment (in press) presents a framework to establish the likelihood of effects through standard Source-Pathway-Receptor relationships. Additional guidance and recommendations are also provided by Cefas (2010).

[illegible] 2 [illegible] r [illegible]

- It is suitable to monitor scour where a receptor which is sensitive to scour has been identified and will be significantly impacted as predicted in the ES (for example benthic communities or mobile sandbanks).
- Scour monitoring for engineering purposes should not form part of a Marine Licence. Instead, OWF operators will want to ensure that the integrity of site infrastructure (including foundations and subsea inter-array and export cabling) will not be compromised by high-energy and dynamic physical processes. All specifications of proposed survey works of seabed morphology and sediment transport should be discussed with the relevant licensing authority to establish if there are any opportunities to align engineering surveys with ecological monitoring requirements. Where feasible, developers should also aim to inform regulators of their schedule of engineering surveys and provide findings to the regulator.
- Assuming scour monitoring continues to be included in Marine Licences, it should only be undertaken at foundations where risk to infrastructure is identified (e.g. where sandy substrates are greater than 1–2m thick or where large mobile bedforms may be present).
- The condition for “scour monitoring after a significant storm” should be removed unless clear rationale and guidance for this condition can be presented. Assuming this condition continues to be a requirement in future Marine Licences, further monitoring specifications need to be included such

as: How soon after a storm; how is a storm classified (i.e. thresholds); locations where scour monitoring would be most valuable (e.g. thick mobile surface sediments).
- It is also important to point out that logistically scour monitoring after a storm would be very difficult. In theory it would require all wind farms to have surveyors on standby in order to fulfil that specific licence condition. Assuming that this particular monitoring would have to be conducted soon (e.g. within a few days) after a specified storm event - the tendering process alone for the surveys would require significant time – logistical survey delays could potentially result in the storm effects not being captured, at significant cost to the developer with no tangible results.
- Where scour monitoring is required, it should be done at select locations across the site which are representative of seabed characteristics – e.g. where large mobile bedforms are present (indicative of the level of seabed mobility) or where palaeochannels may be located.
- Representative sampling based on seabed/shallow geological characteristics and hydrodynamics is more feasible for Round 3 OWFs, since these developments plan to have hundreds of turbines spanning large areas.
- Round 2 OWFs that have not completed monitoring should consider the likelihood of scour based on the geological conditions and hydrodynamics at each individual site and whether or not scour monitoring will add value or knowledge to the project and a decision reached with the licensing authority.

[illegible]

- Suspended Sediment Concentration (SSC) monitoring should be undertaken when a sensitive receptor is identified in the ES and predicted to be impacted by a sediment plume caused by construction activities.
- If no receptor is identified/predicted to be impacted by installation activities, no SSC monitoring should be undertaken; this recommendation is in line with previous Cefas (2010) review.
- Where required, surveys should be boat based and results should be available/measurable in near real time e.g. by the use of calibrated optical units such as Nephelometric Turbidity Units (NTU). It would also be advisable to include the term ‘turbidity’, rather than ‘suspended sediment concentrations’ in future Marine Licences, which essentially allows for real-time monitoring.
- Where SSC monitoring is required, a fixed mooring at the location of a spatially well-defined sensitive receptor might help record changes at that location. As above, data should be available in near real-time and monitored against a set threshold beyond which operations should be halted/reduced. These thresholds should be set in advance and agreed by topic specialists and regulatory authorities on a site (and receptor) specific basis. Baseline and control sites also need to be monitored to establish natural variability, especially during storm events if possible.
- Where SSC monitoring is required, sampling should be undertaken at turbines/locations representative of seabed types present at the site (e.g. chalks, fines etc.).

[illegible]

Current and wake monitoring is no longer a requirement. Following assessment of the results of early monitoring (e.g. at Scroby Sands), the requirement for current and wake monitoring has not been a requirement in licence conditions after Gunfleet Sands, following advice from Cefas and Statutory Nature Conservation Bodies (SNCBs) (Defra, 2005). As such no recommendations will be made for this topic.

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- Coastal monitoring should be undertaken only where a sensitive coastline is identified in the ES which is predicted to be significantly impacted (and agreed with the MMO/ appropriate regulator), particularly where an OWF is close to the coast or located on or near a sandbank. These might include coasts with SPAs or SACs where significant impacts are predicted, or those which experience high rates of erosion or coastal squeeze.
- It is noted that the requirement for coastal monitoring is a current practice only for OWFs which are either very close to the coast and/or are located where the adjacent coast has a protected area.
- Existing beach-profile/coastal monitoring datasets should be utilised where available and applicable. If no monitoring is currently undertaken by the Environment Agency (or similar agencies), it would be advisable that the coastal data collected by the developer is shared with the Environment Agency (EA) for future reference.
- Where beach profile or shoreline monitoring data are not presently available, transects across the shore are advised where significant impacts on the coast are predicted in the ES or there is high uncertainty.

