An Assessment of the Impact of Selected Fishing Activities on European Marine Sites and a Review of Mitigation Measures

July 2007

Jack Sewell, Rebecca Harris,
Hilmar Hinz, Steven Votier and
Keith Hiscock

SR591

Working with the seafood industry to satisfy consumers, raise standards, improve efficiency and secure a sustainable future.

The Sea Fish Industry Authority (Seafish) was established by the Government in 1981 and is a Non Departmental Public Body (NDPB).

Seafish activities are directed at the entire UK seafood industry including the catching, processing, retailing and catering sectors.

Seafish Technology and Training: We promote the sustainable use of fish resources, quality, the reduction of waste and the improvement of safety through practical applied research.

We also develop standards, training programmes and learning support materials. We also promote training opportunities for all sectors of the sea fish industry through a national network of Group Training Associations. Quality award schemes are available for processors and friers.

ISBN – 0 903941 69 4

Seafish Technology

Authors: Jack Sewell, Rebecca Harris, Hilmar Hinz, Stephen Votier, Keith Hiscock.

The Marine Biological Association and the University of Plymouth

Date: July 2007

AN ASSESSMENT OF THE IMPACT OF SELECTED FISHING ACTIVITIES ON EUROPEAN MARINE SITES AND A REVIEW OF MITIGATION MEASURES.

Plymouth Marine Sciences Partnership

AN ASSESSMENT OF THE IMPACT OF SELECTED FISHING ACTIVITIES ON EUROPEAN MARINE SITES AND A REVIEW OF MITIGATION MEASURES.

Jack Sewell, Rebecca Harris, Hilmar Hinz, Stephen Votier, Keith Hiscock.

Executive summary

Introduction

'European Marine Sites' (EMS) include Special Areas of Conservation (SAC) and Special Protection Areas (SPA) established under European Commission Directives.

A proposal to carry out a fishing or aquaculture activity in a European marine site could be subject to an environmental impact assessment, known as an 'appropriate assessment', depending on the nature of the proposal and whether it is likely to have a significant effect (e.g. deterioration or disturbance) on the key features of the site. If there is a likelihood of significant harm, the body that authorises the fishing or aquaculture proposal (known as the 'competent authority') will carry out an appropriate assessment and will request information from the applicant as well as receiving advice from the relevant nature conservation agency.

The appropriate assessment considers the implications of the proposal on the features for which the site was classified (e.g. reefs, sandbanks, coastal bird species etc). The scope and content of an appropriate assessment will depend on the nature, location, duration and scale of the proposed activity and the conservation objectives for the interest features of the site. Following the appropriate assessment, the competent authority must ascertain that the proposal will not have an adverse affect on the integrity of the site before it may grant permission.

The appropriate assessment procedure is set out in the Conservation (Natural Habitats &c.) Regulations 1994, sometimes known as the 'Habitat Regulations', which transposed into UK law the provisions of the European Union's 'Habitats Directive' on the conservation of natural habitats, and of wild fauna and flora.

Objectives of the study

The report summarised here has been commissioned by the Sea Fish Industry Authority (SEAFISH) with the aim of determining the potential impact of fisheries on EMS interest features and site integrity in relation to their conservation objectives. The report also identifies potential mitigation methods to reduce the impact of selected fisheries on EMS interest features and provides recommendations for further work in order to improve the accuracy of future desk-based assessments. It is hoped that the report will reduce the time taken to carry out future appropriate assessments. The report provides the scientifically sound information required to evaluate the potential impact a fishery may have on interest features.

Methods used

The project has taken the form of a desk-based study. Available literature from scientifically sound sources has been reviewed and information regarding potential impacts of different fisheries added to an existing database. Interviews have also been carried out with UK competent authorities (mainly fisheries authorities). Research organisations, non governmental organisations and statutory nature conservation agencies throughout the UK and overseas were also contacted for their views and to identify past, current and future relevant work.

Conservation issues and fishing types

The following conservation issues and fishing types are the primary focus of the report.

- All aspects of bird disturbance, both on the foreshore and at sea, caused by fishing vessels and activities, and on-shore fishing activities.
- All aspects of competition for shellfish resources between fisheries and wetland birds, waterfowl and seabirds.
- All aspects of benthic and consequential impacts of hydraulic suction dredging (all dredge forms that enable fishing for bivalve molluscs buried in seabed sediments by using high pressure water to loosen or fluidise sediments).
- All aspects of benthic and consequential impacts of scallop dredging (toothed scallop dredges whether used for scallops or other bivalve species).
- All aspects of benthic and consequential impacts of oyster culture systems, husbandry techniques, stock enhancement and harvesting.

Description and distribution of relevant habitats and species

The report includes information about Habitats Directive relevant Annex I habitats and Annex II species; seabirds and estuarine/coastal birds occurring around the UK which are on Annex I of the Birds Directive; regularly occurring migratory seabirds and estuarine/coastal birds around the UK not on Annex I of the Birds Directive and other marine species protected by law in the UK under the Wildlife and Countryside Act 1981, which may be affected by the subjects covered. Current distribution of EMS features and status of the features within EMS are also provided where possible.

Source references and information

Throughout the text, the scientific papers and reports that have led to conclusions are identified. References are maintained on an electronic database which can be accessed from http://www.marlin.ac.uk. The database has been used to generate a tabulated summary of the information in each source reference used in the review.

Using the report to assist in appropriate assessments

At the time of preparation, the report and associated database and its Web front-end is considered to provide a comprehensive source of literature and conclusions from the literature on the likely effects of different fishing activities on Interest Features within EMS. When an activity is being considered that requires an appropriate assessment, the proposer should check if existing information is sufficient to identify likely adverse effects on interest features. If there is not sufficient information, then new research may need to be pursued. Summary tables for each fishing type have been used in the report for quick reference. The information within the tables is fully referenced. Information is given for the relevant interest features and an assessment is given on whether the activity is likely to have an acceptable impact on the feature based on the conservation objectives given in the Habitats Directive.

Report Outline

Description and distribution of relevant habitats and species

This section of the report includes information about Habitats Directive Annex I habitats; relevant Annex II species; seabirds and estuarine/coastal birds occurring around the UK which are on Annex I of the Birds Directive; regularly occurring migratory seabirds and estuarine/coastal birds around the UK not on Annex I of the Birds Directive and other marine species protected by law in the UK under the Wildlife and Countryside Act 1981, which may be affected by the subjects covered. Current distribution of EMS features and status of the features within EMS are also provided where possible and maps have been provided showing the distribution of EMS features around the UK.

An overview of relevant fishing activities in the UK EMS based on interviews with competent authorities

An overview is given of the status of hydraulic suction dredging; scallop dredging; oyster culture; fishery related bird disturbance and competition between fisheries and birds for shellfish resources in UK EMS. The information has come from interviews with regional competent authority representatives and as such, represents the views and opinions of this expert group. For England and Wales, all regional Sea Fisheries Committees (SFCs) were interviewed. For Scotland, Scottish Natural Heritage and Scottish Executive were interviewed and for Shetland, the Shetland Council. Unfortunately, it was not possible to arrange interviews with competent authority representatives from Northern Ireland.

Disturbance of birds by fisheries

Specific effects of fisheries are discussed for the following fishing types, which are thought to cause disturbance to bird populations:

- offshore fisheries;
- hand gathering and bait collection;
- mariculture;
- dredging, and
- coastal net fisheries.

Mitigation methods including those currently undertaken in the UK are also discussed.

Competition for shellfish food resources between fisheries and birds

Fisheries where such competition is likely to occur are discussed in detail, these fisheries are:

- dredging;
- tractor dredging;
- hydraulic suction dredging;
- hand gathering, and
- aquaculture.

Mitigation methods including those currently undertaken in the UK and research needs are also discussed.

Hydraulic suction dredging

Potential impacts of hydraulic suction dredging are described for Annex I habitats, and sub features, Annex II species and other protected species, namely:

- Shallow sandbanks which are slightly covered by seawater all the time;
- Eelgrass beds;
- Maerl beds;
- Estuaries;
- Mudflats and sandflats not covered by seawater at low tide;
- Coastal lagoons;
- Large shallow inlets and bays, and
- *Atrina fragilis* (fan mussel).

Methods of mitigating potential impacts on EMS interest features are discussed. The current UK perspective and future and current work are also discussed.

Scallop dredging

Potential impacts of scallop dredging are described for Annex I habitats, and sub features, Annex II species and other protected species, namely:

- shallow sandbanks which are slightly covered by seawater all the time;
- maerl beds;
- eelgrass beds;
- estuaries;
- large shallow inlets and bays;
- reefs;
- rock reefs (including cobble);
- horse mussel beds;
- *Lophelia* reefs;
- file shell reefs;
- *Sabellaria spinulosa* reefs;
- *Eunicella verrucosa* (pink seafan), and *Amphianthus dohrnii* (sea fan anemone);
- *Atrina fragilis* (fan mussel).

Methods of mitigating potential impacts on EMS interest features are discussed. The current UK perspective and future and current work are also discussed.

Oyster culture, husbandry, stock enhancements and harvesting

Potential impacts of oyster culture systems are described for Annex I habitats, and sub features, Annex II species and other protected species, namely:

- Shallow sandbanks which are slightly covered by seawater all the time;
- *Zostera marina* beds;
- Estuaries;
- Mudflats and sandflats not covered by seawater at low tide;
- Large shallow inlets and bays;
- Reefs, and
- bottle-nosed dolphins.

Methods of mitigating potential impacts on EMS interest features are discussed. The current UK perspective and future and current work are also discussed.

Mitigation methods

A number of mitigation methods used currently or currently being investigated are discussed. Reference is made to practices currently utilized in New Zealand, Australia, Canada and the USA, including case studies.

Conclusions and recommendations

Conclusions and recommendations are made, based on the information reviewed throughout the report. Common and recurring issues are discussed and gaps in knowledge are identified, as are areas where future work is recommended.

Acknowledgements

References

Appendices

Firstly, the questionnaire used during semi-structured interviews with competent authorities is given. Secondly, all look-up tables showing the potential impacts of the three main fishing types discussed. Finally, a summary table for references used in the report is included and provides further information about the various studies referenced in the report.

Contents

Executive summary 3

Report outline 5

1. Introduction 13

2. Description and distribution of relevant habitats and species 19

2.1. Habitat Directive Annex I habitats 21

2.1.1. Shallow sandbanks which are slightly covered by seawater all the time 21

2.1.2. Estuaries 22

2.1.3. Mudflats and sandflats not covered by seawater at low tide 23

2.1.4. Coastal lagoons 24

2.1.5. Large shallow inlets and bays 25

2.1.6. Reefs 26

***2.2. Habitats Directive Annex II species* 27**

2.2.1. Common seal *Phoca vitulina* and grey seal, *Halichoerus grypus* 27

2.2.2. Bottle-nosed dolphin, *Tursiops truncatus* 29

2.2.3. Otter, *Lutra lutra* 30

2.2.4. Allis shad, *Alosa alosa* and twaite shad, *Alosa fallax* 31

2.3. Other relevant UK protected species 33

2.3.1. Fan mussel *Atrina fragilis* 33

2.3.2. Pink sea fan *Eunicella verrucosa* 34

2.3.3. Sea fan anemone *Amphianthus dohrnii* 34

2.4. Special Protection Areas (SPA) 34

3. An overview of relevant fishing activities in the UK EMS based on interviews with competent authorities. 35

4. Disturbance of birds by fisheries 43

4.1. Overview 43

4.2. Offshore fisheries 46

4.2.1. Waders 46

4.2.2. Seabirds 46

4.2.3. Wildfowl 48

4.3. Hand gathering and bait collection 48

4.3.1. Waders 48

4.3.2. Seabirds 49

4.3.3. Wildfowl 49

4.4. Mariculture 49

4.4.1. Waders 49

4.4.2. Seabirds 50

4.4.3. Wildfowl 50

4.5. Dredging 50
4.5.1. Waders 50
4.5.2. Seabirds 51
4.5.3. Wildfowl 51
4.6. Coastal net fisheries 51
4.6.1. Waders 51
4.6.2. Seabirds 51
4.7. Mitigation methods 52
4.7.1. UK methods currently utilised 52
4.7.2. Offshore fisheries 53
4.7.3. Hand gathering and bait collection 54
5. Competition for shellfish food resources between fisheries and birds. 57
5.1. Overview 57
5.2. Dredging 57
5.2.1. Waders 57
5.2.2. Wildfowl 57
5.3. Tractor dredging (cockles) 57
5.3.1. Waders 57
5.3.2. Seabirds 58
5.3.3. Wildfowl 58
5.4. Hydraulic suction dredging 58
5.4.1. Waders 58
5.4.2. Seabirds 59
5.4.3. Wildfowl 59
5.5. Hand gathering 60
5.6. Aquaculture 60
5.7. Mitigation methods 60
5.8. Gaps in knowledge and research needs. 61
6. Hydraulic suction dredging 63
6.1. Overview 63
6.2. Potential effects on Annex I habitats 66
6.2.1. Shallow sandbanks which are slightly covered by seawater all the time 66
6.2.2. Estuaries 68
6.2.3. Mudflats and sandflats not covered by seawater at low tide 68
6.2.4. Coastal lagoons 69
6.2.5. Large shallow inlets and bays 69
6.3. Potential effects on Habitats Directive Annex II and protected species 69

6.4. Mitigation methods ... 69
6.4.1. Current UK perspective ... 71
6.5. Future and current work ... 71
7. Scallop dredging ... 73
7.1. Overview ... 73
7.2. Potential effects on Annex I habitats ... 78
7.2.1. Shallow sandbanks which are slightly covered by seawater all the time 78
7.2.2. Estuaries ... 80
7.2.3. Large shallow inlets and bays ... 80
7.2.4. Reefs ... 81
7.3. Potential effects on Habitats Directive Annex II and protected species 83
7.4. Mitigation methods ... 83
7.4.1. Current UK perspective ... 84
7.5. Future and current work ... 87
8. Oyster culture, husbandry, stock enhancements and harvesting. ... 88
8.1. Overview ... 88
8.2. Potential effects on Annex I habitats ... 91
8.2.1. Shallow sandbanks which are slightly covered by seawater all the time 91
8.2.2. Estuaries ... 92
8.2.3. Mudflats and sandflats not covered by seawater at low tide ... 92
8.2.4. Large shallow inlets and bays ... 92
8.2.5. Reefs ... 93
8.3. Potential effects on Habitats Directive Annex II and protected species 93
8.4. Mitigation methods ... 93
8.4.1. Current UK perspective ... 95
8.5. Future and current work ... 95
9. Mitigation methods ... 96
9.1. International measures ... 96
9.1.1. New Zealand ... 96
9.1.2. Australia ... 98
9.1.3. Canada ... 100
9.1.4. USA ... 102
10. Conclusions and recommendations ... 103
11. Acknowledgements ... 105
12. References ... 106

1. Introduction

Following the European Court of Justice Case C-127/02 (the Waddenzee Judgement), the Court ruled that within EMS (European Marine Sites) Fisheries could be considered as 'plans or projects' and as such, new fisheries and those requiring an annual authorization may be subject to the appropriate assessment process if it is thought to have a 'likely significant effect'. Such activities may only be authorized in EMS if the competent authority has made certain that the activity will not adversely affect the integrity of the site and that this is only the case where no reasonable scientific doubt remains as to the absence of such effects [1]. In the UK, locations managed as EMS include those that are possible/draft, candidate and designated SAC (Special Areas of Conservation) and SPA (Special Protection Areas), SSSI (Sites of Special Scientific Interest) and Ramsar sites. Since the Waddenzee Judgement, those wishing to begin new fishing activities or make changes to existing fisheries within designated sites are required to undertake appropriate assessments. The appropriate assessment process can be long and drawn out, some taking several years before decisions are made. The delay caused can create problems for all, using valuable resources from the fishing industry and conservation sector. Many of the delays are due to a shortfall in relevant scientific information. The following report has been commissioned by SEAFISH (The Sea Fish Industry Authority) with the aim of reducing the time taken to carry out appropriate assessments, by providing the scientifically sound information required to evaluate the potential impact a fishery may have on interest features. Interest (or conservation) features are species and habitats specified in the EC Habitats Directive [2] or EC Birds Directive [3] identified when a site is proposed. Conservation objectives for a site must ensure that interest features remain in a 'favorable state'. The following report also reviews some of the mitigation methods which may be adopted to reduce or eliminate potential impacts. Reducing the potential impact a fishery may have on interest features by introducing mitigation measures will increase the likelihood that the activity can take place or continue in a EMS.

The EC Habitats Directive [2] requires that member states must ensure the protection of interest features including Annex I habitats and listed priority species for which the site is designated within SAC and cSAC (candidate Special Areas of Conservation). The Directive states that within SAC, the necessary conservation measures must be applied for the "maintenance or restoration, at favourable conservation status, of the natural habitats and/or the populations of the species for which the site is designated". The requirements of the directive have been transposed into UK law through the Conservation (Natural Habitats &c.) Regulations 1994. Boxes 1 and 2 contain a copy of the relevant articles of the Directive.

Box 1: Article 1(e) of the EC Habitats Directive [2]

Conservation status of a natural habitat means the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species within the territory referred to in Article 2.

The conservative status of a natural habitat will be taken as 'favourable' when:

- its natural range and areas it covers within that range are stable or increasing, and

- the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and

- the conservation status of its typical species is favourable as defined in (i)[See box 2];

Box 2: Article 1(i) of the EC Habitats Directive [2]

Conservation status of a species means the sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations within the territory referred to in Article 2;

The conservation status will be taken as 'favourable' when:

- population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and

- the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and

- there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

Under the EC Birds Directive [3], the UK Government is required to protect certain migratory bird species, as well as those species specifically listed in Annex II of the Directive. The Directive requires Member States to designate SPA for the protection of species. The UK has established SPA in areas previously designated as SSSI or ASSI (Areas of Special Scientific Interest) in Northern Ireland in order to utilise legislation already in existence. Under the Birds Directive, the member states must "take the requisite measures to maintain the population of the species referred to in Article 1 at a level which corresponds in particular to ecological, scientific and cultural requirements, while taking account of economic and recreational requirements, or to adapt the population of these species to that level" [3]. They must also take the "requisite measures to preserve, maintain or re-establish a sufficient diversity and area of habitats" for all these species [3]. Member states are required to develop special conservation measures to protect the survival and reproduction of the listed species in their area of distribution.

Following a previous study undertaken by SEAFISH [4] the following fishing types and conservation issues have been identified as those most commonly involved in the appropriate assessment process and have been the primary focus of this project.

- All aspects of bird disturbance, both on the foreshore and at sea, caused by fishing vessels and activities, and on-shore fishing activities.
- All aspects of competition for shellfish resources between fisheries and wetland birds, waterfowl and seabirds.
- All direct and consequential impacts of hydraulic suction dredging (all dredge forms that enable fishing for bivalve molluscs buried in seabed sediments by using high pressure water to loosen or fluidise sediments).
- All aspects of benthic and consequential impacts of scallop dredging (toothed scallop dredges whether used for scallops or other bivalve species).
- All aspects of benthic and consequential impacts of oyster culture systems, husbandry techniques, stock enhancement and harvesting.

In order to assess the known and potential impacts, an extensive review of past, current and future scientific research looking at the fishing types and conservation issues listed has been undertaken. The project focuses particularly on EMS, although habitats likely to occur in EMS and UK protected species are also included. The authors of this report have attempted to identify areas where information is deficient or to identify the need for future work

The project was based on a desk-based study, which reviewed literature from scientifically sound sources, particularly peer reviewed work. Extensive use has also been made of previous reviews [5, 6] which examined the effects of fisheries on EMS. A database has been adapted from the interagency, 'Effects of Fisheries within European Marine Sites' database [6]. The revised database has added to a searchable, online resource containing relevant, summarised information about the information resources used during this project. A searchable version of the database will be made available online (see www.marlin.ac.uk/fisheriesmanagement). Summaries of relevant reviews are appended in a table at the end of this report (Appendix 3). The report is designed to be an un-biased review of the best current knowledge relating to the fishing methods and bird conservation issues, which are the focus of this report.

Semi-structured interviews were carried out between November 2006 and February 2007, with UK Competent Authorities, including Regional SFCs (Sea Fisheries Committees) and the Environment Agency. The information gained during these interviews has been used to help assess the perceived threats of fishing activities on Interest features within these sites and to assess the efficacy of the measures put in place to mitigate these threats. Research organisations, NGOs (Non-Governmental Organisations) and statutory conservation agencies throughout the UK and overseas were also contacted for their views and to identify past, current and future relevant work. Although the responses received were extremely useful, feedback from this avenue was limited. Where available, the information provided has been used to supplement the review and to help guide suggestions for future work. A copy of the questionnaire is included in Appendix 1.

Fisheries impacts 'lookup tables'

Fisheries impact tables have been developed for sections 5, 6 and 7 of the report. All tables are combined and presented in Appendix 2 of the report. The table structure used to summarise fishing impacts for each section of the report provides a factual alternative to a scoring matrix approach. It was felt that such a table would provide the reader with factual evidence-based information, as opposed to a scoring matrix, which could easily be taken out of context and potentially misused. The reader should be aware that the answer given in the table may not apply to all sites where the feature is present and sites should be assessed on a site-by-site basis using a precautionary approach. Also, many of the reports used are based only on a limited number of observations and the answer may not be relevant for long-term, chronic impacts. The following topics are included in the table and the reader is guided to relevant references for further information.

- **Interest feature (habitat &/or species) –** Refers to the EMS interest feature (habitat or species) or, in the case of birds, groupings or species.
- **Specific features of study site if applicable –** Refers to the specific features, for example, exposure, sediment type, species present etc. The study location is also given where possible. This information should enable the user to match conditions found in their interest area with the appropriate row on the table.
- **Activity details, including target species, gear, scale and timing (if available) –** Refers to features of activity, studied. These parameters are important when assessing the potential impact of future fisheries.
- **Impact details,** including recoverability, scale, community and habitat effects- A summary of relevant recorded impacts are given here.

The column headings requiring yes/no answers are based on conservation objectives from the Habitats Directive and provide a quick look-up reference when evaluating whether an activity is likely to have an unacceptable impact on an interest feature. The answer relates only to the specific feature in question and may not relate to other scenarios. The questions are as follows.

- *Could the activity reduce the range of the interest habitat or species?* – The answer will be 'yes' where there is evidence of long-term reductions in the range of a habitat or species, or where range is reduced and recovery is unknown. The answer will be 'no' when there is evidence that no such impact will take place.
- *Could the activity directly reduce the population of the interest species or interest habitat's 'typical species'? –* The answer will be 'yes' if evidence suggests a direct reduction of populations of interest species or 'typical species' which are long lasting or where recovery is unknown, i.e. through direct mortalities. The answer will be 'no' when there is evidence that no such impact will take place.
- *Could the activity indirectly reduce the population of the interest species or interest habitat's 'typical species'?* - The answer will be 'yes' if evidence suggests an indirect reduction of populations of interest species or 'typical species' which are long lasting, or where recovery rates are unknown but expected to be long e.g. through habitat loss, collateral damage or starvation. The answer will be 'no' when there is evidence that no such impact will take place.
- *Could the activity change the community composition of the habitat?–* The answer will be 'yes' where there is evidence that the fishing activity is likely to cause long-term change to community composition of a habitat or where recovery rate is unknown. The answer will be 'no' when there is evidence that no such impact will take place.
- *Could the activity affect the specific structures and functions, necessary for the maintenance of the interest feature? –* The answer will be 'yes' where evidence is given that the specified activity will affect any of the structures and functions necessary for the maintenance of the specified feature, such as habitat and trophic interactions and where these changes are likely to be long-term or where recovery rates are unknown. The answer will be 'no' when there is evidence that no such impact will take place.
- *Could the activity damage or kill any species of community interest within the feature? –* The answer will be 'yes' where evidence exists that a species, which is endangered, vulnerable, rare, endemic or of community importance, will be directly damaged or killed by the method being described in the feature. The answer will be 'no' when there is evidence that no such impact will take place.

An answer of 'yes' to any of the above questions indicates that the method described is likely to have an unacceptable impact on interest features and measures would likely be required to mitigate impacts of new fisheries, where these features are connected to the designation of a particular EMS. If 'no' is given as an answer, it indicates that the activity is unlikely to have an unacceptable impact on the feature. It is important to note that the answer given will be very specific to the level of activity and location described. Where the term ‘insufficient evidence’ is used, it is recommended that the following topics might form the basis of future study.

- **Number of supporting references –** The number of references found and used to come to the conclusions given. This also gives a level of confidence in the displayed information.
- **Reference numbers-** Allows the user to refer to the relevant references for further details if required. The number correlates with the report reference number and details will be given in a table appended to the final report as well as an online database.

2. Description and distribution of relevant habitats and species

Table 1 lists all current, relevant (in terms of this project) marine habitats and species found around the UK and currently identified under Annex I and II of the Habitats Directive. The table also includes Birds Directive (Annex I) species and migratory birds regularly occurring around the UK, which are likely to be subject to competition for shellfish resources or disturbance from fishing activities. Table 1 also lists some marine species protected by UK law under the Wildlife and Countryside Act 1981, which could potentially be affected by the selected activities.

The following section includes descriptions of the relevant marine habitats and species listed in the Habitats Directive. Current UK marine SAC are listed for each Annex I habitat and Annex II species. A distribution map is also shown for each feature. The grade of the feature in each SAC is shown on these maps and should be interpreted as follows:

A. Outstanding examples of the feature in a European context.

B. Excellent examples of the feature, significantly above the threshold for SSSI/ASSI notification but of somewhat lower value than grade A sites.

C. Examples of the feature which are of at least national importance (i.e. usually above the threshold for SSSI/ASSI notification on terrestrial sites) but not significantly above this. These features are not the primary reason for SAC being selected.

D. Features of below SSSI quality occurring on SAC These are non-qualifying features (“non-significant presence”), indicated by a letter D, but this is not a formal global grade.

All Habitat Directive Annex I habitats are habitat complexes, containing more than one sub-feature. For the purpose of this report, these sub-features are described and reference is made (where relevant) to other Annex I habitats containing these features. Some Annex I habitats are also likely to occur within other Annex I habitat complexes. For example; ‘Mudflats and sandflats not covered at low tide’ are likely to occur within ‘Estuaries’ or ‘Large shallow inlets and bays’. Where this is the case, the reader is directed to other relevant sections of the report to avoid the replication of text. Habitats are listed in the order they appear in the Habitats Directive. Habitats and Species for which no SAC has been proposed or where none of the relevant activities covered by this report occur have not been included as they fall outside the scope of this report. It is acknowledged that some of the activities discussed may affect saltmarsh habitats. However, it was decided that effects on saltmarshes were outside the scope of this project but might be an area for future investigation.

Table 1 Protected marine habitats and species found in UK waters, which may be impacted by hydraulic suction dredging, scallop dredging and oyster culture, and bird species likely to be affected by disturbance or competition for shellfish resources.

UK marine habitats listed in Annex I of the Habitats Directive whose conservation requires the designation of Special Areas of Conservation
Estuaries
Coastal lagoons
Large shallow inlets and bays
Sandbanks which are slightly covered by seawater all the time
Mudflats and sandflats not covered by seawater at low tide
Reefs

UK marine species on Annex II of the Habitats Directive whose conservation requires designation of Special Areas of Conservation	
Grey seal	*Halichoerus grypus*
Common seal	*Phoca vitulina*
Bottle-nosed dolphin	*Tursiops truncatus*
Otter	*Lutra lutra*
Allis shad	*Alosa alosa*
Twaite shad	*Alosa fallax*
Lampern	*Lampetra fluviatilis*
Sea lamprey	*Petromyzon marinus*

Seabirds and estuarine/coastal birds occurring around the UK which are on Annex I of the Birds Directive	
Red throated diver	Gavia *stellata*
Black throated diver	*Gavia arctica*
Great northern diver	*Gavia immer*
Slavonian grebe	*Podiceps auritus*
Storm petrel	*Hydrobates pelagicus*
Leach's petrel	*Oceanodroma luecorhoa*
Avocet	*Recurvirostra avosetta*
Golden plover	*Pluvialis apricaria*
Red-necked phalarope	*Phalaropus lobatus*
Mediterranean gull	*Larus melanocephalus*
Sandwich tern	*Sterna sandvicensis*
Roseate tern	*Sterna dougallii*
Common tern	*Sterna hirundo*
Arctic tern	*Sterna paradisaea*
Little tern	*Sterna albifrons*
Black tern	*Childonias niger*
Smew	*Mergus albellus*
Bar-tailed Godwit	*Limosa lapponica*
Great Bittern	*Botaurus slellaris*
Little Egret	*Egretta garzetta*
Whooper Swan	*Cygnus Cygnus*
Barnacle Goose	*Branta leucopsis*
Eurasian Marsh Harrier	*Circus aeruginosus*
Hen Harrier	*Circus cyaneus*
Ruff	*Philomachus pugnax*

Regularly occurring migratory seabirds and estuarine/coastal birds around the UK not on Annex I of the Birds Directive	
Fulmar	*Fulmaris glacialis*
Manx shearwater	*Puffinus puffinus*
Gannet	*Sula bassana*
Cormorant	*Phalacrocorax carbo*
Shag	*Phalacrocorax aristotelis*
Pink-footed Goose	*Anser brachyrhynchus*
Light-bellied Brent	*Branta bernicla bernicla*
Dark-bellied Brent	*Branta bernicla hrota*
Little Grebe	*Tachybaptus ruficollis*
Wigeon	*Anas Penelope*
Gadwall	*Anas strepera*
Scaup	*Aythya marila*
Shelduck	*Tadorna tadorna*
Eider	*Somateria mollissima*
Long-tailed duck	*Clangula hyemalis*
Common Teal	*Anas crecca*
Northern Pintail	*Anas acuta*
Common scoter	*Melanitta niga*
Velvet scoter	*Melanitta fusca*
Goldeneye	*Bucephala clangula*
Red-breasted merganser	*Mergus serrator*
Goosander	*Mergus merganser*
Oystercatcher	*Haematopus ostralegus*
Ringed plover	*Charadrius hiaticula*
Grey plover	*Pluvialis squaratola*
Lapwing	*Vanellus vanellus*
Knot	*Calidris canutus*
Sanderling	*Calidris alba*
Little Stint	*Calidris minuta*
Purple sandpipe	*Calidris maritime*
Dunlin	*Calidris alpina*
Common snipe	*Gallinago gallinago*
Black-tailed godwit	*Limosa limosa*
Whimbrel	*Numenius phaeopus*
Curlew	*Numenius arquata*
Redshank	*Tringa totanus*
Spotted redshank	*Tringa erythropus*
Greenshank	*Tringa nebularia*
Green sandpiper	*Tringa ochropus*
Common sandpiper	*Actitis hypoleucos*
Turnstone	*Arenaria interpres*
Arctic skua	*Stercorarius parasiticus*
Great skua	*Stercorarius skua*
Little gull	*Larus minutus*
Black-headed gull	*Larus ridibundus*
Common gull	*Larus canus*
Lesser black-backed gull	*Larus fuscus*
Herring gull	*Larus argentatus*
Iceland gull	*Larus glaucoides*
Glaucous gull	*Larus hyperboreus*
Great black-backed gull	*Larus marinus*
Kittiwake	*Rissa tridactyla*
Guillemot	*Uria aalge*
Razorbill	*Alca torda*
Puffin	*Fratercula arctica*

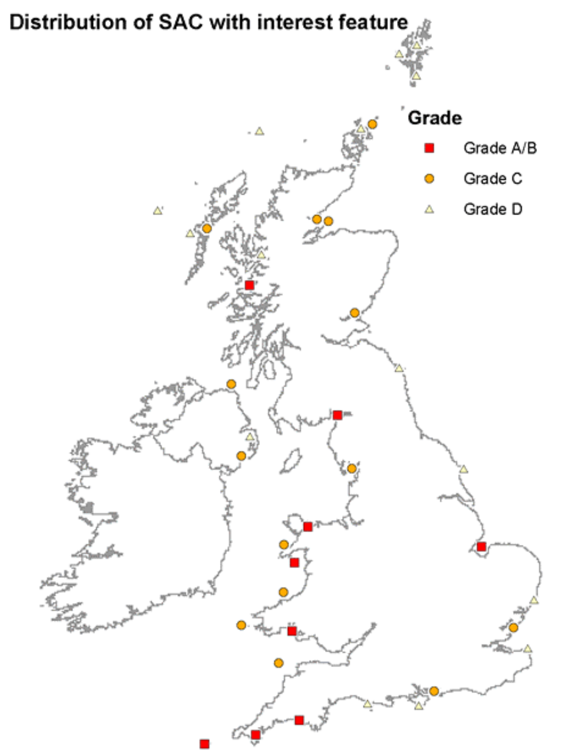
Marine Species protected by law in the UK under the Wildlife and countryside act, which may be affected by the fishing methods discussed	
Fan Mussel	*Atrina fragilis*
Pink seafan	*Eunicella verrucosa*
Seafan anemone	*Amphianthus dohrnii*

2.1. Habitat Directive Annex I habitats

The following sections provide a basic description of each habitat and its interest features. A map showing current SAC around the UK and the current status of these features in each SAC is included. SAC locations are listed in an accompanying table. Where an interest feature may be found within another, this information is given. Typical and important sub-habitats or interest features are described for each habitat.

2.1.1. Shallow sandbanks which are slightly covered by seawater all the time

SAC where Shallow sandbanks are a primary feature	Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd, Fal and Helford, Isles of Scilly Complex, Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau, Plymouth Sound and Estuaries, Solway Firth, Sound of Arisaig (Loch Ailort to Loch Ceann Traigh), The Wash and North Norfolk Coast, Y Fenai a Bae Conwy / Menai Strait and Conwy Bay.
SAC where Shallow sandbanks are a qualifying feature, but not a primary reason for site selection	Cardigan Bay / Bae Ceredigion, Dornoch Firth and Morrich More, Essex Estuaries, Firth of Tay & Eden Estuary, Loch nam Madadh, Luce Bay and Sands, Lundy, Moray Firth, Morecambe Bay, Murlough, Pembrokeshire Marine / Sir Benfro Forol, Rathlin Island, Sanday, Solent Maritime.



Distribution of UK SAC containing Sandbanks which are slightly covered by sea water all the time (habitat code 1110). From: www.jncc.gov.uk.

Shallow sandbanks which are slightly covered by seawater all the time are defined by the European Commission as: "Sublittoral sandbanks, permanently submerged. Water depth is seldom more than 20 m below Chart Datum"[7].

Shallow sandbanks may also occur within Estuaries (see section 2.1.2) or Large, shallow inlets and bays (see section 2.1.5). Shallow sandbanks may also directly connect with Mudflats and sandflats not covered by seawater at low tide (see section 2.1.3). Shallow sandbanks can include four main subtypes; gravelly and clean sands, muddy sands, eelgrass (*Zostera* spp) beds and maerl beds. Substrata can range from stable, sheltered systems to highly mobile, dynamic systems.

Zostera (eelgrass) beds

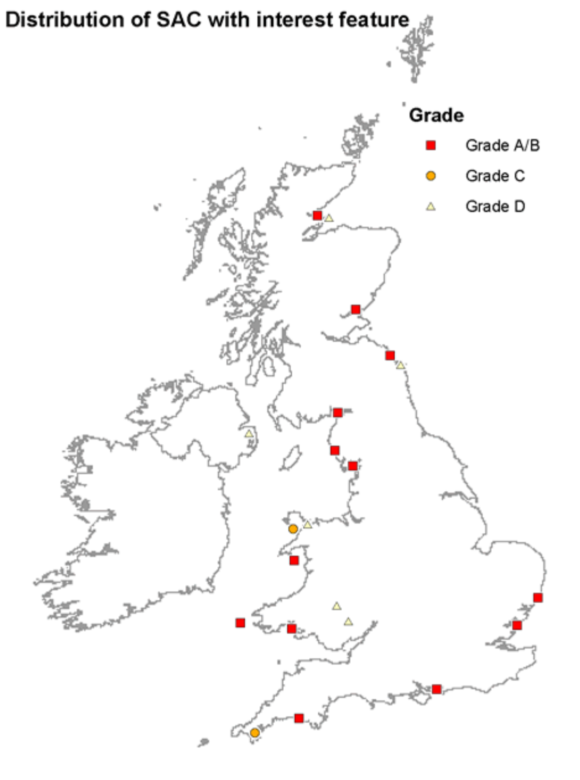
Eelgrass grows in soft sediments in shallow water where sufficient light is available. The network of roots, which are a feature of dense eelgrass beds, serves to accumulate sediments and creates a relatively stable habitat. Eelgrass provides a source of food for many species as well as providing a habitat for many others. It may also act as important nursery area for several fish species[8].

Maerl beds

Maerl is a very slow growing, fragile, calcareous red algae. Maerl beds can take many years to form, growing into complex shapes and providing a heterogeneous habitat. Maerl is very fragile and is easily broken. Once damaged, beds are slow to recover and become homogenized.

2.1.2. Estuaries

SAC where Estuaries is a primary feature	Alde, Ore and Butley Estuaries, Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd, Dornoch Firth and Morrich More, Drigg Coast, Essex Estuaries, Firth of Tay & Eden Estuary, Morecambe Bay, Pembrokeshire Marine/ Sir Benfro Forol, Pen Llyn a`r Sarnau/ Lleyn Peninsula and the Sarnau, Plymouth Sound and Estuaries, Solent Maritime, Solway Firth, Tweed Estuary.
SAC where Estuaries is a qualifying feature, but not a primary reason for site selection	Fal and Helford, Glannau Môn: Cors heli / Anglesey Coast: Saltmarsh.



Distribution of SAC containing Estuaries(habitat code 1130). From: www.jncc.gov.uk

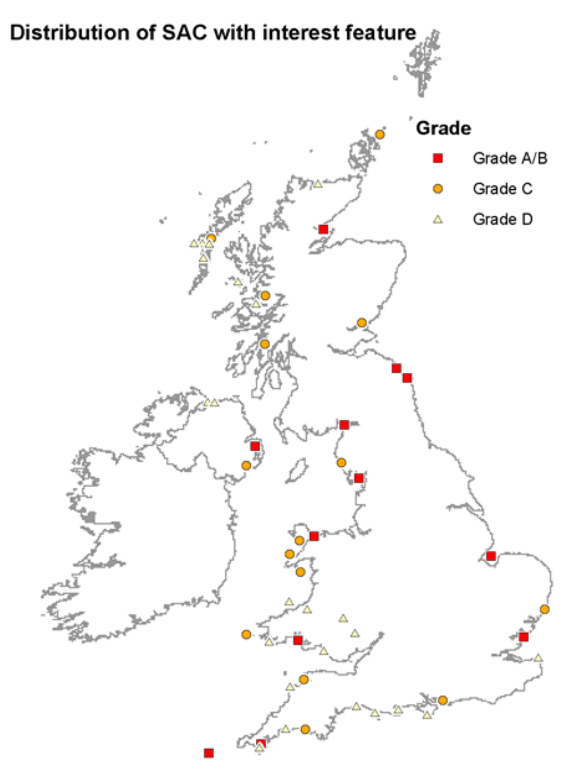
Estuaries are defined by the European commission as: "Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters. River estuaries are coastal inlets where, unlike 'Large shallow inlets and bays' there is generally a substantial freshwater influence. The mixing of freshwater and sea water and the reduced current flows in the shelter of the estuary lead to deposition of fine sediments, often forming extensive intertidal sand and mud flats [See 2.1.3]. Where the tidal currents are faster than flood tides, most sediments deposit to form a delta at the mouth of the estuary" [7].

As well as being physiographic features in their own right, estuaries are habitat complexes that may contain several other Annex I habitats, including Shallow sandbanks (see section 2.1.1), eelgrass beds (see section 2.1.1) and maerl beds (see section 2.1.1) mudflats and sandflats (see section 2.1.3), including *Zostera noltii* beds (see section 2.1.3) and reefs, including rock reefs and biogenic reefs (see section 2.1.6). Estuaries may also incorporate submerged or partially submerged sea caves, an Annex I habitat, although this is not within the scope of this report. The outer parts of some estuaries may also be considered for protection as large, shallow inlets and bays (see section 2.1.5). Estuaries may also contain the various types of salt marsh habitat, included in Annex I of the Habitats Directive, but these are not reviewed in this report.

Tidal flats, saltmarshes, areas of shingle, rocky shores, lagoons, sand dunes and coastal grassland may be elements of coastal and intertidal areas, and muddy and sandy seabed, gravels and rocky areas may be found in the subtidal zone. There is a rich source of invertebrates within the sediments of many estuaries, making them extremely productive areas as well as important feeding and over-wintering grounds for waders and wildfowl. The UK has the largest single national area of estuaries in Europe, making up around one quarter of the total estuarine habitat of North Sea shores and the Atlantic seaboard of Western Europe[9].

2.1.3. Mudflats and sandflats not covered by seawater at low tide

SAC where Mudflats & sandflats … is a primary feature	Berwickshire and North Northumberland Coast, Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd, Dornoch Firth and Morrich More, Essex Estuaries, Fal and Helford, Morecambe Bay, Solway Firth, Strangford Lough, The Wash and North Norfolk Coast, Tweed Estuary, Y Fenai a Bae Conwy / Menai Strait and Conwy Bay, Isles of Scilly Complex.
SAC where Mudflats & sandflats … is a qualifying feature, but not a primary reason for site selection	Alde, Ore and Butley Estuaries, Braunton Burrows, Drigg Coast, Firth of Tay & Eden Estuary, Glannau Môn: Cors heli / Anglesey Coast: Saltmarsh, Loch Moidart and Loch Shiel Woods, Loch nam Madadh, Luce Bay and Sands, Mòine Mhór, Murlough, Pembrokeshire Marine / Sir Benfro Forol, Pen Llyn a`r Sarnau/ Lleyn Peninsula and the Sarnau, Plymouth Sound and Estuaries, Sanday, Solent Maritime.



Distribution of SAC containing Mudflats and sandflats not covered by seawater at low tide (habitat code 1140). From www.jncc.gov.uk

Mudflats and sandflats not covered by seawater at low tide are defined by the European commission as: “Sands and muds of the coasts of the oceans, their connected seas and associated lagoons, not covered by sea water at low tide, devoid of vascular plants, usually coated by blue algae and diatoms” [7].

Mudflats and sandflats occur extensively at the mouths of large rivers (the downstream parts of estuaries) and in bays. The habitat is therefore often a part of ‘Estuaries’ (see section 2.1.2) and ‘Large shallow inlets and bays’ (see section 2.1.5). Mudflats and sand flats can be divided into the following types; Clean sands, muddy sands and mudflats. Eel grass (*Zostera noltii*) beds, exposed at low tide are also included in this habitat type. Mudflats and sand flats are also of particular importance as feeding grounds for wildfowl and waders. Mudflats and sandflats may also be directly connected to sandbanks which are slightly covered by sea water all the time (see section 2.1.1) and salt marsh habitat.

2.1.4. Coastal lagoons

SAC where Coastal lagoons is a primary feature	Bae Ceylon / Cemlyn Bay, Benacre to Easton Bavents Lagoons, Chesil and the Fleet, Loch nam Modadh, Loch of Stenness, Loch Roag Lagoons, North Norfolk Coast, Obain Loch Euphoirt, Orfordness – Shingle Street, Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau, Solent and Isle of Wight Lagoons, Strangford Lough, The Vadills.
SAC where Coastal lagoons is a qualifying feature, but not a primary reason for site selection	Morecambe Bay, Pembrokeshire Marine / Sir Benfro Forol, Solent Maritime, South Uist Machair, Sullom Voe, The Wash and North Norfolk Coast.

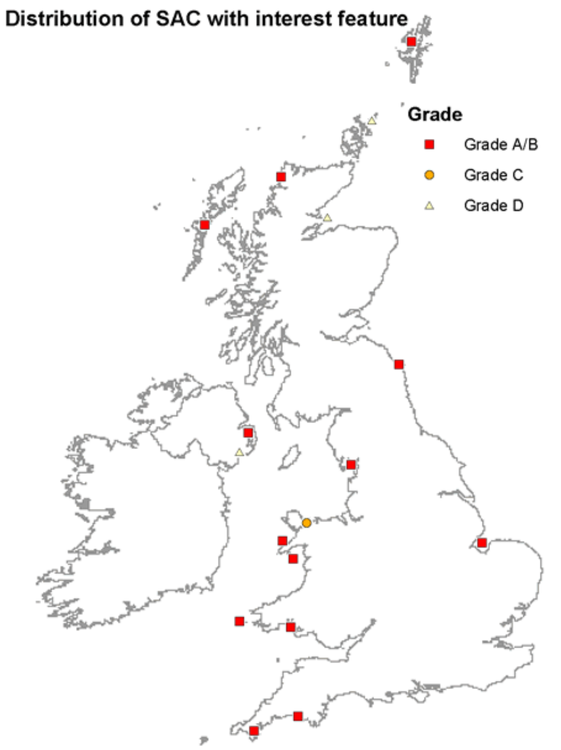
Distribution of SAC containing Coastal lagoons(habitat code 1150). From www.jncc.gov.uk

Coastal lagoons are defined by the European Commission as: "Lagoons are expanses of shallow coastal salt water, of varying salinity and water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding of the sea in winter or tidal exchange"[7].

These habitats may also contain eelgrass beds (see section 2.1.1).

2.1.5. Large shallow inlets and bays

SAC where Large shallow inlets and bays is a primary feature	Berwickshire and North Northumberland Coast, Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd, Fal and Helford, Loch Laxford, Loch nam Madadh, Luce Bay and Sands, Morecambe Bay, Pembrokeshire Marine/ Sir Benfro Forol, Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau, Plymouth Sound and Estuaries, Strangford Lough, Sullom Voe, The Wash and North Norfolk Coast.
SAC where Large shallow inlets and bays is a qualifying feature, but not a primary reason for site selection	Y Fenai a Bae Conwy / Menai Strait and Conwy Bay.



Distribution of SAC containing Large shallow inlets and bays (habitat code 1160). From www.jncc.gov.uk

Large shallow inlets and bays are defined by the European Commission as: "Large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited. These shallow* indentations are generally sheltered from wave action and contain a great diversity of sediments and substrates with a well developed zonation of benthic communities. These communities have generally a high biodiversity. The limit of shallow water is sometimes defined by the distribution of the *Zosteretea* and *Potametea* associations" [7].

There are three sub-types of this habitat complex relevant to the UK, these are: embayments, fjardic sea-lochs and rias (voes in Shetland).

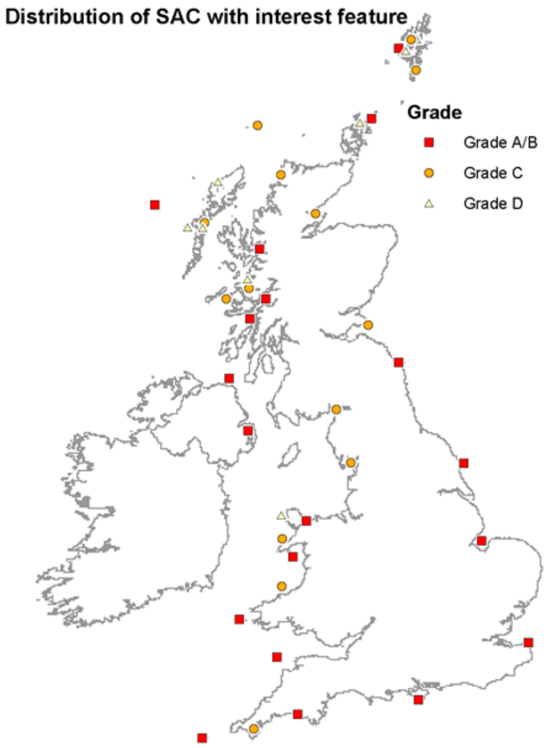
Large 'Shallow inlets and bays' is a habitat complex that may contain several other Annex I habitats, including: Sandbanks which are slightly covered by sea water all the time (see 2.1.1), including eelgrass beds (see section 2.1.1), maerl beds (see section 2.1.1), Mudflats and sandflats not covered by sea water at low tide (see section 2.1.3), and Reefs (see section 2.1.6), including rock reefs and biogenic reefs. The outer parts of some very large estuaries (see section 2.1.2) may also be included in this habitat complex. Descriptions of these other habitats have been omitted from this section and the reader is directed to these sections for fishing types likely to occur in these habitats for further information. Other habitat types not

* In the UK "shallow" is interpreted as a depth of less than 30 m below Chart Datum and depths would be shallower than 30 m across at least 75% of the site.

included elsewhere in the Habitats Directive may also occur within this habitat complex. For example, deep sediment habitats may also occur to some extent in this habitat complex, particularly in some Scottish sea lochs. Mixed sediments and gravelly seabed habitats may also be present.

2.1.6. Reefs

SAC where Reefs is a primary feature	Berwickshire and North Northumberland Coast, Firth of Lorn, Flamborough Head, Isles of Scilly Complex, Loch Creran, Lochs Duich, Long and Alsh Reefs, Lundy, Papa Stour, Pembrokeshire Marine/ Sir Benfro Forol, Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau, Plymouth Sound and Estuaries, Rathlin Island, Sanday, Y Fenai a Bae Conwy / Menai Strait and Conwy Bay, The Wash and North Norfolk Coast, South Wight Maritime, Thanet Coast, Strangford Lough, St Kilda.
SAC where Reefs is a qualifying feature, but not a primary reason for site selection	Cardigan Bay / Bae Ceredigion, Dornoch Firth and Morrich More, Fal and Helford, Isle of May, Loch Laxford, Loch nam Madadh, Luce Bay and Sands, Morecambe Bay, Mousa, North Rona, Solway Firth, Sullom Voe, Sunart, Treshnish Isles.



Distribution of SAC containing Reefs (habitat code 1170). From www.jncc.gov.uk

Reefs are defined by the European commission as: “Submarine, or exposed at low tide, rocky substrates and biogenic concretions, which arise from the sea floor in the sublittoral zone but may extend into the littoral zone where there is an uninterrupted zonation of plant and animal communities. These reefs generally support a zonation of benthic communities of algae and animals species including concretions, encrustations and corallogenic concretions”[7].

This habitat definition may also include stable boulders and cobbles. Reefs are often highly complex, habitats, including overhangs, gullies, walls, outcrops and rockpools. They may also be included in estuaries, coastal lagoons and large shallow inlets and bays. There are several types of biogenic reef, which are relevant to this study. Those discussed in this report include:

Sabellaria alveolata* and *Sabellaria spinulosa reefs are formed by tube-dwelling polychaete worms. Tubes are constructed from particles of sand and may grow together to form reef structures.

The horse mussel *Modiolus modiolus* is a large, slow growing bivalve. Although it is widespread around UK waters, reef structures are comparatively rare. Reefs are formed when individuals attach themselves to one another using bysal threads.

Eventually, large numbers form clumps, which rise above the seabed, aggregating and stabilizing sediment.

Lophelia pertusa is a deep sea, cold water coral. It can form huge colonies on the seabed. Reefs are extremely fragile and hence vulnerable to any physical impact. The complex structures provide a habitat for numerous species. Due to the depth at which they are found, the life history of *Lophelia* is not well understood, although it is believed that the coral is very slow growing and would be slow to recover from damage (if indeed recovery is even possible).

The file shell *Limaria hians* is a species of bivalve mollusk often found in maerl beds and other coarse sediments. The bivalve creates large 'nests', which can become biogenic reefs. The reef structures, in turn, provide a solid substrate for colonization by a range of epifauna and plants[10]. Such reefs are vulnerable to the impacts of mobile gears and recovery after damage is likely to be very slow.

2.2. Habitats Directive Annex II species

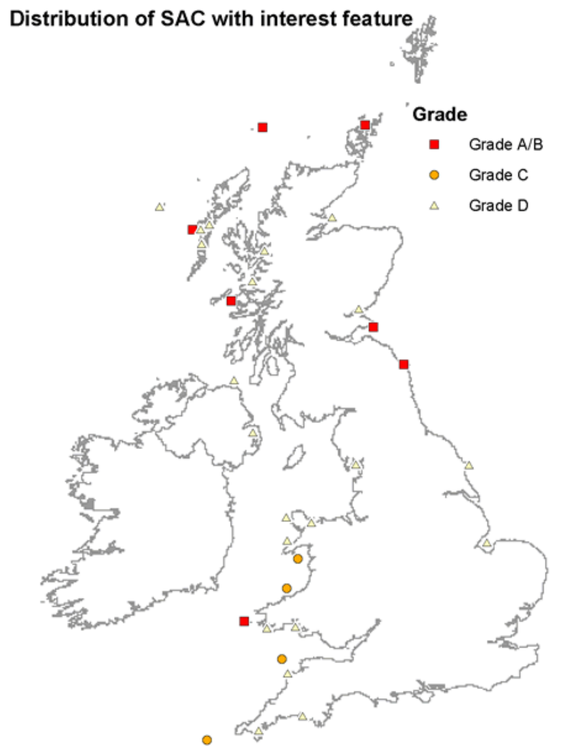
The species listed in this section are described briefly. There is a limited amount of information available describing the adverse effects of the specific fishing activities discussed in this report on the species listed. For this reason, possible impacts, suggested and the few anecdotal and literature based impacts are discussed in this section of the report rather than in the following sections.

2.2.1. Common seal *Phoca vitulina* and grey seal, *Halichoerus grypus*

SAC , which have been designated to protect *Phoca vitulina*	Yell Sound Coast, The Wash and North Norfolk Coast, South-East Islay Skerries, Sanday, Mousa, Firth of Tay & Eden Estuary, Eileanan agus Sgeiran Lios mór, Dornoch Firth and Morrich More, Ascrib, Isay and Dunvegan.
SAC where *Phoca vitulina* is a qualifying feature, but not a primary reason for site selection	Strangford Lough, Murlough.

Distribution of UK SAC containing *Phoca vitulina*. From www.jncc.gov.uk

SAC , which have been designated to protect *Halichoerus grypus*	Treshnish Isles, Pembrokeshire Marine / Sir Benfro Forol, North Rona, Monach Islands, Isle of May, Faray and Holm of Faray, Berwickshire and North Northumberland Coast.
SAC where *Halichoerus grypus* is a qualifying feature, but not a primary reason for site selection	Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau, Lundy, Isles of Scilly Complex, Cardigan Bay / Bae Ceredigion.



Distribution of UK SAC containing *Halichoerus grypus*. From www.jncc.gov.uk

The common seal is most often found in coastal waters, where sand banks, rocks and beaches are popular haul-out sites. The grey seal is also found in inshore waters, in close proximity to the coast, but is also sometimes seen further offshore than the common seal. Whilst very little evidence is available on the impacts of the relevant fishing activities discussed in this report, there is evidence to suggest that human presence on the shore may have adverse effects on grey seals particularly at regular haul-out sites and pupping areas.

During the interviews conducted for this project, concerns were expressed by WWF[11] that there has been a recent down-turn in the common seal population of Strangford Lough (Northern Ireland) following extensive fishing activity. At present it is not known whether this is due to disturbance or lack of food availability within the Lough, but the population is in ‘unfavourable’ conservation status. The Eastern SFC District recorded that, where hydraulic dredging occurs, measures have been put in place to mitigate disturbance to the common seal.

2.2.2. Bottle-nosed dolphin, *Tursiops truncatus*

SAC , which have been designated to protect *Tursiops truncatus*	Moray Firth, Cardigan Bay / Bae Ceredigion.
SAC where *Tursiops truncatus* is a qualifying feature, but not a primary reason for site selection	Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau.

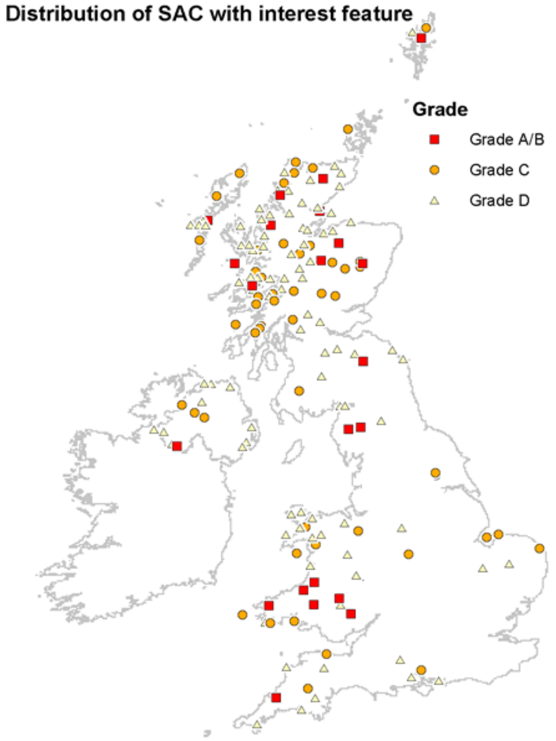
Distribution of UK SAC containing *Tursiops truncatus.* From: www.jncc.gov.uk

The bottle-nosed dolphin is a large dolphin, growing to about four metres long. It spends approximately seven minutes underwater on average and surfaces regularly to breathe. It is found worldwide including the UK and may occur offshore or in coastal waters, including estuaries and inlets and bays. The bottle-nosed dolphin is an active predator, hunting fish and invertebrates. Resident populations are known from Cardigan Bay in west Wales, the Moray Firth in east Scotland and the west coast of Ireland. The species has also been recorded off the south and southwest coasts of England, the western Isles of Scotland and in the Irish Sea. The bottle-nosed dolphin is also legally protected by the Wildlife and Countryside Act 1981 in the UK.

There was very little evidence found to suggest that the bottle-nosed dolphin would be adversely affected by any of the activities discussed in this report. However, subtidal oyster culture activities may cause disturbance to dolphins which have been recorded as showing avoidance behaviour where such activities occur and dolphin populations may therefore be displaced locally[12]. It is also possible that some disturbance and dispersal of prey species may be caused by certain activities, generating large amounts of underwater sound, such as hydraulic dredging and scallop dredging. However, no evidence of the effect of these activities on bottle-nosed dolphins was found during this study. This is certainly an area which may require further study.

2.2.3. Otter, *Lutra lutra*

SAC , which have been designated to protect *Lutra lutra* (marine sites only)	Yell Sound Coast, Rum, Sunart, Loch nam Madadh, Dornoch Firth and Morrich More.
SAC where *Lutra lutra* is a qualifying feature, but not a primary reason for site selection (marine sites only)	Pembrokeshire Marine / Sir Benfro Forol, The Wash and North Norfolk Coast, North Norfolk Coast, Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd, Loch Moidart and Loch Shiel Woods, Mòine Mhór, Pen Llyn a`r Sarnau / Lleyn Peninsula and the Sarnau, South Uist Machair.



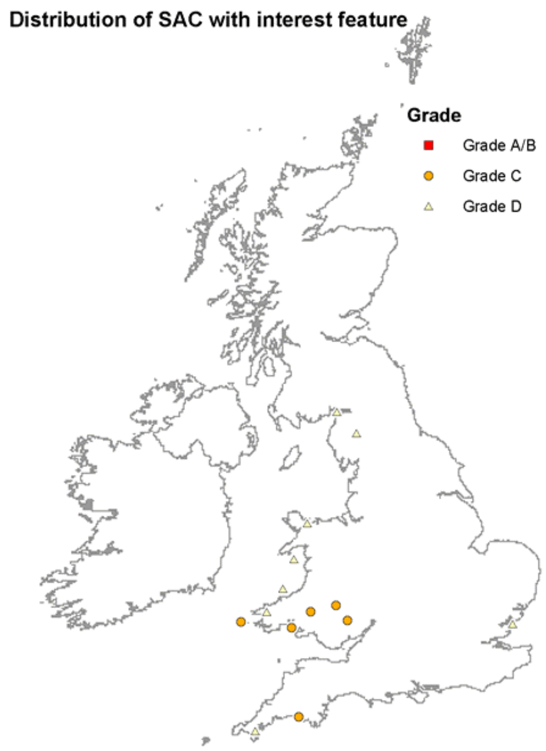
Distribution of UK SAC containing *Lutra lutra*. From: www.jncc.gov.uk

The otter *Lutra lutra* is most commonly found in fresh water habitats around the UK. However, marine populations occur in Scottish waters, where individuals have been known to interact with fisheries. This predatory mammal dives below water and swims to capture fish and large invertebrates.

Although no evidence was found during this study to suggest that the otter is likely to be negatively impacted by any of the fishing methods studied, it is possible that the species may be adversely affected by excessive, sustained disturbance in feeding and breeding areas. Care would need to be taken when establishing fisheries to avoid disturbance in such areas.

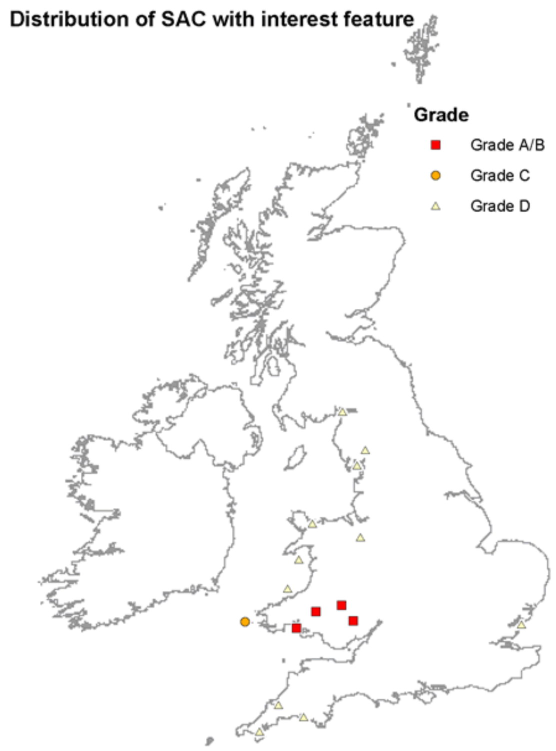
2.2.4. Allis shad, *Alosa alosa* and twaite shad, *Alosa fallax*

SAC , which have been designated to protect *Alosa alosa* (marine sites only)	There are currently no UK SAC designated to protect this species.
SAC where *Alosa alosa* is a qualifying feature, but not a primary reason for site selection (marine sites only)	Plymouth Sound and Estuaries, Pembrokeshire Marine / Sir Benfro Forol, Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd.



Distribution of UK SAC containing *Alosa alosa.* From www.jncc.gov.uk

SAC , which have been designated to protect *Alosa fallax* (marine sites only)	Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd.
SAC where *Alosa fallax* is a qualifying feature, but not a primary reason for site selection (marine sites only)	Pembrokeshire Marine / Sir Benfro Forol.



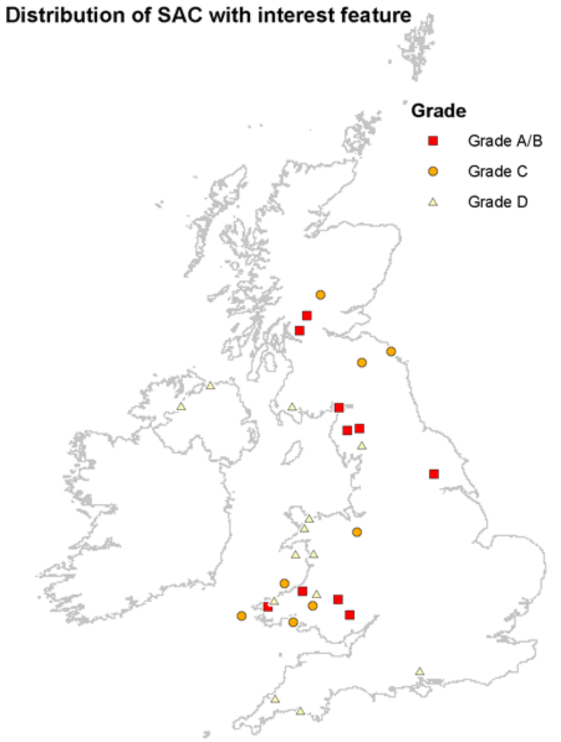
Distribution of UK SAC containing *Alosa fallax.* From www.jncc.gov.uk

The allis and twaite shads are anadromous fish species, meaning that they spend the majority of their adult lives in the ocean, but return to freshwater water bodies to spawn. Whilst at sea, the fish lead pelagic lifestyles, feeding on plankton, and are occasionally caught in pelagic fisheries and gillnets in UK offshore and coastal waters[7]. When fully mature, individuals traverse river systems between April and May in order to spawn and can be found in estuarine areas before and after spawning, when they return to the sea.

No evidence has been found during this review to suggest that shad are directly adversely affected by any of the fishing types discussed.

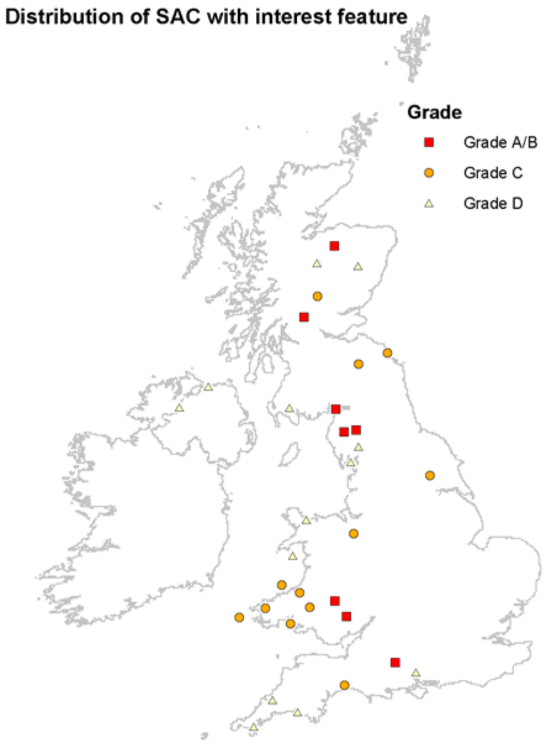
Lampern, Lampetra fluviatilis and sea lamprey, Petromyzon marinus

SAC , which have been designated to protect *Lampetra fluviatilis* (marine sites only)	Solway Firth
SAC where *Lampetra fluviatilis* is a qualifying feature, but not a primary reason for site selection (marine sites only)	Tweed Estuary, Pembrokeshire Marine / Sir Benfro Forol, Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd, Cardigan Bay / Bae Ceredigion.



Distribution of UK SAC containing *Lampetra fluviatilis*. From www.jncc.gov.uk

SAC , which have been designated to protect *Petromyzon marinus* (marine sites only)	Solway Firth
SAC where *Petromyzon marinus* is a qualifying feature, but not a primary reason for site selection (marine sites only)	Tweed Estuary, Pembrokeshire Marine / Sir Benfro Forol, Carmarthen Bay and Estuaries / Bae Caerfyrddin ac Aberoedd, Cardigan Bay / Bae Ceredigion.



Distribution of UK SAC containing *Petromyzon marinus*. From www.jncc.gov.uk

Lampreys are primitive fish. They are eel-shaped and feed on other fish using a jawless mouth disc. Lampreys live an anadromous lifestyle, meaning that they spend the majority of their adult lives in the ocean and return to freshwater.

Due to their body shape, they are rarely caught as bycatch in fishing gears and it is unlikely that they will be adversely affected by any of the fishing activities discussed in this report.

2.3. Other relevant UK protected species

2.3.1. Fan mussel *Atrina fragilis*

Fan mussels are large bivalve molluscs, protected under the Wildlife and Countryside Act 1981. Fan mussels are now extremely rare in UK waters, but occur in a few sheltered areas with muddy or sandy stable sediments. They are large and fragile and live partially buried in the sediment making them vulnerable to damage by mobile gears, including hydraulic suction dredging and scallop dredging. The fan mussel is extremely slow growing and as a result, populations may be very slow to recover from extraction or damage to individuals. Studies of scallop gears in the Mediterranean have shown that fan mussels can be easily impaled by dredge teeth, resulting in mortality[13].

2.3.2. Pink sea fan *Eunicella verrucosa*

Pink sea fans are gorgonian corals which live attached to hard substrata, including reefs. They are protected under the Wildlife and Countryside Act 1981. Pink sea fans are an erect and fragile species, making them vulnerable to mobile gears. The biotope characterised by pink sea fans also includes several rare, scarce and sensitive invertebrate species, which, although not listed on directives, conventions or statutes, are unlikely to return if destroyed by physical disturbance.

2.3.3. Sea fan anemone *Amphianthus dohrnii*

The sea fan anemone is protected under the Wildlife and Countryside Act 1981 and lives in association with the pink sea fan *Eunicella verrucosa*. As a result, any activities likely to affect the sea fan, will also negatively affect the sea fan anemone.

2.4. Special Protection Areas (SPA)

Carmarthen Bay is currently the UK's only offshore SPA. The area has achieved its status as it is an important area for the black scoter[14]. There are, however, plans to extend current coastal SPA and develop new ones, mostly for the protection of feeding areas required by regularly occurring migratory and resident seabird populations[14]. Areas for the protection of Annex I breeding bird populations are currently protected by the designation of SPA in locations around the UK, but do not extend beyond the mean low water mark in England, Wales and Northern Ireland and mean low water springs in Scotland. For brevity, birds are grouped into 'waders', 'seabirds' and 'wildfowl' for the purpose of this report. This is due to similarities in the behaviour of many bird species within these groupings, the large number of species listed and a lack of published material specific to the individual species.

Classified SPA with significant inter-tidal element*	Ynys Feurig, Cemlyn Bay and The Skerries · Skokholm and Skomer · Burry Inlet · Castlemartin Coast · Glannau Aberdaron and Ynys Enlli / Aberdaron Coast and Bardsey Island · Grassholm · Ramsey and St Davids Peninsula Coast · Glannau Ynys Gybi / Holy Island Coast · Traeth Lafan / Lavan Sands, Conway Bay · The Severn Estuary · Tamar Estuaries Complex · Exe Estuary · Chesil Beach and the Fleet · Poole Harbour · Solent and Southampton water · Pagham Harbour · Portsmouth Harbour · Chichester and Langstone Harbours · Dungeness to Pett Level · Thames Estuary and Marshes · Medway Estuary and Marshes · Benfleet and Southend Marshes · The Swale · Foulness · Thanet Coast and Sandwich Bay · Crouch and Roach Estuaries · Blackwater Estuary · Dengie · Colne Estuary · Hamford Water · Deben Estuary · Alde-Ore Estuary · Stour and Orwell Estuaries · Minsmere-Walberswick · Benacre to Easton Bavents · The Wash · North Norfolk Coast · Breydon Water · Great Yarmouth North Denes · Gibraltar Point · Humber flats, Marshes and Coasts · Flamborough Head and Bempton Cliffs · Teesmouth and Cleveland Coast · Ribble and Alt Estuary · Duddon Estuary · Morecambe Bay · The Dee Estuary · The Mersey Estuary · Upper Solway Flats and Marshes · Lindisfarne · Northumbria Coast · Farne Islands · Coquet Island · Inner Clyde Estuary · Firth of Forth Islands · Bridgend Flats (Islay) · Gruinart Flats (Islay) · Laggan (Islay) · Firth of Tay and Eden Estuary · Montrose Basin · Ythan Estuary, Sands of Forvie and Meikle Loch · Loch of Inch and Torrs Warrens · Cromarty Firth · Inner Moray Firth · Moray and Nairn Coast · Loch of Strathbeg · South Uist Machair and Lochs · Monach Isles · North Uist Machair and Islands · Dornach Firth and Loch Fleet · East Sanday Coast · Carlingford Lough · Belfast Lough · Strangford Lough · Lough Foyle · Larne Lough · Rathlin Island.
Potential SPA with significant inter-tidal element*	Mynydd Cilan, Trwyn y Wylfa ac Ynysoedd Sant Tudwal / Mynydd Cilan, Trwyn y Wylfa and the St Tudwal Islands · Dyfi Estuary/Aber Dyfi · Ynys Seiriol/Puffin Island · Isles of Scilly · Mersey Narrows and North Wirral Foreshore · Firth of Forth · Killough Harbour · Outer Ards.

Reproduced from Hiscock and Sewell 2005[6] and updated with information from the Joint Nature Conservation Committee (JNCC)[14].

3. An overview of relevant fishing activities in the UK EMS based on interviews with competent authorities.

The following sections provide an overview of the status of hydraulic suction dredging; scallop dredging; oyster culture; disturbance of birds by fisheries and competition between fisheries and birds for shellfish resources in UK EMS.

The information presented has come from a series of semi-structured interviews, conducted by telephone and in person early in 2007. The questionnaire used is given in Appendix 1 of this report. Interviews were conducted with regional competent authority representatives, who were selected for their knowledge of fisheries operating within their region and their previous experience implementing mitigation methods. The following section of the report therefore represents the views and opinions of the authority interviewed, which relate to the District. For England and Wales, the competent authorities interviewed were the Sea Fisheries Committees (SFC), namely: Northumberland Sea Fisheries Committee; North Eastern Sea Fisheries Committee; Eastern Sea Fisheries Committee; Kent and Essex Sea Fisheries Committee; Sussex Sea Fisheries Committee; Southern Sea Fisheries Committee; Devon Sea Fisheries Committee; Cornwall Sea Fisheries Committee; Scilly Isles Sea Fisheries Committee; South Wales Sea Fisheries Committee; North Wales and North Western Sea Fisheries Committee; Cumbria Sea Fisheries Committee. SFCs are the competent authorities, responsible for the management of fishing activities within their District. For Scotland, Scottish Natural Heritage and Scottish Executive were interviewed and for Shetland, the Shetland Council. Unfortunately, it was not possible to arrange interviews with competent authority representatives from Northern Ireland. As a result, information for this area is not included in the following section of the report.

Northumberland Sea Fisheries Committee

Scallop dredging takes place within the District and within Berwickshire & North Northumberland SAC. There are concerns over the impacts on UK EMS habitats and site integrity, particularly damage to reefs. A by-law has been introduced in order to reduce the impact, limiting the number dredges to ten per vessel.

Hydraulic suction dredging does not take place within the District.

Oyster farming takes place within the District and within Berwickshire & North Northumberland, which is an SAC, SPA and SSSI, and Lindisfarne SPA. There are concerns over the impact on UK EMS species including the little tern, bar-tailed godwit, redshank, wigeon, light-bellied Brent goose, ringed plover, grey plover, whooper swan, dunlin, common eider, shelduck, great cormorant, red-breasted merganser, long-tailed duck, Icelandic greylag goose and scoter. However, no restrictions have been introduced.

Within the District there is concern over the disturbance to birds by fishing activities and the competition for resources in both SPA and SSSI (Lindisfarne). Disturbance is caused as a result of people visiting the mussels. In order to reduce this impact, a maximum of ten people are allowed on the mussel beds at one time. Competition for resources is also caused by the hand gathering of mussels and in order to reduce competition a maximum quota is set each year.

North Eastern Sea Fisheries Committee

Scallop dredging takes place within the District, but not within any areas designated for nature conservation. There are no concerns over the impact on UK EMS species and habitats or site integrity. To protect against any future impacts, scallop dredging has been prohibited within the 3 mile nautical limit under by-law and there is a closed season from June until September.

Hydraulic suction dredging does not take place within the District, although may do in the future. Neither does oyster farming.

Birds are considered to be disturbed in both SPA and SSSI within the District For example, in the Humber Estuary (SPA & SSSI). Damage to the habitat and noise disturbance occurred as a result of fishermen accessing the cockle grounds for hand gathering. To reduce this disturbance a closed season was introduced from May 1st until August 31st. However, due to low stock levels the cockle fishery in the Humber has been closed for the past four years.

Although there is no direct concern over the competition for resources in SPA and SSSI, the precautionary approach has been used in the Humber Estuary. If the cockle fishery were to re-open the SFC would ask for a regulating order to limit the number of fishermen and the catch size.

Eastern Sea Fisheries Committee

Scallop dredging does not take place within the District.

Hydraulic suction dredging takes place within the District and within the Wash, which is one of the most highly designated areas having SAC, SPA, SSSI, NNR (National Nature Reserve) and Ramsar site designations. There are concerns over the impact of hydraulic suction dredging on UK EMS species and habitats. The fishery is managed through a Regulating Order to reduce the impact on common seals, intertidal mudflats and sandflats and bird species, particularly oystercatchers and knots.

Oyster farming takes place within the District and within the Wash, although there are no concerns over the impact of this activity on UK EMS species and habitat or site integrity therefore, there are currently no restrictions on oyster farming.

Within the District, birds are considered to be disturbed in the Wash as a result of the hand gathering for cockles and mussels that takes place throughout the year, although mussel collection normally only occurs in the winter months. Proposed management plans have been put forward for both the cockle and mussel fisheries in order to reduce the impact of disturbance.

For the cockle fishery, this includes a quote of 1450 tonnes/yr (37% of TAC), with a daily quota of 2 tonnes. In addition a monthly handworking licence must be obtained.

For the mussel fishery this includes a total quota of 141 tonnes/yr (10% of TAC), with a maximum daily quota of 4000 kg. The fishery will be open five days a week (Monday – Friday), but once the TAC has been reached the mussel fishery will close.

Within the District there are also concerns over competition for resources in the Wash as a result of hand gathering for cockles and mussels and hydraulic suction dredging. Of concern are the wading birds. Proposed management plans have been put forward for both the cockle and mussel fisheries in order to reduce the impact of competition.

In addition to the hand gathering quota already mentioned, restrictions on the dredged cockle fishery mean a total quota of 2500 tonnes/yr (63% of TAC), with a daily quota of 4 tonnes. The fishery will only operate 4 days a week (Sunday – Wednesday). In addition, the bar spacing on the riddle and dredge must be no greater than 12 mm to allowed undersized cockles to escape. Monthly or annual licences must be obtained.

For the dredged mussel fishery, the total quota is 1405 tonnes/yr (90% of TAC), with a maximum daily quota of 4000 kg, and catch must be contained in bags, boxes or binds. The fishery will be opened 5 days a week (Monday – Friday), but once the TAC has been reached the mussel fishery will close.

Kent and Essex Sea Fisheries Committee

Scallop dredging takes place within the District, but not in any sites designated for nature conservation. There is no concern over the impact on UK EMS species and habitats or site integrity. However, restrictions have been introduced to protect the scallop stock and habitat. There are no District by-laws, but National and EU legislation is enforced. The legislation relates to dredge size and maximum landing size.

Hydraulic suction dredging takes place in the District and a number of sites designated for nature conservation, namely Essex Estuary SAC, Foulness SPA & SSSI, Benfleet & Southend Marshes SPA & SSSI, Dengie SPA & SSSI, Pegwell Bay SSSI and Thames Estuary & Marshes SPA & SSSI. There is concern over the impacts on UK EMS species and habitats and site integrity, particularly the taking of the prey of interest species and the actual impact on the site. Restrictions have been introduced including gear type restrictions and limits on permitted physical damage rate. The Thames Estuary Regulating Order sets a TAC for scallops based on annual surveys.

Oyster farming takes place within the District and a number of sites designated for nature conservation, namely Essex Estuary SAC, Crouch & Roach Estuaries SPA & SSSI, Swale SPA & SSSI, Medway Estuary & Marshes SPA & SSSI, Thames Estuary & Marshes SPA & SSSI, Blackwater Estuary SPA & SSSI, Colne Estuary SPA & SSSI and Hamford Estuary SPA & SSSI. There is no concern over the impact on UK EMS species and habitats or site integrity. For fisheries, restrictions are in place in the form of by-laws providing a minimum landing size and a maximum dredge size.

There is no concern over the disturbance of birds as the cockle harvesting that takes place is all conducted by a mechanical dredge at high tide.

There is potential concern over the competition for resources in SPA, SSSI & Ramsar sites, particularly for oystercatchers and knots. In order to reduce this competition, ensure a strong cockle population and protect the stocks from exploitation, restrictions are in place: the fishery only runs from June to November and during this time there is no fishing at weekends, vessels are limited by the number of trips that can be made (two to four landings a week), and TAC have also been place on the stocks (only 1/3 of the stock is to be harvested).

Sussex Sea Fisheries Committee

Scallop dredging takes place within the District but not in or close to a site designated for conservation, therefore there are no concerns over the impact of scallop dredging on UK EMS species, habitats or site integrity. Restrictions have been put in place within the District but this has been to protect the scallop stocks. Scalloping is prohibited within the 3 mile nautical limit and within the 3-6 mile nautical limit there is a closed season during the summer.

Hydraulic suction dredging is prohibited within the District.

Oyster farming occurs but operations are currently closed by Defra and are under review. If the fishery were to re-open it would not be regulated by the SFC.

There is no evidence to suggest that birds are being disturbed by fishing activities in an SPA or Ramsar site. However, monitoring is taking place in Solent & Dungeness to Pett Level (SPA) and Solent & Chichester (Ramsar sites). There are no restrictions in place in these areas.

There is no concern over competition with birds for shellfish resources as there are no intertidal fisheries within the District.

Southern Sea Fisheries Committee

Scallop dredging takes place within the District, although not currently in a site designated for nature conservation. There is concern over the impact of scallop dredging in Lyme Bay which supports species which are protected under the Wildlife and Countryside Act 1981. There are concerns over the impact of scallop dredging on UK EMS species and site integrity. Restrictions have been introduced, in particular in Lyme Bay, to protect the biodiverse reefs and these restrictions apply to the whole District. These restrictions include a maximum vessel size limit of 12 m, a night curfew (dredging can only take place in daylight hours) and a maximum of six dredges on each side of the vessel.

Hydraulic suction dredging is not believed to take place within the District [although a form of hydraulic dredging, known as ‘pump and scoop dredging’, targeting Manila clams is reported to take place in Poole Harbour].

Oyster farming takes place within the District and within sites designated for nature conservation including, the Solent (EMS), Poole Harbour (EMS, SSSI & Ramsar site) and Fleet (EMS). The SFC has concerns over the impact of oyster farming on UK EMS habitats, but not site integrity or UK EMS species in the area. Currently there are no restrictions in place locally to limit the impact of oyster farming.

Within the District, birds are considered to be disturbed by fishing activities and there are concerns over the competition for shellfish resources. Concerns apply to areas which are designated SPA, SSSI and Ramsar sites. There are no concerns about competition for shellfish resources in the Solent (an SPA) at present as there are no intertidal beds that could be exploited by birds or fisheries leading to competition. Fleet is a SSSI, but there are no concerns at present. Within Poole Harbour (an SPA, SSSI and Ramsar site) fishing has been stopped in four shallow sheltered bays due to concern for disturbance and competition with local bird populations.

Devon Sea Fisheries Committee

Scallop dredging takes place within the District, including in Salcombe to Kingsbridge SSSI. However there are no concerns over the impact of scallop dredging on UK EMS species, habitats or site integrity. Restrictions have been put in place within the

District to protect the habitat including a closed season from July to September. During the open season dredging is only permitted from 7am to 7pm. No more than 12 dredges are allowed to be used at one time and all scallops landed must exceed 100 mm.

Oyster farming and hydraulic suction dredging takes place within the District and also with the Exe Estuary SPA. However, there are no concerns over the impact of either activity on UK EMS species, habitats or site integrity as a result no restrictions on activities are currently in place.

Within the District, birds are considered to be disturbed by fishing activities in SPA and SSSI as a result of hand gathering for oysters and dredging for mussels. However, no restrictions have so far been introduced.

There are also concerns over competition for resources in SPA and SSSI although no restrictions have been introduced.

Cornwall Sea Fisheries Committee

Scallop dredging takes place within the District and in a site (the Fal and Helford SAC) designated for nature conservation. Within the Fal and Helford SAC (designated for subtidal sandbanks and reefs) there are concerns over the impact of scallop dredging on UK EMS species and habitats, particularly maerl beds. Restrictions have been introduced to reduce the impact on subtidal sandbanks, reefs and estuaries; these include by-laws which restrict vessel length and the number of dredges. The District is currently working towards a voluntary agreement to protect these features.

Hydraulic suction dredging and oyster farming do not take place within the District.

There are no concerns over disturbance of birds or competition for resources between birds and fisheries in SPA, SSSI or Ramsar sites as none fall in the District. The only concern is with the inshore bass fishery in St Ives Bay and the bycatch of seabirds [previous research has shown that common guillemots and razorbills have formed part of incidental bycatch in this area[15]]. As a result of this bycatch, an annual trigger figure has been set which, if exceeded, will result in the fishery being shut down.

Scilly Isles Sea Fisheries Committee

There is no scallop dredging, hydraulic suction dredging or oyster farming within the District; the only activities that take place are potting for crabs and lobsters. All other activities take place outside the 6 miles nautical limit.

There is no concern over disturbance to birds as a result of fishing activities or competition for shellfish resources.

South Wales Sea Fisheries Committee

Scallop dredging takes place within the District which, despite being limited, does take place in an area designated for nature conservation: Pembrokeshire SAC. The scallop fishery is unlikely to expand as most scallop beds have already been identified and utilised. There are concerns over the impact of scallop dredging on UK EMS habitats and site integrity, but not UK EMS species. Within the District, restrictions have been introduced to protect the maerl and seagrass habitats which include a closed season (that is enforced under a by-law from 1st July until the 31st

October, and national legislation from 1st June until 31st October), and limits on dredge number, vessel length and engine horsepower. Scallop dredging is also prohibited in intertidal areas unless authorized by South Wales SFC.

Hydraulic suction dredging takes place within the District and also within Carmarthen Bay and Estuaries SAC. There are concerns over the impact of hydraulic suction dredging on UK EMS species and habitats and site integrity. In order to protect the habitat and food source of the scoter duck from the impacts of hydraulic suction dredging, WAG (Welsh Assembly Government) introduced a statutory section 5 order and no hydraulic suction dredging has taken place since 2000.

Oyster farming does not take place within the District.

Within the District, birds are considered to be disturbed in some SPA and SSSI (Burry Inlet) but not Ramsar sites. Within the Burry Inlet, fishermen have been encouraged to concentrate their activities in the summer rather than during winter months, to reduce the effects on wintering birds caused by hand gathering for cockles and mussels.

Within the District there are also concerns over competition for resources within Carmarthen Bay SAC between oystercatchers and fishermen from the cockle fishery. As a result, a closed season has been introduced along with statutory agreements within the SAC.

North Wales and North Western Sea Fisheries Committee

Scallop dredging takes place within the District and within SAC, namely Menai Strait & Conway Bay SAC, Cardigan Bay & Lleyn Peninsula SAC. There are concerns over the impact of scallop dredging on UK EMS habitats and site integrity, particularly to the biogenic reefs. A closed season has been introduced in some areas, with others being closed all year.

Hydraulic suction dredging does not take place within the District.

Oyster farming takes place within the District and oyster culture takes place within the Menai Strait & Conway Bay SAC and Morecambe Bay SAC. There are no concerns over the impacts on UK EMS species and habitats or site integrity and no restrictions have been introduced.

There is no concern over disturbance to birds or the competition of resources as a result of fishing activities within SPA, SSSI or Ramsar sites.

Cumbria Sea Fisheries Committee

Scallop dredging does not take place within the District.

Hydraulic suction dredging takes place within the District and also within the middle of Solway Firth SAC. There are no concerns over the impact of hydraulic suction dredging on UK EMS species, habitats or site integrity. Restrictions have been put in place to protect the habitat and species. Measures include a closed season between April 14th and September 15th; ensuring the blades are set so as to avoid digging too deeply into the seabed, and that the spaces between bars are a set size to allow undersized cockles to escape.

Oyster farming takes place within the District. However it is outside the control of the SFC as the land owners have given permission for the land to be used for oyster farming.

Within the District, birds are considered to be disturbed in both SPA and Ramsar sites as a result of hand gathering for mussels in the Solway Firth. No restrictions have been put in place although the disturbance is ‘taken into consideration’.

Within the District there are also concerns over competition for resources in both SPA and Ramsar sites as a result of hand gathering and hydraulic suction dredging for mussels and cockles in Solway Firth. Restrictions have been put in place to reduce this competition. Measures include a closed season for hydraulic suction dredging and total allowable catches (TAC). There are TAC for both the cockle and mussel stocks where a percentage of the stock is harvested each year leaving the remainder for the birds and regeneration for the next year. There are also minimum removal sizes for both cockles and mussels and daily catch restrictions.

All measures described are considered by the SFC to be successful in terms of compliance.

Scottish Executive & Scottish Natural Heritage (SNH)

Scallop dredging takes place within Scotland and within sites designated for nature conservation including the Firth of Lorn SAC, Luce Bay SAC, Loch Laxford SAC, Ascrib, Islay & Dunvegan SAC and Loch Creran SAC. There are no concerns over the impact of scallop dredging on species included in the Habitats Directive. There are concerns however, over the impact of scallop dredging on site integrity and UK EMS habitats including maerl beds, reefs and sandbanks in the Firth of Lorn, and large shallow inlets and bays in Loch Creran and Luce Bay. In order to reduce the impact of scallop dredging voluntary measures have been put in place in Ascrib, Islay & Dunvegan to protect the sandbanks and maerl beds that involve no dredging within the 20 m contour line. In the Firth of Lorn a temporary closed area is being created while research is carried out into the effects of the dredging. There are also statutory orders which involve gear restrictions, but these are implemented to manage the scallop stock itself.

Hydraulic suction dredging takes place within Scotland and within sites designated for nature conservation including the Solway Firth SAC and SPA, Firth of Lorn SAC and Donoch Firth & Morrich More SAC & SPA. There are no concerns over the impact of hydraulic suction dredging on site integrity. However, there are concerns over the impact on UK EMS species including wildfowl and waders in Dornoch Firth & Morrich More and Solway Firth, and UK EMS habitats including estuaries, bays and sandbanks in Solway Firth. Restrictions have been implemented in order to reduce the impact of hydraulic suction dredging including having a limited number of licences to cap effort. TAC have also been set. The cockle fishery in the Solway Firth is currently closed, although if it was to re-open there would be a limit on the number of licences and the areas where the activity could take place.