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The realistic level of ambition which could be achieved through post consent monitoring relating to underwater noise includes:

- Underwater acoustic pressure measurements to quantify noise levels during pile-driving, at a number of ranges from the sound source, along chosen transects.
- Determination of a source output term (ideally a source level) for pile-driving to allow site-specific noise levels across the site to be estimated through numerical propagation modelling.
- Where possible, underwater noise conditions in the absence of the piling noise should be presented to provide context.
- Underwater acoustic pressure measurements to validate the efficacy of any mechanical mitigation methods which might be employed when pile-driving, during the construction phase.
- Underwater acoustic pressure measurements to quantify noise levels radiated from new technologies employed, during construction or operation, which are believed to hold the potential to have a significant impact on marine fauna.
- Consistency in reported parameters and use of standard metrics to support traceability and data comparability. This should be based on UK guidance (currently being implemented through The National measurement Office, The Crown Estate and Marine Scotland) and ISO standards once they become available.
- Metadata gathered in a consistent manner (this should be achieved through MEDIN).

For underwater noise there is no specific receptor focus, but efforts could be made to correlate the underwater noise data with marine mammal monitoring and fish surveys, for example.

[illegible]

Post-consent monitoring should be more tailored to fulfil specific aims, based on verifying the hypothesis made in the ES but also with the objective of reducing the uncertainty of those predictions for which not enough data are currently available. As such, each licence should be more focused on the site-specific EIA, and monitoring requirements therein, tailored to the evident areas of probable significant impact, but also taking account of the level of uncertainty. If data gathering is required it would be better undertaken with a view to assessing not only the immediate benthic changes associated with an OWF development, but also potentially how these changes could, in time, affect the whole biodiversity of the site and farther afield, with far reaching consequences across the trophic web. Specifically, colonisation of the monopile foundations has to date been investigated with regard to the type of benthic communities likely to develop and their biomass, but much uncertainty still exist on how these new communities may affect the surrounding benthos (through e.g. increase in faecal matter, larvae and food supply, changes in predation patterns, etc.) and the longer term relationship with organisms higher up in the trophic chain. Examples drawn from overseas projects, reviewed as part of this exercise, show that this sort of monitoring can be achieved through small scale studies the results of which can be extrapolated to model the likely scenario on a larger and longer term scale. This in turn would remove the need for short-term large scale benthic studies (as currently undertaken), which could instead be undertaken as a ground-truthing exercise of the modelling studies after a greater number of years (e.g. 5 or more).

Intertidal studies could similarly benefit from more focus on the ecological importance of the habitats, as defined in the ES, and their relationship with fish, shellfish and marine birds, by, for example, identifying bird feeding areas and food availability in the form of the prey invertebrates of birds. Monitoring should therefore assess not only the direct changes to the intertidal communities but also how these could impact other trophic groups, if considered as a potentially significant impact or where high uncertainty exists.

Summary:

- It is suggested that benthic surveys, as currently undertaken, including the entire wind farm area and associated boundary and reference areas are completed pre-construction for the establishment of baseline conditions in line with the site-specific EIA, such that hypothesis testing, as proposed in the ES, may be undertaken as required at a later stage.
- Current benthic survey methods, if required to consider impacts across the entire wind farm area, are appropriate. However, it may be more appropriate to consider the outcomes of the localised effects studies first (see below) such that benthic surveys can focus on appropriate survey arrays and statistical methods, designed to identify change against natural variability. Survey methods need to be applied consistently. It is recommended that the data

analysis methods are substantially based on multivariate methods rather than univariate.

- Where the ES indicates impacts on benthos are ecologically important, e.g. where habitats or species of ecological and/or conservation importance exist, then surveys should continue to be focused on these, employing the most appropriate methodology available and agreed at the time. For example geogenic or biogenic reef features, which can be monitored using dropdown video techniques, quantifying abundances of key indicator species. These will be site-specific and will probably be micro-sited following presentation of final construction plans. Studies of this type will be focused on impact and recovery, either following cable laying or as a result of turbine construction in close proximity to a conservation feature. Regulatory bodies will need to be able to assimilate and agree micro-sited monitoring strategies based on generic descriptions of processes included as part of the mitigation within the EIA.
- It is recommended that focused studies on the localised effects of the turbine placement, if identified as a relevant issue in the EIA, are established, based on modified and updated versions of existing guidelines. The guidelines that presently exist have been ineffective due to poor execution. It is suggested that the focus of the studies, should include:
    - colonisation progress, including assessment of biomass and presence of non-indigenous species (diver studies on turbines – methods already exist although refinement of consistent methods and skill base needed).
    - changes to mobile epifauna/small fish abundance and distribution as a consequence of trophic interaction changes, using gradient or BACI analysis in proximity to example turbines and further afield (video and 2m beam trawl – methods already exist including data analysis).
    - benthic population and habitat conditions in scour zone and area immediately outside of the scour zone, to observe benthic community change due to trophic interaction or other indirect effects of the turbine placement (variety of techniques already exist, aiming to achieve equivalent datasets between diver cores and benthic grabs as appropriate to the site; data analysis to employ both gradient and BACI analyses). It is important that where biological monitoring is conducted it would produce more coherent data if combined with geophysical survey, to aid identification of the physical extent of effects due to turbine placement (see 11.1.1).
- Particular focus is recommended in relation to progressive spatial change in conditions, initially local ecological change but subsequently far field effects, through changes in trophic structure originating from the placement of the turbine. The latter will be over differing timescales to the initial focused studies and will include observation of wider ecological change, captured in long term benthic studies if appropriate (5+ years) as identified in bullet points 1-3, and higher trophic levels as indicated in the appropriate sections for fish, marine mammals and birds.
- The focus of intertidal studies should be on relevant habitat and biotopes features, including biogenic features, and which are of ecological value to other species groups. Current timescales are appropriate but the structure

and nature of the surveys needs to be refined at each site based on local conditions.