Oyster farming takes place within Scotland and within sites designated for nature conservation. There are no concerns over the impact of oyster farming on site integrity, but there are concerns over the impact on both UK EMS species and habitats. Oyster farming is not restricted but is managed in order to reduce competition between fishermen and wading birds. Leases are allocated and if there is potential impact then the leases are not awarded.

Within Scotland, birds are considered to be disturbed by fishing activities within Solway Firth (an SPA, SSSI and Ramsar site) as a result of hand gathering for cockles.

Within Scotland there is concern over competition for resources within SPA including the Solway Firth as a result of hand gathering, hydraulic suction dredging and tractor dredging for cockles. In order to reduce competition in the Solway Firth restrictions have been put in place within the cockle fishery including: a closed season and TAC. These measures will ensure that the biomass isn't overexploited and that it meets requirements of the birds in addition to ensuring that the fishery is sustainable. If the stocks decline, the fishery will be closed.

Shetland Council

Scallop dredging takes place within the District, but not within a site designated for nature conservation. Dredging does, however, take place 500 m outside the Yell Sound Coast SAC which was designated for otters and common seals. There are concerns over the impact of scallop dredging on UK EMS species, UK EMS habitats and site integrity. Restrictions have been implemented within the scallop fishery 500 m off Yell Sound Coast SAC, but the restrictions are to protect the scallop stock. These include a regulating order which applies from MLW (Mean Low Water) to six miles out, where vessels are limited to five dredges per side. Vessels must also be licensed.

Hydraulic suction dredging does not take place within the District and no operations will start in the future due to a regulating order which prohibits hydraulic suction dredging. This is the first order of its kind in Scotland.

Oyster farming takes place within the District but only on a small scale and does not take place within a site designated for nature conservation. There are no concerns over the impact of oyster farming on UK EMS species, UK EMS habitats or site integrity and no restrictions have been put in place.

There are no concerns over the disturbance of birds as a result of fishing activities in an SPA as all SPAs are terrestrial, nor is there concern in any SSSI or Ramsar sites. Birds are disturbed on common mussel beds which are scattered all around the coastline of Shetland as a result of fishermen scaring the birds using air guns, nets and chasing the birds. Restrictions have not been put in place in order to reduce disturbance although fishermen are discouraged from chasing the birds. Nets are in place in order to protect the mussel stocks, but must be of a certain size and colour in order to reduce entanglement.

There are no concerns over competition with birds for shellfish resources within the District.

4. Disturbance of birds by fisheries

4.1. Overview

Background

Fisheries may disturb birds directly, either by displacing them from feeding or resting areas, or indirectly by reducing food supplies leading to increased competition among foraging birds. Assessing the effect of disturbance can be problematic. Most research has focussed on the behavioural responses to disturbance, for example the distance at which disturbance may displace birds or the amount of time taken for birds to return to an area following displacement. However, these responses may be a function of factors other than simply the level of disturbance, such as the availability of alternative feeding and resting areas. Furthermore it can be problematic to translate behavioural responses directly to the impact on population size, which is the primary measure of impacts on birds. Much research has been focussed on linking responses to disturbance to the population level, and major advances have been made using individual-based models, which work on the principal that animals attempt to maximise their chances of survival and reproduction [16, 17]. This empirical approach has been applied mainly to intertidal species (shorebirds and wildfowl) and far less is known about the impact of offshore fisheries on seabirds. Although the same theoretical framework can be applied to this group of birds, logistical problems of gathering appropriate data for seabirds at sea has limited this avenue of research. Evidence does exist indicating that disturbance from shipping can have deleterious impacts on some species of seaduck[18, 19] although the role of disturbance by commercial fisheries in these offshore areas is less clear[18]

A summary of the fishing activities that may lead to bird disturbance within UK EMS is given in Table 2. The information shown in this table is based on interviews with competent authorities. Table 3 gives a more general summary of the activities likely to cause disturbance to birds.

Table 2 Summary of activities, which cause bird disturbance in UK EMS, based on interviews with Competent Authorities.

Activity	Description	Bird species or category affected
Hand gathering for mussels	Noise disturbance caused by boat access to site Access to the site by foot Birds are scared away from beds with air guns, use nets or chase them	Waders Seaducks, oystercatchers, knots & eider common eider
Hand gathering for oysters	Noise disturbance caused by boat access to site	Waders
Hand gathering for cockles	Noise disturbance caused by access to the site and damage to habitat	Seaducks, oystercatchers & other waders roosting birds
Mechanical dredging for mussels	Noise disturbance caused by boat activities	Waders
Oyster dredging		Waders & seabirds
Inshore bass fishery	Caught as bycatch in nets	Auks, razorbills & guillemots
Oyster farming	Access to the site	little tern, bar-tailed godwit, redshank, wigeon, light-bellied Brent goose, ringed plover, grey plover, whooper swan, dunlin, common eider, shelduck, great cormorant, red-breasted merganser, long-tailed duck, Icelandic greylag goose and scoter

Shellfish gathering for cockles, winkles and clams	Noise disturbance and access to the site	Breeding gulls and terns (Mediterranean and black-headed gulls, sandwich tern, common tern and little tern)
Hydraulic dredging for cockles	Exclusion from feeding grounds	Waterfowl and waders
Clam fishery	Noise disturbance caused by boat activities	Avocet, black tailed godwit & shelduck
Shrimping/ recreational angling	Disturbance due proximity to breeding grounds	Terns
Static nets	Nets drown the birds	Divers, auks & shags

Table3 Summary of activities causing disturbance to birds.

Activity	Description of impact	Bird species or category affected
Hand-picking mussels	Direct disturbance, displacing birds from foraging areas resulting in increased energetic costs	All shorebirds which feed in intertidal areas
Hand-raking mussels	Indirect effect reducing bed area and leading to increased disturbance in other suitable areas	Shorebirds which feed on shellfish
Hand-raking cockles	Direct disturbance, displacing birds from foraging areas resulting in increased energetic costs	Shorebirds which feed in intertidal areas
Industrial fisheries for shoaling species (sandeels etc.)	Indirect disturbance reducing forage fish thereby increasing interference competition	Seabirds that feed on pelagic fish
Offshore fishery that produce discards	Increased populations of large scavenging species may impact upon smaller seabird species	Smaller seabird species

General impacts

Intertidal fisheries may cause disturbance if they occur during low tide in areas where shorebirds feed and roost. The disturbance may take a number of forms. Firstly, disturbance may exclude birds from areas they use for feeding, roosting or other activities. If there are alternative sites available then disturbance may simply displace birds from one place to another [20], which is unlikely to have a negative impact. Conversely where there are few alternative locations for birds to redistribute to, or where competition is increased by displaced birds moving into a new location, disturbance may be highly detrimental[17]. Disturbance may also increase energetic costs of flying from one site to another and reduce the amount of time available to feed. Because shorebirds have high energy requirements, relative to their size, these additional costs may lead to increased rates of mortality [21]. However disturbance costs may be offset by moving to alternative areas to forage, if such sites are available. If these sites are highly profitable then the energy lost may be quickly offset[20] making the impact of disturbance negligible. However, one aspect of moving to alternative sites which may have hidden costs for shorebirds is increased risk of predation. Some shorebirds choose not to feed in areas with high intake rates because of higher risk of predation from predators[22], yet disturbance may reduce the shorebirds' choice over such matters. In addition, disturbance may compromise the foraging efficiency of feeding birds or increase their metabolic costs. There is evidence that, for certain shorebird species, some slack exists in their foraging behaviour enabling them to buffer the effects of disturbance. However this flexibility in behaviour may also be important to insure individual birds select the most profitable and safest prey [23].Offshore fisheries may disturb birds from the water surface, and there is evidence that disturbance from shipping activity may exclude common scoters from suitable foraging areas However the role of disturbance from fishing boats in particular appears limited [24]. The level of impact will also depend on a variety of additional factors, including species, time of year, locality and activity type [25]. Indirect disturbance may also lead to increased levels of interactions between species. Increased numbers of large scavenging species may have complex cascading effects throughout the avian community. Such impacts are difficult to detect, requiring long-term and often large-scale datasets. However, a number of studies have established how this disturbance by fisheries may impact on birds.

Shellfisheries

The presence of people in the vicinity of feeding birds has caused changes in bird distribution in estuaries [26] and bird behaviour[23]. Disturbance by shell fishermen caused the displacement of dunlin *Calidris alpina* to alternative feeding grounds which were less profitable with lower prey densities, and a higher density of conspecifics[26]. Whilst the latter is likely to reduce the feeding efficiency of an individual bird, the risk of predation could be decreased due to the increased group density[26]. Group benefits may also allow individuals to spend more time feeding[27]. However, increased human disturbance was neither found to affect bird numbers for godwits *Limosa sp.*[28] on the east coast of England or oystercatchers *Haematopus ostralegus* on the west coast of England[29].

Impacts of disturbance have to be assessed with respect to time of the year. For example, during autumn and winter huge numbers of wildfowl and waders visit Europe from breeding grounds in Arctic and boreal regions. These birds must survive this period in good body condition to be able to complete the return migration to their breeding grounds. Many of these species rely on relative few coastal sites where they may come into contact with shellfish beds harvested by people, during which time disturbance may reduce foraging efficiency and ultimately individual survivorship. At other times of the year numbers of waterfowl may be very much less, when disturbance may be less detrimental. Furthermore, as the winter progresses shellfish stocks may become depleted and of poorer quality which results in increased competition for food, making shorebirds particularly vulnerable to disturbance in late winter [21]. Therefore periods towards the end of the winter months may be considered as times when birds are most vulnerable.

Temporal aspects also need to be viewed on a site-by-site basis. Some wetlands may be important as stop-over sites for migratory species, at which time these species may be considered to be at greater risk from disturbance. Generalities can be difficult to make in this regard since there are differences in timing of migration among different species

In some instances the effect of disturbance may be strongly influenced by prevailing environmental conditions. Assessing the impact of disturbance on oystercatchers *Haematopus ostralegus* in the Baie de Somme, France, Goss-Custard *et al.* [30] found that in years when mid-winter mass mortality of cockles took place, disturbance significantly increased the probability of over-winter mortality. However in years when cockle stocks, and therefore food, were high, up to three disturbances per hour had no effect on mortality. Environmental conditions may have other impacts upon shorebirds. Using individual behaviour-based models to asses the impact of cockle and mussel shellfisheries on oystercatcher survival, Stillman *et al.* [16,17] modelled a hypothetical decrease in winter temperature from 5°C to 0°C. The effect of this was to increase the birds' energy demands and freeze inland fields, preventing foraging when intertidal areas are not accessible. The models predicted significantly higher mortality rates, providing evidence of how fishing activity can have more serious impacts on shorebird during cold weather conditions.

Although the effects of disturbance can be detrimental to shorebirds, they may also be able to buffer such effects. Experimental work with captive oystercatchers feeding on cockles *Cerastoderma edule* revealed that when foraging time was substantially reduced, these birds were able to increase their food intake rates[31]. However these results were not replicated in a detailed field study of individually marked birds. In this latter study Urfi *et al.* [23] found that oystercatchers responded to foraging time lost through disturbance not by increasing intake rates but instead by spending more time on mussel beds. They suggest that wild oystercatchers did not increase intake rate since this might increase the chance bill damage, or of ingesting prey with a high parasite load. Urfi *et al.* [23] also found that oystercatchers habituated to disturbance by humans, reducing the distance at which they took flight, thereby compensating for time lost to foraging.

Offshore fisheries

Few studies have, to our knowledge, assessed the direct impact of disturbance by offshore fisheries to avian communities. The most likely impacts are associated with disrupting birds resting on the surface of the water whilst boats are travelling from one location to another. These impacts seem likely to be minimal given the scale of oceanographic habitats and the availability of alternative resting sites. However the impact of indirect disturbance as a result of fishing activity may be considerable. These disturbances may arise because industrial fisheries can compete directly with seabirds for fish[32], which may result in increased competition for resources among seabirds. Increased levels of interference competition can have detrimental impacts on seabirds by reducing foraging success[33], which may in turn have implications for body condition and mortality.

Alternatively, fishery discards may result in a larger number of large predatory species (such as gulls & skuas) which can cause disturbance to seabird communities directly via predation[34, 35] or indirectly via interference competition[36].

4.2. Offshore fisheries

4.2.1. Waders

There is no evidence to suggest that offshore fisheries will have an impact on wading birds directly. However it is possible that increases in the populations of large polyphagous scavenging species (like large gulls *Larus* and skuas *Stercorarius*) may have a detrimental impact on breeding shorebirds via depredation of eggs, chicks or adult birds. However to date no evidence to this end has been provided.

4.2.2. Seabirds

Incidental bycatch

Perhaps the most serious threat to seabird populations worldwide is accidental mortality as a result of capture and drowning in fishing gear known as bycatch [37, 38,

[39]. Although accidental capture of seabirds can occur across a number of fisheries, monofilament gillnets and long-lining are the most detrimental. Monofilament nets are virtually invisible to birds swimming under the water, and large numbers of diving species have drowned as a result of becoming entangled in nets. Long-lines with baited hooks attract large numbers of seabirds which may swallow hooks in an attempt to steal bait and as a consequence drown.

Bycatch of seabirds in coastal gillnet fisheries has been well documented globally[37] with some the worst mortality rates being associated with the squid and salmon drift-net fisheries in the North Pacific, which are estimated to have killed around 500,000 seabirds per year before its closure in 1992 [40]. Although levels of mortality are not as high as this for many fisheries, the impact on seabird communities is high, particularly where gillnet fisheries occur in areas of high seabird concentration (i.e. around breeding colonies).

Both demersal and pelagic long-line fisheries inadvertently take numbers of seabirds that swallow baited hooks[38]. In some parts of the world the number of seabirds taken can be very large indeed. In the north-eastern Pacific around 13,000 seabirds (mainly northern fulmars *Fulmarus glacialis*) were estimated to be drowned per annum between 1996 and 1999 [41]. Similarly recent estimates of black-footed albatross *Phoebastria nigripes* bycatch from the central North Pacific suggest that as many as 10,000 individuals may be taken in a single year, which will lead to pronounced population declines [42].

In addition ‘ghost fishing’ set nets also present a serious threat to avian communities. Work has shown that lost gill and trammels may persist in the marine environment for many years where they entangle seabirds, as well as fish and crustaceans [43, 15].

Impact of discarding on seabird communities

Current fishery practices lead to the production of vast quantities of waste in the form of offal and the discarding of undersized fish, with an estimated 25-30 million tonnes of fish discarded worldwide each year [44]. Waters around the UK support a number of fisheries, including a large roundfish fishery that generates substantial quantities of waste, which provide an important resource for scavenging seabirds [45]. It is likely that declines in discard availability (via the closure of industrial fisheries or changes in management policy) will affect seabird communities both directly and indirectly. Scavenging species are affected directly in terms of foraging ecology[19], breeding biology [46] and over-winter condition [47]. Indirect effects include increased depredation of smaller seabird species by scavengers finding a shortfall in their energetic requirements [34], which may have implications for seabird community structure. There is evidence to suggest that nesting birds show a preference to feeding on live prey items over discards[18]. It is likely that this preference is linked to reduced reproductive success associated with a diet consisting of high levels of discards [18]. It is possible also that if large scavengers continue to increase, they will exert greater still levels of predation on smaller members of the seabird community [19, 34]. This will have negative consequences for seabird populations, although the precise nature of increased predation is not currently known.

4.2.3. Wildfowl

There is little evidence to suggest that offshore fisheries will have an impact on wildfowl directly. However, in common with waders, the possibility exists that increases in the populations of large polyphagous scavenging species (like large gulls *Larus* and skuas *Stercorarius*) may have a detrimental impact on breeding wildfowl via depredation of eggs, chicks or adult birds. However, to date no evidence to this end has been provided. It is also highly likely that vessel movement associated with offshore fishing activities will disturb diving birds, resting on the surface. For example, there is evidence that common scoters are displaced by shipping activity, in the Liverpool Bay area [24]. However, an additional study has shown that, for this site, the majority of fishing takes place in areas more than 20 m in depth, outside the feeding range of the common scoter and as a result is unlikely to affect feeding scoter except for during inbound and outbound journeys [25].

4.3. Hand gathering and bait collection

Although bait collection is not currently subject to the same management regimes as commercial fisheries, the disturbance caused may be similar to that of commercial hand gathering of cockles and other commercially important species some information relating to bait gathering is therefore included in the following report section. Much of the literature associated with disturbance to birds caused by intertidal hand gathering is also relevant to activities, such as mariculture and cockle collection by hand gatherers. For this reason, some information on these impacts has also been included in this section of the report.

4.3.1. Waders

In general, the presence of humans, particularly in large numbers is likely to cause disturbance to birds. Humans may be present on the shore during hand gathering activities, angling, maintenance of mariculture or set fishing gears. When noisy equipment, such as motorised vehicles are utilised, the range of disturbance may be increased.

Studies have shown that prolonged use of mudflats by bait diggers can force feeding birds to move to other feeding areas. If there is insufficient food in these areas, birds may die [15]. Hand gathering and other activities at low tide are more likely to cause disturbance during feeding and roosting than activities at high tide – this is when birds use the area.

Detailed modelling of the impact of hand-picking and hand-raking on the Exe estuary (south west England) and Burry Inlet (south Wales), respectively, predicted that under current methods and efforts there was no impact on the mortality or body condition of oystercatchers at either site [16]. The same study also suggested that were the intensity of fishing effort to increase there was no reason to suspect that oystercatchers would increase should restrictions be intensified at these sites.

Work from North America indicates that baitworm harvesting may have negative effects on shorebirds using the same staging sites for migration. A study in the Bay of Fundy, Canada revealed that in areas dug for bait (primarily bloodworms *Glycera dibranchiate*) the density of an important amphipod prey for shorebirds *Corophium volutator* was reduced by 39% in dug sediment compared to areas where blood worms were not harvested [48]. The significant differences in *Corophium* abundance were a function of direct mortality from digging activity and reduced recruitment because of alterations in the sediment. This difference manifested itself as a 69% decrease in the foraging efficiency of semi-palmated sandpipers *Calidris minutus* which use the Bay of Fundy as a key stopover site on their long-haul migration to South American. Although the impact of this reduction in foraging efficiency on the semi-palmated sandpiper population is not clear, they may take longer to deposit the fat required to make the long migration southward and reduce the probability of making this journey successfully.

4.3.2. Seabirds

Hand gathering and bait collection may have detrimental impacts on gulls (*Larus* spp.), which use intertidal areas for resting, preening and other activities. A study examining a decline in breeding pairs of the herring gull *Larus argentatus* in Morecombe Bay [49] has suggested that an increase in mussel fishing and cockle gathering on the bay, may have led to increased disturbance of intertidally feeding gulls, leading to a reduction in numbers of breeding gulls. However to our knowledge this impact has not been quantified. It does seem likely however that much of that written under waders can be used to give an idea of potential impacts on seabirds.

4.3.3. Wildfowl

Wildfowl which utilise intertidal areas (Brent goose *Branta bernicla*, common shelduck *Tadorna tadorna*, Eurasian wigeon *Anas penelope*) are susceptible to disturbance from disturbance due to hand gathering and bait collection [50]. For species which feed on invertebrates (e.g. common shelduck), collection of bait may deplete prey stocks directly [50] or digging may alter the structure of the sediment which also has impacts on the infauna [48].

4.4. Mariculture

4.4.1. Waders

Some studies indicate it is unlikely that intertidal mariculture of shellfish including oysters and the common mussel (*Mytilus edulis*) will have a significant negative effect on the feeding behaviour and presence of waders and seabirds [51, 52]. Although disturbance caused by human presence may disrupt the feeding activity temporarily, mussel harvesting can drive oystercatchers away from their preferred food source. In a recent study, such disturbance forced birds to move to nearby fields to feed on earthworms. Authors found that if this shift was unsuccessful, birds died [15]. The (re)establishment of intertidal mussel beds is an important strategy for maintaining the food supply of birds in some areas. It has been shown that the commercial cultivation of mussels can have positive impacts on shorebird communities, but sometimes as a result of indirect effects. Caldow *et al.* [52] experimentally investigated the consequences of intertidal mussel cultivation in the Menai Strait, Wales, and found that numbers of redshank *Tringa totanus* and Eurasian curlew *Numenius arquata* increased in areas where mussels had been laid. Neither of these species feed on mussels and, given that Oystercatchers *Haematopus ostralagus*, which do feed on mussels, did not increase, mussel cultivation likely improved the quality of the benthic fauna.

In addition commercial cultivation may present large quantities of shellfish, in excess of naturally occurring stocks for shellfish-feeding shorebirds. Using a combination of empirical data and behaviour based models Caldow *et al*. [53] (2003) revealed that Oystercatchers consumed very large quantities of commercial mussel stocks at the Menai Strait, providing an important subsidy but also potential for conflict with shellfisheries. However using a number of hypothetical management strategies they revealed that the needs of shellfish growers and shorebirds need not be mutually exclusive.

An additional impact of mussel cultivation is the dredging of seed from wild stocks to establish new beds. If harvesting of seed mussels is not regulated, however, this can lead to extirpation, which has more profound environmental impacts. The removal of the entire intertidal mussel stock by seed harvesting in the Wadden Sea in Holland, combined with other factors, resulted in mass mortality and emigration of the eider *Somateria mollissima* and oystercatcher population that winter in the estuary [54].

Wild populations of *Crassostrea gigas* may, in some cases, form reef-like structures over previously soft intertidal sediments or areas previously dominated by the mussel *Mytilus edulis*. In the Dutch Wadden Sea for example, vast areas of mudflat and mussel bed have been covered by the Pacific oyster [55]. Where this occurs, feeding areas for waders and wildfowl may be drastically reduced or even lost.

4.4.2. Seabirds

Intertidal mariculture for mussels may have implications for gulls (*Larus* spp) which feed extensively on molluscs. However, due to the fact that these generalist predators are able to switch between alternative sources of prey, changes in the availability of mussels are unlikely to have a major impact on these birds.

4.4.3. Wildfowl

Wildfowl that feed extensively on shellfish may interact extensively with mariculture activities. In parts of the UK (primarily Scotland) diving ducks forage extensively on mussel farms and the availability of abundant prey may have positive impacts on mussel populations. However there is good evidence that certain species, in particular eiders, may have detrimental impacts on these stocks [56], resulting in conflict between mussel farmers and eider populations. The impact of this type of predation on mussel aquaculture may be reduced by a range of mitigation measures [57], or by control of eider populations. However the relationship between mussel farming and benefits to eider populations remain unclear – marked declines in the number of eider ducks in Shetland have been reported despite mussel farming flourishing in this part of Scotland.

Mussel beds may also form an important resource for some diving ducks. However evidence to this end remains limited in the currently available literature.

4.5. Dredging

4.5.1. Waders

Dredging for mussels or suction-dredging for cockles has little direct impact on disturbance of waders, since it occurs at high tide. However differences between dredging types may have differential impacts upon wading bird communities. Since hydraulic dredging for cockles only selects target shellfish of a certain size, it does not impact upon the bed area. In contrast mussel dredging removes mussels of all sizes and reduces the overall size of beds permanently increasing disturbance via interference competition among foragers [16].

Mechanical harvesting of e.g. cockles may include some dredging and this can have detrimental indirect disturbance effects on wading birds. Experimental work from the Burry Inlet, Wales revealed that mechanical harvesting resulted in decreased infauna resulting in decreased numbers of birds [58]. Because these birds readily respond to changes in food availability by moving within or among estuaries [59], food reductions lead to increased densities elsewhere leading to increased disturbance via interference competition.

4.5.2. Seabirds

We know of no evidence that dredging will have a direct impact in terms of disturbance on seabirds since most dredging occurs subtidally or at high-tide. The possibility exists that a reduction in the sizes of mussel beds by dredging will reduce food availability to gulls. However because these species feed facultatively on shellfish, it is unlikely that increases competition will lead to increased disturbance.

4.5.3. Wildfowl

Dredging for *Spisula* clams over sandbanks in the southern North Sea has had a negative impact on common scoter populations. The disturbance caused by the large vessels is thought to drive the birds away [15]. Studies in Liverpool Bay have also shown that common scoter are displaced by shipping activity [24] although this is likely to apply only to inbound and outbound traffic in this area as most fishing activity takes place outside the usual feeding grounds of the common scoter [25]. Disturbance to scoters is likely where fishing grounds and scoter feeding grounds overlap. It is likely also that other, similar species will also be affected in this way.

4.6. Coastal net fisheries

4.6.1. Waders

The authors of this report are not aware of any evidence to suggest that wading birds will be significantly negatively impacted by coastal net fisheries as most netting operations do not take place in areas frequented by this group.

4.6.2. Seabirds

Nets made from synthetic materials, which are difficult to see underwater, placed in the vicinity of feeding, diving seabirds are likely to result in high incidental seabird catches. Evidence suggests that several species of national and international importance have been caught in set nets in the past, particularly auks and shearwaters. Large numbers of birds are also caught in drift nets and gill nets around Europe [60]. The number of birds caught increases drastically when nets are set in close proximity to breeding colonies and the overall threat to birds will depend on fishing intensity and the size and importance of local bird populations [61, 62]. Earlier studies examining the impacts of salmon nets near the St Abbs auk colonies have revealed high levels of diving auk bycatch. Shag mortalities have also been observed where nets were set close to roosts. High levels of bycatch were recorded during breeding seasons in particular [63]. A study was conducted in Cardigan Bay between 1991 and 1992 involving 14 inspections of beach-set gillnets. The nets were in close proximity to wintering areas for redthroated divers. The study identified no evidence of redthroated diver mortality in the area, despite the birds being observed feeding nearby [64]. It is likely that low fishing intensity and possibly low bird population densities contributed to the low levels of bird by catch in the fishery.

4.7. Mitigation methods

4.7.1. UK methods currently utilised

Table 4 Summary of methods used to mitigate bird disturbance in UK EMS, based on interviews with Competent Authorities.

Activity	Mitigation Method	Enforcing body	Reasons behind methods
Mechanical and handgathering for clams and cockles	Fishing has been stopped in 4 shallow sheltered bays in Poole Harbour.	Southern SFC	Protect the waders and the eel grass beds
Handgathering for cockles and mussels	Fishermen are encouraged to fish in the summer.	South Wales SFC	Reduce the effects on wintering birds – oystercatcher, knot and wigeon
Inshore bass fishery	Annual trigger figure set (certain number of birds can be caught) if exceeded, the fishery will close.	Cornwall SFC (mentioned in RSPB response)	Reduce the number of diving seabirds that are caught as bycatch in the nets
Hand gathering for mussels	Maximum number of people allowed on the beds at once is 10.	Northumberland SFC	Reduce the impact on wading birds
Hand gathering for cockles	Closed season (May 1st – August 31st), fishery was then closed and has been for the past 4 years.	North Eastern SFC	Reduce noise disturbance and damage to habitat
Dredging for cockles	Maximum annual quota of 2,500 tonnes (63% of TAC). Daily quota of 4 tonnes. Fishery only operates 4 days a week (Sunday – Wednesday). Bar spacing on riddle and dredge must be no greater than 12mm (allow undersized cockles to escape).	Eastern SFC	Protect the food source of wading birds
Dredging for mussels	Maximum annual quota of 1,405 tonnes (90% of TAC). Daily quota of 4000kg. Fishery only operates 5 days a week (Monday – Friday). Once TAC is reached fishery will close.	Eastern SFC	Protect the food source of wading birds
Hydraulic suction dredging for cockles and mussels	TAC have been set – only 1/3 of the stock is to be harvested. Fishery only operates from June – November. No fishing at weekends. Vessels limited by the number	Kent and Essex SFC	Protect the cockle stocks from exploitation and ensure food source for oystercatchers and knots

	of trips that can be made (2-4 landings a week).		

Interviews with SFCs and other organisations indicated that there is some concern regarding disturbance to birds (See Table 4), where fishing activities take place in EMS. A number of regulations and restrictions have been put in place to minimise these impacts. Such measures include: restrictions on time spent fishing; closed seasons; curfews where fishing is only permitted during certain specified times of day; catch/quota limits and restrictions on numbers of gatherers in one area at one time. In general, SFCs considered these measures to be effective, scoring between 3 and 5 in terms of compliance and effectiveness. Where 1 is the lowest possible level of compliance and 5 is the highest. (See Appendix 1 for further details).

4.7.2. Offshore fisheries

Long-lining

In an attempt to reduce the bycatch of albatrosses and other Procellariiformes in the Southern Ocean a number of mitigation measures have been implemented, with varying degrees of success [41] . Similar approaches have been implemented in European waters [65], but work in the Southern Oceans remains the most comprehensive. Some of the key approaches include:

- discouraging scavenging birds from vessels;
- streamer lines;
- keeping baited hooks away from scavenging birds;
- setting lines at night;
- reducing in deck lighting at night;
- weighting hooks to ensure they sink;
- thawing bait to prevent floating;
- not using whole fish for bait since the swim bladder ensures the fish floats;
- bait-throwing devices to ensure bait is clear of propellers;
- discarding offal on the opposite side to the line-setting, and
- not discarding offal during line-setting.

More specifically, three methods have been tested in the North Atlantic longline fishery to reduce seabird bycatch. These are: use of a bird-scaring line; setting lines under water and the use of a line shooter. All three measures reduced the mortality of seabirds when compared to control lines. However the bird-scaring line proved to be the most effective of the three measures tested as it works as both a visual and physical deterrent [66].

Gillnet Fisheries

Melvin *et al*. [67] examined different management and gear-type strategies to reduce the impact of bycatch of seabirds (primarily common guillemots *Uria aalge* and rhinoceros auklets *Cerorhinca monocerata*) in a salmon gillnet fishery in Puget Sound, USA (United States of America). Their results suggested that seabird bycatch could be reduced by the implementation of gear modifications (highly visible upper sections of the net and acoustic pingers), targeting periods of peak salmon abundance and by avoiding periods of peak vulnerability of capture (during dawn and dusk when nets are presumably least visible to the Alcids). However because of considerable variation in the numbers of seabirds in the areas across years, the study stresses that applying the results of this study to other gillnet fisheries should be done with caution and a number of caveats.

4.7.3. Hand gathering and bait collection

The impact of hand gathering and bait collection on wading shore birds should be considered in conjunction with the impact of other activities on estuaries such as birdwatching, dog walking, angling and launching and mooring boats [29]. The most obvious mitigation measures are to avoid disturbance at times of year when shorebirds are at their most vulnerable. All of these activities are busiest in the summer and autumn and therefore do not overlap with months when food is most limited and energetic costs are at their highest [68, 69]. For instance, although the Exe Estuary, Devon, suffers high levels of anthropogenic disturbance it is thought that approximately two-thirds of the birds' total feeding effort is spent when there is no human disturbance [29].

There is evidence to suggest that 'reserve' areas, developed to alleviate the impact of human disturbance of bird populations intertidally are effective in aiding the recovery of wader populations [21, 70].In the Bay of Arcachon, France, an islet has been developed for this purpose, resulting in an increase in wader numbers [70]. The success of the reserve was attributed to the provision of 'absolute tranquillity' and a refuge area for birds at high tide, not accessible from the mainland, where fishing and mariculture activities are not permitted. The development of similar reserve areas may be a suitable mitigation method in the UK, but would require further assessment on a site-by-site basis.

Survey data provided by the RSPB (Royal Society for the Protection of Birds), during the interview process gave compelling evidence that there is a level at which hand gathering shellfish is likely to have a severe impact on nesting birds through disturbance. The evidence is from a study of Langstone Harbour (an SAC, SPA, SSSI and Ramsar site). There is concern in this area over disturbance to breeding gulls and terns (Mediterranean and black-headed gulls, sandwich tern, common tern and little tern), as a result of shellfish gathering for cockles, winkles and clams. However, no restrictions have yet been implemented.

Table 5 Black-headed gulls breeding on Round Nap and South Binness Islands, 1995 to 2006

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Round Nap	22	95	115	25	135	158	101	43	139	104	113	111
S Binness	10	450	1300	2603	2576	2764	3078	2863	4340	4486	4630	4810

Data provided by the RSPB

Table 6 Breeding gulls and terns (pairs AON) on South Binness and Round Nap, 1995 to 2006

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Mediterranean gull		1	5	14	14	38	46	19	33	57	110	264
Black-headed gull	34	549	1415	2628	2711	2922	3179	2906	4479	4590	4743	4920
Sandwich tern		12	91	158	59	88	61	29	144	172	271	204
Common tern	18	81	78	105	136	126	148	88	146	197	151	154

Data provided by the RSPB

The main fishery is by 'local' hand gatherers exercising their historical right to gather shellfish. Gathering is usually conducted by individuals on a very small scale and occasional. This group usually respects a request not to gather from island areas, frequented by seabirds. In 2002, a 'group' of collectors was observed collecting large quantities of shellfish, using a van and vessel and collecting from previously avoided island areas. There was a noticeable reduction in the number of breeding bird pairs for several species. Tables 5 and 6 indicate that whilst low level hand gathering appears to have a minimal effect on bird pairs, the more intense activity had a more obvious one. The recovery of bird numbers in subsequent years when this activity had returned to previous levels suggests some potentially effective mitigation methods. Reducing the number of gatherers operating at one time and restricting the area used (even if by a voluntary agreement) appears to be effective.

5. Competition for shellfish food resources between fisheries and birds.

5.1. Overview

Shellfisheries in the UK may include hand gathering for species such as clams mussels and cockles. On a larger scale, dredging using towed gears and hydraulic dredges subtidally and the use of tractor dredges in intertidal areas all extract shellfish. Where fisheries target species also utilised by bird populations for food, competition between fisheries and birds may occur, for example, where eider ducks occur in the vicinity of mussel farms[56]. Due to the nature of this report, the effects of birds on fisheries are not discussed. The potential impacts of fisheries on birds caused by competition for shellfish resources are however discussed.

5.2. Dredging

5.2.1. Waders

Models investigating the impact of shellfishing on the Exe Estuary revealed that dredging for mussels could have a negative impact on oystercatcher survival since it reduced the size of mussel beds[16]. However this impact was less than that of hand-raking for mussels, which not only reduced the size of mussel beds but also disturbed birds during the low-tide fishing activity.

A desk based study was undertaken to predict how removal of mussel crumble from a mudflat in the Burry Inlet to expose cockle beds would affect oystercatchers [71]. It was predicted that providing sufficient mussels or cockles remained, the removal of mussel crumble would not have a significant impact on feeding oystercatchers.

5.2.2. Wildfowl

Studies have shown that extensive, industrial cockle dredging in the Wadden Sea was the main cause of a large common eider duck (*Somateria mollissima*) mortality between 1999 and 2000 when approximately 21,000 birds died [72]. A study, which aimed to calculate the potential for a sustainable cockle fishery in the Wadden Sea concluded that it would be impossible for the area to sustain a cockle fishery and its population of wintering birds [73]. The poor cockle recruitment periods, which contributed to poor stocks was partially blamed high levels of epibenthic predators (shrimps), preying on benthic cockle larvae. The study provides an example of an environmental variable, which may not be related to fishing activity directly, compounding the potential impact of a fishery. Although such variables cannot always be accounted for, it is useful to bare these influences in mind when making management decisions.

5.3. Tractor dredging (cockles)

5.3.1. Waders

A study investigating the effects of tractor dredging for cockles showed that, following a short period of increased feeding activity immediately after dredging (probably due to temporarily increased food availability), the feeding activity of curlews and gulls was reduced for up to 80 days and for oyster catchers 50 days [58].

Experimental work in the Burry Inlet, Wales, revealed that tractor dredging for cockles initially increased the availability of non-target invertebrates, which were taken by waders [58]. However, populations of infauna were significantly depleted for more than 50 days following harvesting and this was associated with a reduction in the number curlews *Numenius arquata* for more than 80 days and oystercatchers *Haematopus ostralegus* for more than 50 days, compared with control sites [58]. This clear negative impact of mechanical harvesting was, however, slightly reduced in clean sandy areas compared with muddy sand, the latter taking longer to recover from the activity of harvesting [58].

Hall & Harding [74] concluded that cockle-dredging negatively impacted upon benthic fauna, which could have negative effects for waders which feed on such infauna. Nevertheless the same authors found that these non-target invertebrate populations recovered quickly and therefore had relatively little impact on the overall infauna community.

5.3.2. Seabirds

At present there is no evidence to suggest that tractor dredging will have a negative impact upon seabird populations. There is evidence that gulls respond to mechanical harvesting of cockles by feeding on invertebrates inadvertently brought to the surface [58]. However these opportunities are likely to be beneficial to generalist predators like gulls, which are quickly able to switch to alternative sources of food when this is no longer available.

5.3.3. Wildfowl

The impact of tractor dredging on wildfowl is likely to be directly in terms of disturbance or indirectly by altering infauna communities

5.4. Hydraulic suction dredging

5.4.1. Waders

In some cases short-term increases of waders in the harvesting area, followed by a long term significant reduction in feeding opportunities for these birds has been noted [75]. In contrast, research linked to the Solway fishery concluded that because natural changes are very large the fishery may not have a significant effect on bird numbers unless a high proportion of the cockles are harvested [76].

A simulation model tested on the Exe estuary has been developed to explore the consequences of changes in fishing activities and bird numbers on commercial shellfish stocks and on the birds themselves [77]. Key predictions include that where a number of conditions apply it is possible to exploit shellfish stocks without increasing the winter mortality of shorebirds. Also, that the effects of a given intensity of shellfishing depend crucially on local conditions. Such local conditions include climate and general abundance of food. The model also indicates that as fishing effort increases, shorebird mortality may be hardly affected initially but then may suddenly increase dramatically once a threshold level of fishing effort has been reached [77]. In some cases short-term increases of gulls and waders in the harvesting area, followed by a long term significant reduction in feeding opportunities for these birds, has been noted [75]. Studies in the Wash suggest that dredging for cockles may have a direct impact on oystercatcher mortality, but are less likely to affect knot populations in the area [78].

Nevertheless it has been found that hydraulic suction dredging in the Burry Inlet removes cockles at much higher rates than hand-picking currently employed. The consequences of these differences are that a total of 60 suction dredgers would result in the death of all of the oystercatchers at the Burry Inlet, whereas a team of 500 hand-rakers would have no effect [77].

In an 11-year study in the Dutch Wadden Sea, Piersma *et al.* [79] revealed that suction dredging for cockles greatly enhanced the loss of fine silts and this was a major factor in long-term reductions in settlement and stocks of target shellfish (cockles, mussels, Baltic tellin and soft-shelled clam). These declines are likely to have severe impacts of wading birds, which rely on these resources for daily maintenance during the winter months and during stop-over periods on migration.

In a recent study, van Gils *et al.* [80] investigated the consequences of annual mechanical cockle dredging (presumably suction dredging, but this is not stated explicitly in the paper) in the Dutch Wadden Sea on a large wintering population of red knots *Calidris canutus islandica*. From 1998 to 2002 the quality of shellfish declined in the area as a function of dredging activity. Knots, as with other migratory wading birds, are able to adjust the length of their gizzard as an adaptive response to a reduction in food quality [81], and this was their response to the decline in cockle quality in the Wadden Sea. Yet despite this highly adaptive response to changing conditions, the survival of knot declined significantly over the period of the cockle dredging, strongly suggesting that this fishery is instrumental in reducing populations in the Dutch Wadden Sea and a decline in the European wintering population as a whole. This provides some of the most damming evidence that mechanical fishing for cockles can drastically impact upon wading bird populations. Atkinson *et al.* [82] found that in years when hydraulic suction dredging for cockles occurred in the Wadden Sea, oystercatcher numbers fell dramatically and oystercatchers died over three consecutive winters, rather than moving elsewhere to find alternative feeding grounds.

5.4.2. Seabirds

At present there is no evidence to suggest that hydraulic suction dredging will have a negative impact upon seabird populations. The possibility exists that a reduction in the sizes of mussel beds by dredging will reduce food availability to gulls. However, as these species feed facultatively on shellfish, it is unlikely that increases competition will lead to increased disturbance.

5.4.3. Wildfowl

Dredging for *Spisula* clams over sandbanks in the southern North Sea has had a negative impact on common scoter populations. Excessive fishing is thought to have depleted their food supply [15]. This is also a secondary food supply for the common eider and the fishery may have contributed to the high mortalities in the Wadden Sea between 1999 and 2000, mentioned previously [72]. Emerging fisheries targeting *Spisula* and *Ensis* should be aware of potential negative effects on populations of diving ducks.

5.5. Hand gathering

There is evidence that in areas where traditional hand gathering of cockles takes place, even a reduction of less than 25% of available cockles will be enough to reduce spring oystercatcher numbers. Reduced numbers are likely as a result of poor over-winter food supply, caused by human extraction of cockles. There is also concern, based on this evidence, that if more efficient methods are used, bird numbers may be reduced further [83]. A report examining changes to cockle gathering practices in Morecombe Bay suggests a rapid increase in the intensity of this activity since 2002. The author expresses concern over the potential impact of hand gathering at such high levels on the area, which is a designated SPA and SAC. In particular, reference is made to related activities such as the 'drying out' of large vessels on cockle beds to collect hand gathered cockles and noise disturbance caused by access to the beds [84].

5.6. Aquaculture

Although not all aquaculture activities will remove shellfish from wild stocks, mussel aquaculture in particular requires the harvesting of wild spat. In areas where this spat is a required food source for birds, competition may occur. For example in the Wadden Sea, massive mortalities of eider ducks have been associated with greatly reduced mussel stocks as a consequence of harvesting spat for aquaculture [85]. However, some studies have shown that mussel culture may provide a valued food source for the oystercatcher, perhaps counteracting the impacts of reduced cockle stocks caused by human exploitation [86]. Aquaculture may also be beneficial to some species of bird, providing an energy subsidy in the form of foraging opportunities. One well-documented example of this is the utilisation of mussels by eider ducks in parts of northern Britain [56].

5.7. Mitigation methods

One widely used approach to reduce the impact of shellfisheries on birds is to ensure that sufficient shellfish food is left to meet the energetic demands of the respective bird population [87, 88]. Such an approach was adopted in the Dutch Wadden Sea where the equivalent of 70% of the energy requirements of the bird community was preserved, with the 30% shortfall to be met by alternative foods [89]. Simulations with behaviour-based models from five different embayments revealed that between 2.5 and 7.7 times the shellfish required by oystercatchers *Haematopus ostralegus* are required to ensure that these birds would survive the winter period [88]. The reason that such an approach to mitigation is not successful is partially because of wastage during foraging but primarily the result of increased density in the remaining patches of shellfish leading to intra-specific competition and increased levels of sub-ordinate individuals being attacked by dominant birds. To avoid such problems, management may best be focussed on ensuring shellfish stocks are maintained at levels of between 2.5 and 8 times the biomass required by wading birds [88]. It has been suggested that fishing practices that reduce shellfish numbers, but do not reduce the area covered by shellfish beds are less likely to have a negative effect on bird populations than fishing practices that reduce the area covered by shellfish. The prediction is based on a reduction in interfearance competition between feeding birds [90]. It may therefore be possible to mitigate the impacts of shellfisheries on bird numbers by spreading the load of such fisheries rather than decimating stocks in small areas.

Given the evidence that mechanical dredging for cockles in the Dutch Wadden Sea has been implicated in a significant decline in the European wintering population of red knots [80], mitigation may be best focussed on ceasing dredging in this area altogether. The Wadden Sea example is of particular importance since the population concerned represents between 30-50% of the world population of a single sub-species. In instances where significant proportions of a species' population winters in a single location, such draconian approaches may be the only appropriate mitigation method.

Studies have examined areas of the Wadden Sea which have been designated as marine protected areas to allow for food stock to recover for over-wintering oyster catchers [91]. Authors found that despite the protection and designated no fishing zones, no discernable differences between oystercatcher numbers and condition were found between protected and unprotected areas. Furthermore, there was no increase in numbers resulting from the protection [91]. These findings indicate that recovery from the effects of food stock reduction may be slower than expected. Also, further studies may be required in order to investigate the effectiveness of designating such areas for other bird species.

It has been suggested that the introduction of mussel culture in areas where cockle numbers have been reduced by human activities may help to reduce the impact on oystercatcher populations [86]. The introduction of mussel cultivation should therefore be explored as a potential management tool to reduce the impacts of anthropogenic cockle decline on oystercatcher populations.

Tractor dredging of cockles

There is now good evidence to suggest that mechanical harvesting of cockles can have negative impacts on benthic fauna, which are an important source of food for many wading bird species [58]. Infauna are impacted incidentally yet by reducing availability fisheries are inadvertently resulting in increased competition for food. Although infauna populations may have the ability to recover from the effects of harvesting [74], harvesters ought to be excluded from areas with high densities of wading birds since even short periods of reduced food availability may be detrimental or increase competition at alternative sites [58].

It has been suggested that creating buffer areas between fished areas and unfished areas or developing new mudflat may be effective mitigation methods to reduce the impact of expanding shellfisheries [92]. Such measures will be very species specific, with models suggesting that larger mitigation areas will be required for some species than others [92]. This would need to be fully assessed prior to the establishment of any mitigation area to ensure sufficient area is protected to meet the requirements of each interest feature present.

5.8. Gaps in knowledge and research needs.

Where a significant proportion of a species or sub-species winters in a very small number of locations, these populations are at particular risk from the deleterious effects of competition for shellfish food between fisheries and birds. As far as we are aware, no single study has identified those areas that support such sensitive populations of birds, nor their interaction with fisheries. Abundant data exist on the distribution of different shell-fish-feeding birds that might be considered at risk, but much of this is collected by dedicated bands of amateur observers or ringers. Therefore, an important gap in our knowledge might be to source such literature and document it in a single location. It should also be highlighted that there are still many gaps in our knowledge about the origins of particular wintering populations of shellfish feeders (particularly shorebirds). Although extensive bird-ringing studies have elucidated patterns [93], much remains unknown about interchange of different non-breeding waterbirds populations between sites.

Much the same can be said of our understanding of the arrival and departure of different populations of birds which are likely to come into conflict with shellfisheries. One important component of mitigation is to select periods of the year when numbers of wading birds are at their least. However, beyond stating that the winter months are detrimental in general and periods of particularly harsh weather should be avoided in particular, data on more specific times of the year are not readily accessible in the literature. Data on bird arrivals and departure are collected annually by the British Trust for Ornithology via the Wetland Bird Survey (WeBS) scheme which monitors non-breeding waterbirds in the UK (see www.bto.org/survey/webs). A detailed analysis of this dataset may prove fruitful in identifying times of the year and specific locations where shellfishing may be particularly detrimental to waterbirds.

6. Hydraulic suction dredging

6.1. Overview

Suction dredgers or (hydraulic continuous lift dredgers) are deployed from specially adapted or specially built shallow draft vessels. Water jets are used to penetrate and fluidise the sediment down to depths of 30 cm or more. Teeth are often attached to dredges to allow for deeper penetration into the seabed. Razor clams (*Ensis siliqua, Ensis ensis, Ensis arcuatus*) and surf clams (*Spisula* spp) are the most commonly targeted species, although hydraulic dredges are also use to harvest cockles (*Cerastoderma edule*), particularly in the Wash and Thames estuaries. Hydraulic suction dredging is usually carried out in areas of sand and/ or mud sediments. These areas range from highly wave exposed areas with mobile sediments to sheltered areas with stable sediment. The potential impacts and recovery time will depend on these parameters amongst others.

The preferred habitat for the most important razor clam species includes habitats listed under the habitats directive [94]. As a result, there is an urgent need for sustainable management of fisheries targeting these species in UK waters. Table 7 includes a full list of interest features, which could potentially be affected by hydraulic suction dredging.

Table 7 Species and habitats relevant to UK EMS, likely to be affected by hydraulic suction dredging.

Annex I habitats that this fishing type is likely to effect	Shallow sandbanks which are slightly covered by seawater all the time (2.1.1), Estuaries (2.1.2), Mudflats and sandflats not covered by seawater at low tide (2.1.3), Coastal lagoons (2.1.4), Large shallow inlets and bays (2.1.5).
Annex II, birds directive and Wildlife and Countryside Act species likely to be affected by this fishing type	Fan mussel Atrina fragilis (2.3.1)

Where a dredge is towed, a dredge track is typically created in the seabed. The track is usually a furrow or depression in the seabed, fringed by a build up of sediment on each side, referred to as the track shoulder [95]. A silt cloud may be created by the dredge, which settles in the surrounding area [95]. Sediment settlement has been recorded to reach 21 m away [96]. Another study found that sediment plumes may settle to form layers 75 mm thick [95], which may smother the surrounding seabed. The depth of dredge furrow is also related to a number of factors. For example, depth decreases as sediment density increases, water pressure increases or speed decreases [97]. When tow speed increases, damage to target and non-target species also increases [97]. In common with most mobile gears, it is the long-lived, slow growing, fragile species, which are most likely to suffer long term negative impacts from hydraulic suction dredging [98]. Fast growing, opportunistic species are likely to recover quickly following dredging and any effects will be shorter lived in dynamic systems. Table 8 gives a summary of the information reviewed, to suggest the effects of hydraulic suction dredging on UK EMS interest features.

Table 8 Summary of Hydraulic dredging impacts by habitat or interest feature

Interest feature (habitat and/ or species)	Specific features of study site if applicable.	Activity details, including target species, gear, scale and timing (if available)	Impact details, including recoverability, scale, community and habitat effects.	Could the activity reduce the range of the interest habitat or species?	Could the activity directly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity indirectly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity change the community composition of the habitat?	Could the activity affect the specific structures and functions necessary for the maintenance of the interest feature?	Could the activity damage or kill any species of community interest within the feature?	Number of references	Reference number
Large, shallow inlets and bays, Mudflats and sandflats not covered by seawater at low tide	Mudflat in Auchencairn Bay, Solway Firth	Suction dredge (not specified)	Reduced species numbers, reduced numbers of individuals. Some recovery after 56 days, but not complete.	No	Insufficient evidence	Insufficient evidence	Yes	Insufficient evidence	Insufficient evidence	1	74
Mudflats and sandflats not covered by seawater at low tide	Stable, cohesive intertidal mud and sediments, various locations.	Suction dredge, targeting cockles.	Tracks cause erosion of sediment. Tracks are present for several weeks following disturbance, but likely part of a natural cycle of erosion and cohesion.	No	Yes (recovery likely within a relatively short timescale)	Insufficient evidence	Yes (recovery likely within a relatively short timescale)	Insufficient evidence	No	1	76
Mudflats and sandflats not covered by seawater at low tide	Intertidal mudflats, Wadden Sea. (fairly high energy habitat)	Hydraulic suction dredge for cockles, fairly large scale	Sediment lost (habitat loss), reduced abundance of typical species, and reduced recruitment levels, correlated with dredging activity. Loss of suitable habitat for mussels.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	2	79, 99
Mudflats and sandflats not covered by seawater at low tide	S Rockaway Beach, southwestern Long Island, N.Y	1.2 m Hydraulic Clam dredge, individual experimental pass	Physical signs of dredging had almost disappeared after a few hours. Damage to target species and increased predation.	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	95

Mudflats and sandflats not covered by seawater at low tide, Shallow sandbanks which are slightly covered by seawater all the time	Fine sand, with coarse gravelly material, Gormanstown, Co Meath, Ireland	Hydraulic razor clam dredge. Examining physical and biological impacts of dredging.	Short term effects on biota, physical effects not visible after 40 days.	No	Yes (recovery after 40 days)	Insufficient evidence	Yes (recovery after 40 days)	Yes (recovery after 40 days)	Insufficient evidence	1	98
Shallow sandbanks which are slightly covered by seawater all the time	Ancona Maritime District, Central Adriatic Sea, Italy	2.4-3 m wide dredge on sledge runners to avoid digging into sediment.	Quick increase in scavenging species. No discernable impact on community as whole, but some change apparent.	No	Yes (recovery likely)	Insufficient evidence	Insufficient evidence	No	No	1	108
Shallow sandbanks which are slightly covered by seawater all the time, Maerl beds	Maerl bed, Stravanan Bay, Clyde Sea, Scotland	Hydraulic dredge, single passage	Maerl buried, redistributed and fragmented.	Yes	Yes	Yes	Yes	Yes	Yes	1	96
Mudflats and sandflats not covered by seawater at low tide	Mobile, intertidal sandLavan Sands, Wales	Hydraulic cockle dredge, single pass	Some impacts on biota, but recovery very fast.	No	No	No	Insufficient evidence	Insufficient evidence	No	1	111
Mudflats and sandflats not covered by seawater at low tide	Blackshaw Flats, Solway Firth	Hydraulic cockle dredge, repeated pass to simulate 3 month licence period	Some statistically insignificant impacts on biota, but recovery very fast.	No	No	No	Insufficient evidence	Insufficient evidence	No	1	111
Mudflats and sandflats not covered by seawater at low tide	Mudflats, hard and soft composition, Traeth Lafan	Area dredged for 3 month period.	Some physical disturbance, greater in harder sediment, recover over winter.	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	113
Shallow sandbanks which are slightly covered by seawater all the time	*Zostera* beds, fine sand/ mud, Solway Firth.	Hydraulic suction dredge targeting cockles.	Can be very damaging, has led to disappearance of beds in some areas.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	2	109, 76
Shallow sandbanks which are slightly covered by seawater all the time	Sandy area with high tidal flow, Western Isles, Loch Gairloch, Scotland and Sound of Ronay, near Grimsay, Outer Hebrides	Water jet dredgers, targeting Razor clams (single pass) (*Ensis* spp)	Single pass through, immediate change to community structure. No effects remained after 11 weeks (75) or 40 days (27). Fast recovery due to inward migration of mobile species from surrounding area.	No	No	Insufficient evidence	Yes (Recovery fast)	Insufficient evidence	No	3	106, 103, 104

Shallow sandbanks which are slightly covered by seawater all the time, large shallow inlets and bays	Sheltered, shallow, low tidal flow, sediment area, Lamlash Harbour on the Isle of Arran, Scotland	UMBSM Hydraulic suction dredge for razor clams, single pass.	Change to sediment structure, long lasting (beyond 100 days)	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	Yes	No	1	114

6.2. Potential effects on Annex I habitats

6.2.1. Shallow sandbanks which are slightly covered by seawater all the time

Depending on the stability of the sediment surface at the time and the prevailing tide or wind conditions, evidence of the tracks left by the dredge head, can persist for several months [76]. The immediate effect of hydraulic dredging on infauna can be significant. Studies have shown up to 30% reductions in the number of species and 50% reduction in number of individuals. Comparison between dredged and undredged areas have shown recovery times varying from 14-56 days [74]. Another study in an area of mobile sand has shown that even after 24 hours, many of the physical features of the dredge track may become difficult to discern from the surrounding seabed [95]. However, effects of hydraulic cockle dredging may last more than a year, even in dynamic systems [99]. The evidence suggests that factors other than how dynamic a system is may influence the potential impact and recovery time at a site and that impact and recovery will be very site specific.

There is also evidence that high levels of bycatch may be associated with hydraulic blade dredging for razor clams. One study estimated that for every 10 kg of marketable razor clams caught, 29 kg of heart urchins (*Echinocardium cordatum*) would be disturbed, 23.5 kg of which would be brought to the surface and discarded and would be unlikely to re-bury [100]. In the same study, between 20 and 100% of otter shells (*Lutraria lutraria*) were damaged in each haul. This species is a slow growing and long-lived species and any recovery would be likely to be slow.

In general the overall decrease in biomass of target species and non-target species is likely to be more pronounced in areas with stable environmental conditions and diverse communities. In sites with moderately mobile sediments it is possible for natural disturbances to have a greater effect than dredging [101, 102]. Sites with more tube-dwelling and sedentary species appear to take longer to recover to pre-fishing levels than areas with more mobile fauna.

The time of year of exploitation will also influence recovery [44]. Avoiding dredging during periods of larval settlement or spawning, for example, can reduce time required for the restoration of infaunal communities. The sediment may change at least in the short term, but how long this remains the case also depends on the exposure and stability of the site. Stable, unexposed sites are likely take longer to recover than sites which are exposed and unstable, which are likely to recover more quickly.

When razor shells are targeted, studies have indicated that the fishing operation initially causes substantial physical disturbance to the substrate with trenches and holes throughout the fished area (0.5 - 3.5 m wide and 0.25 - 0.6 m deep) [103].The length of time these features remain depends on the degree of wave exposure at the site. Tracks were reported to be visible for a few days after dredging but not after 11 weeks [104]. In the same study, no statistically significant difference could be found in communities present in dredged and undredged areas after five days.

In another study [103], recovery to pre-fishing levels of non-target species was shown after 40 days. The effect on long-lived bivalve species, which include the target species, could be more serious since *Ensis siliqua* is estimated as living to 25 years [103].

A comparative study of the effects on *Ensis arcuatus* showed that suction dredging directly affected the size-class structure of the population and that shells from the dredged site showed signs of damage. Animals subsequently returned to the seabed were slow to re-bury and were considered to be highly vulnerable to attack from predatory crabs [105].

Experimental studies on the use of water jet dredgers concluded that there was little difference between the effects of this gear when compared to suction dredgers. In a sandy area swept by strong tidal flow where the gear was tested, trenches were created, there was fluidisation of sediments and although an immediate reduction in species abundance and biomass was apparent, the biological effects were only considered to be short-term [106].

Suction dredging may also be used to gather spat for mariculture. In one study, this caused an 80-90% reduction in non-target fauna and left a trench 10 cm deep [107]. A sediment plume was created but reduced to background levels within 40 days. Regeneration of species diversity and abundance, after harvesting in the winter had occurred by summer. Natural sedimentation had nearly restored the sediment structure to pre-harvesting conditions after four months suggesting that there may be minimal long-term effects if sites are left to recover. In Scotland, Manila clam harvesting has only been trialled and no commercial production has taken place.

A study was undertaken examining the effects of hydraulic dredging for clams in the Adriatic Sea, in an area of fine, well sorted sand [108]. When studying the differences between faunal assemblages at dredged and undredged sites, a sharp increase in scavenging species was identified immediately after dredging, which subsided. No other statistically discernable difference was found where all phyla were studied together. However, when examining phyla separately, discernable effects were observed between dredged and undredged areas. The use of an intermediately affected species was recommended (in this case *Abra alba*) to help monitor impacts rather than examining whole assemblages as this may reduce the time and cost of monitoring and potentially provide more accurate results.

Eelgrass beds

The use of hydraulic dredges targeting bivalves has in the past led to the complete disappearance of areas of eelgrass [109]. Subtidal eelgrass beds or sections of them may sometimes become exposed at extreme low tides.

Where dredging was carried out in a sheltered area with eel grass (*Zostera*) beds, (Auchencairn Bay, Solway Firth), breaking the sward allowed erosion that produced clearly visible grooves down the shore [76]. Studies examining the impact of clam kicking (an activity, which may have similar impacts to hydraulic suction dredging) in seagrass beds in North Carolina, USA revealed a severe decline in seagrass biomass in study areas. Recovery was not evident at the site for two years, and biomass remained in a reduced state for at least four years after the initial impact [110].

Maerl beds

Effects of hydraulic dredging on maerl may be damaging and long-lasting. Live maerl becomes covered in silt as a result of suction dredging (up to 21 m away) [96]. The dredge captures a high diversity and large numbers of benthic organisms including many large long-lived deep-burrowing animals and many large fragile organisms are killed. Maerl thalli are buried, displaced or removed by the dredge, leading to significant damage to maerl beds [96] Due to the slow growth rate of maerl, it is unlikely that this habitat would return to its original status following hydraulic dredging.

6.2.2. Estuaries

Where hydraulic suction dredging is carried out in estuaries, many of the potential impacts discussed in sections 6.2.1, 6.2.3 and 6.2.5 will apply. Please refer to these sections of the report for further information.

6.2.3. Mudflats and sandflats not covered by seawater at low tide

Many of the impacts discussed in section 5.2.1 may also apply to intertidal sand and mud flats and this section should be referred to for additional information.

A study comparing two intertidal, highly wave exposed sand flats was carried out [111]. The first was treated with a single hydraulic cockle dredge pass. The second was repeatedly dredged, to simulate a three month licence. Both sites were highly wave exposed areas of fine, well sorted sand with low silt content. The site subjected to a single dredge recovered quickly although a significant reduction in *Hydrobia ulvae* snails was observed (an important food source for some wildfowl and waders). For the second site, impacts on non-target species also appeared to be small and statistically insignificant. A conclusion was made that hydraulic cockle dredging is unlikely to have a significant impact on non-target infaunal species at the study sites. Studies also indicate that where hydraulic suction dredging occurs, species sharing the same spatial niche as the species being targeted may also be captured and killed, damaged or redistributed [112] as a result of the activity [81]

The impact and recovery rate on sand and mudflats is largely dependant on sediment characteristics and the nature of other environmental parameters at the site. A study investigating habitat and community impacts of hydraulic suction dredging in Traeth Lafan, Wales showed a distinct variation in recovery rates between different sediment types [113]. In muddy sediments tracks were visible for several weeks following disturbance. However sediment in these areas appeared highly mobile, and holes were in-filled to bed level within a relatively short timeframe. Where sediment was more compacted and harder and more stable, teeth on the dredges were set deeper, which led to localised errosion of the sediment. In October, when dredging ended, hummocks and trenches were clearly visible. However, by January, the seabed had begun to flatten out and take on a ‘more normal’ appearance. It is likely that the recovery was also accelerated by strong winds during the winter period. Importantly, there is evidence to suggest that although trenches caused by hydraulic dredges may be infilled within weeks, fluidisation of the sediment may persist far longer[112].

There is evidence to suggest that bivalve faeces play an important role in binding sediments. Dredging removes bivalves, thereby reducing the input of faeces in addition to removing other finer silt components of the sediment. Combined, these factors contribute to reduced sediment stability [78].

6.2.4. Coastal lagoons

Although no literature could be found discussing the impacts of hydraulic suction dredging in lagoons, it is possible that dredging could take place in these habitats. Due to the stable, sheltered nature of the substrata in these areas, it is likely that impacts on benthic species would be high and recovery slow.

6.2.5. Large shallow inlets and bays

Where hydraulic suction dredging is carried out in shallow inlets and bays, many of the potential impacts discussed in sections 6.2.1, 6.2.3 and 5.2.5 will apply. Please refer to these sections of the report for further information. Sediments in these sheltered habitats are likely to be more stable than in wave exposed sites, therefore, it is likely that impacts in these areas may be more long-lasting and severe than in wave exposed areas. A study conducted in a Scottish harbour concluded that sheltered areas take far longer (over 100 days) to recover following a pass by a hydraulic suction dredge than an exposed site (40 days) [114]. Such findings suggest that shallow inlets and bays, which are often sheltered and stable may suffer longer term change as a result of dredging than exposed sites.

6.3. Potential effects on Habitats Directive Annex II and protected species

No literature was found to indicate a direct impact of hydraulic suction dredging on any Annex II species. The nature of hydraulic dredging means that if hydraulic suction dredging were undertaken in areas with *Atrina fragilis* present, individuals may be damaged by the gears used.

6.4. Mitigation methods

Studies have shown that hand gathering [110] or tractor dredging at low tide may cause physical damage to eelgrass beds and would not be recommended as alternative methods of exploiting stocks of clams, cockles or razor clams.

Studies suggest that hand raking is less physically damaging to intertidal sand and mudflats than hydraulic suction dredging. Hand raking will leave sediment ‘in situ’, whilst dredging may lead to removal and resuspension of sediments [115]. However, it is also likely that a switch from hydraulic suction dredging (which occurs at high water) to hand raking (which occurs at low water) may have further impacts in terms of disturbance on bird populations which feed on mudflats at this time. For the reasons given, a measure involving a hand gathering as an alternative to hydraulic suction dredging would need to be carefully assessed in terms of potential impacts on other interest features prior to its introduction.

In Canada, in addition to restricting razor clam fisheries to hand gathering, restrictions includes a minimum landing size for razor clams, non-transferable designation cards, a total catch ceiling (for the year) and closed seasons, have also been applied. Closed areas and restrictions on the number of days spent fishing have also been applied [116]. It is not clear whether such measures would be effective in UK waters, but a combination of measures such as this would certainly be required in order to protect interest features and target species effectively where fisheries occur. Similar regulations have also been imposed for Manila clam fisheries [117].

Where suction dredging for Manila clams has been trialled in Scotland, it has been suggested that restricting harvesting to early winter could ameliorate site restoration if the main mechanisms for re-colonisation is through larval settlement. However, the potential impacts of this timing on bird colonies should also be explored.

Studies of a novel dredge head with a vibrating sorting mechanism have been undertaken [118]. The mechanism is able to sort undersized individuals from the catch 'in situ', thereby reducing bycatch of undersized individuals and some non-target species and avoiding the redistribution of bycatch species, which occurs with current gears. Although some positive results were recorded, higher levels of damage to catch were recorded and higher levels of bycatch of associated fauna occurred.

A novel shear vane has been developed, which can aid monitoring of hydraulic suction dredge impacts by testing changes in sediment stability in dredge tracks [114]. Such developments in monitoring techniques are useful tools in monitoring the impacts of hydraulic suction dredge fisheries and should be utilised to reduce the cost of regular monitoring.

6.4.1. Current UK perspective

Table 9 provides a current perspective of mitigation measures in use in UK EMS to reduce the impacts of hydraulic suction dredging on interest features.

Table 9 Mitigation measures for hydraulic suction dredging enforced by competent authorities in UK EMS

Type of restriction	Enforcing body	Fishing type	Level of compliance	Reasons behind restriction
Have a set number of licences (6 vessels & 1 tractor). Have set TAC which are not to be exceeded.	Scottish Executive	Hydraulic suction dredging	4	Protect the habitat and wading birds
Restrictions on gear type and damage rate. Thames Estuary Regulating Order – TAC which is set each year, gear type.	Kent & Essex SFC	Hydraulic suction dredging	4	Protect cockle stocks and habitat
For cockles: TAC have been set 2500 tonnes/yr (63%), daily quota of 4 tonnes. Operates 4 days a week (Sunday – Wednesday). Bar spacing on riddle & dredge no greater than 12mm. For mussels: TAC have been set 1405 tonnes/yr (90%), daily quota of 4000kg. Operates 5 days a week (Monday – Friday). Once TAC is reached fishery closes.	Eastern SFC	Hydraulic suction dredging	5	Protect the habitats and food source of the oystercatcher
Solway Firth fishery has been closed, if it's to re-open will be a set number of licences as well as limits on the areas where hydraulic suction dredging can take place.	Scottish Natural Heritage	Hydraulic suction dredging	3	Protect the wildfowl and waders
Closed season April 14th – September 15th. Blades are set so don't dig too deep into the seabed. Spaces between bars are a set size to allow undersized cockles to escape.	Cumbria SFC	Hydraulic suction dredging	5	Protect the habitats and species in the Solway Firth (why it was designated)
WAG introduced a statutory section 5 order – no hydraulic suction dredging has taken place since 2000.	South Wales SFC	Hydraulic suction dredging (razor clam fishery)	5	Protect the habitat and food source of the scoter duck

(Note: Levels of compliance range from 0 (severe lack of compliance) to 5 (large amount of compliance))

6.5. Future and current work

Work is currently underway to develop seeding and stock enhancement programs, involving hatchery and re-stocking techniques to replenish razor clam fisheries. Although it is not known how successful measures such as this may be, if large scale hydraulic suction dredging for razor clams were to take place in UK waters, measures such as this may be required to reduce the potential loss of razor clams that the fishery would cause [119]. Measures are currently being developed to reduce the potential for a 'boom and bust' fishery model should such fisheries be permitted in UK waters [119].

There appears to be a need to investigate the potential long term and chronic impacts of hydraulic suction dredging. Whilst there are numerous studies investigating the impact of single gear passes, or the impacts of a single vessel operating at one time, data from established areas that experience repeated dredging activity is minimal. It is therefore important to consider the potential cumulative effects of numerous vessels operating in a fishery. There also seems to be a need for further study into the long-term ecological impacts of fluidisation of the sediment caused by hydraulic gears. It is likely that such impacts may often be overlooked since they are not always obvious during visual observations. Coastal hydraulic suction dredging, particularly the noise generated, may have adverse effects on some Annex II species, including seals and cetaceans, although the authors could find no literature to prove or disprove this theory. Impacts on these groups of species should be explored, particularly to advise future fisheries, which may be planned for areas where such species are present.

7. Scallop dredging

7.1. Overview

The two main species targeted by scallop dredgers in UK waters are the king scallop *Pecten maximus* and the queen scallop *Aequipecten opercularis,* the latter of which is often referred to as a 'queenie'. The two species are very different in size (the queen scallop being much smaller) and display different behaviour following disturbance. As a result, the gears used to target scallops may vary slightly depending on which species is targeted. However, the principal method of dredging is similar for both species. In the UK, a variety of dredge designs are used, ranging greatly in size. Table 10 lists the species and habitats, which are relevant to the report and may be affected by scallop dredging.

Table 10 Species and habitats relevant to UK EMS, likely to be affected by scallop dredging.

Annex I habitats that this fishing type is likely to effect	Shallow sandbanks which are slightly covered by seawater all the time (2.1.1), Estuaries (2.1.2), Large shallow inlets and bays (2.1.5), reefs (2.1.6).
Annex II, birds directive and Wildlife and Countryside Act species likely to be affected by this fishing type	Fan mussel(2.3.1), pink sea fan (2.3.2) and sea fan anemone (2.3.3)

Within the following section of the report, some predictions of the potential impacts of scallop dredges are based on the impacts of other towed gears. Whilst it is acknowledged that impacts will be slightly different between gears, some common impacts will occur. There is evidence to suggest that dredging is more damaging in terms of habitat, ecology and processes than otter trawling or beam trawling [120, 121].

Many of the dredge designs used in the UK are large and heavy and often towed across the seabed at speed. This practice causes physical abrasion at the surface and in the top layers of sediment. Large, heavy, metal dredges, such as the Newhaven dredges are often used to catch scallops living on the surface of sediments or buried in shallow depths of sediment. Such dredges bear spring loaded teeth that dig into the seabed or scrape hard substratum causing significant damage and change to the community. Some habitats, such as coarse sand, are likely to foster naturally mobile communities that may be impacted less by towed gears. Some sediments will include sensitive species such as the fan mussel *Atrina fragilis*. Where rocky areas occur, the pink sea fan *Eunicella verrucosa* may occur. Both of these species are vulnerable to physical damage caused by dredging and both are protected under the Wildlife and Countryside Act 1981. Biogenic reef habitats such as maerl and horse mussel beds and non-biogenic hard substratum are likely to contain sensitive species that will be damaged by the dredge leading to long-term adverse effects. Where these species form biogenic reefs or are a key component of a habitat (e.g. maerl or eelgrass), removal or damage may reduce the extent of these features and would be unacceptable under the Habitats Directive.

Quantifying the level of damage to the seabed and seabed organisms may often prove problematic. It has been suggested that immediate impacts of dredging may be more severe on sandy and muddy bottoms than hard complex bottoms, but of a much longer duration on hard complex bottoms [122]. It is in heterogeneous habitats with shells and stones present or where the substratum is of biogenic origin that the greatest reduction in species richness and the loss of fragile often slow-growing and long-lived species occurs. Recovery will also be slower in these habitats[122,115]. Rose *et al.* [112] concluded that the length of time the effects of fishing are likely to last are directly related to the rate at which the seabed features are produced. In high energy environments the features are constantly being renewed and the effects of fishing will be less persistent, therefore indicating that recovery from dredging will be faster in high energy, highly mobile envirnments, but particularly slow, if possible at all, in stable, low energy environments.

The recovery of a site following dreging is dependant on a number of variables [102,115]. A useful summary of these are provided by the Department of Fisheries and Oceans, Canada [122] as follows:

- specific features of the seafloor;
- species present;
- gear used, methods used, frequency of activity at the impacted site and
- history of human activities (past fishing activities).

All of these features should be taken into account when assessing the potential impact of a fishery at a new site.

Collatoral impacts of scallop dredging in general may be difficult to monitor. Collatoral damage may occur to species, which: avoid gears; escape from gears; are discarded from the vessel and are affected by subsequent habitat damage or predation[123]. Although these impacts are difficult to quantify, they are undoubtedly of great importance to the ecology of benthic ecosystems. Some work has been undertaken to monitor some of these colatoral impacts. In both beam trawls and otter trawls, the greatest amount of mortality remains on the seabed rather than occurring as bycatch [124, 125, 126]. A similar situation also results from scallop trawling [127]. The destruction of seabed organisms may therefore be hidden and underestimated. In addition, areas which have been dredged historically may show less of an impact after subsequent trawls, particularly in relation to impacts on bycatch species [128]. It is therefore important that such factors are taken into account when estimating the potential damage of scallop dredging at a specific site. Evidence of degradation to the ecosystem may not be immediate, suggesting that some indirect ecological changes may be taking place [129]. For example, organisms, which are disturbed or exposed by dredging may become more vulnerable to predation or be smothered the settlement of sediment. In one study a 20-30% decrease in abundance of most species was recorded 3.5 months after dredging, and some differences were still apparent after eight months. In other instances, recovery may be quite rapid, for instance within six months [130]. In another study more than 50% of the common taxa of macrofauna were affected and significant differences from adjacent reference plots were still apparent after three months [131].

There is evidence that long-term change to seabed habitat and community composition will occur in areas dredged over long periods [132]. Over scales of 40 - 60 years, such changes are influenced primarily by how long an area has been dredged for rather than the intensity of activity. Changes include reduced numbers of slow growing, fragile species and increased numbers of fast growing scavenging species and an overall reduction in seabed particle size which is unrelated to original sediment type [132]. Other studies have shown that over shorter time periods, intensity of dredging activity can affect the level at which sandy and gravely seabed communities may be altered [133]. Typically, sensitive species are replaced over time by small bodied organisms which are, less susceptible to disturbance. Areas fished more intensively tend to contain communities typical of sites with higher physical stress[133]. Differences in community structure and habitat have also been associated with levels of intensity for other mobile gear types [134]. A study examining the long-term effect of mobile gear fisheries in the North Sea showed a definite change of habitat and community type across a range of species, caused by fishing activity. Changes were correlated with changes in fishing power of the fleet [135]. Where habitat forming species are removed, even if these are fast growing, refuge may be reduced for a number of species, including juvenile scallops. This loss of refuge may lead to increased predation [136] and negatively impact populations of harvestable species [137].

In mixed sediment habitats, the collection and sorting of stones and shells by the dredge will remove encrusting and emergent sponges, soft corals, hydroids and anemones [136,137]. There is also strong evidence to suggest that reduced habitat complexity resulting from fishing activities will directly lead to reduced species diversity [138]. When comparing dredged sites with undredged sites, dredged sites typically contain less attached epibenthic species and large, habitat forming species [122, 139,140, 141, 142, 143, 144], which may also provide important habitat for commercially important species. In common with other forms of dredging, predatory fish, whelks, hermit crabs, scavenging starfish and brittlestars are attracted to dredge tracks to feed on damaged and exposed animals. For this reason, numbers of scavengers generally increases at recently dredged sites [145, 146, 147, 148]. Burrowing and tube-dwelling infauna may be less affected than epifauna [149], particularly where an epifaunal crust is present. This is due to increased protection and an ability to burrow deeper to escape the pass of the dredge. Areas with large obstacles, such as boulders, which make dredging difficult, are considered to be 'self protected' as dredging can not usually take place[150]. However, areas with complex and varied habitat types, which include fragile, slow growing species, are likely to be highly vulnerable to the impacts of mobile dredging gear [144, 150]. In general, the use of mobile gears, including scallop dredges, will damage structural biota and homogenise and flatten [151] the seabed [122, 144]. In general, scallop dredging over biogenic habitats is extremely damaging [121]. The authors of a meta analysis of all published scientific literature looking at seabed recovery following fishing with mobile gears concluded, based on figures extracted from the literature reviewed, that the effects are likely to last from 972 to 1175 days once dredging has stopped [115]. Conversely, areas dominated by fast growing species will recover quickly [115]. It is worth considering, that although the direct impact of dredging may be great, In some situations seasonal and inter-annual changes such as storm events may be greater than those caused by dredging[129, 140, 152]. Table 11 gives a summary of the information reviewed, to suggest the effects of scallop dredging on UK EMS interest features.

Table 11 Summary of Scallop dredging impacts by habitat or interest feature

Interest feature (habitat &/ or species)	Specific features of study site if applicable.	Activity details, including target species, gear, scale and timing (if available)	Impact details, including recoverability, scale, community and habitat effects.	Could the activity reduce the range of the interest habitat or species?	Could the activity directly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity indirectly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity change the community composition of the habitat?	Could the activity affect the specific structures and functions necessary for the maintenance of the interest feature?	Could the activity damage or kill any species of community interest within the feature?	Number of refs	Reference number
Sandbanks which are slightly covered by seawater all the time, fan mussel	Relatively undisturbed site, including large slow growing infauna, including *Atrina fragilis.* Adriatic Sea	'Rapido' trawl, 3m wide, toothed dredge, used to target scallops. Single pass.	Obvious mortality to fan mussels. Reburial of coralline algae damage to large fragile organisms. (Long term recovery not monitored)	No	Yes	Insufficient evidence	Yes	Insufficient evidence	Yes	1	13
Large shallow inlets and bays, Sandbanks which are slightly covered by seawater all the time,	Mixed, stable sediment, sandy, gravely seabed with cobbles and boulders, various locations worldwide	Mobile gears including scallop dredge	Homogenisation of seabed. Loss of structural features, loss of large, fragile species.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	8	137, 158, 127, 128, 142, 122, 140, 165
Large shallow inlets and bays, Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	*Zostera marina* beds, Back Sound, North Carolina (USA)	Clam kicking, followed by dredging with metal dredge, through eelgrass beds, similar gear to a scallop dredge.	Loss of eelgrass biomass, full recovery had not occurred after four years.	Yes	Yes	Yes	Yes	Yes	Yes	1	110
Sandbanks which are slightly covered by seawater all the time,	Exposed, subtidal sandflats, Mercury Bay, New Zealand	Single experimental pass with scallop dredge.	Loss of structural emergent species recovery not apparent after three months	No	Insufficient evidence	Insufficient evidence	Yes	Yes	No	1	131

Sandbanks which are slightly covered by seawater all the time, reefs	Sediment habitats and boulder/ coble communities in the Irish Sea and Chaleur Bay, Gulf of St Lawrence	Long term, repeated dredging activity	Loss of habitat heterogeneity, loss of fragile, slow growing species. Community shift from undisturbed to disturbed community structure. Reduction in particle size, including cobbles and boulders dislodging and overturning boulders.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	3	132, 133, 141
Reefs	Rock reef, with abundant kelp, Bay of Fundy, Canada.	Single passage of a scallop dredge	Large flora and fauna severely damaged following trawl, but damage was no longer apparent after three months. Suggest that repeated trawling may cause more long-term damage.	No	Yes (recovery within 3 months)	Yes (recovery within 3 months)	Yes (recovery within 3 months)	Insufficient evidence	Insufficient evidence	1	148
Sandbanks which are slightly covered by seawater all the time, Maerl	Maerl beds, : Firth of Clyde and Clyde Sea, Scotland. And Bay of Brest, France	Passage of 3x77cm rock hopper scallop dredges with 9x10cm dredge teeth and Passage of three Newhaven dredges	Severe damage to the reef and ecosystem, still apparent up to four years. Potential community shift.	Yes	Yes	Yes	Yes	Yes	Yes	4	159, 160, 162
Sandbanks which are slightly covered by seawater all the time, Maerl	Maerl beds, : The Stravanan Bay, Isle of Bute and The Caol Scotnish, Loch Sween. Scotland	Scallop dredged area compared to undredged site	Dredged are had reduced habitat complexity caused by damage and burial of maerl.	Yes	Insufficient evidence	Insufficient evidence	Yes	Yes	Yes	1	161
Large shallow inlets and bays, Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	Eelgrass beds, on both hard and soft sediments, North Carolina, USA	Hand pulled scallop dredge.	Loss of eelgrass biomass and shoot number resulted, effects were long lasting	Yes	Yes	Yes	Insufficient evidence	Yes	Yes	1	163

Reef	Mudstone reefs, cobble and bulder seabed, Lyme Bay	Passage of 12 X spring loaded dredges.	Caused extensive physical damage to boulders and mudstone reefs. Displaced number of feature. Risk of system switching. Pink sea fans amongst species killed.	Yes	Yes	Insufficient evidence	Yes	Yes	Yes	1	154
Reef	File shell reef, Clyde Sea, Scotland.	Passage of three Newhaven dredges	Reef destroyed, individuals exposed and killed. No full recovery after four years.	Yes	Yes	Yes	Yes	Yes	Yes	1	159
Sandbanks which are slightly covered by seawater all the time,	Sandy seabed, 20 km east of Venice Lagoon, northern Adriatic Sea.	Rapido trawl, immediate and long-term effects studied.	Loss of epifauna, increase in scavenging species.	Insufficient evidence	Insufficient evidence	Yes	Yes	Insufficient evidence	Insufficient evidence	1	164
Estuaries	Silty, muddy bottomed estuary, Damariscotta River estuary, Maine, USA.	23 passes of a 2 m wide Bedford-style scallop dredge.	Reduced diversity of macrofauna, assemblages had not recovered six months after dredging.	No	Yes	Yes	Yes	Insufficient evidence	Insufficient evidence	1	130

7.2. Potential effects on Annex I habitats

7.2.1. Shallow sandbanks which are slightly covered by seawater all the time

In relation to scallop dredging, "species diversity and richness, total number of species, and total number of individuals all decrease significantly with increasing fishing effort"[134]. The causes include "selective removal of sensitive species and, more importantly, habitat homogenization" [134]. This has serious implications for the maintenance of ecosystem, functions and the overall integrity of these features.

Where sublittoral sediment habitats are subject to natural disturbance from wave action and tidal currents, adverse effects on fauna are likely to be shorter-lived. There is evidence to suggest that reduced habitat complexity in simple sandy seabed habitats resulting from dredging can be directly correlated with reduced species diversity [138].

A study undertaken near Salcombe, Devon, revealed that areas dredged regularly contained a lower biomass of species and fewer emergent epifauna, which reduced habitat complexity in these areas. The study also revealed the dredged sites had fewer dog cockles (*Glycymeris glycymeris)* a species particularly vulnerable to damage by mobile gears [153].

Tracks are created on the seabed, fine sediments are lifted into suspension and large rocks can be overturned [145, 149, 154, 155]. A mound of sediment may be carried in front of the dredge bar and deposited around the sides in distinct ridges, most obviously in the case of the spring-loaded scallop dredges [146]. Investigations into the effects of oyster dredging and the use of modified oyster dredges to harvest clams have shown that the top 10-15 cm may be removed by the action of the dredge, sediment plumes created, and tracks made on the seabed. It is quite likely that similar effects will result from smaller scallop dredges. The gravel fraction in the sediment can be reduced and sediments become anoxic after dredging [156]. The suspended sediment may also have an indirect effect on species some distance from the dredging operation, where smothering occurs. There is evidence to suggest that scallop dredging over area of fine, organically rich sediment, dominated by tube forming burrowing fauna may completely alter the type of habitat present. Habitats such as these may become characterised by larger grain size with lower levels of organic material [157].

Level, sandy sediments have often been found to be little affected and/or to recover within a few weeks after single passes or after cessation of studies involving multiple passes. Where dredge teeth penetrate the sediment, burrowing species such as burrowing urchins may be caught as bycatch. The presence of such species as bycatch in dredges may be used to monitor the impact of dredges on benthic communities [158].

In a study carried out in the Skomer Marine Nature Reserve the numbers of the sea anemones *Cerianthus lloydii* and *Mesacmaea mitchellii*, and the sand mason worm *Lanice conchilega* within and alongside dredge paths were similar to pre-dredge levels several weeks later [149]. Meta analyses using data from all available papers describing the impact of mobile fishing gears on a variety of benthic habitats identified that muddy, gravely sands are amongst the most severely impacted by fishing activity, whilst fine, mobile sands are amongst the least impacted [115],[121]. The results of the analyses highlight the importance of identifying the physical nature and potential sensitivity of a sandbank before fisheries commence on a site-by-site basis.

Maerl beds

Maerl beds are highly susceptible to the effects of mobile fishing gear especially heavy scallop dredges [159, 160] and are unlikely to recover for many years if at all. File shell (*Limaria hians)* reefs are also damaged by scallop dredging and may not recover [160, 161]. According to a recent study [160] examining the impacts of scallop dredging using a gang of three Newhaven dredges with a 77 cm mouth width, the species most affected were large fragile organisms that are killed directly. Such large fragile organisms included reefs of file shells that had not recovered after four years. The study also revealed that for each kilogram of scallops collected there was 8-15 kg of bycatch [160]. Furthermore, scallop dredging over maerl reduces structural heterogeneity and therefore reduces the diversity of associated organisms [161]. There is evidence that some burrowing species may not be directly impacted by scallop dredges. However, these species will be affected at stages of their lifecycle where they are nearer the surface [162]. Evidence of such impacts may be delayed and not immediately obvious. It is also suggested that the preservation of maerl beds will help fisheries in nearby areas by acting as stock areas for commercially important bivalve species [163]. Such evidence provides support for avoiding dredging in maerl bed areas to benefit both the habitat and fishery interests.

Eelgrass beds

Effects of scallop dredging across eelgrass beds have also been investigated and show significant reduction in eelgrass biomass and shoot numbers on both soft and relatively hard seabeds with the potential for both short and long-term effects on the settlement of juvenile scallops and other invertebrates [163]. Beds may also be affected by smothering and increased water turbidity caused by scallop dredging 'plumes' of suspended sediment. The impact of 'clam-kicking' (a practice, which involves pulling a heavily chained trawl across the seabed, similar to scallop dredging) has been studied on eelgrass beds in the USA [110]. The study revealed that at very low intensities, eelgrass biomass recovered within a year. However, at high intensities recovery did not begin before two years and biomass remained reduced after four years.

7.2.2. Estuaries

Scallop dredging does occur in estuaries and many of the impacts likely to occur in estuarine systems are discussed in sections discussing impacts on subfeatures (see sections 7.2.1 and 7.2.4). Some of the information reviewed for section 7.2.3 is also relevant. To avoid repetition, the reader is directed to these sections for further information. The information given in section 7.1 may also be relevant.

7.2.3. Large shallow inlets and bays

On mixed substrata in particular, species composition in dredged areas may differ greatly compared to undredged areas. Scallop dredging may significantly reduce the number of species, number of individuals and lower biomass of macrofauna [164]. Species that appear adversely affected include hydroids, infaunal polychaetes, and amphipods, crabs, erect bryozoans, large bivalves, sea urchins, brittlestars and sand eels [165, 166].

A study on the effects of mussel dredging, an activity comparable to scallop dredging, in a sheltered fjord in Denmark showed an increase in suspended particular matter immediately after dredging, but a return to initial conditions after one hour [167]. Oxygen levels decreased significantly but there was little change in nutrient levels except in the case of ammonia. This work suggests that water quality can be reduced by mussel dredging because of increasing nutrient loads, oxygen consumption and possibly phytoplankton production. The total annual release of suspended particles as a consequence of mussel dredging at this site was nevertheless considered to be relatively unimportant compared with the total annual wind-induced resuspension [168] or the effect of land run-off. Changes in the benthic flora and fauna as a consequence of repeated mussel dredging [168] were considered to have a more severe effect than suspension of sediments and increased nutrient loads caused by the action of the dredges [13]. Studies also suggest that following scallop dredging the 'food quality' of sediments in silty sand habitats may be significantly reduced for four to six months [130]

Toothed dredges, including 'rapido' dredges (currently used in the Mediterranean) and Newhaven style dredges, may pierce and kill large, fragile organisms, particularly the fan mussel *Atrina fragilis* [13], which is a UK BAP species protected by the Wildlife and Countryside Act 1981 and can be found in soft, wave-sheltered sediments.

On gravelly seabeds around the Isle of Man, community composition has been shown to be related to the intensity of commercial dredging effort [132]. Effects may differ from those in areas of soft sediment due to the extreme patchiness of animal distribution, greater abundance of epifauna and the combined effect of the toothed gear and stones caught in the dredges. Impacts may also be apparent in lightly dredged areas, including the loss of a number of species including some potentially fragile tube-dwellers [164].

Recovery of habitats and species from these forms of dredging can take place but the timescale will vary depending on the conditions at the site and the outcome will not necessarily be identical to pre-dredging conditions [169]. Tracks are likely to become in filled, although at low energy sites this may be with fine sediment, creating some habitat variation [157].

Interviews with WWF revealed that Strangford Lough is in unfavourable conservation status due to previous damage from trawling activities therefore the sub-feature of horse mussel reefs are currently under restoration. There is a particular concern that there are likely to be knock-on impacts from the damage to the one interest feature that will affect the ecological functions within the lough. Lack of stabilisation of the seabed from horse mussel reefs may also lead to increased suspended sediment and poor water quality. Questions also remain as to whether the horse mussel will be able to become re-established due to climatic conditions.

7.2.4. Reefs

Rock (including cobble)

Fragile species such as the filigree worm (*Filograna implexa)* and ross *(Pentapora foliacea)* appear to be particularly vulnerable to damage and removal by towed gears[140, 149]. Slow growing species are often unable to recover to pre-dredging numbers or sizes even if there is no dredging for several years. Where large cobbles and boulders are removed or broken down by gear, habitat heterogeneity will be lost and, in the case of removal of suitable substrate, structure forming species may be lost. Rock reef structures, which may provide a substrate for fragile epifauna, may be broken and fragmented by scallop dredges [153],[154]. Such an impact could be considered to reduce the range of this habitat type. Of additional concern is that rock structures will not be able to return to their original state once severe physical damage occurs, leading to permanent loss of habitat.