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The purpose of monitoring is to compare impacts as predicted in the ESs with actual impacts at the OWFs, where significant impacts are predicted or there is high uncertainty. Fish and to a lesser degree shellfish (many having dispersive planktonic phases) are highly mobile receptors. Some species will migrate or travel long distances in order to track seasonally available resources including feeding, spawning, nursery and over wintering grounds. This makes accurate monitoring of these populations difficult as the variability in the proportion of the population sampled due to movements between sites is unknown. This is further compounded by the survey conditions (such as the state of tide, sea surface temperature, hour of the day etc.) varying considerably between sampling events. As well as this, the typical area of predicted impact is large and extends many tens of kilometres beyond the wind farm boundary in the case of piling noise. At such large scales and with such mobile species it makes sense to assess impacts across a larger scale than individual sites, and licence conditions should state that inter and intra-zone cumulative monitoring occurs.

Current post consent monitoring at OWFs is of too broad a scale to be able to distinguish between predicted impacts and natural variation in fish and shellfish populations, in all but the most acute of impacts. Only impacts of moderate or greater significance have any chance of being identified. Therefore, the range of parameters requiring monitoring needs to be narrowed and should be dictated by the occurrence of sensitive receptors, and predictions and mitigation highlighted in the ES. Greatest focus should be placed upon impacts of concern for which the highest uncertainty remains. Furthermore, sensitive receptors need to be identified at the stakeholder level, with a coherent and consistent concern voiced throughout the EIA process. This can then be used as a reasonable justification for any research or post consent monitoring requirements.

Greater emphasis needs to be placed upon gathering reliable baseline ecological data from a variety of spatial and temporal scales on sensitive receptors, as identified in the ES, so as to better determine the natural variability of the populations. Any changes outside of these thresholds identified could then be attributed to impacts from the project. The greatest challenge is for survey design that can describe change (if any) on fish populations attributable to OWF development and the consequences of any such change on other parameters (e.g. fish as a food supply for marine mammals). We acknowledge that this may be beyond the scope of what can be achieved in site-based monitoring, so an industry / government collaborative approach may be the best way to address this.

[illegible] M [illegible] r [illegible]

The main potential impacts to marine mammals from OWFs identified in EIAs and non-UK impact monitoring studies to date are auditory injury and behavioural displacement as a result of noise generated during construction, most notably by piling. Monitoring the extent of auditory injury in wild marine mammals is extremely challenging and cannot be addressed by a developer on a site-specific basis. However, predictions can be made based on noise modelling, which in turn can be validated by on-site noise measurements during construction. Behavioural displacement can to some extent be predicted beforehand and then validated during monitoring before, during and after construction if uncertainty remains about the potential for disturbance. The practical investigation of the population consequences of these impacts are not likely to be within the scope of individual development PCM programmes.

Given the large spatial scales over which marine mammal populations generally operate (including seal haul out sites outside the site of interest, but with the potential to still be affected) there are limits to what can be achieved through post–consent monitoring programmes on a site-specific basis. Marine mammal density and abundance is likely to be highly variable over baseline conditions over the scale of a monitoring area that includes the wind farm site plus zone of potential impact and the power to detect change and attribute it to activities associated with the development may therefore in some cases be low. The ability to link cause and effect to detect change using 'traditional' monthly visual methods (whether air or boat based) may then be too low. It will be virtually impossible to determine population level changes as a result of activities on a particular site (even on large sites), or to determine cumulative effects of neighbouring sites. In those cases, a more regional and co-operative approach to monitoring across a number of sites may be the only way to appropriately design a study to answer a site-specific uncertainty. One has to be aware that a regional approach is not the same thing as 'strategic' research.

There needs to be a distinction between site-specific issues and more 'strategic' or research issues that are outside the scope of what would be expected of developers. Site monitoring should be linked to the validation of impact predictions made in the EIA for that project, focusing on issues of identified significant and potentially significant risks. However in the case of marine mammals, in many cases, site-specific issues, i.e. uncertainties over the impact of noise on marine mammals using a specific site (because we do not have the empirical data to predict the nature and scale of effect and are basing predictions on expert judgement and by extrapolating from different situations and species), are actually the same as the more generic research questions – e.g. how do marine mammals respond to piling noise, over what scale, how long till they come back into an area, and all of these questions will add to the uncertainty surrounding site-specific assessment of impacts.

Based on the discussion above we give the following recommendations, list aims that can be achieved by Post Consent Monitoring, and give examples for monitoring methods, their strength and weaknesses, as well as potentials to improve those methods for PCM.