Reefs may be extremely vulnerable to the impacts of dredging, particularly where they occur as ‘islands’ in areas dominated by soft sediment [62]. Rocky reef habitats, which are particularly stable and relatively undisturbed may also be more vulnerable to the impacts of dredging and In some studies, ‘desertification’ of reef habitats, formerly inhabited by slow growing, species with poor dispersal mechanisms has occurred [60]. It is clear therefore that the ability of dominant, key or special interest species to recolonise an area following disturbance is a vital factor when predicting the ability of a habitat to return to favourable status. In situations where recolonisation is likely to be hindered by any mechanism, recoverability and the likelihood of an area returning to favourable status will also be reduced.

In areas of pebbles and cobbles, a study conducted on the Georges Bank [170] revealed clear evidence that areas with high levels of dredging activity had a very different community structure and habitat structure to sites with low activity. Typically, areas of high activity where characterised by smooth cobbles and pebbles with far fewer epifauna and structure forming species.

In the bay of Fundy, Canada, scallop dredges have been used to catch sea urchins over hard substrate with large boulders. This activity results in severe damage to large kelp fronds by overturning and dislodging boulders and leading to a decreased numbers of urchins[148]. Effects on benthos in UK habitats would likely be comparable to those in this study, should this scallop dredges be used over hard substrata in UK waters.

Horse mussel beds

Biogenic habitats such as horse mussel beds may be completely displaced following dredging. Horse mussel beds are concretions of large slow-growing bivalves, *Modiolus modiolus* which form an important habitat for many other species. Dredging for queen scallops (*Aequipecten opercularis*) on beds of horse mussels is likely to result in the destruction of the horse mussel beds. Experience in the Strangford Lough cSAC provides a salutary lesson for statutory authorities. Horse mussel communities once covered much of the bottom of Strangford Lough forming very extensive reefs and providing habitat for hundreds of other species. Most of the area where they once lived has now been destroyed by fishing and a recent survey [171] found only one remaining living pristine reef. Fishermen use mobile gear to trawl for queen scallops that live in the habitat provided by the horse mussel clumps. It is now unquestionable that the commercial trawling has caused the destruction of the reefs. The extent and the diversity of associated communities of horse mussel beds in the Irish Sea is believed to have been greatly reduced since surveys in the 1950s, almost certainly as a result of use of mobile fishing gear [158].

Interviews conducted during the project revealed that WWF believe there needs to be an assessment of remaining fishing activities in Strangford Lough, including potting. A result from the ban on mobile gears was a significant increase from potting effort and this and other activities such as anchoring boats are to be considered within the Strangford Lough management and restoration plans. However, WWF said that their concerns about the further destruction of the reef from scallop dredging (and other mobile gears) should be alleviated by the introduction of the ban on trawling within the Lough and the subsequent restoration plan [11].

Lophelia reefs

There is evidence that dredges can cause severe damage to deep water *Lophelia* reefs [172]. This impact has not been extensively studied but the fragile nature of these reefs and the extremely long potential recovery time makes the reefs very vulnerable. Mobile gears in general are likely to flatten and homogenise this heterogeneous habitat.

File shell reefs

There is strong evidence that scallop dredging will have a variety of direct impacts on file shell reefs [10, 160, 161], which may be severe and long lasting. Nests built by the bivalve are easily damaged by the passage of mobile gears, particularly scallop dredges. Individuals may also be directly destroyed or exposed to predators [10]. Studies have shown that recovery from such an impact is likely to be slow, with no recovery evident after four years [160,161].

Sabellaria reefs

Sabellaria alveolata and *Sabellaria spinulosa* reefs are both likely to be physically damaged by the passage of mobile gears such as a scallops dredges, which immediately decrease the extent and range of these biogenic reef habitats. The removal of *Sabellaria* reefs can significantly reduce habitat complexity in an area and reefs are often replaced by faster growing polychaete species which lack the same habitat forming abilities [173].

7.3. Potential effects on Habitats Directive Annex II and protected species

Toothed dredges, such as Newhaven style dredges, may pierce and kill the fan mussel *Atrina fragilis* [153]. In some areas, it is believed that scallop dredging has completely wiped out populations of fan mussels [174]. Whilst mussels may be able to survive minor damage to their anterior end, complete removal from the sediment will prove fatal as the species is unable to re-bury itself [174].

7.4. Mitigation methods

A study conducted by Cefas examined the potential effects of different types of scallop fishery closures around the UK [175]. The study, which was based on a review of available evidence, examined a number of potential scenarios for closure regimes. The study revealed that seasonal closures are unlikely to be effective in terms of protecting long-lived species, including habitat forming species although faster growing species may benefit from short periods of recovery. Rotational closures of less than five years would allow some recovery, but habitats and longer lived, slow-growing species would return to a dredged state once fishing recommenced. The only type of closure found to be effective for the recovery and protection of fragile, long-lived species, including habitat forming species, was a permanent closure. It was also found that such a closure may benefit surrounding fisheries in terms of larval supply and spill-over of commercially important species in addition to maintaining the sustainability of surrounding fisheries and genetic variation amongst stock. Another study examining the potential benefits of avoiding dredging over maerl beds suggests similar benefits to surrounding fisheries from this type of closure [162]. Studies of area closures in Georges Bank revealed that closing areas to scallop dredging protected scallop populations and non-target demersal fish species [176]. Protecting demersal fish may have greater effects on ecosystems, which may benefit interest features, including piscivorous marine mammals. Commercial demersal fisheries may also benefit.

Mobile fishing gear, especially where heavy or penetrating gear is used, is likely to cause damage to seabed species. To avoid damaging sensitive seabeds and, where water is shallow enough and conditions allow, hand gathering of scallops by experienced divers is far less damaging to sensitive seabed species and habitats and can be more selective. Where using an alternative gathering method is not a viable option, novel gears are currently under development, which reduce physical damage to seabeds. Such designs may avoid contact with (and damage to) the seabed to exploit natural scallop behaviour of swimming away from the seabed when disturbed [177].

When developing and testing novel gears and alternative fishing techniques, it is important that collateral impacts, which may not be immediately obvious, and other larger scale ecosystem impacts should be taken into account. Gears which improve selectivity and reduce physical contact with structural features will help ameliorate these impacts [123]. Such measures have been deployed and changes enforced, with varying success in other fisheries.

On a UK wide and global level, a variety of restrictions have been implemented in order to preserve scallop populations. Measures include, those which improve the selectivity of gear to target mature individuals and retain healthy, juvenile populations [178]. Measures, which control effort, such as closed seasons and limits on time spent fishing, are also commonly used.

In Australia, regulations have been developed which require fishers to report any damage to protected species within seven days and to report all bycatch [179]. While it has not been possible within the scope of this project to identify how successful the regulations have been, it is likely that this measure would help monitor any potential impacts on interest features (in the UK) and steer appropriate action to mitigate impacts in the future.

There remains very little doubt that scallop dredging using traditional dredges has severe and long-term impacts on habitats such as reefs and stable sediments. However, flat areas with soft, mobile sediments are likely to suffer less long-term damage. Gears such as the peninsula dredge also operate more efficiently in this type of habitat [151]. Agreements or restrictions requiring activities to be restricted to this habitat type in dynamic systems may be a way of protecting fragile features. However, further study may be required in order to assess any site specific impacts, and long-term and cumulative effects such a measure would have.

Where size limits are set for scallops, it would be preferably to select for size prior to capture to avoid the need to return undersized individuals. These may be displaced from their preferred habitat and returned individuals may display slower righting and recessing rates, making them vulnerable to predation [180].

It is essential that any measures, which are imposed to mitigate the impacts of scallop fisheries are monitored as a matter of course. Parameters such as the quality and range of interest features should be measured to ensure that they are not being negatively impacted. Any agreements which allow dredging to take place should include provisions to allow for restrictions to be tightened if required following review. Measures which improve fishery productivity as well as protecting interest features, such as closures of selected areas, would obviously be preferable for the fishing industry and environmental protection. Other joint agreements used in Australia include a requirement for stock to reach a certain level before fishing is allowed. Other measures include interdepartmental spatial agreements and zoning allowing for ‘fallow’ areas to be left for periods of time. Such measures are supported by agreements between separate responsible management bodies [181].

7.4.1. Current UK perspective

Table 12 provides a current perspective of mitigation measures in use in UK EMS to reduce the impacts of scallop dredging on interest features.

Table 12 Mitigation measures for scallop dredging enforced by competent authorities in UK EMS

Type of restriction	Enforcing body	Fishing type	Level of compliance	Reasons behind restriction
Closed season during the summer in the 3-6 mile limit. Prohibited within 3 mile limit.	Sussex SFC	Scallop dredging	4	Protect scallop stocks

Closed season from July – September, during open season dredging is only allowed between 7am & 7pm. Max. 12 dredges at one time.	Devon SFC	Scallop dredging	4	Protect the habitat
Max. Vessel size – 12m. Night curfew – dredging can only take pace in daylight hours. Max. 6 dredges on each side.	Southern SFC	Scallop dredging	3	Protect biogenic reefs
Limits to max number of dredges, vessel length and horsepower. Prohibited in intertidal areas unless authorized by SFC. Closed seasons (by-law 1st July – 31st October and national legislation 1st June – 31st October).	South Wales SFC	Scallop dredging	5	Protect maerl and seagrass beds
By-laws restricting vessel length and number of dredges. Currently working towards a voluntary agreement.	Cornwall SFC	Scallop dredging	5	Protect subtidal sandbanks, reefs and estuaries
Open season from November to May and other areas that are closed all year.	North Wales and Western SFC	Scallop dredging	3	Protect the biogenic reefs
By-law to restrict the number of dredges per vessel – max 10 (5 each side).	Northumberland SFC	Scallop dredging	4	Protect the reefs
Prohibited within 3 mile nautical limit. Closed season June – September within 3-6 mile nautical limit.	North Eastern SFC	Scallop dredging	4	Protect the habitat
National legislation only – min. landing size and max dredge size.	Kent & Essex SFC	Scallop dredging		Protect scallop stock and habitat
Regulatory Order which applies from MLW to the 6 mile nautical limit. Max. of 5 dredges per side of vessel. All vessels must be licensed.	Shetland Council	Scallop dredging	5	Protect scallop stocks
Gear restrictions to manage the stock. Process of setting up a closed area – whole of Firth of Lorn SAC. Number of statutory orders under the Inshore Scottish Fisheries Act 1984.	Scottish Executive	Scallop dredging	5	Protect the reefs

Voluntary measure – no dredges within 20m contour line (specific to 1 SAC – Ascrid, Islay & Dunvegan). Research being conducted in 2 SAC to allow for conclusions to be made into the best management of the site (Firth of Lorn SAC and Loch Creran SAC).	Scottish Natural Heritage	Scallop dredging		Protect the sandbanks and maerl
Completely banned in Strangford Lough SAC	WWF – N. Ireland	Scallop dredging	1	Protect horse mussel beds and reef features

(Note: Levels of compliance range from 0 (severe lack of compliance) to 5 (large amount of compliance))

A range of mitigation measures are currently deployed around the UK (see table12). There is a perception from Competent Authorities that compliance with these measures is high, with scores from 3 – 5 for all measures.

In Strangford Lough, no scallop dredging takes place following a ban introduced in December 2003. This ban was established following the destruction of large areas of horse mussel beds. There is widespread concern that the introduction of a ban at this time was too late to protect the interest species.

Seasonal closures are used in a number of areas around the UK (see table12) with relatively high levels of compliance. However, it is likely that seasonal closures will not be sufficient to protect all interest features, particularly those which included slow-growing, fragile species.

Studies of closed areas around the Isle of Man have indicated that closing areas to dredging may allow biomass and species diversity to reach levels higher than areas still dredged. The abundance of tube dwelling and epibenthic species has also been show to be higher in closed areas. However, large, slow-growing, longer-lived benthic species may not recover [141], indicating that areas dredged previously will benefit from closures, but in the short term, will be unlikely to reach previous favourable status in terms of species recovery. Consequently, recovery of an area containing long-lived species should not be relied on where favourable status of a habitat is required. Instead, these areas should be protected prior to any activity such as scallop dredging likely to impact them.

A voluntary inshore potting agreement near Salcombe, Devon, has been developed to allow fixed gear fisheries to co-exist with scallop dredging activities. Complex spatial and temporal agreements have been developed, with the agreement of fishermen, resulting in some areas where dredging is not allowed. The agreement seems to have benefited benthic communities in the area by protecting species and habitats sensitive to disturbance by mobile gears [153].

In Scotland, a range of measures are available for the management of scallop fisheries and it is likely that a combination of these measures (listed by Symes and Ridgeway [182]) may be useful in protecting scallop populations and EMS interest features. These measures include:

- developing measures to increase size at first capture;
- increasing minimum landing size;

- increasing dredge selectivity;
- reducing fishing effort;
- closed seasons;
- limits on vessel size;
- limited number of licences;
- spread of dredges;
- length of fishing time;
- TAC and individual vessel quotas, and
- measures to protect vulnerable habitats.

It is likely that a combination of complementary measures such as these will be most effective in protecting EMS features and scallop stocks.

7.5. Future and current work

SNH are currently conducting research into the efficacy of mitigation methods in the Firth of Lorn SAC and Loch Creran SAC. Conclusions will be used to develop best management practice for the sites.

In New Zealand, new measures to increase the sustainability and reduce the environmental impact of scallop fisheries are currently being trialled. At the end of 2007, the results of these trials will be assessed to establish whether objectives have been met [183]. The measures being trialled include: Total Allowable Catches (TAC), closed seasons, size limits, continued monitoring, zoning of areas for commercial and non-commercial fishers and monitoring bycatch levels from different zones.

Much work has been undertaken to develop gears which improve selectivity and reduce non-catch mortality or increase capture efficiency. However, the development of gears which are less damaging to habitats and non-target species appear to be far fewer. This may be due to the economic benefits of maintaining a harvestable stock. If scallop dredging were to be undertaken in certain EMS, without compromising the integrity of interest features, gears would be required which would not damage the seabed habitats and which did not result in large amounts of non-target species bycatch. Such ‘seabed friendly’ scallop trawls have been developed [177], but further study may be required to assess their efficacy. Investigations into alternative methods of scallop harvesting, such as diver gathering, should be undertaken. Potential markets for such ‘environmentally friendly’, high quality products should also be explored to identify whether fisheries could operate profitably and in harmony with EMS interest features.

8. Oyster culture, husbandry, stock enhancements and harvesting.

8.1. Overview

A number of methods of oyster cultivation are used in UK waters with issues for consideration at the seed collection, on-growing, and harvesting stages of the process [184]. Oysters may be suspended in lantern nets, laid in trays or poches (large meshed sacks) on the shore, attached to ropes suspended in midwater or re-laid in more suitable areas for re-growing.

Oyster growing is usually carried out in sheltered areas such as lagoons, estuaries, inlets and bays. For the purpose of this report, some of the effects of culturing other bivalve species in UK waters have been reviewed for comparison, because some impacts will be similar. Table 13 lists the species and habitats, which are relevant to the report and may be affected by oyster culture systems.

Table 13 Species and habitats relevant to UK EMS, likely to be affected by oyster culture systems.

Annex I habitats that this fishing type is likely to effect	Shallow sandbanks which are slightly covered by seawater all the time (2.1.1), Estuaries (2.1.2) Mudflats and sandflats not covered by seawater at low tide (2.1.3), Large shallow inlets and bays (2.1.5), reefs (2.1.6)
Annex II, birds directive and Wildlife and Countryside Act species likely to be affected by this fishing type	Seabirds, wildfowl and waders

The two commercially important oyster species in the UK are the Pacific oyster *Crassostrea gigas*, and the flat or native oyster *Ostrea edulis*. The latter of these species is native to our waters and was once abundant in many estuarine and coastal areas around Europe. In recent decades declining stocks have been blamed on overfishing, disease, changes to waters quality and temperature and the introduction of non-native species. At present the majority of native oysters sold in the UK come from wild stocks. In some areas, native oyster stock is collected from the wild and re-seeded. It is thought that the spread of disease has deterred oyster growers from cultivating this species, instead opting for the more resilient Pacific oyster [185]. Pacific oysters have been cultivated throughout Europe because they grow larger and more quickly than native species and are more resilient to disease. When the Pacific oyster was first cultivated in UK waters, it was not thought that the species would be capable of spawning successfully due to cold water temperatures. However, as our seas become warmer, wild populations are becoming established and may pose a severe threat to a variety of habitats and species [55].

There has been concern about the inadvertent introduction of alien species (such as the seaweed *Sargassum muticum*, the slipper limpet *Crepidula fornicata* and the American oyster drill *Urosalpinx cinerea*) via movement of shellfish and which have all adversely affected natural communities. Such species may ‘hitchhike’ on shellfish which are imported or moved around the UK as seed stock for cultivation [186]. Species imported for mariculture or to boost native stocks are also likely to spread and grow unchecked in the wild. For instance, the Pacific oyster *Crassostrea gigas* is now frequently found on rocky shores and on sediments in some estuaries in south-west England and populations of the oyster have taken over previously productive mussel beds in the Wadden Sea [187]. There is evidence to suggest that *Crassostrea* *gigas* is now becoming locally abundant in some UK waters in the vicinity of oyster culture operations.

The effects of on-growing depend on the habitat, type and scale of cultivation. Changes in sediment composition and benthic community structure have been observed under long-lived cultures of *Mytilus edulis* for example. A three year study showed that faecal matter and detached mussels increased sedimentation under the lines at a rate of 10 cm/yr. The effects on the sediment under the culture were reduced grain size, high organic content and a negative redox potential. Benthic fauna were replaced by opportunistic polychaetes and only limited recovery was observed when the site was re-sampled six months after harvesting [188]. In these respects the effects are similar to those beneath finfish cages. Examination of the sediment structure and the infauna beneath Manila clam lays revealed no significant differences in particle size, organic content or photosynthetic pigment between control areas and the lays while the clams were growing[107]. There were also no significant differences in the faunal diversity beneath the lays when compared to control sites, but there was a greater density of benthic species under the lays. The infauna were dominated by deposit feeding worms *Lanice conchilega* and the bivalve *Mysella bidentata* compared to the white ragworm *Nephtys hombergii* in the control area. In another study, species effects were seen in the first six months with the infauna dominated by opportunistic species [189]. The nets used to contain the clams and provide protection from predators, have been found to increase sedimentation and settlement of green macroalgae and are likely to have had a major influence on some infaunal species [189].

Effects on benthic communities of small scale culture may be limited and localised. In homogenous habitats, oyster culture structures and oyster trays may increase habitat complexity and alter the prey available to top predators and increase the nursery potential of a previously homogeneous habitat [190]. If the area covered is large there is potential for conflict with bird feeding or roosting sites [184]. Studies in Tasmania examined the effects of *Crassostrea gigas* longline culture on benthic community and habitat composition. The study examined species present and sediment composition beneath long established culture systems. No significant impact from culture systems locally or in the surrounding areas was identified[191]. Table 14 gives a summary of the information reviewed, to suggest the effects of oyster culture systems on UK EMS interest features.

Table14 Oyster culture impacts by habitat or interest feature, summary table

Interest feature (habitat and/ or species)	Specific features of study site if applicable.	Activity details, including target species, gear, scale and timing (if available)	Impact details, including recoverability, scale, community and habitat effects.	Could the activity reduce the range of the interest habitat or species?	Could the activity directly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity indirectly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity change the community composition of the habitat?	Could the activity affect the specific structures and functions necessary for the maintenance of the interest feature?	Could the activity damage or kill any species of community interest within the feature?	Number of references	Reference number
Bottle-nosed dolphin	Bottle-nosed dolphin	Oyster culture structures, Shark Bay, Australia	Displacement of individuals, locally	Yes	No	Insufficient evidence	N/A	Insufficient evidence	No	1	109
Estuaries, Mudflats and sandflats not covered by seawater at low tide, waders, wildfowl	Variety of wading birds and wildfowl .	Intertidal oyster trestles on mudflats, Saleen estuary, Study of bird behaviour and bird counts at low tide. Johnsbrook, SW Ireland.	No effects on feeding behaviour. Fewer birds in trestle area.	No	No	Insufficient evidence	No	Insufficient evidence	No	1	51
Mudflats and sandflats not covered by seawater at low tide,	Mudflats and sand flats and mussel beds, Wadden Sea Germany.	Escaped, wild Pacific oysters growing on mud and sand flats	High survival rate of oyster and limited selectivity will reduce available settlement habitat for mussels	Yes	Insufficient evidence	Yes	Yes	Yes	Insufficient evidence	1	187
Large, shallow inlets and bays,	Shallow inlet, dynamic sediment, resuspended regularly by wave action Shippagan, New Brunswick, Canada	Study impacts on benthos of suspended low intensity (8 kg m-^{2}) culture.	No discernable effects recorded	No	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	192
Large, shallow inlets and bays,	Sheltered bay, 14.4m deep sandy silt, Gkasho Bay, Japan	Study of sediment beneath pearl oyster culture	No discernable effects recorded	No	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	193

Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	Eelgrass beds, Willapa Bay, Washington	Suspended longline culture	Eelgrass growth and biomass was very similar to control sites and did not seem to be affected.	No	No	Insufficient evidence	No	Insufficient evidence	No	1	194
Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	Eelgrass beds, Willapa Bay, Washington	Dredged ground culture and hand harvested ground culture	Biomass and growth of eelgrass was reduced	Yes	Yes	Insufficient evidence	Insufficient evidence	Yes	No	1	194
Large, shallow inlets and bays,	Mahurangi Harbour, northern New Zealand	Oyster farm, of 1m wide racks	Sediment beneath racks and 5m radius of racks contained higher levels of silt clay. Community was indicative of a disturbed site and differed to undisturbed areas nearby.	No	Insufficient evidence	Yes	Yes	Insufficient evidence	No	1	196
Large, shallow inlets and bays, Mudflats and sandflats not covered by seawater at low tide,	Intertidal mudflat, Dungarvan Bay, SE Ireland.	Oyster culture trestles, with access lanes	Sediment beneath trestles was not organically enriched and community was similar to undisturbed sites. Lanes were more compacted and community was indicative of a disturbed site.	No	No	Insufficient evidence	Yes	Insufficient evidence	No	1	197

8.2. Potential effects on Annex I habitats

8.2.1. Shallow sandbanks which are slightly covered by seawater all the time

The potential impact of oyster mariculture is largely dependant on the sediment characteristics and hydrology at the site in question. There is evidence to suggest that in more dynamic areas, with more mobile seabed characteristics, the effects of Oyster culture on seabed community composition will be minimal [192]. It is also likely that in these circumstances there will be little difference between suspended culture and table culture of oysters. A Japanese study has been carried out that compares the impacts of fish farming and pearl oyster (*Pinctada martensi*) culture on benthic community structure [193]. The study was carried out in a sheltered, shallow water (14 m) inlet over a relatively mobile sandy silt seabed. Authors noted that fish farming led to anoxic sediment conditions below pens and impaired benthic community structure. However, in areas beneath oyster culture areas, it was concluded that there was no conspicuous disturbance.

***Zostera marina* beds**

Studies have been carried out in Willapa Bay, Washington, to compare the impacts of hand gathering oysters, suspended longline cultures, dredged culture areas and areas where no oyster culture takes place [194]. By studying a variety of measures that indicate eelgrass bed health namely, standing biomass, percent cover, growth rate and density of vegetative and flowering shoots, the authors of the study concluded that these parameters were all highest in areas where suspended culture or no activity took place. Parameters were reduced significantly in dredging and hand gathering areas, although these two treatment sites did not differ significantly from each other.

Other studies have shown that introduced oyster reefs can directly reduce growth of *Zostera marina*. Whilst *Crasosstrea* beds are unlikely to encourage the same biodiversity levels as *Zostera marina* beds, both encourage higher levels than nearby clean sand or mud[191]. If *Zostera marina* beds were an interest feature for a EMS, this impact would be unacceptable as the coverage of eelgrass would be impaired or reduced.

8.2.2. Estuaries

Resource competition and smothering resulting from the introduction of non-native species associated with oyster mariculture has likely been a major factor in the decline of the non-native oyster *Ostrea edulis* in estuaries and mixed sediment seabed around the UK [174].

There is evidence that wild populations of *Crassostrea gigas* that have spread from culture systems may cause changes to the trophic structure of estuarine systems [191] and may compete with native filter feeding species for food, including commercially grown oysters nearby [190].

Many of the impacts discussed in sections 8.2.1, 8.2.3, 8.2.4 and 8.2.5 may be relevant to estuarine systems.

8.2.3. Mudflats and sandflats not covered by seawater at low tide

Non-native oysters that spread and grow unchecked in the wild can displace mussels by covering mud and sand flats. Such impacts have been recorded from the Wadden Sea [187]. The loss of settlement resources for mussels will severely reduce potential feeding area for birds.

8.2.4. Large shallow inlets and bays

In areas with high resuspension of sediment and good water flow, effects on seabed diversity and sediment characteristics are likely to be minimal [192, 195]. However, in more sheltered areas, typically with low water flow, it is likely that high rates of sedimentation and high levels of organic matter will occur [196]. Such habitat changes may lead to reduced numbers of slow growing, sensitive species, typical of stable habitats and become dominated by fast growing opportunistic species such as Capitellid polycheates.

A study undertaken in Dungarven Bay, Ireland [197], examined potential differences between community composition and organic enrichment at sites beneath trestles and in access lanes between trestles. Results were compared with a control site to identify any impacts. The study revealed a higher diversity of organisms in the access lanes than the control sites, but slightly lower diversity beneath trestles. The authors of the study did not find any evidence that the sediment beneath trestles was subjected to excessive organic enrichment. The range of results from studies examining the impact of trestle tables at different sites worldwide suggests that whatever impacts may occur are extremely site specific and would need to be taken into account when planning new oyster culture systems at protected sites.

Where individuals spread and grow unchecked in the wild, high levels of trophic competition may occur with other cultured oysters and native suspension feeding bivalves. Intensive oyster farming may exceed the carrying capacity of a site, particularly in enclosed areas, by increasing oxygen demand and elevating levels of organic matter[184].

There is potential for bird disturbance when tending to beds although some bird species make use of tables and beds as feeding areas.

8.2.5. Reefs

On flat rock, non-native oysters that spread from cultivation systems and grow unchecked in the wild can increase habitat complexity and settlement space for epifauna and flora. The addition of habitat resource may also lead to increased biodiversity.

Hitchhiking organisms, particularly *Crepidula fornicata* can have severe negative effects on cobble seabed areas. Cobbles and shells are covered by clumps of *Crepidula* and their faeces and pseudofaeces, resulting in a change of habitat type.

Introduced species can impair native oyster reefs through competition for food and space, non-native predatory species such as the American oyster drill and disease.

Sabellaria alveolata reefs may be damaged physically by the settlement and growth of Pacific oysters and potential settlement space may be reduced due to competition with the oysters. Reefs are also vulnerable to trampling [174]. Crossing areas of reef regularly during intertidal access to oyster culturing areas would potentially reduce areas of reef and such activity should be avoided.

8.3. Potential effects on Habitats Directive Annex II and protected species

There is some evidence to suggest that cetaceans may be displaced by oyster culture structures. Studies in Australia have shown displacement of bottle-nosed dolphins from oyster culture areas [12]. It is possible that such displacement will have an impact on foraging and reproductive behaviour and in areas where bottle-nosed dolphins are considered an interest feature, a precautionary approach to minimise potential impacts is recommended.

8.4. Mitigation methods

The loss of native oysters (*Ostrea edulis*) contributed to by the introduction of non-native oysters and associated fauna and flora could potentially be mitigated by the regeneration of native oyster beds in UK waters [198]. Such measures would also require good management of native oyster fisheries and would make use of the policy tools currently in place to protect stocks effectively [198].

The site and scale at which oyster culture is permitted to take place is important. Sheltered areas and seabeds with low levels of wave exposure and stable habitats may be the most severely affected by nutrient enrichment and changes to sediment characteristics. Therefore, as a mitigation measure, areas such as this should be avoided. Sites in more mobile, dynamic areas should be given priority for mariculture development.

The most serious impact of non-native oyster mariculture is through the spread of cultivated species in the wild and the spread of non-native, attached biota transported with cultivated species. Measures should be explored to reduce these impacts. Hot water sterilisation of oysters has been used in the past, although the methods currently used are not 100% effective.

The Pacific oyster is a warm-temperate species requiring sea temperatures to reach 18 °C for spawning to take place and a sustained temperature of above 22 °C for at least two weeks for the metamorphosis from larvae to spat to take place. Where these temperature regimes occur, it should be acknowledged that spawning may be successful and that wild, breeding populations may become established [55]. Avoiding activities in areas where these conditions are likely to occur may be one way of reducing the potential for infestation by this species. Ruesink *et al.* [191] discuss the possibility of using the ICES risk assessment protocol for the assessment of marine introductions prior to the introduction of non-native oyster species to an area (see Box 3). Such a protocol may be useful in assessing the potential impacts of introducing these species to a new area. The code recognises the potential impacts of the species themselves as well as any attached, non-native species.

Box 3 The four points emphasised by the ICES protocol for the assessment of the risk of marine introductions. Taken from Ruesink *et al.* [191]

Probability of colonization and establishment in the area of introduction, which depends on the match between the environment and the species' needs for food, reproduction, and habitat. This section also requires information on resistance to invasion from biotic or abiotic factors in the environment.

Probability of spread from the point of introduction, which includes the species' ability to disperse and the extent of suitable environmental conditions.

Magnitude of impact on native (especially natural) ecosystems, which includes trophic interactions, habitat transformation, and interactions with native species of concern (threatened or declining).

Probability of transport of a harmful pathogen or parasite. This final risk can be mitigated by a variety of methods to inspect and quarantine incoming organisms and release of only their progeny.

Hydraulic suction dredges have been utilised in New Jersey in order to remove oyster drills [199]. Oyster drills are a predatory invasive species in the UK which are transported along with oysters. It is possible that such a technique could be utilised in UK oyster culture areas to reduce oyster drill populations and potentially reduce the potential for the species to spread. However, studies examining the other effects of this practice suggest that the method does not completely remove oyster drills and populations are able to recover within three months [199]. In addition, populations of slower growing non-pest species may be impacted [199]. It is suggested that before this method is used, an assessment of any potential site specific side effects should be undertaken.

Options for the destruction of 'wild' non-native oyster populations should be explored, particularly where such populations are likely to become problematic. Methods of cleaning and sterilising stock prior to transportation between sites will help to reduce the spread of non-native species within UK and European waters. Limiting the transportation of live oyster stock in general may also reduce such a spread.

In Japan, a novel technique is being tested which involves using an artificial mid-layer seafloor beneath oyster cultures to reduce the organic load originating from oyster stock. So far, results indicate that a substrate made up of empty shells is very effective and may help promote the self purifying ability of oyster cultures [200].

In Western Australia, a scoring matrix has been developed to aid the management of pearl oyster spat fisheries and mariculture systems. The scoring matrix is based on the ecological and environmental risks associated with the practice and scores are assigned depending on likelihood and consequence. The score generated by the process was used to make decisions about managing and restricting the fishery [201]. This Environmental Risk Assessment process may prove useful when assessing required restrictions and management measures for fisheries or mariculture activities in UK EMS. The technique used in Australia used a variety of parameters and may be useful as a model for such a process, being adapted for relevance to EMS requirements.

8.4.1. Current UK perspective

Of all the Competent Authorities interviewed, only the Kent and Essex SFC have any measures in place to mitigate the potential impacts of oyster mariculture and associated fisheries (see Table 15). The minimum landing size and gear restrictions (maximum dredge size) were in place to protect native oyster stocks from over exploitation.

Table 15 Mitigation measures for oyster farming enforced by competent authorities in UK EMS

Type of Restriction	Enforcing Body	Fishing Type	Level of Compliance	Reasons behind Restriction
Min. landing size. Max dredge size.	Kent & Essex SFC	Oyster farming/ dredging	4	Protect oyster stocks from over exploitation

(Note: Levels of compliance range from 0 (severe lack of compliance) to 5 (large amount of compliance))

Compliance with this measure was perceived as being good (level 4). Protecting native oyster stocks may help to protect the 'typical' species of interest habitats and also maintain habitat structure. Although compliance with this measure is high, more work may be required, in order to assess how effectively the features are protected.

8.5. Future and current work

There appears to be a need to assess methods of reducing the spread of non-native oysters, particularly in EMS, where mudflats and sandflats are qualifying features. Such infestations, whilst potentially leading to new habitat development, will reduce the range of the qualifying feature. There is also a need to better understand the climatic conditions required for non-native oysters to reproduce in order to avoid sighting oyster culture in areas where these conditions exist.

The development of a risk matrix for the introduction of oyster culture systems may be a useful tool for the management of such activities. The development of such a tool could be based on similar tools used overseas and would potentially accelerate the decision making process when assessing applications for new activities.

9. Mitigation methods

9.1. International measures

Mitigation measures used in New Zealand, Australia, Canada and USA are explored in more detail in the following section of the report, with examples from a number of fisheries. The following information has been obtained through contact with overseas fishery management authorities and by making use of relevant online resources.

9.1.1. New Zealand

Within New Zealand the Ministry of Fisheries aims to ensure that fisheries are used in a sustainable way, by researching fisheries, managing the process of access or allocation of fisheries and ensuring that those who use these resources comply with the legislation and regulations [202]. In New Zealand the following commercial shellfish species are targeted oysters, cockles, scallops and green-lipped mussels. To ensure these fisheries are harvested in a sustainable way various management measures have been put in place that regulate, who can fish, what methods of fishing can be used, what species, can be harvested and limits on harvesting levels. The majority of commercially important species are managed under the quota management system (QMS) [203] which was first introduced in 1986. To fish commercially in New Zealand a fishing permit must be held. Permits cover all species that are harvested and sold. For QMS species a share in the total quota for that species must be bought in addition to the fishing permit. Each year the government will set a commercial catch limit for each QMS species and then for that year each quota owner will receive notification of their catch entitlement for their particular species. Commercial fishers must land their catch through a 'licensed receiver' and catch weights must also be reported to the Ministry of Fisheries. If a fisher lands a QMS species for which he does not hold a quota, or for which he holds an insufficient quota, then a penalty must be paid [204]. There are also a variety of other management controls in New Zealand which apply to species managed under QMS and those species outside QMS. The controls commonly enforced are [205]:

- closed seasons;
- closed areas;
- size limits;
- gear restrictions, and
- prohibited species.

Details of the restriction in place will vary between fisheries and two examples are provided below.

Foveaux Strait commercial dredge oyster fishery

The Foveaux Strait commercial dredge oyster fishery has been fished for more than 100 years and the type of management in place has varied. The fishery was closed from 1993-1996 due to a disease outbreak of *Bonamia exitiosa* which lead to major mortality of the oyster population and caused the fishery to become unsustainable. The fishery currently has a number of management strategies in place including: [206]

- the Quota Management System (QMS);
- permit requirements for all commercial fishers;

- TAC;
- a fishing year that runs from October 1^{st} to September $30^{th;}$
- a requirement for all dredged oysters landed to be reported and all undersized oysters returned to the sea;
- closed areas;
- a minimum legal size of 58 mm;
- restrictions on the size of the oyster dredge (two x 3.35 m wide dredges per vessel);
- a daily bag limit of 50 dredge oysters for the recreational fishery;
- a seasonal closure from March 1^{st} to August 31^{st} which applies to most dredge oyster stocks, and
- a requirement that all species taken as bycatch must be reported.

Future plans include minimizing the impact of *Bonamia*, continuing stock surveys, evaluating dredge design to minimize impact on the environment and developing a compliance strategy to reduce illegal fishing.

Coromandel scallop fishery

The Coromandel scallop fishery has been in operation since the late 1960s and currently there are only seven boats operating within the fishery. To ensure the fishery remains sustainable, various measures have been put in place to protect both the scallop stock and the environment. Because the scallop populations within the Coromandel scallop fishery vary from year to year a pre-season biomass survey is conducted annually to enable the TAC for that year to be set. Therefore, commercial catch limit varies from year to year which helps to ensure a sustainable fishery in most years. Other measures that have been put in place to complement the TAC include:[183]

- a limited commercial season from July to December (therefore excluding the main period of spatfall in January and February);
- a commercial size limit of 90 mm;
- future plans to continue monitoring for TAC, and
- the fact that some scallop beds are reserved for non-commercial fishers to help reduce tension between the sectors.

The Coromandel scallop fishery obtains its catch with the use of dredges. This method can cause incidental mortality not only to scallops but also the plants and animals that live in the seabed. As a result of this there are a number of measures that have been put in place to reduce the impact of dredging on the environment which include: [183]

- areas that have been closed to commercial dredging including the Firth of Thames and inner Hauraki Gulf (but within which recreational dredging may still occur);
- commercial dredging takes place in the same area to limit the impact;

- a closed commercial season starting December 21st i.e. in time to protect the time of maximal spatfall, and
- monitoring of bycatch from the fishery.

In addition, a draft standard is under development that will assess the levels of environmental and seabed impact which is considered acceptable as a result of the fishing method [183].

9.1.2. Australia

Within Australia the statutory authority responsible for the sustainable use and efficient management of Commonwealth fish resources on behalf of the Australian community is the Australian Fisheries Management Authority (AFMA). The AFMA manages more than 20 Commonwealth fisheries which generally extend from 3 nautical miles out to the limit of the Australian Fishing Zone (AFZ), which extends out 200 nautical miles from Australia's coastline. The majority of the commercial inland and coastal fisheries, recreational fishing, and inland and coastal aquaculture are the responsibility of the seven States [207]. These are listed below along website addresses where further information is available.

- Government Department of Primary Industries and Resources SA – South Australia (http://www.pir.sa.gov.au)
- Government Department of Fisheries – Western Australia (http://www.fish.wa.gov.au)
- Department of Primary Industries – New South Wales (http://www.dpi.nsw.gov.au)
- Government Department of Industries and Fisheries – Queensland (http://www.dpi.qld.gov.au)
- Government Department of Primary Industries and Fisheries Tasmania – Tasmania (http://www.dpiw.tas.gov.au)
- Government Department of Primary Industries, Fisheries and Mines – Northern Territory (http://www.nt.gov.au)
- Government Department of Primary Industries, Water and Environment – Victoria (http://www.dpi.vic.gov.au)

Below are examples of the fisheries management measures used by the Commonwealth for fisheries that occur in the 3–200 nautical mile zone and from some of the different States who cover fisheries in the inshore coastal zone.

Bass Strait Central Zone Scallop Fishery

The fishery for scallops within the Bass Strait has been divided into three zones and the AFMA is responsible for the management of the central zone. The other two zones are managed by the States of Victoria and Tasmania under the Offshore Constitutional Settlement agreements (fisheries are about 20 nautical miles off the coast of those States) [181, 208]. The fishery began in the inshore waters of Tasmania and Victoria prior to 1963, but expanded into Bass Strait in the 1970s. A lack of restrictions led to overexploitation and resulted in the Bass Strait fishery being closed in 1991 as a result of stock collapse. The fishery re-opened in 1991 under a statutory management plan that reduced and limited entry to the fishery [179]. The Central Zone closed during the 1999 season but reopened the following year. An area east of Flinders Island remained closed during the 2001/02 season. Surveys of this area in 2002/03 indicated an increase in the distribution and abundance of scallops and the AFMA allowed fishing to resume in parts of the closed area in 2003. Additional parts of this closed area were re-opened in 2004 [207].

The Fishery is currently managed under a management plan and Statutory Fishing Rights (SFR) which involves using a number of input and output controls as opposed to annual fishing permits which were used up until January 1st 2005. Quota SFR are what will be required by fishermen to allow them to commercially harvest scallops, and this will determine how many scallops can be harvested based on the number of Quota SFR held and the TAC set for that particular year[179]. The additional input and output controls used to manage the fishery are listed below [179]:

- There is a Minimum Landing size of 90 mm for commercial scallops but no limit for doughboy scallops.
- There is an open season that runs from May 1st to December 20th.
- Fishermen must use either a scallop dredge harvester or trawl nets.
- There are no restrictions on the size or design of the scallop dredge, but fishermen are restricted to just one dredge.
- There are closed areas all year in the east & west of the fishery which enables protection of scallop broodstock, in addition to maintaining and protecting the reproductive potential of scallops and the habitat.
- There are only two scallop species that are covered by the quota, namely commercial scallops (*Pecten fumatus*) and doughboy scallops (*Mimachlamys asperrimus*).
- No scallops can be processed at sea.

Note: From 2005 until February 1st 2007 fishermen were also required to hold a Boat SFR. However, since then only Quota SFR will be required to operate within the Bass Fishery.

Western Australia

In Western Australia the Government Department of Fisheries is responsible for the sustainable development of the State's fisheries. There are a number of shellfisheries under the management of Western Australia. Currently, these include three commercial scallop trawl fisheries; Shark Bay Scallop Fishery, Abrolhos Island and Mid West Trawl Fishery, and the South West Trawl Fishery [209]. An additional fishery, the South Coast Trawl Fishery, is also proposed. In addition, there are mussel fisheries in Cockburn Sound, Warnbro Sound, Albany Harbours and Wilson Inlet on the south coast [210] and a pearl oyster fishery along the North West Shelf (this is a diver operated fishery only) [211].

The aims of the current management strategies within the scallop fishery in Shark Bay are to ensure an adequate spawning stock and that the scallops are taken at the right age to ensure a good condition when the meat reaches the market. Various input controls which restrict effort are in place to ensure this happens. These include [209]:

- gear restrictions (a minimum mesh size of 100 mm which allows juvenile scallops to escape);
- a closed season during the summer months., and
- a maximum of 13 crew per vessel.

Future developments for this fishery include attempts at rearing some species in hatcheries and ocean-ranching is currently being tested by the industry. A balance must also be achieved between harvesting scallops before their condition deteriorates with spawning and maintaining high enough levels of the spawning stock.

Queensland

In Queensland the Government Department of Industries and Fisheries is responsible for conserving and protecting fisheries resources, while at the same time maintaining commercial and recreational sectors. The department is also responsible for taking the lead in developing a policy framework for the management of Queensland's fisheries resources [212].

There are commercial shellfisheries for both scallops and oysters within Queensland's coastal waters. The oyster fishery is relatively small and licences are issued in accordance with the Fisheries Act 1994 for up to 15 years. The primary growing areas are located within Moreton Bay [213]. Scallops (saucer scallops *Amusium japonicum balloti* and *Amusium pleuronectes*) are caught in the East Coast Otter Trawl Fishery, but often appear as bycatch in prawn trawls. In order to manage trawl fisheries, various regulations have been put in place which include [214]:

- gear restrictions such as limiting the number of otter trawls that can be towed to one and limiting the net mesh size;
- the requirement of fishers to hold a Commercial Fisher Licence;
- a requirement for the vessel to be licensed as a Queensland Commercial Fishing Vessel (QFV);
- a requirement for the boat licence to be endorsed for that particular fishery;
- restrictions on the size of the vessel to reduce effort;
- the designation of a number of closed areas where trawling has been either restricted or prohibited in order to protect the habitat and nursery grounds, maintain a broodstock and reduce bycatch, and
- limited operating times (most of the licences work on the effort quota system and trawlers are only allowed to work a certain number of nights based on the quota they hold).

9.1.3. Canada

The Department of Fisheries and Oceans (DFO) is responsible for ensuring sustainable fisheries and aquaculture within Canadian waters by developing and implementing policies and programs in support of Canada's scientific, ecological, social and economic interests in oceans and fresh waters. Within the DFO there are six administrative regions: Newfoundland and Labrador, Maritimes, Gulf, Québec, Central and Arctic, and Pacific. Control over the amount of stock harvested from the sea is the primary management tool employed by DFO, whereby a TAC for each fish stock is established and rigorously enforced. Size limit restriction on the minimum landing size of species, gear restrictions and international enforcement are all tools used to manage the fisheries of Canada. The fishing industry has also developed a Code of Conduct for Responsible Fishing Operations in order maintain sustainable fisheries both in fresh water and marine [215]. The implementation of the code contributes directly to the conservation of fish stocks and the protection of the aquatic environment by proving guidelines and general principles for all commercial fishing operations that take place within Canadian waters. Below are sample examples of measures implemented for various fisheries throughout some of the regions.

Pacific Region

Within the Pacific region the following commercial shellfisheries take place:

- razor clam (hand digging),
- clam (hand picking/digging) and
- scallop (both trawl and diving).

The razor clam fishery is jointly managed by the Council of the Haida Nation and Fisheries and Oceans Canada. There are a number of restrictions that have been put in place in order to manage the fishery and the plans which have been put in place for the 2007 commercial fishing season are listed below [116].