[illegible]

- PCM monitoring should focus on noise related impacts, should be question driven and should focus on metrics other than population size/abundance (e.g. relative density or other measures of activity).
- Effort should be made to validate predictions made in the ES in terms of the likely levels of noise animals may have been exposed to during construction,

particularly validating noise exposure at the ranges predicted for typical marine mammal disturbance – often many tens of kilometres from the source.
- Where disturbance has been highlighted as a potentially significant impact, determine spatial changes in distribution and relative abundance relation to site and construction activity.
- Adopt Before-After-Gradient (BAG) designs, spatial density modelling and careful spatial and temporal design of monitoring taking into account the natural variability and with consideration of the statistical power to detect changes.
- Measure cumulative noise exposure over complete piling events (particularly at further distances from the source) as well as from concurrent piling events of adjacent sites and compare those to modelled predictions.
- The marine mammal specialists should liaise closely with underwater noise specialists to ensure that data collected during underwater noise monitoring are suitable for validating predictions made in the ES in terms of potential impacts to marine mammals.
- Ensure consistency in the reported parameters and use of standard metrics for reporting noise.
- Match the scale of assessment to the scale of predicted impact. The typical area of predicted impact is often large and can extend tens of kilometres beyond the wind farm boundary.
- Statutory guidance should be developed and given on the methodologies, thresholds and metrics to be employed in assessing the impact of noise on marine mammals (see section 11.3).

The degree of the feasibility of PCM to achieve the above and the methodologies applied are highly species and case/site-specific. It is therefore recommended that a marine mammal scientist specialised in the design and implementation of these methods is involved in determining how the available suite of methodologies is applied to each site during the determination of post consent monitoring specifications. Similar independent expert review needs to be applied to data analysis and interpretation of the PCM.

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- Consideration should also be given to the potential for monitoring of population scale impacts using a collaborative regional approach (see Sections 8 and 9).
- Collaborative regional approaches should also be considered in the light of the larger scale projects of R3 compared to R1 and 2, and their potential impact on protected species and protected sites.
- Identify synergies where site-specific monitoring can inform generalities for use at other sites and other assessments.
- Ensure that the feedback loop between research and monitoring and impact prediction is facilitated by regular review and synthesis of research and monitoring.
- Design and implement strategic research projects at key ‘indicator sites’ in a way that recognises the principal uncertainties and most common site-specific issues.

- Enhance collaboration or joint industry initiatives supervised by a co-ordinating body.

There are a number of other sources that provide useful detailed guidance on the range of techniques and methodologies available for monitoring marine mammals (SMRU Ltd 2010; Cefas 2012).

Investment should be also put into the improvement of mitigation measures, including the use of acoustic deterrents and noise reduction measures. For the latter, a review on the state of the art of current approaches would be desirable (e.g. building on work undertaken in Germany, or through the ORJIP projects).

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In general post consent monitoring needs to reflect; a) the likely significance of the impact associated with effects as described in the ESs or HRAs, focussing on those which are predicted to have high significance or; b) the need to reduce uncertainty in the predicted impacts of particular effects, e.g. those assessed more qualitatively or which are dependent on particular assumptions. To date, post consent monitoring has focused on the development site but consideration might also be given monitoring impacts of effects at protected sites if this would reduce the uncertainty in predictions. For example, understanding the relative connectivity between qualifying bird features of SPAs and the development is a fundamental part of the HRA process. The deployment of tracking devices on birds to inform on the foraging areas of birds from specific colonies, within or even outside the breeding season and the relative overlap with the development site may provide important information that improves the certainty in impact predictions. Similarly, the collection of colony counts or demographic information may improve the accuracy of predictions where such information is lacking or out-of-date and thus might be considered.

In terms of impacts of effects observed at the development site, OWFs may affect bird populations through:

- Disturbance/displacement from the wind farm area leading to an effective loss of habitat
- Direct mortality due to collisions
- Barrier effects for migrating birds or those making regular movements to and from breeding colonies.

Recommendations as to realistic aims and objectives for post-consent monitoring will vary between these effects. Consideration is also required as to the survey methodologies used to collect data and to survey design.

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The primary requirement of post-consent monitoring for birds should be to ensure that data on the numbers of birds using the site (and, depending on survey design, wider areas around this or reference sites) are collected in a manner that allows adequate statistical comparisons to be made between baseline, during construction and post-construction periods. In practice, survey methods may develop over the periods of monitoring and such innovation should not be suppressed. This is, of course, particularly pertinent to the detection of displacement effects, but is also highly relevant to the monitoring and the overall assessment of barrier effects and collision risk.

Guidance on standardised seabirds at sea census techniques for both boat and visual aerial surveys (in relation to assessments for OWFs in the UK) are available through a COWRIE-funded project by Camphuysen *et al*. (2004). Although there has been a relatively recent review of digital aerial surveys techniques (Thaxter and Burton 2009), funded by COWRIE, significance advances have occurred in the last few years and therefore there is an urgent need for an update.

Flight height data – which may be used to inform on the potential for collisions (see below) – have been traditionally collected through boat-based surveys (which have been primarily undertaken as a means of collecting information on numbers of birds). Such data may be used directly in collision risk modelling, though have more recently been used to generate flight height distributions that have enabled improved model outputs (Cook *et al*. 2012). Recently developed digital aerial survey techniques also provide the potential to collect information on bird flight heights, although further evaluation of the accuracy and precision of this information is required. Such techniques, together with radar, may be advantageous over boat-based surveys because of the potential for observer differences and limited accuracy of observations of high-flying birds with the latter. Issues of species identification, however, have perhaps limited the use of both digital aerial survey techniques and radar in informing on flight heights to date, although improvements in the former in this respect mean that it is likely that such techniques will be used more frequently in the future. Consideration of best practice in relation to use of these methods might thus usefully also consider a review of the data on flight heights of birds that these methods may potentially provide.