- The season is expected to open on April 14th 2007.
- The catch ceiling for 2007 is 142.9 tonnes.
- Fishermen must have a designation card (non-transferable) and these, in addition to ID cards, must be carried at all times.
- Razor clams must exceed 90 mm to be landed.
- Designated areas where fishing activity can take place.
- All harvesting is restricted to hand digging.
- The fishery is closed from January to March and July to August in 2007.
- During the opening months, fishing can only take place on set days.
- All vehicles accessing the sites are not to be driven below the 1.5 m tide level in order to avoid damage to shellfish stocks.

The intertidal Heiltsuk clam fishery has been harvested since the 1900s and is currently managed by annual TAC and a minimum landing size. There are currently a number of management strategies to ensure the fishery is sustainable which include[117]:

- set areas where fishing is allowed;
- a minimum landing size of 38 mm for all Manila or little neck clams;
- TAC for Manila clams of 102,056 pounds;
- a ban on all harvesting methods apart from hand picking/digging, and
- a requirement for ID and proof of designation to be carried at all times.

Gulf Region

Prince Edward Island lies within the Gulf Region where there is a long established oyster fishery. Harvesting is carried out using rakes or tongs from the bottom of tidal rivers, estuaries and bays. The fishery has two separate seasons (spring and autumn) which results in the need for two separate licences to harvest oysters commercially. The spring, autumn and recreational oyster fisheries are managed by a number of different effort controls including [216]:

- gear restrictions;
- area closures;
- size limits;
- seasonal restrictions;
- a limited number of permanent licences, and
- daily and weekly close times.

The future long term objectives of oyster fisheries include [216]:

- improving the scientific information base on oysters.
- improving the statistical data collection for both commercial oyster fisheries and recreational fisheries, and
- ensuring the conservation of the oyster stocks.

9.1.4. USA

Within the USA the management, conservation and protection of living marine resources within the United States Exclusive Economic Zone (3-200 mile offshore) lies with the National Marine Fisheries Service (part of NOAA). Within the National Marine Fisheries Service there are six regional offices: Alaska, Pacific Islands, Northwest, Northeast, Southwest and Southeast. The various restrictions in place for fisheries in the United States include limits on fishing effort, closed seasons, fishing gear restrictions, the number of fishermen allowed to fish for a certain species, and total allowable catches for each species.

One example where of both seasonal and year-round closures are enforced is the Georges Bank, commercial scallop fishery, New England. Seasonal closures have taken place since the 1970s in an attempt to protect the groundfish stocks although these have had little impact [176]. In December 1994 three large areas were closed year-round to all types of gear that could retain groundfish. Results from 1994 – 1998 indicated that the biomass of scallops in the closed area increased 14-fold and in July 1998 the total biomass of scallops was nine times denser and the harvestable biomass was 14 times denser in the closed areas than the adjacent areas [176]. The closed areas also led to a significant reduction in the fishing mortality of the depleted groundfish stocks. The closed areas provided the greatest protection to shallow-sedentary assemblages of fish species – mainly flounders and skates, less protection was provided to migratory species – Atlantic cod and haddock[176]. This study therefore shows that closing areas year round to certain fishing types (in this case scallop dredging) are more beneficial than having areas closed for only part of the fishing season. The closures resulted in not only the protection of non-target species, but also an increase in the stock size of the target species.

10. Conclusions and recommendations

A substantial amount of research has been conducted studying the effects of towed fishing gears, including hydraulic and scallop dredging, on benthic communities [115]. There is however less advice available on tolerable levels of fishing intensity. Recent work, published by Hiddink *et al.* [217, 218] describes a model, whereby biomass and production recovery can be calculated for different fishing intensities. Such models could be used by managers to predict the fishing intensity, from which a seabed may be able to recover. Used appropriately, the model may be useful in guiding the appropriate assessment process and may enable appropriate fishing levels to be set. Studies on fishing impacts up until now have mostly taken a small scale experimental approach where, for example, a specific section of the seafloor is trawled by a single pass or by multiple passes. Damage to marine organisms and recovery rates are subsequently compared before and after trawling or between a trawled area and a control site. Although these results give an indication of the severity of the initial impacts and relative rates of recovery of benthic communities, they are unsuitable to be used as a precise management tool for several reasons. Firstly, although some of these studies occur at pristine sites or areas where fishing activity is rare, inevitably a proportion of these experiments have been conducted within areas which have been subject to trawling or dredging activity in the past. Therefore, experimental treatments or control sites may already be in an altered state and not represent the natural baseline. Secondly, the scale at which these experiments have been conducted is mostly not representative of the scale and intensity of real fishing grounds. As only a small plot is disturbed by the experiment the reported recovery will mainly occur from organisms migrating into the plot from the surrounding undisturbed areas. On real fishing grounds the disturbance occurs over much larger spatial scales and is often a chronic event vitally different from many of the impact experiments referred to in this report. Recovery rates on real fishing grounds will therefore be much longer and will depend heavily on larval supply rather than on migration for recovery. Due to the chronic nature of most fisheries, benthic communities may remain within an altered and mostly less productive state. The reader is therefore advised to be cautious when interpreting data of impacts and recovery times from specific studies mentioned in this report and not to take these by their face value.

For many of the fishing methods described in the report, it is very important to consider the potential cumulative impact of increased levels of fishing when undertaking appropriate assessments. Whilst an activity may have only a minor impact when operating at a small scale, cumulative effects may occur as intensity increases.

Few studies to date exist which have investigated the effects of towed fishing gears on real fishing ground [121], [139], [219] however there is now an increasing number of yet unpublished studies (e.g. see EU Response project report [220]) which have attempted to tackle this problem. Although no such studies, to our knowledge, are available for hydraulic or scallop dredging for UK waters. These so called comparative fishing impact studies have largely only recently become possible due to the release of real effort data in form of overflight or satellite vessel monitoring data. However most of this data will only include relatively large vessels and for studies to include inshore hydraulic suction and scallop dredging, higher resolution data including smaller fishing vessels will be essential. Generally this type of effort data enables the comparison of areas which have similar habitat characteristics but differ in their fishing intensities. These studies should be much more suitable to advise on tolerable fishing levels. It would therefore be highly advisable to support comparative fishing effort studies in the future and for the fishing industry to encourage the collections and release of high resolution effort data to science. Only with such data can progress towards establishing tolerable and sustainable levels of fishing be made. Ultimately, policy makers, scientist, the industry and NGOs will have to decide what this tolerable level of fishing should be and what state of benthic habitats is desired by society.

Where certain activities are found to be unacceptable in EMS, alternative, less damaging methods of exploiting resources may be possible and should be explored. For example, methods such as hand gathering and ranching may prove less damaging to interest features than scallop dredging and should be explored as alternatives where possible.

It is likely that for hydraulic suction dredging, scallop dredging and oyster culture systems, those features which are stable and wave-sheltered will be most severely impacted by physical damage and changes to ecosystem structure and composition. These systems will also show far slower recovery rates than dynamic systems. Recovery is likely to be directly related to the rate at which the components of a habitat are able to reform in an area following damage or loss. Dynamic systems such as sand banks with high wave and wind action acting upon them will recover quickly, provided that sufficient boundary habitat exists to allow recolonisation by any species which are lost. Biogenic structures, particularly slow growing ones, will be very slow to recover and for species such as maerl, full recovery may not be possible. Loss of habitat is not considered to be acceptable for interest features in an EMS and any activity which causes loss of habitat should be avoided where recovery is slow or unknown.

11. Acknowledgements

The Authors would like to thank the following people for their support through the provision of information and resources or through participation in interviews: Adam Knapp (Seafood Services Australia), Beth Leslie (NAFC),Bryan Jones (Environment Agency), Charlotte Marshall (MBA), Colin Penny, (Defra), Dan Cresswell (Devon SFC), David Donnan (Scottish National Heritage), David McCandless (North Eastern SFC), Eamon Murphy (Scottish Executive), Emma Sheehan (University of Plymouth), Ian Carrier (Southern SFC), Dr Jason Hall-Spencer (University of Plymouth), Jayne Evans (MBA), John Hiskett (Norfolk Wildlife Trust), Jon Green (Northumberland SFC), Joss Wiggens (Kent & Essex SFC), Kate Reeves, (WWF), Kate Tanner (RSPB), Mark Gray (Seafish), Martin Holmes (Shetland Council),Matthew Mander (Eastern SFC), Mike Kaiser (University of Bangor), Phil Coates (South Wales SFC), Peter Matthews (Clearwaters Canada), Peter Rushmer (Eastern SFC), Renny McKeown (Environment and Heritage Service), Robert Clark (Sussex SFC), Sam Davis (Cornwall SFC), Steve Atkins (North Wales & North Western SFC), Steve Watt (Isles of Scilly SFC), Tim Robbins (Devon SFC), Trevor Howell (Fisheries Research Services), William Lart (Seafish).

12. References

The following references have been used in the preparation of this report and are numbered according to their superscript numbers which are given throughout the text. Most references have been included in the report database and are displayed in the appended table (Apendix 3).

[1] ODPM, 2005. *Government Circular: Biodiversity and Geological Conservation Statutory Obligations and Their Impact Within The Planning System*. ODPM Circular 06/2005, Office of the Deputy Prime Minister*.* London.

[2] Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora

[3] Council Directive 79/409/EEC on the conservation of wild birds

[4] Lake, N., 2006. European Marine Sites and the current impact of environmental appropriate assessments on the management and operation of commercial fisheries and aquaculture activities. *Report prepared for the Sea Fish Industry Authority.*

[5] Gubbay. S. & Knapman, P.A, 1999. *A review of the effects of fishing within UK European marine sites*. Peterborough: English Nature (UK Marine SACs Project). 134 pages.

[6] Sewell, J. & Hiscock, K., 2005. Effects of fishing within UK European Marine Sites: guidance for nature conservation agencies. *Report to the Countryside Council for Wales, English Nature and Scottish Natural Heritage from the Marine Biological Association*. Plymouth: Marine Biological Association. CCW Contract FC 73-03-214A.

[7] European Commission, 2003. *Interpretation Manual of European Union Habitats*. Version EUR25. Commission of the European Community, Brussels.

[8] Gregory, R.S., 2004. *Eelgrass as nursery habitat for juvenile fish in the coastal marine environment*. *Status and conservation of eelgrass (Zostera marina) in Eastern Canada.* Technical Report Series No. 412. (Hanson, A.R. ed.) Canadian Wildlife Service, Atlantic Region. Pages 18-19.

[9] Davidson, N.C., Laffoley, D. d'A., Doody, J.P., Way, L.S., Gordon, J., Key, R., Pienkowski, M.W., Mitchell, R., & Duff, K.L. 1991. Nature Conservation and Estuaries in Great Britain. Peterborough, Nature Conservancy Council.

[10] Hall-Spencer, J.M. & Moore, P.G., 2000. *Limaria hians* (Mollusca: Limacea): a neglected reef-forming keystone species. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **10**, 267-277.

[11] WWF, 2007. – Response to questionnaire

[12] Watson-Capps, J.J. & Mann, J., 2005. The effects of aquaculture on bottlenose dolphin (*Tursiops* sp.) ranging in Shark Bay, Western Australia. *Biological Conservation,* **124**, 519-526.

[13] Hall-Spencer, J.M., Froglia, C., Atkinson, R.J.A. & Moore, P.G., 1999. The impact of rapido trawling for scallops *Pecten jacobaeus* (L.) on the benthos of the Gulf of Venice. *ICES Journal of Marine Science,* **56**, 111-124.

[14] JNCC, 2007. www.jncc.gov.uk

[15] Tasker, M.J., Camphuysen, C.J., Cooper, J., Garthe, S., Montececchi, W.A. & Blaber, S.J.M., 2000. The impacts of fishing on marine birds. *ICES Journal of Marine Science,* **57**, 531-547.

[16] Stillman, R.A., Goss-Custard, J.D., West, A.D., Le V. Dit Durell, S.E.A., McGrorty, S., Caldow, R.W.G., Norris, K.J., Johnstone, I.G., Ens, B.J., Van Der Meer, J. & Triplet, P., 2001. Predicting shorebird mortality and population size under different regimes of shellfishery management. *Journal of Applied Ecology,* **38**, 857-868.

[17] Stillman, R.A., Goss-Custard, J.D., West, A.D., Le V.Dit Durell, S.E.A., Caldow, R.W.G., McGroty, S. & Clarke, R.T., 2000. Predicting mortality in novel environments: tests and sensitivity of a behaviour-based model. *Journal of Applied Ecology,* **37**, 564-588.

[18] Camphuysen, C.J. & Garthe, S., 2000. Seabirds and commercial fisheries: population trends of piscivorous seabirds explained? *In: The Effects of Fishing on Non-target Species and Habitats: Biological, onsevation and socio-economic issues* (ed. M.J. Kaiser & S.J. de Groot), pp. 163-184.

[19] Votier, S.C., Bearhop, S., Ratecliffe, N., Phillips, R.A. & Furness, R.W., 2004. Predation by great skuas at a large Shetland seabird colony. *Journal of Applied Ecology,* **41.** 1117-1128.

[20] Gill, JA, Norris, K. & Sutherland, W.J., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation,* **97**, 265-268.

[21] West A.D., Goss-Custard J.D., Stillman R.A., Caldow R.W.G., Le V Dit. Durell S.E.A., & McGroty S., 2002. Predicting the impacts of disturbance on shorebird mortality using a behaviour-based model. *Biological Conservation*, **106**, 319-328.

[22] Yasué, M., Quinn, J.L. & Cresswell, W., 2003. Multiple effects of weather on the starvation and predation risk trade-off in choice of feeding location in Redshanks. *Functional Ecology,* **17**, 727–736

[23] Urfi, A.J., Goss-Custard, J.D. & Le V. Dit., Durell, S.E.A., 1996. The ability of oystercatchers Haematopus ostralegus to compensate for lost feeding time: field studies on individually marked birds. *Journal of Animal Ecology*, **33**, 873-883.

[24] Kaiser, M.J., Galanidi, M., Showler, D.A., Elliott, A.J., Caldow, R.W.G., Rees, E.I.S., Stillman, R.A. & Sutherland, W.J., 2006. Distribution and behaviour of Common Scoter *Melanitta nigra* relative to prey resources and environmental parameters. *Ibis,* **148.** 110-128.

[25] Kaiser, M.J., 2005. *Predicting the displacement of common scoter Melanitta nigra from benthic feeding areas due to offshore windfarms*. Centre for Applied Marine Sciences, School of Ocean Sciences, University of Wales, BANGOR. COWRIE - BEN - 03 – 2002.

[26] Goss-Custard, J.D., 1980. Competition for food and interference among waders. *Ardea,* **61**, 31-52.

[27] Coleman, R.A., Salmon, N.A. & Hawkins, S.J., 2003. Sub-dispersive human disturbance of foraging oystercatchers (*Haematopus ostralegus*). *Ardea,* **97**, 263-272.

[28] Gill, J.A., Sutherland, W.J. & Watkinson, A.R., 1996. A method to quantify the effects of human disturbance for animal populations. *Journal of Applied Ecology*, **33**, 786-792.

[29] Goss-Custard, J.D., & Verboven, N., 1993. Disturbance and feeding shorebirds on the Exe estuary. *Wader Study Group Bulletin*, **68** (Special Issue).

[30] Goss-Custard J.D., Triplet P., Seur F., & West A.D., 2006. Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation,* **127**, 88-97.

[31] Swennen, C., Leopold, M.F. & de Bruijin, L.L.M., 1989. Time-stressed oystercatchers Haematopus ostralegus can increase their intake rate. *Animal Behaviour*. **38**, 8-22.

[32] Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P. & Wilson, L.J., 2004. The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *Journal of Applied Ecology*, **41**, 1129-1139.

[33] Shealer, D.A. & Burger, J., 1993. Effects of Interference Competition on the Foraging Activity of Tropical Roseate Terns. *The Condor*, **95**, 322-329.

[34] Votier S.C., Furness R.W., Bearhop S., Crane J.E., Caldow R.W.G., Catry P., Ensor K., Hamer K.C., Hudson A.V., Kalmbach E., Klomp N.I., Pfeiffer S., Phillips R.A., Prieto I. & Thompson D.R., 2004b. Changes in fisheries discard rates and seabird communities. *Nature,* **427**, 727-730.

[35] Votier, S.C., Bearhop, S., Ratcliffe, N. & Furness, R.W., 2004a. Reproductive consequences for great skuas specializing as seabird predators. *Condor*, **106**, 275-287.

[36] Maniscalco, J.M., Ostrand, W.D., Suryan, R.M. & Irons, D.B., 2001. Passive interference competition by Glaucous-winged gulls on black-legged kittiwakes: a cost of feeding in flocks. *The Condor,* **103**, 616–619.

[37] Furness, R.W., 2003. Impacts of fisheries on seabird communities. *Scientia Marina*, **67**, 33-45.

[38] Lewison, R.L., Crowder, L.B., Read, A.J. & Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology & Evolution,* **19**, 598- 604.

[39] Phillips, R.A., Silk, J.R.D., Croxall, J.P. & Afanasyev, V., 2006. Year-round distribution of white chinned petrels from South Georgia: Relationships with oceanography and fisheries. *Biological Conservation*, **129**, 336-347.

[40] DeGange, A. R., Day, R.H., Takekawa, J.E. & Mendenhall, V.M., 1993. Losses of seabirds in gill nets in the North Pacific. *In: The status, ecology, and conservation of marine birds of the North Pacific*. (ed. K. Vermeer, K. T. Briggs, K. H. Morgan, & D. Siegel-Causey) Canadian Wildlife Service Special Publication, Ottawa: Ontario.

[41] Brothers, N., Cooper, J., & Lokkeborg, S., 1999. *The Incidental Catch of Seabirds by Longline Fisheries: Worldwide Review and Technical Guidelines for Mitigation*. FAO Fisheries Circular. Food and Agriculture Organization of the United Nations, Rome. p. 100.

[42] Lewison, R.L. & Crowder, L.B., 2003. Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecological Applications*, **13**, 743-753.

[43] Kaiser, M.J., Bullimore, B., Newman, P., Lock, K., Gilbert,S., 1996. Catches in 'ghost fishing' set nets. *Marine Ecology Progress Series*, **145**, 11-16

[44] Alverson, D.L., Freeberg, M.H., Murawski, S.A. & Pope, J.G., 1994. *A global assessment of fisheries bycatch and discards*. FAO Fisheries Technical Paper 339.

[45] Hudson, A.V. & Furness, R.W., 1989. The behaviour of seabirds foraging at fishing boats around Shetland. *Ibis*, **131**, 225-237

[46] Hamer, K.C., Furness, R.W. & Caldow, R.W.G., 1991. The effects of changes in food availability on the breeding ecology of great skuas *Catharacta skua* in Shetland. *Journal of Zoology (London),* **223**, 175-188

[47] Hüppop, O. & Wurm, S., 2000. Effects of winter fishery activity on resting numbers, food and body condition of large gulls *Larus argentatus* and *L. marinus* in the south-eastern North Sea. *Marine Ecology Progress Series*, **194**, 241-247

[48] Shepherd, P.C.F. & Boates, J.S., 1999. Effects of commercial baitworm harvest on semipalmated sandpipers and their prey in the Bay of Fundy hemispheric shorebird reserve. *Conservation Biology*, **13**, 347-356.

[49] Kim, S.-Y. & Monaghan, P., 2006. Interspecific differences in foraging preferences, breeding performanace and demography in herring (*Larus aregentatus*) and lesser black-backed gulls (*Larus fuscus*) at a mixed colony. *Journal of Zoology,* **270**, 664-671.

[50] Fowler, S.L., 1999. *Guidelines for managing the collection of bait and other shoreline animals within UK European marine sites*. English Nature (UK Marine SACs Project). 132 pp

[51] Hilgerloh, G., O' Halloran, J.O., Kelly, T.C. & Burnell, G.M., 2001. A preliminary study on the effects of oyster culturing structures on birds in a sheltered Irish estuary, *Hydrobiologia,* **465**, 175-180.

[52] Caldow, R.W.G., Beadman, H.A, S. McGrorty, S., Kaiser, M.J, Goss-Custard, J.D, Mould, K. & Wilson, A.., 2003. Effects of intertidal mussel cultivation on bird assemblages. *Marine Ecology Progress Series,* **259**, 173-183.

[53] Caldow R.W.G., Beadman H.A., McGrorty S., Stillman R.A., Goss-Custard J.D., Durell Le V. S.E.A., West A.D., Kaiser M.J., Mould K. & Wilson, A. 2004. A behaviour based modeling approach to reducing shorebird-shellfish conflicts. *Ecological Applications*, **14,** 1411-1427

[54] Smit, C., Danker, N., Ens, B.J. & Meijboom, A., 1998. Birds, mussels, cockles and shellfish fishery in the Dutch Wadden Sea: how to deal with low food stocks for eiders and oystercatchers? *Senckenbergiana maritime*, **29**, 141-153.

[55] Cognie, B., Haure, J. & Barillé, L., 2006. Spatial distribution in a temperate coastal ecosystem of the farmed oyster Crassostrea gigas (Thunberg). *Aquaculture,* **259**, 249 - 259.

[56] Ross, B.P. & Furness R.W., 2000. *Minimising the impact of eider ducks on mussel farming*. University of Glasgow.

[57] Ross, B.P., Lien, J. & Furness R.W., 2001. Use of underwater playback to reduce the impact of eiders on mussel farms. *ICES Journal of Marine Science*, **58**, 517-524

[58] Ferns, P.N., Rostron, D.M. & Siman, H.Y., 2000, Effects of mechanical cockle harvesting on intertidal communities. *Journal of Applied Ecology*, **37**, 464-474.

[59] Rehfisch, M.M., Clark, N.A., Langston, R.H.W. & Greenwood, J.J., 1996. A guide to the provision of refuges fro waders: an analysis of 30 years of ringing data from the Wash. *Journal of Applied Ecology*, **33**, 673-687.

[60] Northridge, S., di Natale, A., Kinze, C., Lankester, K., Ortiz de Zarate, V. & Sequeira, M., 1991. Gill net fisheries in the European Community and their impacts on the marine environment. MRAG Ltd. *A report to the European Commission's Directorate General Environment, Nuclear Safety and Civil Protection*.

[61] Harrison, N. & Robins, M., 1992. The threat from nets to seabirds., *RSPB Conservation Review*, **6**, 51-56.

[62] Dayton, P.K., Thrust, D.F., Agardi, M.T. & Hofman, R.J., 1995. Environmental effects of marine fishing. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **5**, 205-232.

[63] Bourne, W.R.P., 1989. New evidence for bird losses in fishing nets, *Marine Pollution Bulletin,* **10**, 482.

[64]Thomas, D., 1993. *Marine wildlife and net fisheries in Cardigan Bay*. RSPB/CCW Report, 55pp.

[65] Dunn, E. & Steel, C., 2001. *The impact of longline fishing on seabirds in the north-east Atlantic: recommendations for reducing mortality*. RSPB, NOF, JNCC, BirdLife International.

[66] Løkkeborg, S., 2003. Review and evaluation measures of three mitigation measures: bird-scaring line, underwater setting and line shooter, to reduce seabird bycatch in the north Atlantic longline fishery. *Fisheries Research,* **60**, 11-16.

[67] Melvin, E.F., Parrish, J.K. & Conquest, L.L., 1999. Novel tools to reduce seabird bycatch in coastal gillnet fisheries. *Conservation Biology*, **13**, 1386-1397.

[68] Dugan, P.J., Evans, P.R., Goodyear, L.R. & Davidson, N.C., 1981. Winter fat reserves in shorebirds: disturbance of regulated levels by severe weather conditions. *Ibis*, **123**, 359-363.

[69] Davidson, N.C. & Evans, P.R., 1982. Mortality of Redshanks and Oystercatchers from starvation during severe weather. *Bird Study*, **29**, 183-188.

[70] Campredon, P., 1979. Data on the wintering of waders in the Arcachon basin (Gironde). *Oiseau et la Revue Francaise d'Ornithologie,* **49**, 113-131.

[71] West, A.D., Goss-Custard, J.D., McGrorty, S., Stillman, R.A., Le V. dit Durell, S.E.A, Stewart, B., Walker, P., Palmer, D.W. & Coates, P.J., 2003. The Burry Inlet shellfishery and oystercatchers: using a behaviour-based model to advise on shellfishery management policy. *Marine Ecology Progress Series,* **248**, 279-292.

[72] Camhuysen, C.J., Berrevoets, C.M., Cremers, H.J.W.M., Dekinga, A., Dekker, R., Ens, B.J., van der Have, T.M., Kats, R.K.H., Kuiken, T., Leopold, M.F., van der Meer, J. & Piersema, T., 2002. Mass mortality of common eiders (*Somateria mollissima*) in the Dutch Wadden Sea, winter 1999/2000: starvation in a commercially expoited wetland of international importance. *Biological Conservation,* **106**, 303-317.

[73] Beukema, J.J. & Dekker, R., 2006. Annual cockle *Cerastoderma edule* production in the Wadden Sea usually fails to sustain both wintering birds and a commercially fishery. *Marine Ecology Progress Series.,* **309**, 189-204.

[74] Hall, S.J. & Harding, M.J.C., 1997. Physical disturbance and marine benthic communities: the effects of mechanical harvesting of cockles on non-target benthic infauna. *Journal of Applied Ecology,* **34**, 497-517.

[75] Ferns, P.N., 1995. The effects of mechanised cockle harvesting on bird feeding in the Burry Inlet. *Burry Inlet & Loughor Estuary Symposium, March 1995. Part 1.* Nov-18.

[76] Rees, E.I.S., 1996. Environmental effects of mechanised cockle fisheries: a review of research data. *Report to the Marine Environmental Protection Division, MAFF.* School of Ocean Sciences, University of Wales, Bangor: UK. 42pp.

[77] Stillman, R.A., Goss-Custard, J.D., McGrorty, S., West, A.D., Durell, S.E.A., le V. dit, Clarke, R.T., Caldow, R.W.G., Norris, K.J., Johnstone, I.G., Ens, B.J., Bunskoeke, E.J., v.d Merwe, A., van der Meer, J., Triplet, P., Odoni, N., Swinfen, R. & Cayford, J.T., 1996. Models of Shellfish Populations and Shorebirds: Final Report. *Institute of Terrestrial Ecology Report to the Commission of the European Communities, Directorate-General for Fisheries*.

[78] Bell, C.M. & Walker, P., 2005. Desk study to assess the impact of cockle suction dredging on The Wash and North Norfolk Coast European Marine Sites. *English Nature Research Reports,* No 670.

[79] Piersma, T., Koolhaas, A., Dekinga, A., Beukema, J.J., Dekker, R. & Essink, K., 2001. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea., *Journal of Applied Ecology,* **38**, 976-990.

[80] van Gils, J.A., Piersma, T., Dekinga, A., Spaans, B. & Kraan, C., 2006. Shellfish dredging pushes a flexible avian top predator out of a marine protected area. *PLoS Biology,* **4**, 2399-2404.

[81] Piersma, T. & Drent, J., 2003. Phenotypic flexibility and the evolution of organismal design. *Trends in Ecology and Evolution*, **18**, 228-233.

[82] Atkinson, P.W., Clark, N.A., Dodd, S.G. & Moss, D., 2005. Changes in fisheries practices and oystercatcher survival, recruitment and body mass in a marginal cockle fishery. *Ardea*, **93**, 199-212.

[83] Norris, K., Bannister, R.C.A. & Walker, P., 1998. Seasonal changes in the number of oystercatchers *Haematopus ostralgus* wintering on the Burry Inlet in relation to the biomass of cockles *Cerastoderma edule* and its commercial exploitation. *Journal of Applied Ecology,* **35**, 75-85.

[84] Andrews, J., 2003. Sands of change. Portrait of the cockle fishery in Morecombe Bay: November 2002 - October 2003. *Shellfish News,* **16**, 21-24.

[85] Black, K.D., 1996. *Aquaculture and sea lochs*. Scottish Association for Marine Science, Oban.

[86] Atkinson, P.W., Clark, N.A., Bell, M.C., Dare, P.J., Clark, J.A. & Ireland, P.L., 2003. Changes in commercially fished shellfish stocks and shorebird populations in the Wash, England. *Biological Conservation,* **114**, 127-141.

[87] Fahy, E., Carroll, J. & Murran, S., 2005. The Dundalk Cockle *Cerastoderma edule* fishery in 2003-2004. *Irish Fisheries Investigations,* **14**

[88] Goss-Custard, J.D., Stillman, R.A., West, A.D., Caldow, R.W., Triplet, P., Le V Dit Durell, S.E. & McGrorty, S., 2004. When enough is not enough: shorebirds and shellfishing. *Proceedings of the Royal Society London B: Biological Sciences*, **271**, 233-237.

[89] ICWSS, 2002. *Shellfish fisheries. An overview of policies for shellfish fishing in the Wadden Sea*. Wilhemlshaven, Germany: Common Wadden Sea Secretariat.

[90] Rimington, N., 2002. *The relationship between mussel and oystercatcher populations in the Burry Inlet, Part 2*. CCW Contract Science Report No 491.

[91] Verhulst, S., Oosterbeek, K., Rutten, A.L. & Ens, B.J., 2004. Shellfish Fishery Severely Reduces Condition and Survival of Oystercatchers Despite Creation of Large Marine Protected Areas. *Ecology and Society,* **9**. 17.

[92] Le V. dit Durell, S.E.A., Stillman, R.A., Triplet, P., Aulert, C., Ono dit Biot, D., Bouchet, A., Duhamel, S., Mayot, S. & Goss-Custard, J.D., 2005. Modelling the efficacy of proposed mitigation areas for shorebirds: a case sudy on the Seine estuary, France. *Biological Conservation,* **123**, 67-77.

[93]Wernham, C.J., Tom, M.P., Marchant , J.H., Clark, J.A., Siriwardena, G.M. & Baillie, S.R., 2002. *Migration Atlas: movements of the birds of Britain and Ireland*. T. & A.D. Poyser, London.

[94] Fahy, E., Norman, M., Browne, R., Roantree, V., Pfeiffer, N., Stokes, D., Carroll, J. & Hannafy, O., 2001. Distribution, population structure, growth and reproduction of the razor clam *Ensis arcuatus* (Jeffreys) (Solenaceae) in coastal waters of western Ireland. *Irish Fisheries Investigation,* **10**, 24pp.

[95] Meyer, T.L., Cooper, R.A. & Pecci, K.J., 1981. The performance and environmental effects of a hydraulic clam dredge. *Marine Fisheries Review*, **43**, *14-22.*

[96] Hauton, C., Hall-Spencer, J.M. & Moore, P.G., 2003. An experimental study of the ecological impacts of hydraulic bivalve dredging on maerl, *ICES Journal of Marine Science,* **60.** 381-392.

[97] Addison, J., Palmer, D., Lart, W., Misson, T. & Swarbick, J., 2006. Development of a suitable dredge for exploitation of razorfish (*Ensis directus*) in The Wash. Cefas Contract No. C2323.

[98] Fahy, E. & Gaffney, J., 2001. Growth statistics of an exploited razor clam (*Ensis siliqua*) bed at Gormanstown, Co Meath, Ireland. *Hydrobiologia,* **465**, 139-151.

[99] Hiddink, J.G., 2003. Effects of suction-dredging for cockles on non-target fauna in the Wadden Sea. *Journal of Sea Research,* **50**, 315-323.

[100] Hauton, C., Atkinson, R.J.A. & Moore, P.G., 2003. The impact of hydraulic blade dredging on a benthic megafaunal community in the Clyde Sea area, Scotland. *Journal of Sea Research,* **50**, 45-56.

[101] Rostron, D.M., 1995. The effects of mechanised cockle harvesting on the invertebrate fauna of Llanrhidian sands. *Burry Inlet & Loughor Estuary Symposium, March 1995. Part 2.* 111-117

[102] Jennings, S. & Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology,* **34**, 201-352.

[103] Hall, S.J., Basford, D.J. & Roberts, M.R., 1990. The impact of hydraulic dredging for razor clams *Ensis* sp. on an infaunal community. *Netherlands Journal of Sea Research,* **27**, 119-125.

[104] Tuck, I.D., Bailey, N., Harding, M., Sangster, G., Howell, T., Graham, N. & Breen, M., 2000. The impact of water jet dredging for razor clams, *Ensis* spp., in a shallow sandy subtidal environment. *Journal of Sea Research,* **43**, 65-81.

[105] Robinson, R.F. & Richardson, C.A., 1998. The direct and indirect effects of suction dredging on a razor clam (*Ensis arcuatus*) population. *ICES Journal of Marine Science,* **55**, 970-977.

[106] Fisheries Research Services, 1998. *A Study of the effects of water jet dredging for razor clams and a stock survey of the target species in some Western Isles populations*. Marine Laboratory Aberdeen Report No. 8/98.

[107] Kaiser, M.J., Edwards, D.B. & Spencer, B.E., 1994. Infaunal community changes as a result of commercial clam cultivation and harvesting. *Aquatic Living Resources,* **9**, 57-63.

[108] Morello, E.B., Froglia, C., Atkinson, R.J.A. & Moore, P.G., 2005. Impacts of hydraulic dredging on a macrobenthic community of the Adriatic Sea, Italy. *Canadian Journal of Fisheries and Aquatic Sciences,* **62**, 2076–2087.

[109] Oro, D. & Ruix, X., 1997. Exploitation of trawler discards by breeding seabirds in the north-western Mediterranean: differences between the Ebro Delta and the Balearic Islands areas. *ICES Journal of Marine Science,* **54**, 695-707.

[110] Peterson, C.H., Summerson, H.C. & Fegley, S.R., 1987. Ecological consequences of mechanical harvesting of clams. *Fishery Bulletin N.O.A.A,* **85**, 281-298.

[111] Moore, J., 1991. *Studies on the Impact of Hydraulic Cockle Dredging on Intertidal Sediment Flat Communities: Final Report*. Nature Conservancy Council, CSD Report, no. 1256, Peterborough, pp. 46.

[112] Rose, C., Carr, A., Ferro, D., Fonteyne, R. & MacMullen, P., 2000. Using gear technology to understand and reduce unintended effects of fishing on the seabed and associated communities: background and potential directions. *ICES Working Group on Fishing Technology and Fish Behaviour.*

[113] Cook, W., 1991. Studies on the effects of hydraulic dredging on cockle and other macroinvertebrate populations 1989-1990. *North Western and North Wales Sea Fisheries Committee*.

[114] Hauton, C. & Paterson, D.M., 2003. A novel shear vane used to determine the evolution of hydraulic dredge tracks in sub-tidal marine sediments., *Estuarine, Coastal and Shelf Science,* **57**, 1151-1158.

[115] Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield. P.J. & Karakassis, I., 2006. Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series,* **311**, 1-14.

[116] FOC, 2006. *Joint Management Plan Razor Clam January 1 to December 31, 2007*. Pacific region, Council of the Haida Nation/Fisheries and Ocean Canada.

[117] FOC, 2006. *Intertidal Clam Joint Management Plan November 15, to March 31, 2007.* Pacific region, Heiltsuk Tribal Council/Fisheries and Ocean Canada.

[118] Rambaldi, E., Bianchini, M., Priore, G., Prioli, G., Mietti, N. & Pagliani,T., 2001. Preliminary appraisal of an innovative hydraulic dredge with vibrating and sorting bottom on clam beds (*Chamelea gallina*). *Hydrobiologia,* **465**, 169-173.

[119] McDonough, N.A. & Patino, D.M., 2005. Developing stock enhancement techniques for two razor clam species in the European Atlantic Area. *Journal of Shellfish Research,* **24**, 1, 329.

[120] ICES, 2006. Report of the Working Group of Ecosystem Effects of Fishing Activities (WGECO), 5-12 April 2006. 174.

[121] Collie, J.S., Hall, S.J., Kaiser, M.J. & Poiner, I.R., 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology,* **69**, 785-798.

[122] Department of Fisheries and Oceans'. 2006. Impacts of Trawl Gears and Scallop Dredges on Benthic Habitats, Populations and Communities. *DFO Canadian Science Advisory Secretariat,* Science Advisory Report 2006/025.

[123] Broadhurst, M.K., Suuronen, P. & Hulme, A., 2006. Estimating collateral mortality from towed fishing gear. *Fish and Fisheries,* **7**, 180-218.

[124] Bergman, M.J.N. & Van Santbrink, J.W., 2000. Fishing mortality of populations of megafauna in sandy sediments. In *The Effects of Fishing on Non-target Species and Habitats: Biological, conservation and socio-economic issues* (ed. M.J. Kaiser & S.J. de Groot), pp. 49-78.

[125] Bergman, M.J.N. & van Santbrink, J.W., 2000. Mortality in megafaunal benthic population caused by trawl fisheries on the Dutch continental shelf in the North Sea. *ICES Journal of Marine Science,* **57,** 1321-1331

[126] Moran, M.J. & Stephenson, P.C., 2000. Effects of otter trawling on macrobenthos of demersal scalefish fisheries on the continental shelf of north-western Australia. *ICES Journal of Marine Science,* **57,** 510-516.

[127] Jenkins, S.R., Beukers-Stewart, B.D. & Brand, A.R., 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. *Marine Ecology Progress Series,* **215**, 287-301.

[128] Garcia, E.G., Ragnarsson, S.A. & Eiriksson, H. 2006. Effects of scallop dredging on macrobenthic communities in west Iceland., *ICES Journal of Marine Science.,* **63.** 434-443.

[129] Currie, D.R. & Parry, G.D., 1996. Effects of scallop dredging on a soft sediment community: a large scale experimental study. *Marine Ecology Progress Series,* **134**, 131-150.

[130] Watling, L., Findlay, R.H., Mayer, L.M. & Schink, D.F., 2001. Impact of a scallop drag on the sediment chemistry, microbiota and faunal assemblages of a shallow subtidal marine benthic community. *Journal of Sea Research,* **46**, 309-324.

[131] Thrush, S.F., Hewitt, J. E., Cummings, V. J. & Dayton, P.K. 1995. The impact of habitat disturbance by scallop dredging on marine benthic communities; what can be predicted from the results of experiments?, *Marine Ecology Progress Series,* **129**, 141-150.

[132] Bradshaw, C., Veale, L.O. & Brand, A.R. 2002. The role of scallop-dredging disturbance in long-term changes in Irish Sea benthic communities: a re-analysis of an historical dataset. *Journal of the Sea Research,* **47**, 161-184.

[133] Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E. & Brand, A.R., 2000. Chronic fishing disturbance has changed shelf sea benthic community structure. *Journal of Animal Ecology,* **69**, 494-503.

[134] Blanchard, F., LeLoc'h, F., Hily, C. & Boucher J., 2004. Fishing effects on diversity, size and community structure of the benthic invertebrate and fish megafauna on the Bay of Biscay coast of France. *Marine Ecology Progress Series,* **280**, 249-260.

[135] Frid, C.L.J., Harwood, K.G., Hall, S.J. & Hall, J.A., 2000. Long-term changes in the benthic communities on North Sea fishing grounds. *ICES Journal of Marine Science,* **57**, 1303-1309.

[136] Kaiser, M.J., Armstrong, P.J., Dare, P.J. & Flatt, R.P., 1998. Benthic communities associated with a heavily fished scallop ground in the English Channel. *Journal of the Marine Biological Association,* **78**, 1045-1059.

[137] Auster, P.J., Malatesta, R.J., Langton, R.W., Watling, L., Valentine, P.C., Donaldson, C.L.S., Longton, E.W., Shephard, A.N. & Babb, I.G., 1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (northwest Atlantic): implications for conservation of fish populations. *Reviews in Fisheries Science,* **4**, 185-202.

[138] Thrush, S.F., Hewitt, J.E., Funnell, G.A., Cummings, V.J., Ellis, J., Schultz, D., Talley, D. & Norkko, A., 2001. Fishing disturbance and marine biodiversity: role of habitat structure in simple soft-sediment systems. *Marine Ecology Progress Series,* **221**, 255-264.

[139] Blyth, R.E., Kaiser, M.J., Edwards-Jones, G., & Hart, P.J.B., 2004. Implications of a zoned fishery management system for marine benthic communities. *Journal of Applied Ecology,* **41**, 951-961.

[140] Collie, J.S., Escanero, G.A. & Hunke, L., 1996. *Scallop dredging on Georges Bank: Photographic evaluation of effects on benthic epifauna*. CM, 1996/Mini: 9.

[141] ICES, 1996. *Report of the Working Group on Ecosystem effects of fishing activities*. C.M. 1996/Assess/ Env:1. Ref: G.

[142] Collie, J.S., Escanero, G.A. & Valentine, P.C., 2000. Photographic evidence of the impacts of bottom fishing on benthic epifauna. *ICES Journal of Marine Science,* **57**, 987-1001.

[143] Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2001. The effect of scallop dredging on Irish Sea benthos: experiments using a closed area. *Hydrobiologia,* **465**, 129-138.

[144] Thrush, S.F., Hewitt, J.E., Cummings, V.J., Dayton, P.K., Cryer, M., Turner, S.J., Funnell., G.A., Budd, R.G., Milburn, C.J. & Wilkinson, M.R., 1998. Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. *Ecological Applications,* **8**, 866-879.

[145] Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. *Journal of the Fisheries Research Board of Canada,* **30**, 173-180.

[146] Chapman, C.J., Mason, J. & Drinkwater, J.A.M., 1977. Diving observations on the efficiency of dredges used in the Scottish fishery for the scallop, *Pecten maximus* (L). *Scottish Fisheries Research,* **10**, 16.

[147] Ramsay. K., Kaiser. M.J. & Hughes, R.N., 1998. Responses of benthic scavangers to fishing disturbance by towed gears in different habitats. *Journal of Experimental Marine Biology and Ecology,* **224**, 73-89.

[148] Robinson, S.M.C., Bernier, S.& MacIntyre, A., 2001. The impact of scallop drags on sea urchin populations and benthos in the Bay of Fundy, Canada, *Hydrobiologia,* **465**, 103-114.

[149] Bullimore, B., 1985. An investigation into the effects of scallop dredging within the Skomer Marine Reserve. *Skomer Marine Reserve Subtidal Monitoring Project. Report to the Nature Conservancy Council.*

[150] Devon Wildlife Trust, 1993. *Lyme Bay: A report on the nature conservation importance of the inshore reefs and the effects of mobile fishing gear*.

[151] Currie, D.R. & Parry, G.D., 1999. Impacts and efficiency of scallop dredging on different soft substrates. *Canadian Journal of Aquatic Science,* **56**, 539-550.

[152] Schwinghamer, P., Gordon, D.C. Rowell, T.W., Prena, J., McKeown, D., Sonnichson, G. & Guignes, J.Y., 1998. Effects of experimental otter trawling on surficial sediment properties of a sandy-bottom ecosystem on the Grand Banks of Newfoundland. *Conservation Biology,* **12**, 1215-1222.

[153] Kaiser, M.J., Spence, F.E. & Hart, P.J.B., 2000. Fishing-Gear Restrictions and Conservation of Benthic Habitat Complexity. *Conservation Biology,* **14**, 1512-1525.

[154] Sea Fish Industry Authority. 1993. *Benthic and ecosystem impacts of dredging for pectinids* (reference 92/3506). Consultancy Report No.71.

[155] ICES, 1992. *Report of the study group on ecosystem effects of fishing activities*. C.M. 1992/G:11.

[156] Southern Science, 1992. An experimental study on the impact of clam dredging on soft sediment macro invertebrates. *Report to English Nature*.

[157] Langton, R.W. & Robinson, W.E., 1990. Faunal associations on scallop grounds in the western Gulf of Maine. *Journal of Experimental Biology and Ecology,* **144**, 157-171.

[158] Veale, L.O., Hill, A.S., Hawkins, S.J. & Brand, A.R. 2000. Effects of long-term physical disturbance by commercial scallop fishing on subtidal epifaunal assemblages and habitats. *Marine Biology,* **137.** 325-337.

[159] Hall-Spencer, J.M. & Moore,P.G., 2000. Impact of scallop dredging on maerl grounds. *In: The Effects of Fishing on Non-target Species and Habitats: Biological, conservation and socio-economic issues* (ed. M.J. Kaiser & S.J. de Groot), pp. 105-117.

[160] Hall-Spencer, J.M. & Moore, P.G., 2000. Scallop dredging has profound long-term impacts on maerl habitats. *ICES Journal of Marine Science,* **57**, 1407-1415.

[161] Kamenos, N.A., Moore, P.G. & Hall-Spencer, J.M., 2003. Substratum heterogeneity of dredged vs un-dredged maerl grounds. *Journal of the Marine Biological Association of the United Kingdom,* **83**, 411-413.

[162] Hall-Spencer, J.M., Grall, J., Moore, P.G. & Atkinson, R.J.A., 2003. Bivalve fishing and maerl-bed conservation in France and the UK-retrospect and prospect. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **13**, S33-S41.

[163] Fonseca, M.S., Thayer, G.W., Chester, A.J. & Foltz, C., 1984. Impact of scallop harvesting on eelgrass (*Zostera marina*) meadows:implications for management. *North American Journal of Fisheries Management,* **4**, 286-293.

[164] Pranovi, F., Raicevich, S., Franceschini, G., Farrace, M.G. & Giovanardi. O., 2000. Rapido trawling in the northern Adriatic Sea: Effects on benthic communities in an experimental area. *ICES Journal of Marine Science,* **57**, 517-524.

[165] Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2000. The effects of scallop dredging on gravelly seabed communities. *In: The Effects of Fishing on Non-target Species and Habitats: Biological, Consevation and Socio-economic issues* (ed. M.J. Kaiser & de S.J. Groot) pp. 83-104.

[166] Eleftheriou, A., Robertson, M.R., 1992. The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. *Netherlands Journal of Sea Research,* **30**, 289-299.

[167] Riemann, B. & Hoffman, E., 1991. Ecological consequences of dredging and bottom trawling in the Limfjord, Denmark. *Marine Ecology Progress Series,* **69**, 171-178.

[168] Dyekjaer, S.M., Jensen, J.K. & Hoffman, E., 1995. *Mussel dredging and effects on the marine environment*. C.M. 1995/E:13 ref.K.

[169] Lindeboom, H.J & de Groot, S.J., 1998. *The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems.* RIVO-DLO Report C003/98

[170] Collie, J.S., Escanero, G.A. & Valentine, P.C., 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. *Marine Ecology Progress Series,* **155**, 159-172.

[171] Roberts, D., 2003. Work Package 2 - The current status of Strangford *Modiolus*. KA 2.1: Diving Survey 2003.

[172] Freiwald, A., Fossa, J.H., Grehan, A., Koslow, T. & Roberts, J.M., 2004, *Cold-water coral reefs*. UNEP-WCMC, Cambridge, UK pp. 37-39

[173] Rogers, S.I., Kaiser, M.J. & Jennings, S., 1998. Ecosystem effects of demersal fishing: a European perspective. *In: Effects of fishing on the seafloor of New England* (ed. E.M. Dorsey & J. Pederson)*.* 68-78.

[174] UK Biodiversity Group. 1999. *Tranche 2 Action Plans - Volume V: Maritime species and habitats*. English Nature.

[175] The Centre for Environment, Fisheries and Aquaculture Science, 2002. *Framework for evaluating the application of seasonal or rotational scallop fishery closures.* MF0228, Defra: London.

[176] Murawski, S.A., Brown, R., Lai, H.-L., Rago, P.J. & Hendrickson, L., 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experiment. *Bulletin of Marine Science,* **66**, 775-798.

[177] Drouin, M., 2003. A seabed-friendly scallop trawl. *Pacific Fishing,* **24**, 25-26.

[178] Rudders, D.B., Dupaul, W.D. & Kirkley, J.E., 2000. A comparison of size selectivity and relative efficiency of sea scallop *Placopecten magellanicus* (Gmelin, 1791), Trawls and dredges. *Journal of Shellfish Research,* **19**, 757-764.

[179] AFMA, 2004. *Bass Strait Central Zone Scallop Fishery – A guide to the 2005 Management Arrangements*. Australian Fisheries Management Authority.

[180] Maguirea, J. A., Coleman, A., Jenkins, S. & Burnell, G.M., 2002. Effects of dredging on undersized scallops. *Fisheries Research,* **56**, 155 - 165.

[181] Cotterell, E. & Johnson, D., 2006. Management of commercial scallops in the bass strait central zone scallop Fishery, Australia. *Journal of Shellfish Research,* **25**

[182] Symes, D. & Ridgway, S., 2003. Inshore fisheries regulation and management in Scotland; Meeting the challenges of Environmental Integration. *Scottish Natural Heritage.*

[183] Ministry of Fisheries, 2006. *Coromandel scallops fisheries plan 'Proof of Concepts'* (Second draft).

[184] Kaiser, M.J., Laing, I., Utting, S.D. & Burnell, G.M., 1998. Environmental impacts of bivalve mariculture. *Journal of Shellfish research,* **17**, 59-66.

[185] Kennedy, R.J. & Roberts, D., 1999. A Survey of the current status of the flat oyster Ostrea edulis in Strangford Lough, Northern Ireland, with a view to the restoration of it oyster beds. *Biology and Envionment: Proceedings of the Royal Irish Academy,* **99**, 79 - 88.

[186] Eno, N.C., Clark, R.A. & Sanderson, W.G., 1997. *Non-native marine species in British waters: a review and directory*. JNCC.

[187] Diederich, S., 2006. High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. *Journal of Experimental Marine Biology and Ecology,* **328**, 211-227.

[188] Mattson, J. & Linden, O., 1983. Benthic macrofauna succession under mussels, *Mytilus edulis*, cultured on hanging long-lines. *Sarsia,* **68**, 97-102.

[189] Spencer, B. E., Kaiser, M. J. & Edwards, D. B., 1997. Ecological effects of intertidal Manila clam cultivation: observations at the end of the cultivation phase. *Journal of Applied Ecology,* **34**, 444-452.

[190] Leguerrier, D., Niquil, N., Petiau, A. & Bodoy, A., 2004. Modelling the impact of oyster culture on a mudflatfood web in Marennes-Oléron Bay (France), *Marine Ecology Progress Series,* **273**, 147-162.

[191] Ruesink, J.L., Lenihan, H.S., Trimble, A.C., Heiman, K.W., Micheli, F., Byers, J.E. & Kay, M.C. 2005. Introduction of non-native oysters: ecosystem effects and restoration implications. *Annual Review of Ecology, Evolution, and Systenatics,* **36**, 643 - 689.

[192] Mallet, A.L., Carver, C.E. & Landry, T., 2006. Impact of suspended and off-bottom Eastern oyster culture on the benthic environment in eastern Canada. *Aquaculture,* **255**, 362-373.

[193] Yokoyama, S., 2002. Impact of fish and pearl farming on the benthic environments in Gokasho Bay: Evaluation from seasonal fluctuations of the macrobenthos. *Fisheries Science.* **68**, 258 – 268.

[194] Wisehart, L.M., Hacker, S.D., Tallis, H.M., Ruesink, J.L., Oyarzun, F. & Dumbauld, B.R., 2004. The effects of different aquaculture techniques on Zostera marina biomass, density, and growth rates in Willapa Bay, Washington. *Journal of Shellfish Research,* **23**,

[195] Crawford, C., 2003. Environmental management of marine aquaculture in Tasmania, Australia. *Aquaculture.,* **226**, 129-138.

[196] Forrest, B.M. & Creese, R.G., 2006. Benthic impacts pf intertidal oyster culture, with consideration of taxonomic sufficiency. *Environmental Monitoring and Assessment,* **112**, 159-176.

[197] De Grave, S., Moore, S,J, & Burnell, G., 1998. Changes in benthic macrofauna associated with intertidal oyster, *Crassostrea gigas* (Thunberg) culture. *Journal of Shellfish Research,* **17**, 1137-1142.

[198] Laing, I., Walker, P. & Areal, F., 2005. *A feasibility study of native oyster (Ostrea edulis) stock regeneration in the United Kingdom.* CARD Project FC1016.

[199] Ismail, N.S., 1985. The effects of hydraulic dredging to control oyster drills on benthic macrofauna of oyster grounds in Delware Bay, New Jersey. *Internationale Revue der Gesamten Hydrobiologie,* **70**, 379-395.

[200] Osamu, K., Tamiji, Y., Osamu, M., Toshiya, H. & Haruyoshi, T., 2004. Artificial midlayer seafloor: simple and new devices to reduce organic loads from oyster rafts to the sediment. *Bulletin of the Japanese Society of Scientific Fisheries,* **70**, 722 - 727.

[201] Wells, F.E. & Jernakoff, P., 2006. An assessment of the environmental impact of wild harvest pearl aquaculture (*Pinctada maxima*) in Western Australia. *Journal of Shellfish Research,* **25**, 141-150.

[202] MOF, 2006. *About us.* Ministry of Fisheries. [cited 25 April 2007]. Available from: <http://www.fish.govt.nz>

[203] Lock, K. & Leslie, S., 2007. *New Zealand's Quota Management System: A History of the First 20 Years*. Motu Working Paper 07-02 Motu Economic and Public Policy Research. Ministry of Fisheries. [cited 25 April 2007]. Available from: <http://www.fish.govt.nz>

[204] MOF, 2007. *How commercial fishing is managed*. Ministry of Fisheries. [cited 25 April 2007]. Available from: <http://www.fish.govt.nz>

[205] MOF, 2006a. *Management controls*. Ministry of Fisheries. [cited 25 April 2007]. Available from: <http://www.fish.govt.nz>

[206] MOF, 2006b. *Foveaux Strait dredge oyster fishery plan 'Proof of Concepts'* (Second draft) December 2006. [cited 25 April 2007]. Available from: http://www.fish. govt.nz

[207] AFMA, 2005a. *The commercial fishing industry*. Australian Fisheries Management Authority. [cited 26 April 2007]. Available from: <http://www.afma.gov.au>

[208] AFMA, 2005b. *The Bass Strait Central Zone Scallop Fishery*. Australian Fisheries Management Authority. [cited 26 April 2007]. Available from: <http://www.afma.gov.au>

[209] Sporer, E. & Kangas, M., 2005. Shark Bay Scallop Managed Fishery Status Report. *In: Status of the Fisheries Report 2004/05* (ed. J.W. Penn, W.J. Fletcher & F. Head), Department of Fisheries, Western Australia, pp. 97-100.

[210] Lawrence, C., 2005. Mussel Farming. *In: Status of the Fisheries Report 2004/05* (ed. J.W. Penn, W.J. Fletcher & F. Head), Department of Fisheries, Western Australia, pp. 76-77

[211] Hart, A. & Murphy, D., 2005. Pearl Oyster Managed Fishery Status Report. *In: Status of the Fisheries Report 2004/05* (ed. J.W. Penn, W.J. Fletcher & F. Head), Department of Fisheries, Western Australia, pp. 172-177.

[212] France, C., 2007. *Fisheries*. Government Department of Industries and Fisheries. [cited 26 April 2007] Available from: <http://www.dpi.qld.gov.au>

[213] GDFI, 2005. *Queensland Oyster Industry Development Plan*. Government Department of Industries and Fisheries. [cited 26 April 2007] Available from: <http://www.dpi.qld.gov.au>

[214] GDFI, 2006. *Commercial Trawl Fisheries in Queensland*. Government Department of Industries and Fisheries. [cited 26 April 2007] Available from: <http://www.dpi.qld.gov.au>

[215] DFO, 1998. *Canadian Code of Conduct for Responsible Fishing Operations*. Department of Fisheries and Oceans. [cited 26 April 2007] Available from: <http://www.dfo-mpo.gc.ca>

[216] DFO, 2002. *Integrated Fisheries Management Plan*. Department of Fisheries and Oceans. [cited 26 April 2007] Available from: <http://www.glf.dfo-mpo.gc.ca>

[217] Hiddink, J.G., Jennings, S. & Kaiser, M.J., 2006. Indicators of the Ecological Impact of Bottom-Trawl Disturbance on Seabed Communities. *Ecosystems* **9,**1190–1199.

[218] Hiddink, J.G., Jennings, S. & Kaiser, M.J., 2007. Assessing and predicting the relative ecological costs of disturbance to habitats with different sensitivities. *Journal of Applied Ecology,* **44**, 405–413

[219] Jennings S., Pinnegar J.K., Polunin N.V.C. & Warr K.J., 2001. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. *Marine Ecology Progress Series,* **213**, 127-142

[220] EU, 2001. *Response EU project final report: Response of benthic communities and sediment to different regimes of fishing in European Seas*. Contract QLRT-2001-00787

Appendix 1: Questionnaire

The following questionnaire was used during telephone and 'in person' interviews with Competent Authority staff Between November 2006 and February 2007.

1) Do the following fishing activities take place (or have they taken place since 1990) in your area of interest or are there plans to open these fisheries in the future (please give details)?

- Scallop dredging
- Hydraulic suction dredging
- Oyster farming

2.1) Within your area of interest are any of the above fisheries carried out in or close to:

- A site designated for nature conservation (e.g. a European marine site, a Site of Special Scientific Interest (SSSI), Marine Nature Reserves etc)
- An area that supports a species or habitat that is protected under the Wildlife & Countryside Act 1981 (e.g. the pink sea fan) but not designated as a protected area (e.g. Lyme Bay.

If so, please state which fisheries take place in which sites (provide the site name if possible) or areas supporting protected species/habitats.

2.2) If no, do you consider that there is the potential for the development of these fisheries in these protected areas in the future? Please give details.

3.1) In your area of interest are you aware of any concerns (from yourselves and/or other parties) over the impact of any of the three fishing activities on:

- UK EMS Species (Y/N)
- UK EMS Habitats (Y/N)
- site integrity (coherence of its ecological structure and function, across its whole area, that enables it to sustain the habitat, complex of habitats and/or levels of populations of the species for which it was classified) (Y/N)

3.2) If Yes please give details of these concerns, including:

- What is the concern? (activity and marine feature)
- Who is concerned? (SFC, statutory conservation agency, NGO etc)
- Where is it a concern? (name sites and interest features if possible)

4.1) Have any of the three fishing activities been restricted (e.g. gear design, temporal/spatial arrangements, effort limitation, voluntary/statutory etc) in order to reduce their impact on the environment? Or are there any plans to implement any such measures in the near future? (Y/N)

4.2) If yes, please could you provide the following information?

- Which fishery?
- Why? (which feature required protection and from what activity
- What kind of restriction and where was it established? (If in a EMS which one)
- Did the restriction follow an appropriate assessment (or pre-assessment) in a European marine site or assessment to seek permission to take place within a SSSI, or both?

4.3) How effective (give mark 0-5 for each) do you think these restrictions have been in terms of:

- Protecting the marine feature or species of interest
- Implementation and compliance
- Support from the industry
- Support from environmentalists

0=totally ineffective or negative, 1=very ineffective – 5=extremely effective

4.4) Please give suggestions about how the restriction and/or compliance could be improved, especially if any scored 2 or less?

5.1) In your area of interest are birds disturbed by fishing or related activities in an SPA? (Y/N)

5.2) If yes,

- Which species (or category) are affected?
- How are the birds being disturbed? (e.g. access to the fishing grounds, fishing operations on shore or at sea, cultivation activities etc)
- Do the activities occur at a particular time of year? If so, why?
- How often are they disturbed? (often, occasionally)
- Who is concerned? (SFC, NCA, NGO, public etc)

6.1) In your area of interest are birds disturbed by fishing or related activities in an SSSI? (Y/N)

6.2) If yes,

- Which species (or category) are affected?
- How are the birds being disturbed? (e.g. access to the fishing grounds, fishing operations on shore or at sea, cultivation activities etc)
- Do the activities occur at a particular time of year? If so, why?
- How often are they disturbed? (often, occasionally)
- Who is concerned? (SFC, NCA, NGO, public etc)

7.1) In your area of interest are birds disturbed by fishing or related activities in a Ramsar site? (Y/N)

7.2) If yes,

- Which species (or category) are affected?
- How are the birds being disturbed? (e.g. access to the fishing grounds, fishing operations on shore or at sea, cultivation activities etc)
- Do the activities occur at a particular time of year? If so, why?
- How often are they disturbed? (often, occasionally)
- Who is concerned? (SFC, NCA, NGO, public etc)

8.1) In your area of interest are birds disturbed by fishing or related activities in any areas not already mentioned? (Y/N)

8.2) If yes,

- What areas?
- Which species (or category) are affected?
- How are the birds being disturbed? (e.g. access to the fishing grounds, fishing operations on shore or at sea, cultivation activities etc)
- Do the activities occur at a particular time of year? If so, why?
- How often are they disturbed? (often, occasionally)
- Who is concerned? (SFC, NCA, NGO, public etc)

9.1) Has fishing and/or shellfish/finfish farming been restricted (e.g. access arrangements, spatial/temporal restrictions on operations, effort limitation, voluntary/statutory etc) in order to reduce bird disturbance? Or are there any plans to do so in the future? (Y/N)

9.2) If yes,

- Which fishery?
- Why? (Which feature required protection and from what activity
- What kind of restriction and where was it established? (if in a EMS which one)
- Did the restriction follow an appropriate assessment (or pre-assessment) in a European marine site or assessment to seek permission to take place within a SSSI, or both?

9.3) How effective (give mark 0-5 for each) do you think these restrictions have been in terms of:

- Protecting the area or species of interest
- Implementation and compliance
- Support from the industry
- Support from environmentalists

0=totally ineffective or negative, 1=very ineffective – 5=extremely effective

9.4) Please give suggestions about how the restriction and/or compliance could be improved, especially if any scored 2 or less?

10.1) Are there concerns (from yourselves and/or other parties) over competition for shellfish resources between fisheries and wetland birds, waterfowl and seabirds in an SPA? (Y/N)

10.2) If Yes,

- Which bird species (or category) is affected?
- Which shellfish resource is being targeted or affected by the fishing activity?
- Which fishery and what method of fishing is being used to target the shellfish or effects the survival of the shellfish species that is important for the birds?
- When and how often does the fishery take place (usually)
- Who is concerned? (SFC, NCA, NGO, public etc)

11.1) Are there concerns (from yourselves and/or other parties) over competition for shellfish resources between fisheries and wetland birds, waterfowl and seabirds in an SSSI? (Y/N)

11.2) If Yes,

- Which bird species (or category) is affected?
- Which shellfish resource is being targeted or affected by the fishing activity?
- Which fishery and what method of fishing is being used to target the shellfish or effects the survival of the shellfish species that is important for the birds?
- When and how often does the fishery take place (usually)
- Who is concerned? (SFC, NCA, NGO, public etc)

12.1) Are there concerns (from yourselves and/or other parties) over the competition for shellfish resources between fisheries and wetland birds, waterfowl and seabirds in a Ramsar site? (Y/N)

12.2) If Yes,

- Which bird species (or category) is affected?
- Which shellfish resource is being targeted or affected by the fishing activity?
- Which fishery and what method of fishing is being used to target the shellfish or effects the survival of the shellfish species that is important for the birds?
- When and how often does the fishery take place (usually)
- Who is concerned? (SFC, NCA, NGO, public etc)

13.1) Are there concerns (from yourselves and/or other parties) over the competition for shellfish resources between fisheries and wetland birds, waterfowl and seabirds in any other areas not already mentioned? (Y/N)

13.2) If Yes,

- Which bird species (or category) is affected?
- Which shellfish resource is being targeted or affected by the fishing activity?
- Which fishery and what method of fishing is being used to target the shellfish or effects the survival of the shellfish species that is important for the birds?
- When and how often does the fishery take place (usually)
- Who is concerned? (SFC, NCA, NGO, public etc)

14.1) Has fishing been restricted (e.g. catch limits, effort limitation, spatial/temporal restrictions, voluntary/statutory etc) in order to reduce competition for shellfish resources between fisheries and wetland birds, waterfowl or seabirds? (Y/N)

14.2) If yes,

- Which fishery?
- Why? (Which feature required protection and from what activity
- What kind of restriction and where was it established? (if in a EMS which one)
- Did the restriction follow an appropriate assessment (or pre-assessment) in a European marine site or permission to take place within a SSSI, or both?

14.3) How effective (give mark 0-5 for each) do you think these restrictions have been in terms of:

- Protecting the area or species of interest
- Implementation and compliance
- Support from the industry
- Support from environmentalists

0=totally ineffective or negative, 1=very ineffective – 5=extremely effective

14.4) Please give suggestions about how the restriction and/or compliance could be improved, especially if any scored 2 or less?

Please include any further information, including reports and surveys that you feel may give further information relevant to this project.

Appendix 2: Impact Summary tables

Hydraulic dredging impacts by habitat or interest feature, summary table

Interest feature (habitat &/ or species)	Specific features of study site if applicable.	Activity details, including target species, gear, scale and timing (if available)	Impact details, including recoverability, scale, community and habitat effects.	Could the activity reduce the range of the interest habitat or species?	Could the activity directly reduce the population of the interest species or interest habitat's "typical species"?	Could the activity indirectly reduce the population of the interest species or interest habitat's "typical species"?	Could the activity change the community composition of the habitat?	Could the activity affect the specific structures and functions necessary for the maintenance of the interest feature?	Could the activity damage or kill any Species of community interest within the feature?	Number of references	Reference numbers
Large, shallow inlets and bays, Mudflats and sandflats not covered by seawater at low tide	Mudflat in Auchencairn Bay, Solway Firth	Suction dredge (not specified)	Reduced species numbers, reduced numbers of individuals. Some recovery after 56 days, but not complete.	No	Insufficient evidence	Insufficient evidence	Yes (some recovery after 56 days, but incomplete)	Insufficient evidence	Insufficient evidence	1	74
Mudflats and sandflats not covered by seawater at low tide	Stable, cohesive intertidal mud and sediments, various locations.	Suction dredge, targeting cockles.	Tracks cause erosion of sediment. Tracks are present for several weeks following disturbance, but likely part of a natural cycle of erosion and cohesion.	No	Yes (recovery likely within a relatively short timescale)	Insufficient evidence	Yes (recovery likely within a relatively short timescale)	Insufficient evidence	No	1	76
Mudflats and sandflats not covered by seawater at low tide	Intertidal mudflats, Wadden Sea. (fairly high energy habitat)	Hydraulic suction dredge for cockles, fairly large scale	Sediment lost (habitat loss), reduced abundance of typical species, and reduced recruitment levels, correlated with dredging activity. Loss of suitable habitat for mussels.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	2	79, 99
Mudflats and sandflats not covered by seawater at low tide	S Rockaway Beach, southwestern Long Island, N.Y	1.2 m Hydraulic Clam dredge, individual experimental pass	Physical signs of dredging had almost disappeared after a few hours. Damage to target species and increased predation.	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	95

Mudflats and sandflats not covered by seawater at low tide, Shallow sandbanks which are slightly covered by seawater all the time	Fine sand, with coarse gravelly material, Gormanstown, Co Meath, Ireland	Hydraulic razor clam dredge. Examining physical and biological impacts of dredging.	Short term effects on biota, physical effects not visible after 40 days.	No	Yes (recovery after 40 days)	Insufficient evidence	Yes (recovery after 40 days)	Yes (recovery after 40 days)	Insufficient evidence	1	98
Shallow sandbanks which are slightly covered by seawater all the time	Ancona Maritime District, Central Adriatic Sea, Italy	2.4-3 m wide dredge on sledge runners to avoid digging into sediment.	Quick increase in scavenging species. No discernable impact on community as whole, but some change apparent.	No	Yes (recovery likely)	Insufficient evidence	Insufficient evidence	No	No	1	108
Shallow sandbanks which are slightly covered by seawater all the time, Maerl beds	Maerl bed, Stravanan Bay, Clyde Sea, Scotland	Hydraulic dredge, single passage	Maerl buried, redistributed and fragmented.	Yes	Yes	Yes	Yes	Yes	Yes	1	96
Mudflats and sandflats not covered by seawater at low tide	Mobile, intertidal sandLavan Sands, Wales	Hydraulic cockle dredge, single pass	Some impacts on biota, but recovery very fast.	No	No	No	Insufficient evidence	Insufficient evidence	No	1	111
Mudflats and sandflats not covered by seawater at low tide	Blackshaw Flats, Solway Firth	Hydraulic cockle dredge, repeated pass to simulate 3 month licence period	Some statistically insignificant impacts on biota, but recovery very fast.	No	No	No	Insufficient evidence	Insufficient evidence	No	1	111
Mudflats and sandflats not covered by seawater at low tide	Mudflats, hard and soft composition, Traeth Lafan	Area dredged for 3 month period.	Some physical disturbance, greater in harder sediment, recover over winter.	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	113
Shallow sandbanks which are slightly covered by seawater all the time	*Zostera* beds, fine sand/ mud, Solway Firth.	Hydraulic suction dredge targeting cockles.	Can be very damaging, has led to disappearance of beds in some areas.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	2	109, 76

Shallow sandbanks which are slightly covered by seawater all the time	Sandy area with high tidal flow, Western Isles, Loch Gairloch, Scotland and Sound of Ronay, near Grimsay, Outer Hebrides	Water jet dredgers, targeting Razor clams (single pass) (*Ensis* spp)	Single pass through, immediate change to community structure. No effects remained after 11 weeks (75) or 40 days (27). Fast recovery due to inward migration of mobile species from surrounding area.	No	No	Insufficient evidence	Yes (recovery fast)	Insufficient evidence	No	3	106, 103, 104
Shallow sandbanks which are slightly covered by seawater all the time, large shallow inlets and bays	Sheltered, shallow, low tidal flow, sediment area, Lamlash Harbour on the Isle of Arran, Scotland	UMBSM Hydraulic suction dredge for razor clams, single pass.	Change to sediment structure, long lasting (beyond 100 days)	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	Yes	No	1	114

Scallop dredging impacts by habitat or interest feature, summary table

Interest feature (habitat &/ or species)	Specific features of study site if applicable.	Activity details, including target species, gear, scale and timing (if available)	Impact details, including recoverability, scale, community and habitat effects.	Could the activity reduce the range of the interest habitat or species?	Could the activity directly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity indirectly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity change the community composition of the habitat?	Could the activity affect the specific structures and functions necessary for the maintenance of the interest feature?	Could the activity damage or kill any Species of community interest within the feature?	Number of references	Reference numbers
Sandbanks which are slightly covered by seawater all the time, fan mussel	Relatively undisturbed site, including large slow growing infauna, including *Atrina fragilis.* Adriatic Sea	'Rapido' trawl, 3m wide, toothed dredge, used to target scallops. Single pass.	Obvious mortality to fan mussels. Reburial of coralline algae damage to large fragile organisms. (Long term recovery not monitored)	No	Yes	Insufficient evidence	Yes	Insufficient evidence	Yes	1	13
Large shallow inlets and bays, Sandbanks which are slightly covered by seawater all the time,	Mixed, stable sediment, sandy, gravely seabed with cobbles and boulders, various locations worldwide	Mobile gears including scallop dredge	Homogenisation of seabed. Loss of structural features, loss of large, fragile species.	Yes	Yes	Yes	Yes	Yes	Insufficient evidence	8	137, 158, 127, 128, 142, 122, 140, 165
Large shallow inlets and bays, Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	*Zostera marina* beds, Back Sound, North Carolina (USA)	Clam kicking, followed by dredging with metal dredge, through eelgrass beds, similar gear to a scallop dredge.	Loss of eelgrass biomass, full recovery had not occurred after four years.	Yes	Yes	Yes	Yes	Yes	Yes	1	110
Sandbanks which are slightly covered by seawater all the time,	Exposed, subtidal sandflats, Mercury Bay, New Zealand	Single experimental pass with scallop dredge.	Loss of structural emergent species recovery not apparent after three months	No	Insufficient evidence	Insufficient evidence	Yes	Yes	No	1	131
Sandbanks which	Sediment habitats	Long term,	Loss of habitat	Yes	Yes	Yes	Yes	Yes	Insufficient	3	132,

are slightly covered by seawater all the time, reefs	and boulder/ coble communities in the Irish Sea and Chaleur Bay, Gulf of St Lawrence	repeated dredging activity	heterogeneity, loss of fragile, slow growing species. Community shift from undisturbed to disturbed community structure. Reduction in particle size, including cobbles and boulders dislodging and overturning boulders.						evidence		133, 141
Reefs	Rock reef, with abundant kelp, Bay of Fundy, Canada.	Single passage of a scallop dredge	Large flora and fauna severely damaged following trawl, but damage was no longer apparent after three months. Suggest that repeated trawling may cause more long-term damage.	No	Yes (recovery within 3 months)	Yes (recovery within 3 months)	Yes (recovery within 3 months)	Insufficient evidence	Insufficient evidence	1	148
Sandbanks which are slightly covered by seawater all the time, Maerl	Maerl beds, Firth of Clyde and Clyde Sea, Scotland. And Bay of Brest, France	Passage of 3x77cm rock hopper scallop dredges with 9x10cm dredge teeth and Passage of three Newhaven dredges	Severe damage to the reef and ecosystem, still apparent up to four years. Potential community shift.	Yes	Yes	Yes	Yes	Yes	Yes	4	159, 160, 162
Sandbanks which are slightly covered by seawater all the time, Maerl	Maerl beds, The Stravanan Bay, Isle of Bute and The Caol Scotnish, Loch Sween. Scotland	Scallop dredged area compared to undredged site	Dredged are had reduced habitat complexity caused by damage and burial of maerl.	Yes	Insufficient evidence	Insufficient evidence	Yes	Yes	Yes	1	161
Large shallow inlets and bays, Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	Eelgrass beds, on both hard and soft sediments, North Carolina, USA	Hand pulled scallop dredge.	Loss of eelgrass biomass and shoot number resulted, effects were long lasting	Yes	Yes	Yes	Insufficient evidence	Yes	Yes	1	163

Reef	Mudstone reefs, cobble and bulder seabed, Lyme Bay	Passage of 12 X spring loaded dredges.	Caused extensive physical damage to boulders and mudstone reefs. Displaced number of feature. Risk of system switching. Pink sea fans amongst species killed.	Yes	Yes	Insufficient evidence	Yes	Yes	Yes	1	154
Reef	File shell reef, Clyde Sea, Scotland.	Passage of three Newhaven dredges	Reef destroyed, individuals exposed and killed. No full recovery after four years.	Yes	Yes	Yes	Yes	Yes	Yes	1	159
Sandbanks which are slightly covered by seawater all the time,	Sandy seabed, 20 km east of Venice Lagoon, northern Adriatic Sea.	Rapido trawl, immediate and long-term effects studied.	Loss of epifauna, increase in scavenging species.	Insufficie nt evidence	Insufficient evidence	Yes	Yes	Insufficient evidence	Insufficient evidence	1	164
Estuaries	Silty, muddy bottomed estuary, Damariscotta River estuary, Maine, USA.	23 passes of a 2 m wide Bedford-style scallop dredge.	Reduced diversity of macrofauna, assemblages had not recovered six months after dredging.	No	Yes	Yes	Yes	Insufficient evidence	Insufficient evidence	1	130

Oyster culture impacts by habitat or interest feature, summary table

Interest feature (habitat &/ or species)	Specific features of study site if applicable.	Activity details, including target species, gear, scale and timing (if available)	Impact details, including recoverability, scale, community and habitat effects.	Could the activity reduce the range of the interest habitat or species?	Could the activity directly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity indirectly reduce the population of the interest species or interest habitat's 'typical species'?	Could the activity change the community composition of the habitat?	Could the activity affect the specific structures and functions necessary for the maintenance of the interest feature?	Could the activity damage or kill any Species of community interest within the feature?	Number of references	Reference numbers
Bottle-nosed dolphin	Bottle-nosed dolphin	Oyster culture structures, Shark Bay, Australia	Displacement of individuals, locally	Yes	No	Insufficient evidence	N/A	Insufficient evidence	No	1	109
Estuaries, Mudflats and sandflats not covered by seawater at low tide, waders, wildfowl	Variety of wading birds and wildfowl.	Intertidal oyster trestles on mudflats, Saleen estuary, Study of bird behaviour and bird counts at low tide. Johnsbrook, SW Ireland.	No effects on feeding behaviour. Fewer birds in trestle area.	No	No	Insufficient evidence	No	Insufficient evidence	No	1	51
Mudflats and sandflats not covered by seawater at low tide,	Mudflats and sand flats and mussel beds, Wadden Sea Germany.	Escaped, wild Pacific oysters growing on mud and sand flats	High survival rate of oyster and limited selectivity will reduce available settlement habitat for mussels	Yes	Insufficient evidence	Yes	Yes	Yes	Insufficient evidence	1	187
Large, shallow inlets and bays,	Shallow inlet, dynamic sediment, resuspended regularly by wave action Shippagan, New Brunswick, Canada	Study impacts on benthos of suspended low intensity (8 kg m-^{2}) culture.	No discernable effects recorded	No	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	192
Large, shallow inlets and bays,	Sheltered bay, 14.4m deep sandy	Study of sediment beneath pearl	No discernable effects recorded	No	No	Insufficient evidence	Insufficient evidence	Insufficient evidence	No	1	193

	silt, Gkasho Bay, Japan	oyster culture									
Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	Eelgrass beds, Willapa Bay, Washington	Suspended longline culture	Eelgrass growth and biomass was very similar to control sites and did not seem to be affected.	No	No	Insufficient evidence	No	Insufficient evidence	No	1	194
Sandbanks which are slightly covered by seawater all the time, *Zostera* beds	Eelgrass beds, Willapa Bay, Washington	Dredged ground culture and hand harvested ground culture	Biomass and growth of eelgrass was reduced	Yes	Yes	Insufficient evidence	Insufficient evidence	Yes	No	1	194
Large, shallow inlets and bays,	Mahurangi Harbour, northern New Zealand	Oyster farm, of 1m wide racks	Sediment beneath racks and 5m radius of racks contained higher levels of silt. Clay and community was indicative of a disturbed site and differed to undisturbed areas nearby.	No	Insufficient evidence	Yes	Yes	Insufficient evidence	No	1	196
Large, shallow inlets and bays, Mudflats and sandflats not covered by seawater at low tide,	Intertidal mudflat, Dungarvan Bay, SE Ireland.	Oyster culture trestles, with access lanes	Sediment beneath trestles was not organically enriched and community was similar to undisturbed sites. Lanes were more compacted and community was indicative of a disturbed site.	No	No	Insufficient evidence	Yes	Insufficient evidence	No	1	197

Appendix 3: Table of reference information, produced using fisheries effects database

All references 'Reviewed by: Gubbay & Knapman,1999' are adapted from: Gubbay. S. & Knapman, P.A, 1999. A review of the effects of fishing within UK European marine sites. Peterborough: *English Nature* (UK Marine SAC Project). 134 pages.

All references 'Reviewed by Sewell & Hiscock, 2005' Are adapted from: Sewell, J. & Hiscock, K., 2005. Effects of fishing within UK European Marine Sites: guidance for nature conservation agencies. Report to the Countryside Council for Wales, English Nature and Scottish Natural Heritage from the Marine Biological Association. Plymouth: Marine Biological Association. CCW Contract FC 73-03-214A.

All references 'Reviewed by: Sewell *et al*., 2007' Have been reviewed and summaries developed for this report. All summaries can be accessed and searched through an online database at www.marlin.ac.uk.

Ref Number 9 Ref: Gislason, H., 1994. Ecosystem effects of fishing activities in the North Sea. *Marine Pollution Bulletin*, 29, 520-527. Location: North Sea Reviewed by: Gubbay & Knapman, 1999,	Description: Review paper. Habitat effects: Towed fishing gears such as bottom and beam trawls physically disturb the seabed causing alterations in microbial communities, resuspension of particles, nutrients and pollutants and the relocation of stones and boulders. Inshore fisheries have led to destruction of reefs built by species such as the polychaete worm Sabellaria or by calcareous algae. Fishing has led to structural changes in habitat that have resulted in changes in species assemblages Community effects: Fixed nets such as gill nets are more likely to entangle non-target species. Diving seabirds are especially vulnerable to entanglement in fixed nets such as gill nets. No evidence that mortality due to entanglement has precluded the observed increase in population size of many species of seabirds which has taken place during this century in the North Sea. Harbour porpoises especially vulnerable to entanglement in gill nets. Recent estimate of the bycatch of the Danish gill net fishery in the eastern North Sea gave an annual bycatch of 4629 porpoises. Incidental bycatch could be a significant contributing factor to the overall decline harbour porpoise abundance in European waters. Seal populations have been able to sustain or increase their populations whilst subject to fishery induced mortality. No species exists in isolation, fishery-induced changes in the density of one species will have repercussions on its predators, prey and competitors. Heavy towed gears in contact with the seabed can kill or injure animals living in the top most layers of sediment. The percentage of benthic organisms caught in a beam trawl which die varies from zero for hermit crab, whelks and starfish to 100 percent for shells such as *Artica islandica*. Beam trawl is the most important fishing gear which penetrates the seabed. General fisheries generated mortality results in reduced abundance of long-lived benthic species and increased abundance of short-lived species. Bycatch and offal produced by gutting the fish at sea thrown overboard provides food for seabirds and other scavenging animals. Changes in the amount of discards may affect the relative and absolute abundance of various species of seabirds. Increased abundance of scavenging seabirds since the start of the century. Large or unattractive discard items will fall to the seabed where they can become available to sub-surface scavengers. Fishing produces litter in the form of lost gear and other waste comparable with that produced by shipping in general. Litter from fishing such as lost or discarded nets may entrap seabirds and mammals.

Ref Number 10 Ref: Hall-Spencer, J.M. & Moore, P.G., 2000. *Limaria hians* (Mollusca: *Limacea*): a neglected reef-forming keystone species. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 10, 267-277. Study date: 1995-1999 Location: Loche Fyne Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at the importance of the marine bivalve *Limaria hians* as a reef-forming species in the United Kingdom and the key architectural role this species plays with benthic communities. Observations of *Limaria hians* reefs were made in Loch Fyne, this involved more than 80 dives (30-60 minutes long). During the survey period a commercial scallop dredge (with 6 Newhaven dredges per side) was towed though a section of the reef (an area at Creag Gobhainn). Dives 3 hours after dredging and over the following 3 days allowed the effects of the dredging to be recorded. Due to the nature of this habitat suggestions for the future were also made. Habitat effects: Three hours after dredging it was clear the reef had been ripped apart, with vast amounts being removed along the dredges path (this was from a single pass of the gear). Left on the dredge track were damaged *Limaria hians*, which attracted a large number of scavengers. During dives over the following 3 days the flesh from the file shells were consumed by a number of species within 24 hours including juvenile cod, edible whelks, hermit crabs, dogfish, dragonets, swimming crabs and brittlestars. Further notes: The conservation of *Limaria hians* reefs is important due to both their sensitivity to damage from anthropogenic impacts and their high biodiversity. Studies in the Clyde Sea have shown that the *Limaria hians* were once widespread and common, but have now disappeared from areas where they were once strongholds and now only dead shells remain. Over the last 30 years studies have indicated that scallop dredging is likely to be the cause of this decline not only in the Clyde Sea but also off the Isle of Man. The study concludes that in the long-term the remaining examples of these reefs should be surveyed in detail and given protection under the network of SACs.
Ref Number 12 Ref: Watson-Capps, J.J. & Mann, J., 2005. The effects of aquaculture on bottlenose dolphin (*Tursiops* sp.) ranging in Shark Bay, Western Australia. *Biological Conservation,* 124, 519-526. Study date: 1998-2003 Location: Shark Bay, Western Australia. Reviewed by: Sewell *et al.,* 2007	Description: Study aims to determine if the ranging patterns of bottlenose dolphins have been altered by oyster farming in Shark Bay. To answer this three questions were addressed: i) do bottlenose dolphins change their use of an area once farming begins; ii) do bottlenose dolphins move away from the farm; iii) do bottlenose dolphins move around (not through) the farm? Community effects: Study indicated that bottlenose dolphins have been displaced by aquaculture. There was a significant decrease in the use of the extension area when the oyster farming was introduced. The strongest evidence came from the movement around the oyster farms, when compared to ecologically similar areas nearby, the adult females stayed to the outside of the farm rather than going through the pearling lines. Displacement also has the potential to affect foraging capabilities and reproductive success. Further notes: Management agencies should forecast that farms with ropes and panels may at least displace some dolphins. It is therefore important to consider that if dolphin welfare is of a concern then the precautionary approach is required.
Ref Number 13 Ref: Hall-Spencer, J.M., Froglia, C., Atkinson, R.J.A. & Moore, P.G., 1999. The impact of rapido trawling for scallops *Pecten jacobaeus* (L.) on the benthos of the Gulf of Venice. *ICES*	Description: Experimental tow using one 3 m wide rapido trawl over a relatively undisturbed sandy-bottomed scallop bed. Authors used underwater video before, during and one and 15 hours after trawling and catch analysis to study the effects of the trawl on the benthos. Habitat effects: 3 m wide tracks were left, following the trawl. Sediment was flattened, with no worm tubes or burrows that had been there previously. Tracks were littered with animal and shell fragments.

Journal of Marine Science, 56, 111-124. Location: Gulf of Venice, Adriatic Sea. Reviewed by: Sewell & Hiscock, 2005	Community effects: Mobile scavenging organisms, particularly spider crabs, hermit crabs and some fish species increased in abundance in trawled areas. Significant decrease in abundance of and obvious damage to the fan shell *Atrina fragilis*. Coralline rhodoliths were smashed and dispaced or buried by the trawl. Large numbers of soft bodied tunicates were killed by the passage of the trawl and/or caught as bycatch. Trawl teeth speared soft bodied invertebrates and large, hard-shelled bivalves. Damage to benthos was limited to organisms living within the top 2 cm of sediment. Large, fragile organisms, generally sustained the highest levels of damage when caught by the trawl, whilst smaller, hard-shelled organisms were fatally damaged only in low proportions.
Ref Number 15 Ref: Tasker, M.J., Camphuysen, C.J., Cooper, J., Garthe, S., Montececchi, W.A. & Blaber, S.J.M., 2000. The impact s of fishing on marine birds. *ICES Journal of Marine Science,* 57, 531-547. Location: Review of studies in various locations Reviewed by: Sewell & Hiscock, 2005	Description: Review of direct and indirect threats of fisheries to seabirds, based on existing literature. For the purpose of this review, only issues relevant to species and fishing types used in and around the UK are summarised here. Community effects: Long-lines: Due to their feeding behaviour, most surface scavanging sea birds are pre-adapted to follow fishing vessels, feeding on discarded material and stealing bait from hooks. Birds will therefore often become hooked on longlines as the hooks are thrown overboard and birds will drown as the line sinks. Seabird mortality may be less if lines are set at night. Gillnets: In the north west Atlantic, a number of species of diving birds, also found in the UK are caught in high numbers by gill nets, while they hunt large shoals of small fish. In Greenland, large numbers of guillemot have been recorded as caught by salmon drift net fisheries. Gillnets set for bass in St Ives Bay, Cornwall have taken an annual bycatch of hundreds, possibly thousands of razorbills and guillemot. Studies around Wales have shown 'hot spots' of bycatch around bird colonies. Further notes: Virtually all types of gear used in bird feeding areas are capable of taking bird bycatch. Guillemots have been rcorded in sandeel trawls in the North Sea around feeding colonies.Birds may become entangled in lost or discarded fishing gear (lines and nets). Studies of dead bird strandings have shown that large numbers of gannets and cormorants are killed by lost fishing gear in the North Sea. Gannets are known to build nests using nylon line. As a result, adults and chicks may become entangled and die of starvation. Studies have shown that sustained disturbance to birds in estuaries by bait diggers can lead to shifts of birds to alternative areas. If there is insufficient food in these location, birds may die. Clam dredgers operating on banks used as feeding grounds by the common scoter in the southern North Sea may have led to disturbance and food depletion of the seaduck species. Overfishing of predatory fish can lead to higher numbers of small forage fish and benefit predatory birds. Conversly, fisheries targetting small forage fish such as herring, sprat and sand eels may reduce the food available for predatory birds, reducing bird numbers and breeding performance. Shellfisheries for mussels and cockles in the Wadden Sea have resulted in extra mortalitry of common eiders and oystercatchers. A study also showed that the presence of mussel fishers on a UKmudflat forced oystercatchers away from their prefered food source to feed on earth worms in nearby fields if this switch was unsuccesful the birds died. Some species of bird profit from discards by the fishing industry in the North Sea.
Ref Number 16 Ref: Stillman, R.A., Goss-Custard, J.D., West, A.D., Le V. dit Durell, S.E.A., McGrorty, S., Caldow, R.W.G., Norris, K.J., Johnstone, I.G., Ens, B.J., Van Der Meer, J. & Triplet, P., 2001. Predicting shorebird mortality and population size under different regimes of shellfishery management. *Jounral of Applied Ecology,* 38, 857-868.	Description: Behaviour-based model was used to look at the effects that current management regimes of a mussel (Exe estuary) and cockle (Burry Inlet) fishery have on the number and survival of overwintering oystercatchers. Community effects: Currently neither mussel fishery or cockle fishery have caused oystercatcher mortality to be higher than it would be if fishing was absent, indicating current intensities of fishing activity do not significantly affect oystercatchers. However, changes in management practices can affect oystercatcher mortality and population size, these include increasing fishing effort, reducing minimum landing size or increasing daily quota (these effects can be made worse when prey is unusually scarce or periods of cold weather.