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Particular consideration is needed as to the design of surveys, such that aims and objectives are met. The following provides recommendations with respect to the key effects.

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There is much uncertainty as to the scale of displacement that may be associated with wind farms and how this varies over time, through and post-construction. Post-consent monitoring has the potential to add significantly to the evidence base on this issue, although only if studies are well-designed. In this respect, we provide the following recommendations:

- Pre-construction monitoring data collected over the initial period should be used to conduct a power analysis in order to inform on the adequacy of the spatial scale of monitoring and the ultimate power to detect change and thus refine or adjust the monitoring design as necessary. The power to detect change from survey data alone is related to the frequency of surveys, their temporal extent and spatial coverage. Therefore power analyses can help determine the most appropriate survey design in order to be able to effectively demonstrate disturbance/displacement effects.
- Details regarding the analyses to be undertaken should be determined at the outset of the study.

- Due to difficulties in identifying reference sites which are truly comparable in terms of their environmental conditions, the use of Before and After Control Impact (BACI) survey designs for monitoring the displacement of seabirds has recently been questioned. Use of alternatives such a Before-After-Gradient (BAG) approach, in conjunction with the use of density surface modelling techniques is thus recommended.
- The use of density surface modelling techniques enables environmental correlates to be accounted for such that changes in densities that might be a result of the construction or operation of the wind farm may be better evaluated. The inclusion of temporally varying covariates rather than solely static covariates (ideally environmental data that is collected synoptically to the timing of the bird surveys) would greatly help in this respect.

[illegible]

The need to be able to monitor collisions offshore, and thus to be able to validate the avoidance rates used in models, has long been recognised and is the subject of a developing ORJIP project. However, it should be recognised that, until technology is further developed, it is unlikely to be feasible to undertake such monitoring at all sites. Given this, one present option might be to focus monitoring at some consented sites towards the collection of information on the numbers of birds exposed to collision (i.e. on the numbers flying through a site and their flight heights) such that collision risk analysis could be undertaken informed by the results on avoidance rates from the ORJIP project or similar programmes. However, the potential for future innovation to enable collision monitoring at individual sites to become more cost effective or for strategic projects to be taken forward between developments should be noted.

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In the majority of cases, barrier effects have not been properly assessed as data were drawn from the boat surveys undertaken to monitor changes in bird numbers on the wind farm site. Radar is more likely to be able to demonstrate barrier effects and has been used at several OWFs although the final post construction reports were not yet available.

Where consideration of barrier effects is required, the aim should be to determine the numbers of birds exposed to the effect, the proportion of these avoiding the wind farm site, the increase in flight distance resulting from the wind farm and thus the energetic consequence. The methods used to determine the numbers of birds exposed to the effect and avoiding the wind farm site will vary by site and species.

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Recommendations on the guiding principles associated with the spatial and temporal scale of monitoring.

Where possible, recommendations on what periodicity of sampling and what spatial scales will be most appropriate for a range of categorised wind farms will be given. The guiding principles will be built up on the basis of temporal and spatial extent of required monitoring to be confident that conclusions drawn from monitoring data are correct, i.e. for how long and over what time scale do you have to collect monitoring data to be confident in the findings? Where not possible or appropriate to do so, current knowledge gaps will be identified.

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Some monitoring and subsequent reporting occurs over a timescale which prevents any reactive change to mitigate impacts for example suspended sediment monitoring. In other cases monitoring, designed to reduce uncertainty, occurs over a range of conditions and locations such that the uncertainty remains unquantifiable.

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Across all topics monitoring should be receptor driven using EIA and HRA impact statements as a hypothesis for investigation. Monitoring should be used where there is uncertainty in an impacts significance which could lead to a potentially significant impact on a sensitive receptor. Surveys should be designed so that data collected can reduce uncertainty in impact significance statements.

Hypotheses to be tested in monitoring should be clearly stated in monitoring plans and monitoring reports so that the objectives are not lost.

Monitoring should not be required for impacts where there is already high certainty. For impacts where there is a significant impact with a high degree of certainty, mitigation should be used to protect the environment. There may, however, be circumstances where uncertainty remains in the effectiveness of mitigation proposed. In these instances monitoring should be used to reduce uncertainty, testing the hypothesis questioning the effectiveness of mitigation.

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It is not possible to define exactly what monitoring (e.g. frequency and spatial distribution) should be undertaken for each individual OWF site since monitoring should be targeted based on site-specific conditions. As OWFs become significantly larger through R3, it will not be logistically feasible to survey the entire site. Instead monitoring locations and frequency should be representative of conditions at the site.

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- If required, and identified as producing significant impacts within the ES, spatially, representative turbines should be selected based on ground conditions.
- With regard to frequency of surveys, for sites with a low likelihood of impact (where scour is likely to be restricted or is not expected at all):
    - A survey should be undertaken once following the completion of turbine installation (no less than after a period wherein scour equilibrium is expected to have been reached) at turbine/cable locations highlighted to be most likely to experience scour (i.e. where sediments are likely to be mobile or poorly consolidated, such as in palaeochannels).
    - A further survey should be carried out six months to one year later to conclude that scour is equilibrated/impeded by the underlying geology and monitoring can be ceased.
    - There should be the option to increase monitoring should the results of these reports differ to what is expected based on predictions made in the ES (e.g. significantly deeper than predicted, or with greater lateral extent/overlap with scour from other structures).
- For sites with a sensitive receptor (such as those built on sandbanks or within areas of large mobile bedforms):
    - Surveys every six months for three years is acceptable
    - The option should be there to increase monitoring should results differ to what is expected.

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Where demonstrated in the ES (and agreed by the licensing authority) that monitoring is needed:

- Spatially, SSC monitoring (ideally this should be changed to turbidity monitoring using optical instrumentation in future Marine Licences) should be carried out where overlap is predicted between a sensitive receptor and the plume. Boat based monitoring should be carried out at or near the receptor where the threshold will be relevant to any potential impact – e.g. if the threshold beyond which a sensitive receptor is considered at risk from the effects is breached far from the receptor this will have less impact than if it is breached at the location of the receptor.
- SSC monitoring should be undertaken during construction until the plume is dispersed or returns to background levels. Baseline or reference sites should also be identified in advance.
- Monitoring SSC for different construction activities (e.g. drilling, piling, jetting) at representative locations across the development site should be undertaken, to ensure that the variability in sediment composition, water depth, construction activity and tidal currents are taken into account.

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- Coastal monitoring should only be undertaken where hydrodynamic changes are predicted to overlap with a sensitive coastline and predicted to result in significant impacts, as identified in the ES. It is noted that this is currently best practice.

- Where a potentially sensitive coastal segment may be impacted, it is recommended that as a minimum, yearly surveys are undertaken for longer than the current three years, with reporting and results presented perhaps every five years.
- As outlined in Section 5.1.4 the use of existing datasets (e.g. Environment Agency) is recommended where possible.

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The guiding principles associated with the spatial and temporal scale of monitoring with relation to the measurement of underwater noise resulting from pile-driving during OWF construction should include consideration of the following (these guiding principles should also be informed by measurement guidance documents and ISO standards when they become available):

- Substantial variation in the acoustic pressure level radiated into the water from the piling is expected. This can vary per foundation due to differences in geology, water depth, foundation specifications and required hammer energies. Further local variation in the acoustic pressure level will also occur both spatially (due to variations in bathymetry and sediment type, for example) and temporally (due to changing tide height, flow and temperatures). However, the measurement data that can be obtained during any given piling operation are determined by logistical factors such as the time at which the piling is carried out and the time it takes to fully install the foundation. For monopiles, this generally limits the monitoring to one dataset or transect per pile, during which there may have been time dependent influences such as tidal variation. The requirement for four foundation pieces to be measured does not necessarily reduce the uncertainty as variation would be expected between different foundations, and measurements cannot always isolate this variation due to the spatial and temporal variations in propagation conditions that occur whilst monitoring the foundation installations.
- Capturing all of these variables is unlikely to be practicable and for the purpose of post consent monitoring, priority should be given to validating the acoustic pressure level predictions in terms of the realistic worst case (and this should include noise level mitigation methods used). The factors which are thought to result in the greatest variation, and potentially the highest noise levels, should be considered and this should inform which foundations are measured rather than the monitoring being of the first four or four of the first few.
- A static measurement location should be used in at least one location to monitor the underwater noise for the entire duration of a given foundation installation to fully characterise the result of the soft-start and varying hammer energies during the foundation insertion.
- Range dependent monitoring should aim to obtain measurements as a function of range from the foundation, capturing the noise level both close to the pile and further away. Ideally, measurements should be completed over a range which allows satisfactory validation of any predictions made in the ES (this need not be as far as the outer ranges predicted for impact but should be

of suitable length to validate the propagation model used) and should be sufficient to validate any propagation model used in the monitoring report to estimate noise levels for directions around the foundation which were not measured. It is acknowledged that only one transect is likely to be measured per pile; that the length of this transect will likely be limited by the piling duration; and that the shortest measurement range possible will be limited by safety exclusion zones around the piling vessels. The use of suitable static recorders may enable some of these limitations to be overcome.

- Special consideration may be required for measurements where concurrent piling might be taking place either in the same OWF, or neighbouring offshore developments.
- For the measurement of other static noise sources (for example, alternative construction methods or operational wind turbines) consideration of spatial and temporal factors stated above would also apply.

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UK studies to date are in agreement that, over the timescale of the recent investigations no large scale (i.e. within the area of the wind farm and boundary areas) benthic community changes that could be attributed to OWF developments have been detected. These have been conducted over a three year post construction period; hence any future large scale benthic monitoring need not be conducted within this same timeframe unless local conditions dictate the need. In all cases the monitoring will be built upon the basic principles that the EIA will have predicted an impact, including its nature, level of certainty, significance and timescale, and that these will be accounted for in a hypothesis. Notwithstanding these two basic principles the potential for new knowledge and or unforeseen impacts should be taken into account and built into the potential to modify the monitoring requirements. It is recommended that monitoring should be refocused in the following manner; acknowledging that some of this monitoring already exists:

- Specific focused studies on conservation / ecologically important features should be based on appropriate BACI design, with methods related to the habitat, and timescales related to the ecological character of the feature, e.g. *Sabellaria* reef feature, annual assessment of impact and or recovery over a three year period, using dropdown video and benthic grab sampling; damage to sensitive intertidal habitats/biotopes through biotope mapping surveys at one, three and five year intervals.
- Benthic ecological assessment, covering the area of the wind farm and boundary areas, through pre-construction baseline grabbing, video and 2m beam trawl surveys, as currently. If possible a number of benthic grabs, videos and 2m beam trawl sites to be located within close proximity to a number of proposed turbines.
- Local colonisation studies on a small number of representative turbines (depending on variation in local conditions) to assess occurrence of non-indigenous species (NIS) (diving/video including sampling) and development of biomass (diving sampling), noting that NIS may be some of the first species to occur.
- Subsequent consideration of the consequence of the impacts of scour/organic deposition (geophysical survey, diving coring and or grab sampling in close

proximity to a number of turbines) and trophic level impacts on local epifaunal and small/juvenile fish populations within appropriate radius of turbine (video and if practical 2m beam trawl), in both cases repeating baseline sampling.
- Longer term consideration, including the whole, or relevant parts of, the wind farm and boundary areas, employing benthic grab, video and 2m beam trawl studies, as a repeat of the baseline surveys, built on the outcomes of the above localised studies.

It should be emphasised that where impacts, that have arisen during the initial phase of monitoring, are less than predicted, then consideration may be given to increasing the interval between surveys and *vice versa*. This should be discussed and agreed with the regulator and their specialist advisors.

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Sampling periodicity and spatial scale of PCM should be site-specific and based upon the sensitive receptors predicted to be impacted that occur at a site. For example, if there is concern during the construction phase of a project about the effects of piling noise acting as a barrier to spawning migration for a particular species of fish species, then baseline data (i.e. CPUE from commercial fisheries) should be gathered on the abundance of this species during previous years. If during the first year of PCM following piling activity, the population is found to be within that observed naturally, then it is likely that there is no impact to that population and as such is of less concern.

Acute impacts to fish and shellfish relate to piling noise during construction works. Effects on fish and shellfish populations have the potential to cause dramatic and rapid declines as fish are displaced from the area. However as the duration of construction activity is relatively short (though increasing with R3), recovery to levels similar to baseline conditions is known to occur within a number of years after the cessation of works as has been shown at Barrow and North Hoyle OWFs (nPower renewables 2008, BoWind 2008). Operational impacts have more chronic long term effects on fish and shellfish populations related to changes to the hydrodynamic regime, reef and FAD effects and potentially EMF emissions and operational noise.

The monitoring of acute construction impacts needs specific monitoring occurring over the short term targeted at sensitive receptors for which significant impacts have been predicted or where there is high uncertainty in the impact statement. This will be increasingly important for the larger Round 2 and Round 3 projects as the duration and scale of construction activities increases by an order of magnitude. In cases where many sensitive receptors occur as with piling noise, a selection of the species considered to be most likely to show a change in their population should be agreed by an expert panel of ecologists, statutory advisors and the regulator. Monitoring of acute effects should be supported by targeted research on sensitive species.

For the monitoring of the comparatively longer lasting effects from operational wind farms including reef/FAD effects, EMF and changes to the hydrodynamic regime, these effects can continue to be monitored at the broad scale but the temporal activity of sampling should be lengthened Instead of monitoring in years 1 to 3 (as at present) it is proposed that monitoring occurs in years 1, 5 and 10 so as to best determine long term effects of the development. It may be necessary to increase the number of replications so as to better understand natural variability at the site and to bolster the statistical analyses. Careful survey design would enable key questions (i.e. for EMF – is fish behaviour changed and if so to what extent? For FAD are fish numbers within the OWF different to those outside?), to be specifically addressed. This should be addressed by research, rather than site-specific modelling, unless significant impacts are predicted. Operational effects have been relatively well studied at least during the short term (1-7 years) with few if any significant impacts reported to the fish and shellfish populations. Any impacts reported to date such as the depletion of gobies within Horns Rev have gone largely unnoticed up the food web, with no effects reported on larger predatory fish species as the role this species played within the food chain was likely replaced by colonising benthos and the attraction of increased numbers of small fish species within the array. The integration of these aspects of the studies with the benthic populations and trophic interactions is important, potentially including species or phyla level biomass and productivity calculations. It is likely that operational effects on selected populations could be monitored at the regional scale with a few sites within each region e.g. Southern North Sea, English Channel, Irish Sea monitored for the long term effects to fish and shellfish.

Post-consent monitoring has the potential to inform significantly on the scale of displacement and disturbance that may be associated with piling noise during the construction period of OWFs and how this varies over time. The scale of the monitoring should be sufficiently large so as to demonstrate whether changes in fish and shellfish abundances within the impacted area (noise radii) differ from those away from the impact. Before-after-gradient (BAG) surveys would be a suitable means to monitor the effects of construction noise. However where greatest uncertainty remains, e.g. the habituation of fish to piling noise, EMF effects on diadromous species, masking effects of operational noise on cod and haddock spawning calls etc. strategic research should be conducted to help resolve these issues unlikely to be picked up during PCM.

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SMRU Ltd (2010) provides details of the issues that need to be addressed when considering impact monitoring for marine mammals at OWF sites. Whilst there is value in industry best practice guidance on the principles underlying good monitoring design, being too prescriptive can act as a barrier to the development of better methodologies. The following principles are likely to be universal: that the scale of the monitoring is appropriate for the temporal and spatial variability in the metric under investigation, and power analyses should be carried out in order to determine the minimum effort for sampling that is required in order to be able to detect change; the monitoring must be designed such that any responses can be tied to specific causes and that the contribution of alternative drivers for change are accounted for as much as possible; at individual OWF sites it would be impossible to determine impacts at population level for most marine mammal species and therefore efforts should focus on key uncertainties, particularly relating to responses during the construction period and the nature and the timeframe recovery afterwards.

While the monitoring design will be site and species specific, some general rules can be set:

- To adequately characterise the baseline levels of inter-annual variation in marine mammal density or use of a particular area, several years of pre-construction monitoring may be required. Depending on the timeframe between baseline characterisation and consent and planned construction, and the methods employed during the corresponding EIA characterisation survey it is possible that the EIA characterisation survey data could form part of this requirement.
- Power analyses of baseline data should be conducted to ensure that the methodologies are appropriate for detecting change of a given magnitude.
- Pre-construction monitoring data collected over the initial period should be used to conduct a power analysis in order to refine or adjust the monitoring design if necessary – ideally this could be done on the baseline survey data to ascertain the likely power to detect change.
- The sampling periodicity should account for seasonal variation, i.e. being at least on a monthly basis.
- The spatial resolution should ensure an appropriate coverage of the wind farm site and the potential impact footprint to allow the detection of changes in distribution of animals in relation to the development.

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Post-consent monitoring has the potential to add significantly to the evidence base on the scale of displacement that may be associated with wind farms and how this varies over time.

Spatial scale

Quantification of the spatial scale of monitoring is required at the outset, and it is important to note that the appropriate scale is likely to be site-specific, due to variation in the bird species considered and the environmental characteristics that determine their local distributions. The recommendations of Camphuysen *et al.* (2004) suggested that surveyed areas should be six times the size of the wind farm footprint. Current draft guidance from SNH and Marine Scotland (Jackson and Whitfield, 2011) also advocate a prescriptive approach stating that the buffer width around the wind farm which should be surveyed should be determined by broad size classes of the development (size <5km^2 = ≥ 1km buffer; size 5km^2-10km^2 = ≥ 2km buffer; size >10km^2 = ≥ 4km buffer). However, Rexstad and Buckland (2012), analysing data from the Kentish Flats OWF, suggested that such study areas may be small for the purpose of describing the spatial redistribution of seabirds as a consequence of wind farm construction and operation.

It is recommended, therefore, that the size of the area to be surveyed should be determined on a site-by-site basis. Pre-construction monitoring data collected over the initial period should be used to conduct a power analysis in order to inform on the adequacy of the spatial scale of monitoring and the ultimate power to detect change and thus refine or adjust the monitoring design as necessary.

The scale of survey area should be adequate to be able to demonstrate whether changes in the densities of birds differ between the area of the wind farm and surrounding areas where birds might be expected to be displaced to. A larger area will also expand the range in any explanatory covariates used in a density-surface modelling approach (Rexstad and Buckland 2012). In the case of Robin Rigg, where a density-surface modelling approach has been used, a survey area of very approximately 320km^2 has been covered in comparison to the wind farm footprint of 18km^2.

Consideration should be given as to whether monitoring may be combined across sites where they are proximate. While such combined monitoring may be an ideal, monitoring at a site-level still has the potential to add significantly to the evidence base on this issue, although only if studies are well-designed.

Temporal scale

To adequately characterise the baseline numbers of seabirds, at least three years of pre-construction monitoring would preferably be required in order to account for inter-annual variation. Depending on the timeframe between the collection of data used to inform the ES and consent and planned construction, and the methods employed for the surveys used to inform the ES, it is possible that these data could form part of this requirement.

Consideration should be given in the survey methodology and design as to when the key receptors being investigated will be present in the study area, and analyses and reporting tailored accordingly. Sampling effort should aim to capture sufficient information at the appropriate temporal scale for the required analyses. The frequency of monitoring should thus be determined by analyses that evaluate the power to detect changes from the surveys undertaken.

Although there may be relatively limited scope, the potential for examining variation in changes in distributions through the course of the construction period should also be addressed.

Post-construction, analyses should be undertaken (with respect to displacement and other effects) annually. Annual evaluation should help inform on the effectiveness of the monitoring and any changes required and the need for continuing monitoring beyond an initial agreed period (e.g. three years). With respect to displacement, annual evaluation will also enable the potential for displacement effects to reduce through habituation to be explored.

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Monitoring should aim to provide information on the numbers of birds exposed to collision risk (i.e. on the numbers flying through a site and their flight heights). The aim of this monitoring should be to provide evidence of the potential exposure of birds to collision risk at the site and how this may have changed from the pre-construction period, through and post-construction, rather than to directly collect information on collision mortality at the site-level. These data can then be used to undertake collision risk analyses informed by the results on avoidance rates from the ORJIP project or similar programmes. The need for any monitoring over and above this, should be informed by the results of these collision risk analyses.

As above, the potential for collision may vary over time and hence studies should aim to collect adequate data to provide information on the numbers of birds exposed to collision risk on an annual basis.

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Monitoring should aim to provide information on the numbers of birds exposed to barrier effects, the proportion of these avoiding the wind farm site, the increase in flight distance resulting from the wind farm and thus the energetic consequence. As above, the potential for barrier effects may vary over time and hence studies should aim to collect adequate data to provide information on an annual basis.

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