Location: Exe estuary, SW England and Burry Inlet, S Wales. Reviewed by: Sewell *et al.,* 2007	
17 Ref: Stillman, R.A., Goss-Custard, A.D., Caldow, R.W.G., McGrorty, S. & Clarke, R.T., 2000. Predicting mortality in novel-environments: tests and sensitivity of a behaviour-based model. *Journal of Applied Ecology,* 37, 564-588. Study date: 1976-1991 Location: Exe Estuary Reviewed by: Sewell *et al.,* 2007	Description: Paper presented a model to test how populations may be affected under new environmental conditions, this is particularly important when the future impact that development of proposed mitigation measures may have on populations. The model was based on the main assumption that an individual within a population will always act in order to maximize its fitness. The model was tested on the oystercatcher feeding on blue mussels in the Exe estuary during the non breeding season and was designed to predict how much of the oystercatchers mortality rate would be affected by environmental changes. The starving number of birds between September and March was the principle determinant for the model. The mortality of oystercatchers on the Exe estuary was measured between 1976 (September) and 1980 (March), the model was the calibrated. The main test of the model was its ability to then predict the starvation rates in a sample of subsequent years (1980-1991). Further notes: The model predicted to a good degree of accuracy the following: i) stage of winter when the birds starved ii) relative mass of the birds using different feeding methods iii) how long the birds spent feeding on mussels during both the day and night at low tide iv) dates where birds supplement their diet with other prey fields as the mussels beds were unavailable due to the high tide. The paper concluded that this type of behaviour-based would provide a good starting point for predicting how demographic parameters would be affected by novel environments.
Ref Number 18 Ref: Camphuysen, C.J. & Garthe, S., 2000. Seabirds and commercial fisheries: population trends of piscivorous seabirds explained? *The Effects of Fishing on Non-target Species and Habitats: Biological, onsevation and socio-economic issues* (ed. M.J. Kaiser & S.J. de Groot), pp. 163-184. Location: North Sea Reviewed by: Sewell & Hiscock, 2005	Description: The paper examines the provision of discards and offal as a food source for sea birds, Overfishing of large predatory fish and overfishing of small fish by commercial fisheries. The aim was to explore the hypothesis that the recent increased range of many seabirds in the North Sea was influenced by commercial fisheries. Community effects: *Larus* gulls used discards to a considerable extent. Black-legged kittiwakes largely ignored discards and prefered to feed on small, live fish. Non-breeding birds used discards most frequently. Nesting birds made a greater effort to feed on natural resources this may be related to reduced breeding success resulting from a diet consisting of high amounts of discards. The authors found no evidence that seabirds profited from the removal of predatory fish. Several examples show how overfishing of certain stocks can reduce the reproductive output of some seabirds.

Ref Number 19 Ref: Votier, S.C., Bearhop, S., Ratecliffe, N., Phillips, R.A. & Furness, R.W., 2004. Predation by great skuas at a large Shetland seabird colony. *Journal of Applied Ecology,* 41, 1117-1128. Study date: Breeding seasons of 1999 and 2001 Location: Hermaness National Nature Reserve, Unst, Shetland. Reviewed by: Sewell *et al.,* 2007	Description: Using a bio-energetics model (described by Phillips *et al*. 1999) to estimate the amount of prey consumed by the great skuas at Hermaness, Shetland. Including the composition of the prey consumed and how changing input parameters effects the prey that the great skua consumes. Community effects: The total energy required by the great skua colony increased from 1999 (491.5x106 kJ) to 2001 (546.6x106 kJ) by 11.2%. Most of the prey consumed by great skuas was fish followed by seabirds. In 1999, 80,000 kg of fish were consumed and 7,610 kg of seabirds; in 2001 the amount of fish consumed increase to 90,000 kg, despite predicted declines in discards, the number of seabirds consumed declined but only by 150 kg. During the 1999 and 2001 breeding seasons it was estimated that the great skuas consumed more than 12,500 and 13,000 birds respectively. The three most commonly consumed bird species were auks, northern fulmars and black-legged kittiwakes. Changing the input parameters had a profound affect on the diet of the great skua, a decrease of 50% in the number of fish consumed resulted in an increase of more than 50% of bird species consumed. This current level appears to be unsustainable for prey populations indicating the importance that fishery discards have in the system in determining seabird predation.
Ref Number 20 Gill, JA, Norris, K. & Sutherland, W.J., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation,* 97, 265-268. Reviewed by: Sewell *et al.,* 2007	Paper discussing whether changes in behaviour caused by human presence are likely to be good measures of the relative susceptibility of species. The authors suggest that their use may result in confusion when determining conservation priorities.

Ref Number 21 Ref: West, A.D., Goss-Custard, J.D., Stillman, R.A., Caldow, R.W.G., le V. dit Durell, S.E.S. & McGrorty, S., 2002. Predicting the impacts of disturbance on shorebird mortality using a behaviour-based mode. *Biological Conservation,* **106**, 319-328. Location: Exe Estuary Reviewed by: Sewell *et al.,* 2007	Description: A behavior-based was used to evaluate and predict the impact that disturbance could have on the individual survival and long-term population size of oystercatchers (*Haematopus ostralegus*) in the Exe Estuary. The study also explored if the current levels of disturbance affected fitness and population size, and evaluated alternative policy operations for managing the disturbance. The design of the model looked at the disturbance of birds at their preferred feeding grounds. Different simulations were conducted to assess the effects of various types and intensities of disturbance and the effects of some mitigation methods put in place to reduce the disturbance. The impact of disturbance was measured as the number of birds surviving as well as the percentage of starving birds over one winter at different sizes. Community effects: The results from the model indicated that for if the same overall area was disturbed a number of small disturbances would be more damaging than and a few large disturbances. The model also indicated that if time and energy costs arising from disturbance were considered then disturbance would actually be more damaging to the oystercatchers than permanent habitat loss. In order to eliminate the predicted population consequences results indicated that this could be achieved by preventing disturbance during the winter when feeding conditions were harder. Further notes: Even though the model showed that disturbance caused increases in mortality, the current levels of disturbance occurring in the Exe Estuary were not predicted to cause increases in mortality.
Ref Number 22 Ref: Yasué, M., Quinn, J.L. & Cresswell, W., 2003. Multiple effects of weather on the starvation and predation risk trade-off in choice of feeding locations in Redshanks. *Functional Ecology,* **17**, 727-736. Study date: October 18th 2001 to March 1st 2003 Location: Firth of Forth, SE Scotland Reviewed by: Sewell *et al.,* 2007	Description: The paper looks at how weather affected the daily habitat choice of the Redshanks (*Tringa totanus*), taking into account the trade-off between predation risk and starvation risk at two habitats (saltmarshes and mudflats), where predation risk by the Sparrowhawks was considered to be higher on saltmarshes. The hypothesis that was tested stated that a riskier habitat would only be chosen when weather conditions meant that the individuals were not able to meet their energy requirements in the safer habitat. Data was collected 3 hours either side of low water between October 28th 2002 and March 1st 2003 from part of the Tyninghame Estuary, additional data on predation risk was collected during the winters of 1989 to 1992. Community effects: Results indicated that the frequency of the attacks that occurred on the Redshanks by the Sparrowhawks was 21 times higher on the saltmarsh than the mudflat (48 attacks occurred on the saltmarsh compared to only 3 on mudflat). The amount of feeding time lost as a result of raptor disturbance was greatest on the saltmarsh than on the mudflats. The energy budget of the mudflat was significantly lower than the energy budget of the saltmarsh, the Redshanks that fed on the saltmarsh required 43% less feeding time in order to meet their daily requirements than the Redshanks feeding on the mudflats. Habitat choice: the number of Redshanks feeding on each habitat was initially the same, but in mid-winter there was an increase in the number feeding on the saltmarsh. As the starvation risk increased more Redshanks fed on the saltmarsh.

Ref Number 23 Urfi, A.J., Goss-Custard, J.D. & Le V. Dit., Durell, S.E.A., 1996. The ability of oystercatchers *Haematopus ostralegus* to compensate for lost feeding time: field studies on individually marked birds. *Journal of Animal Ecology*, 33, 873-883 Reviewed by: Sewell *et al.,* 2007	Paper examining whether oystercatchers are able to compensate for lost feeding time, by increasing their feeding rate. Study used five tagged birds feeding on mussel beds and monitored responses to disturbance. Species effects: The birds did not increase their rate of feeding, but fed for longer periods, indicating some 'slack' in their normal feeding time.
Ref Number 24 Ref: Kaiser, M.J., Galanidi, M., Showler, D.A., Elliott, A.J., Caldow, R.W.G., Rees, E.I.S., Stillman, R.A. & Sutherland, W.J., 2006. Distribution and behaviour of Common Scoter *Melanitta nigra* relative to prey resources and environmental parameters. *Ibis,* 148, 110-128. Study date: February and March 2004 (see further notes). Location: Liverpool Bay. Reviewed by: Sewell *et al.,* 2007	Description: Large scale study was undertaken using aerial observations to assess the spatial distribution of the Common Scoter in relation to prey abundance and environmental and anthropogenic variables that affect the efficiency of foraging. To assess prey types two 0.1m2 grab samples were taken and the contents sieved over 1mm mesh (see further notes). Community effects: Disturbance appears to affect common scoter distribution, as shipping activity increased the number of birds observed declined. Only 2.65% of common scoter were observed during overflight observation in areas of heavy shipping activity, whereas 18% were observed in areas of intermediate shipping activity. The study concludes that Common Scoter distribution is strongly influenced by the distribution and quantity of prey; these factors however are influenced by a combination of physical parameters. Further notes: Due to a low number of observations as a result of weather observations from previous winter season (August 2002 – April 2003) were also included to provide more accurate results. For the grab samples Liverpool Bay was divided into two main areas: the Lancashire coast (north of the Shell Flat to the centre of the River Mersey) and the North Wales coast (Red Wharf Bay to the centre of the Mersey River).

Ref Number 25 Ref: Kasier, M.J., 2005. Predicting the displacement of common scoter *Melanitta nigra* from benthic feeding areas due to offshore windfarms. COWRIE - BEN - 03 - 2002 Location: Liverpool Bay, UK Reviewed by: Sewell *et al.,* 2007	Description: Study examining the potential impact of windfarms on common scoter populations in Liverpool Bay Community effects: Relevant findings from the paper include. The common scoter is displaced by shipping activity and resting flocks are often put to flight following disturbance. Male and female birds arrive in the bay at different times of the year, meaning that activities at different times may affect different sectors of the population. Direct observations indicate that most fishing activity in the area takes place in water depths exceeding 20m, which is beyond the depth at which the scoter is likely to forage and therefore does not interfere with scoters except on their inbound and outbound journeys.
Ref Number 26 Goss-Custard, J.D., 1980. Competition for food and interference among waders. *Ardea,* 61, 31-52. Reviewed by: Sewell *et al.,* 2007	Paper examining the response of birds, in estuaries in response to shellfishermen. Species effects: The dunlin *Calidris alpina* was driven to alternative feeding grounds which were less profitable with lower prey densities, and a higher density of conspecifics. Whilst the latter is likely to reduce the feeding efficiency of an individual bird, the risk of predation could be decreased due to the increased group density.

Ref Number 27 Ref: Coleman, R.A., Salmon, N.A. & Hawkins, S.J., 2003. Sub-dispersive human disturbance of foraging oystercatchers (*Haematopus ostralegus*). *Ardea,* 97, 263-272. Study date: Spring 1999 Location: Calshot Spit, Hampshire, UK Reviewed by: Sewell *et al.,* 2007	Description: The study examined how the behaviour oystercatchers changed in response to experimentally applied sub-dispersive human disturbance. The following hypotheses were tested: 1) disturbance will increase walk rates, 2) disturbance will increase the amount of time that birds spend vigilant and 3) as a result of the disturbance the foraging efficiency would be reduced. During spring 1999 observations were made for 5 minute periods on the following: walk rates, feeding rates, vigilance scans and foraging success. Information on weather conditions, incidental disturbance and group size was also recorded. All observations were made through a 60x telescope and all behaviours were dictated into hand-held tape recorder. The experimental disturbance was caused by an assistant working to and from the foraging flock, initially once then two to four passes in 5mins. One disturbance trial was carried at low tide once a day-the level of disturbance applied was randomly selected. Community effects: As a result of the disturbance the speed at which the oystercatchers walked away from the disturbance almost doubled, but the amount of time spent walking was not affected. Disturbance also increased the number of scan events and their average length, this therefore meant that the amount of time in-between scans for foraging decreased. The frequency of the disturbance did not affect the number of feeding attempts – there was no difference in the number of feeding attempts made between birds that were disturbed and those that were undisturbed.
Ref Number 28 Gill, J.A., Sutherland, W.J. & Watkinson, A.R., 1996. A method to quantify the effects of human disturbance for animal populations. *Journal of Applied Ecology*, 33, 786-792 Reviewed by: Sewell *et al.,* 2007	Study describes a method of quantifying the effect of disturbance, based on measuring the trade-off between resource use and risk of disturbance. Study examines the impact of disturbance on Pink-footed geese, *Anser brachyrhynchus* feeding in arable fields. The impact of disturbance is calculated based on the food remaining and the number of geese this food would have been able to support.
Ref Number 29 Goss-Custard, J.D., & Verboven, N., 1993. Disturbance and feeding shorebirds on the Exe estuary. *Wader Study Group Bulletin*, 68 (Special Issue). Reviewed by: Sewell *et al.,* 2007	Study examined the response of oystercatcher numbers to disturbance in the Exe Estuary. Species effects: The authors found that disturbance did not affect bird numbers in the estuary.

Ref Number 30 Goss-Custard J.D., Triplet P., Seur F., & West A.D., 2006. Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation,* 127, 88-97. Reviewed by: Sewell *et al.,* 2007	Study showing how individual-based behavioural models can establish critical thresholds for the frequency with which wading birds can be disturbed before they die of starvation. Species effects: Modelling shows that the birds can be disturbed up to 1.0-1.5 times/h before their fitness is reduced in winters with good feeding conditions (abundant cockles *Cerastoderma edule* and mild weather) but only up to 0.2-0.5 times/h when feeding conditions are poor (scarce cockles and severe winter weather). Individual-based behavioural models enable critical disturbance thresholds to be established for the first time.
Ref Number 31 Swennen, C., Leopold, M.F. & de Bruijin, L.L.M., 1989. Time-stressed oystercatchers *Haematopus ostralegus* can increase their intake rate. *Animal Behaviour*. 38, 8-22 Reviewed by: Sewell *et al.,* 2007	Experimental work with captive oystercatchers feeding on cockles *Cerastoderma edule.* Species effects: The study revealed that when foraging time was substantially reduced, these birds were able to increase their food intake rates.
Ref Number 32 Ref: Frederiksen, M., Wanless, S., Harris, M.P., Rothery, P. & Wilson, L.J., 2004. The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *Journal of Animal Ecology,* 41, 1129-1139. Study date: 1986 to 2002. Location: Isle of May, SE Scotland. Reviewed by: Sewell *et al.,* 2007	Description: The role of the sandeel fishery was assessed in relation to the decline in the population of the black-legged kittiwakes. Demographic data collected from 1986 to 2002 was examined for changes and correlations between population parameters, local sandeel fishery and environmental factors. The results were incorporated into a deterministic and stochastic matrix population model. Community effects: From 1969 to 1990 there was a continuing increase in the number of completed kittiwake nests (4801 nests to 8129 nests), however numbers declined to 3666 in 2002. Breeding success has varied considerably from 1.24 fledged chick per nest in 1986 to 0.02 in 1998. It was during the 1986-1989 season that breeding success was high (1.07), however, the following 10 years (1990-1999) was when the Wee Bankie sandeel fishery was active and breeding success fell to a mean of 0.30. The fishery closed in 2000 leading to a small recovery from 2000-2002 (mean = 0.68). The results indicate that kittiwakes are almost completely dependant on sandeels during the breeding season; this therefore means that any activities that reduce the abundance and availability of sandeels will likely have a negative effect on kittiwakes and lead to declines in the population. Further notes: ‘Activities that endanger their main food supply should be avoided and extend indefinitely the closure of sandeel fisheries within the feeding range of kittiwake colonies in the western North Sea’. Fishery assessed, sandeel fishery.

Ref Number 33 Shealer, D.A. & Burger, J., 1993. Effects of Interference Competition on the Foraging Activity of Tropical Roseate Terns. *The Condor*, 95, 322-329. Reviewed by: Sewell *et al.,* 2007	Study examining the effect of mixed species flocks on the roseate tern. Authors examined foraging behaviour in birds of single species and mixed species flocks. Species effects: The authors discovered that the terns were able to forage more effectively in single species flocks, but could not detect any negative impact on survivorship or reproductive success.
Ref Number 34 Ref: Votier, S.C., Furness, R.W., Bearhop, S., Crane, J.E., Caldow, R.W.G., Catry, P., Ensor, K., Hamer, K.C., Hudson, A.V., Kalmbach, E., Klomp, N.I., Pfeiffer, S., Phillips, R.A., Prieto, I. & Thompson, D.R., 2004. Changes in fisheries discard rate and seabird communities. *Nature,* 427, 727-730. Study date: 1986 to 2002 Location: North Sea Reviewed by: Sewell *et al.,* 2007	Description: The aim was to show if there was a link between discard availability and discard use by a generalist predator and scavenger the great skua and test the use of other prey species in its diet. Proportions of discards of white fish species within the diets of great skua were compared with data from ICES on the estimates of quantities of fish discards. Community effects: There was a positive correlation between discard estimates and the importance of both whiting and haddock in the great skuas diet. Results indicated that declines in discard availability have coincided with declines in sandeel biomass, which has lead to the prey switching tendency of the great skuas. Although the great skua may not suffer population declines as a result of declines in sandeel numbers other seabird may, particularly as the great skua can switch from discards to sandeels to seabirds. Models indicated that a 5% increase in birds in the great skuas diet is equivalent to an additional 1,000 northern fulmar or 2,000 black-legged kittiwake. Further notes: Great skua feeds not only on white fish but also sandeels and other seabirds. Over the past 40 years the proportion of white fish that has been caught and subsequently discarded has decreased significantly (proportion of haddock discarded has remained unchanged).

Ref Number 35 Votier, S.C., Bearhop, S., Ratcliffe, N. & Furness, R.W., 2004a. Reproductive consequences for great skuas specializing as seabird predators. *Condor*, 106, 275-287 Reviewed by: Sewell *et al.,* 2007	Study examining the effects of Skua predation on smaller seabirds, particularly regarding reproduction and survival. The parameters were compared with individuals feeding only on fish. Species effects: Specialist bird predators spent less time foraging than skuas feeding predominantly on fish. Results of radio-telemetry indicated that bird-specialist skuas have smaller home ranges than other birds. In a comparison of reproductive performance, specialist bird predators consistently hatched earlier among years. They also showed larger clutch volumes and improved chick condition, but these were subject to annual variations. Hatching success and fledging success for specialist bird predators and specialist fish predators were similar. Specialist bird predators showed similar annual survival compared with fish-feeders over the same period. Specializing as a bird predator may be limited to the best birds in the population, but their poorer than predicted breeding success reveals the need for further study into the relationship between diet and reproductive success in this species.
Ref Number 36 Maniscalco, J.M., Ostrand, W.D., Suryan, R.M. & Irons, D.B., 2001. Passive interference competition by Glaucous-winged gulls on black-legged kittiwakes: a cost of feeding in flocks. *The Condor,* 103, 616–619. Reviewed by: Sewell *et al.,* 2007	Study analysing data from two independent studies of foraging Black-legged Kittiwakes (*Rissa tridactyla*). Species effects: kittiwakes made fewer feeding attempts in flocks that had greater numbers of gulls. Although kittiwake success rate per feeding attempt did not change as the number of gulls increased. Kittiwakes were more likely to avoid flocks that had a greater number of Glaucous-winged Gulls. Gulls successfully pirated less than one percent of fish captured by kittiwakes. The author's findings suggest that passive interference may be costly for smaller birds that feed in multispecies feeding flocks.
Ref Number 37 Ref: Furness, R.W., 2003. Impacts of fisheries on seabird communities. *Scientia Marina,* 67, 33-45 Reviewed by: Sewell *et al.,* 2007	Description: Seabird populations have been affected by fishing activities as a result of incidental mortality where birds have become caught in nets and drowned and direct mortality as a result of changes in food supply due to depleted stocks or discards. The paper highlight fisheries management issues that are likely to affect the future conservation status of vulnerable seabird populations. Community effects: The bycatch of seabirds in longline fisheries is considered to be the most serious fishery issue at present, affecting both pelagic and demersal fisheries. Mitigation measures are legally required in a number of regions and fisheries, but not all fisheries adopt them. Set-nets have also caused a decline in regional seabird populations due to a high mortality rate in monofilament nets. Mortality in the North Pacific of 500,000 seabirds each year until 1992 (fishery was closed) resulted from the high seas salmon (gill net) and squid (drift net) fisheries. Further notes: Discard rates also affect bird populations, but are something that will be reduced in the North Sea in the future. The reduction of discards has become a major objective of the FAO's policy for responsible fishing and is also a recognized management objective of ICES and the EC. However, to manage this issue is not easy because discard rates as they are for the sake of the birds would not be practical.

Ref Number 38 Ref: Lewison, R.L., Crowder, L.B., Read, A.J. & Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna.*Trends in Ecology and Evolution,* 19, 589-604. Reviewed by: Sewell *et al.,* 2007	Description: The paper looked at the current research that addressed the question of bycatch. How many species are being caught and removed from the population and what effects this removal has. There were concerns with data limitation as bycatch was often unrecorded when reported or wasn't reported at all, which led to a level of uncertainty. It was also important to consider the effects of fisheries bycatch on a global scale. Community effects: Studies showed that a number of marine megafauna are at risk from extinction as a result of fisheries bycatch. Longline fisheries have been linked to decreases in the albatross populations, trawl fisheries have been linked to a the number of sea turtles that wash up dead on the shores and gillnet, driftnet, purse seine and trawl fisheries have led to threats to the populations of small cetaceans. In order to reduce seabird bycatch in pelagic longline fisheries gear modifications have been introduced including bird scaring lines which keep the birds away from the baited hooks, weighted lines which enable the hooks to sink faster out of reach of the birds, side-setting which halves the scavenging area and line-setting devices which place the baited hooks immediately underwater. Further notes: Continued research is needed to address the issues of data limitation in fisheries bycatch and although mitigation measures can start at a national level the problem of fisheries bycatch is a global problem, therefore co-ordination is required on a global scale for both monitoring and mitigation.
Ref Number 39 Ref: Phillips, R.A., Silk, J.R.D., Croxall, J.P. & Afanasyeu, V., 2006. Year-round distribution of white-chinned petrels from South Georgia: Relationships with oceanography and fisheries. *Biological Conservation,* 129, 336-347. Study date: 2003-2005 Location: South Georgia Reviewed by: Sewell *et al.,* 2007	Description: The aims of the current study were to: 1) Identify of the key wintering areas used by the white-chinned petrels from South Georgia. 2) Extend of sample tracks that are collected during the winter. 3) Assess the individual variability in site preference. 4) Determine what oceanographic factors influence site selection. 5) Quantify spatio-temporal overlap with fisheries – focus on conservation and management. The Global Location Sensors (GLS-I loggers) were attached to plastic leg rings and deployed on the tarsi of 35 adult white-chinned petrels, each bird was taken from a different burrow and the burrow marked with a wooden stake (burrows visited 9 times during the incubation period in the following 2 years and at the end of the study to remove the devices). The key wintering areas were identified by generating kernel density maps, white-chinned petrels at South Georgia lay between November 13th and December 10th, the location of the tagged birds indicated that each made a trip to the Patagonian Shelf right before this period. In order to assess areas of high and low utilization during the winter period, kernel density contours were laid over maps of bathymetry and monthly sea surface characteristics were recorded. The distribution of the tracked white-chinned petrels was also compared with number of reported hooks set by major longline fisheries operating in overlapping and adjacent fishing grounds. Community effects: Ten birds were tracked for 266-664 days (mean 366), all of which migrated to the Patagonian Shelf and shelf-break waters. Several major fisheries overlapped with the distribution of white-chinned petrels, many of these fisheries are suspected to have high seabird bycatch rates. This is an area which needs to be addresses and although closed areas and seasons may not be viable solution encouraging well-regulated licensing procedures may be an option. An economic incentive for fishermen to use mitigation methods would be in order to reduce bait loss when line setting as white-chinned petrels frequently dive for the bait. Measures need to be introduced otherwise the outlook is bleak.

Ref Number 40 DeGange, A. R., Day, R.H., Takekawa, J.E. & Mendenhall, V.M., 1993. Losses of seabirds in gill nets in the North Pacific. *In: The status, ecology, and conservation of marine birds of the North Pacific*. (ed. K. Vermeer, K. T. Briggs, K. H. Morgan, & D. Siegel-Causey) Canadian Wildlife Service Special Publication, Ottawa: Ontario. Reviewed by: Sewell *et al.,* 2007	Chapter examines the seabird mortality in gill nets in the North Pacific. Some of the worst mortality rates are associated with the squid and salmon drift-net fisheries in the North Pacific, which are estimated to have killed around 500,000 seabirds per year before its closure in 1992
Ref Number 41 Brothers, N., Cooper, J., & Lokkeborg, S., 1999. *The Incidental Catch of Seabirds by Longline Fisheries: Worldwide Review and Technical Guidelines for Mitigation*. FAO Fisheries Circular. Food and Agriculture Organization of the United Nations, Rome. p. 100. Reviewed by: Sewell *et al.,* 2007	Extensive review paper, discussing the incidental capture of seabirds by longlining worldwide. Guidelines and mitigation methods are given.
Ref Number 42 Ref: Lewison, R.L. & Crowder, L.B,. 2003. Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecological Applications*, 13, 743-753. Study date: 1994-2000 Location: Central North Pacific Reviewed by: Sewell *et al.,* 2007	Description: An estimation of seabird bycatch from a fishery consisting of several fleets in central North Pacific. The assessment method was based on bycatch observation data from one fleet, following this scenario analysis was used to estimate the bycatch for the rest of the fleet, best and worst case scenarios were also provided. Community effects: Population trajectories suggested that even with the best-case mortality level, 1.9% (5,200 individuals /year) of the population would be killed by pelagic long-lines each year, declines in the population would be likely over the next 20 years. The worst case scenario suggested that as many as 10,000 individuals are killed each year. Further notes: Seabird species assessed was black-footed albatross.

Ref Number 44 Alverson, D.L., Freeberg, M.H., Murawski, S.A. & Pope, J.G., 1994. *A global assessment of fisheries bycatch and discards*. FAO Fisheries Technical Paper 339. Reviewed by: Sewell *et al.,* 2007	Technical paper assessing global fisheries by-catch and discards. Current fishery practices lead an estimated 25-30 million tonnes of fish being discarded worldwide each year
Ref Number 45 Hudson, A.V. & Furness, R.W., 1989. The behaviour of seabirds foraging at fishing boats around Shetland. *Ibis*, 131, 225-237 Reviewed by: Sewell *et al.,* 2007	Study examined the behaviour of seabirds in relation to trawler discards. Species effects: Discards were used extensively by seabirds, with almost all offal being consumed. Feeding was highly competitive between feeding birds and immature birds were not observed in the area.
Ref Number 46 Ref: Hamer, K.C., Furness, R.W. & Caldow, R.W.G., 1991. The effects of changes in food availability on the breeding ecology of great skuas *Catharacta skua* in Shetland. *Journal of Zoology,* 223, 175-188. Study date: 1973-1989 Location: Foula, Shetland Reviewed by: Sewell *et al.,* 2007	Description: Looking at data over a 16 year period the paper studied various aspects of the breeding ecology of the great skuas in Shetland. How adults responded to changes in the availability of sandeels and how these changes could affect the annual breeding statistics and long-term reproductive potential was also considered. The relationship between chick diet and sandeel availability was examined, samples were obtained from food that was regurgitated by the chicks during ringing. Pellets of non-digestible material deposited at sites frequented by non-breeders and in breeding territories were also collected. The amount of time that great skuas spent away from their territories provided an indication as to the availability of prey. Breeding success was evaluated by marking nests in early May and the eggs laid in the nests were measure. The nests were then visited at regular intervals until the surviving chicks had fled the nests. Community effects: Diets: Results indicated that during the 1970s and the early 1980s the chicks fed primarily on sandeels, but by 1983/84 the proportion of sandeels in the diets of the chicks fell from 95% to 61%, the change in diet was compensated for by an increase in whitefish. From 1984-1987 the composition of the chicks diets remained fairly constant. In 1987/88 the proportion of sandeels within the chicks diet fell again from 56% to 5%, the proportion of whitefish increased from 42% to 77% and the proportion of bird meat increased from 3% to 18%. The changes that were seen in the chicks' diets were closely related to changes in the abundance of sandeels. Adult territorial attendance: Changes to chicks' diets also correlated with changes in the territorial abundance of the adults. From 1987-1989 the average attendance of adults per territory was 1.5 during both incubation and the first 2 weeks after hatching, this changed to 1.2 adults per territory during the remainder of the pre-fledging period. These results indicated a 50% reduction in attendance from the 1976 breeding season. Possible indicating an increase in both time and effort spent foraging for food.

Ref Number 47 Ref: Hüppop, O. & Wurm, S., 2000. Effects of winter fishery activities on resting numbers, food and body condition of large gulls *Larus argentaus* and *L. marinus* in the south-eastern North Sea. *Marine Ecology Progress Series,* 194, 241-247. Study date: December 1997 to March 1998 Location: Island of Helgoland, south-eastern North Sea Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at the extent to which fishery discards and offal influence the food choice of large gulls resting on Helgoland, their resting numbers and their body mass and condition. The period of heavy fishing (December 1997 to March 1998) was compared to times when fishing was suspended during this time frame (Christmas to New Year 1997 and February 1998). Community effects: The results indicated a noticeable different in the diets of the gulls between times when fishing took place and times when fishing did not occur. During times of high intensity fishing (first half of December 1997), more than 80% of the pellets contain discards, indicating that gulls feed primarily on discards when available (the dominant species found was cod). During the periods when fishing activities did not occur, the gulls fed on food items within the rocky intertidal zone, terrestrial food and garbage (some pellets however still contained discard remains – gulls may have foraged outside of the study area). Fishing activity was also shown to affect the body condition of the gulls. The mean body mass of the adult herring gulls decreased by 13% during times of no fishing activity and the mean body mass of the adult great black-backed gulls decreased by 24% during times of no fishing activity. Results indicated a poorer body condition for adult gulls at times with no fishing activity, for immature gulls there was no significant difference in body condition between times of fishing activity and no fishing activity. Further notes: Both the herring gull and black-backed gull benefit from fisheries discards at Helgoland, changes in the availability of this food source during the wintering months is likely to influence winter mortality rates and possible the population dynamics of large gulls.
Ref Number 48 Shepherd, P.C.F. & Boates, J.S., 1999. Effects of commercial baitworm harvest on semipalmated sandpipers and their prey in the Bay of Fundy hemispheric shorebird reserve. *Conservation Biology*, 13, 347-356. Reviewed by: Sewell *et al.,* 2007	Study examining the effects of commercial baitworm harvesting (digging) on the semipalmated sandpiper. Species effects: Foraging efficiency decreased by 68.5% in dug sediment, corresponding to observed reductions in prey density. All the significant, negative effects of baitworm harvesting on Semipalmated Sandpiper foraging behaviour and on the density and age structure of their principal prey, *C. volutator*, were realized after only one season of digging.
Ref Number 49 Ref: Kim, S.-Y. & Monaghan, P., 2006. Interspecific differences in foraging preferences, breeding performanace and demography in herring (*Larus aregentatus* and lesser black-backed gulls (*Larus fuscus* at a mixed colony. *Journal of Zoology,* 270, 664-671. Study date: 2002-2003 Location: Walney Island, Cumbria Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at the breeding performance of two gulls and aims to determine what factor may be influencing the differences that have been observed in the populations. Ratios of birds feeding at different sites and their diets were considered as were any disease incidents. Community effects: Results indicated that the number of breeding pairs of the herring gull has decreased from about 17,000 to 4,000 between 1969 and 2005, where as the number of breeding pairs for the lesser black-backed gull has remained between about 15,000 and 24,000. A number of factors are likely to be involved in the differences between the two populations and the availability of food is likely to be one. In Morecambe Bay the number of mussel fishermen has increased over the past 10 years and recently cockle fishing has taken place, as a result the more intertidal feeding herring gull populations may have been negatively affected during both breeding and wintering periods by reduced shellfish availability. A decrease in landings suggests that the amount of food available around the docks for foraging birds has also declined affecting particularly the herring gull. However, the fishery discards at sea, which favour the lesser black-backed gull, do not appear to have changed.

Ref Number 51 Ref: Hilgerloh, G., O' Halloran, J.O., Kelly, T.C. & Burnell, G.M., 2001. A preliminary study on the effects of oyster culturing structures on birds in a sheltered Irish estuary. *Hydrobiologia,* 465, 175-180. Location: Saleen estuary, Johnsbrook, SW Ireland. Reviewed by: Sewell & Hiscock, 2005	Description: Study examining differences in seabird and wader community composition in an area of oyster cultivation, compared to a reference area with no oyster cultivation. Trestles measuring 40cm heigh, 90cm wide and 3m llong were used for cultivation in an area of one hectare. Of this, an area of 4500 m2 of trestles was covered with oyster bags. Observations of bird behaviour and counts were carried out. Community effects: All species observed in the study were seen at both sites. The outcome of the study indicates that oyster structures did not effect the feeding behaviour of the birds and the six species with the most data available did not appear to be affected by the trestles. However, the number of birds overall in trestle areas was lower than reference area (except for redshank and dunlin). Some wildfowl species such as the wigeon fed on green algae, growing on trestle tables, only when the water around the table was deep enough to swim, but not covering the tables. The authors mention that elswhere, Brent geese have been observed displaying similar behaviour. The authors observe that feeding rate is generally higher in days with shorter tidal exposure.
Ref Number 52 Ref: Caldow, R.W.G., Beadman, H.A, S. McGrorty, S., Kaiser, M.J, Goss-Custard, J.D, Mould, K. & Wilson, A., 2003. Effects of intertidal mussel cultivation on bird assemblages. *Marine Ecology Progress Series,* 259, 173-183. Location: Manai Strait, Wales. Reviewed by: Sewell & Hiscock, 2005	Description: An experimental study to quantify the effects of mussel *Mytilus edulis* culture on bird assemblages on an intertidal mudflat. Bird behaviour was monitored over two winters in an area of 4.31 ha, comprising of experimental mussel culture and control plots. Community effects: Laying of the mussels had no effect on species presence/absence. Although no species were lost from the experimental plots, the bird assemblage in them changed.This reflected variation in the distribution of the 5 most abundant species. However, none of these key species declined in abundance following the laying of mussels. Curlew *Numenius arquata* and redshank *Tringa totanus* increased in abundance, although, oystercatchers *Haematopus ostralegus* did not.
Ref Number 54 Ref: Smit, C., Danker, N., Ens, B.J. & Meijboom, A., 1998. Birds, mussels, cockles and shellfish fishery in the Dutch Wadden Sea: how to deal with low food stocks for eiders and oystercatchers? *Senckenbergiana maritime,* 29, 141-153. Location: Dutch Wadden Sea Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at the fishery policy that has come into force since 1993 and the effects that low food stocks have had on oystercatchers and eiders, which depend on cockles and mussels. Community effects: In the early 1990s low food stocks resulted in food shortages for both oystercatchers and eiders, from this food shortage three main effects could be seen: i) effects on numbers, ii) effects on distribution and iii) effects on mortality. Effects on numbers: in January 1991 the number of eiders was 35% lower than the average number between 1970 and 1990, in the following 1992/93 season the number fell to around 64,000 birds, this figure was considered to be half of the ‘normal’ number of birds. Low numbers of oystercatchers were also recorded in 1991, but from 1992 to 1995 there was a recovery period. However, after a cold winter the number of oystercatchers fell sharply, when most of the cockle died, numbers dropped further in 1997. Effects on distribution: during the winter of 1990/91 a high number of eiders were recorded in the North Sea, this was something that had not been since before, at the same time numbers in the German Wadden Sea also increased. Despite increases in other areas the number of eiders in the Dutch part of the Wadden Sea has decreased since 1990. In the 1990s a large number of oystercatchers were recorded inland and in some case 100s km or more away from the Wadden Sea. The mild winters of 1991/92 and 1992/93 may have allowed for inland feeding. Effects of mortality: the number of beached eiders has increased slowly since 1989 and peaked in 1992 with over 19,000 found dead. High oystercatcher mortality occurred in 1987 due to a combination of cold temperatures and low food stocks.

	Large scale bird counts and habitat characteristics in the Dutch Wadden Sea have indicated that the distribution of oystercatchers in this area are partly controlled by the distribution of intertidal mussel beds. A similar situation was evident on the island of Ameland for both oystercatchers and eiders, where the number of overwintering oystercatchers increased from 1975-1990, during this time the area of intertidal mussel beds also increased. However, in 1990 the area of intertidal mussels disappeared and the number of oystercatchers dropped, by the mid 1990s the mussel beds had started to recover and the number of oystercatchers increased. Eiders in the same area showed the same pattern. Further notes: Cockle stocks can be considered highly variable and unpredictable food source, however, current fisheries policies within the Dutch Wadden Sea are based on the fact that cockles are a major food source for eiders and oystercatchers. The fact that in poor stock years these birds have left the area in search of other food sources and have suffered increases in mortality indicates that cockles and alternative prey species have not always provided sufficient food. Mussel beds are less susceptible to cold temperatures and therefore provide a more reliable food source in years when there are few cockles. An important conclusion from this study is that intertidal mussel beds need to be re-established and need to be safeguarded especially as these beds have not re-emerged on a large scale since 1990.
Ref Number 55 Ref: Cognie, B., Haure J., Barillé, L., 2006. Spatial distribution in a temperate coastal ecosystem of the farmed oyster Crassostrea gigas (Thunberg). *Aquaculture,* **259**, 249-259. Study date: Oct 2002 Location: Bourgneuf Bay, south of the Loire estuary, France Reviewed by: Sewell *et al.,* 2007	Description: Study examining Wild poulations of Crassostrea gigas originating from farmed stock in a semi-enclosed bay. Boergneauf Bay had a total of 1,000 ha of oyster beds at the time of study. Authors surveyed colonisation of oysters on variety of substrates in the study area. Community effects: Authors noted that 'wild' oyster populations in the bay were approximately 2.4 times greater than farmed oyster poulations, representing significant trophic competition, potentially inhibiting the growth of farmed oysters.
Ref Number 56 Ref: Ross, B.P. & Furness, R.W., 2000. Minimising the impact of eider ducks on mussel farming. *University of Glasgow.* Location: Scotland Reviewed by: Sewell *et al.,* 2007	Description: Report looks at the impacts that eider ducks have on mussel farms in Scotland, particularly as the eider ducks are consuming mussels from cultivated lines. Various methods that could be used to reduce the impact are discussed. Community effects: Within the UK the population of eider ducks has increased by about 2.5% each year (population size would double every 30 years), however in Shetland the population is on a downward trend of about 4% per year and has been for the past 20 years for which the reason is unknown. Recent surveys that have been conducted in the Argyll and the Clyde (west Scotland) on eider distribution have shown a strong association between mariculture and local concentrations of eiders. Mariculture has influenced the local distribution of eiders in west Scotland at particular times of year. Results from a survey conducted in September 1998 showed that of the 558 eiders in Mull, 380 were on large mussel farms in Loch Scridian, 105 were around salmon cages in Loch Spelve and 25 were on other mussel and fish farms. Only 18 were found on the remaining coastline of the Island (away from aquaculture systems). Between 1998 and 1999 there was a decrease in the number of eiders on Mull, which happened to not only coincide with the closure of a salmon farm, but also that in 1998 mussel farmers lost 90% of their stock to eiders so carried out a number of deterrent methods to reduce their losses in 1999.

	Further notes: Current methods used to deter eider ducks fall into one of three categories: visual, acoustic and biological. Questionnaires that were competed by mussel farmers indicated 10 methods regularly used as a deterrent against diving ducks; nets, boat chasing, shoot to kill as a deterrent, shoot to scare, mannequin/scary man, gas cannon, pyrotechnics, siren/noises, scary eye and ultrasonic sound generator. Of these techniques netting the farm completely proved to be the most effective method and ideally should only be installed during times when predation tends to be high. Having a human presence on the site can reduce eider feeding activity by 80-99% , the problem being that the ducks will feed from dawn, taking a large amount of stock before the workers arrive. Chasing ducks by boat is a commonly practiced method by mussel farmer, but is expensive in both time and money and birds often return after a period of chasing and continue feeding. An underwater playback system (UPS) which plays chase boat noises is often a good deterrent when there is no human presence (particularly between dawn and when the workers arrive). Although laser light can reduce eider activity it is an expensive and labour intensive method that must be used around dawn to be effective.
Ref Number 57 Ref: Ross, B.P., Lien, J. & Furness, R.W., 2001. Use of underwater playback to reduce the impact of eiders on mussel farms. *ICES Journal of MarineScience,* 58, 517-524. Study date: 1998-1999 Location: Loch Striven and Loch Creran, Argyll Reviewed by: Sewell *et al.,* 2007	Description: Study aimed to assess how effective an underwater playback system (UPS) was at deterring eiders from feeding on mussel farms in Scotland. Two survey sites were assessed: Loch Striven and Loch Creran (before the surveys took place observation tents were set up at least 100m from the mussel farms to allow the birds to become used to their presence). In Loch Striven the trials were broken down into blocks of 6/7 day observation periods, the first period before the UPS was switched on, the second with the UPS switched on constantly during daylight hours and the third with the UPS switched off. In Loch Creran the observations before and after the UPS use were the same, the difference being that the UPS was switched on for 21 days constantly during daylight hours to determine long-term effects (the 21days were broken down into 3 lots of 7 day blocks). The UPS unit was secured to the central raft for raft based farms or to a moored platform in the centre of long-line farms (speaker was held 3 metres below the surface of the water). During the trails boat-chasing was carried out by the farmers as usual. Community effects: As a result of the UPS there was a 50-80% reduction in the number of eiders feeding on the mussel beds, the control showed no reduction in numbers (playback was of an unassociated noise). The return time of birds to the beds after being chased away also increased. Therefore if the UPS reduces the number of eiders feeding on the mussels beds in a similar way as the presence of workers does, then the UPS maybe a useful deterrent when workers are not present on the mussel beds. Further notes: A recording was made from a floating platform using a hydrophone suspended 3 metres below the surface of the water, the scare boat start 150-200 metres away and approached at full throttle and then left. The recording was 2-3 minutes long which was repeatedly transferred onto a 15 minute tape (interval between each recording was twice the length of the initial recording). The number of eiders in each flock were recorded as was the position of the flock in relation to the farm. Individuals what were recorded diving and surfacing within 10 metres of the farm boundary were recorded as feeding on the mussel beds and those that were recorded 10-200 metres away were recorded as not feeding on the mussel beds.

Ref Number 58 Ref: Ferns, P.N., Rostron, D.M. & Siman, H.Y., 2000. Effects of mechanical cockle harvesting on intertidal communities. *Journal of Applied Ecology,* 37, 464-474. Location: Burry Inlet, South Wales Reviewed by: Sewell & Hiscock, 2005	Description: A tractor-towed cockle dredge was used on both muddy sand and clean sand, intertidal areas to extract cockles. The effects of dredging on invertebrates and their predators were examined. Community effects: A significant proportion of the most abundant species was lost from both sites. In muddy sand, populations of *Pygospio elegans* and *Hydrobia ulvae* remained significantly depleted for more than 100 days and had not recovered 174 days after harvesting. Some species of polychaete and amphipod remained depleted for more than 50 days. Although bird feeding activity of gulls and waders increased for a short period following dredging due to increased food availability, this was followed by a significant reduction of bird activity compared to control areas. For curlews and gulls, this reduced level of activity continued for 80 days and for oystercatchers, 50 days. In the area of clean sand, invertebrate communities were less dense and recovered more quickly. Further notes: The authors conclude that tractor dredging for invertebrates caused sufficiently high mortality of non-target species that harvesters should be excluded from areas of high conservation importance.
Ref Number 59 Ref: Rehfisch, M.M., Clark, N.A., Langston, R.H.W. & Greenwood, J.J.D., 1996. A guide to the provision for refuges for waders: an analysis of 30 years of ringing data from the Wash, England. *Journal of Applied Ecology,* 33, 673-687. Study date: 1959-1993 Location: The Wash Reviewed by: Sewell *et al.,* 2007	Description: The aim of the study was to determine how far apart roost refuges should be in order to benefit populations of wading birds. From 1959 to 1993 the Wash Waders Ringing Group collected the largest set of data on ringed waders from any site worldwide. Catches were made every month, although were more frequent from July to August, by cannon-netting or mist netting. Birds were ringed at 85 roost sites around the Wash. By analysing the movements of the waders between the roosts it would provide a way to determine the mobility of the different species and how the spacing of refuges may effect the normal roost movement. A model was used to describe the wader dispersal between roosts and then used to estimate the effect of inter-refuge distance on the number of waders reaching at least one refuge during normal roost movements. This may implicate how refuges are created and managed. Community effects: Despite the fact that waders fly long distances during migration, the study indicated that once at their wintering ground they only travel short distances. The overall outcome indicated that 50% of the populations would be catered for if refuges were 7-10km apart, however this would increase to 75% of the populations if the refuges were 3-6km apart. Further notes: The following species were caught over the time period, with the number of individuals in brackets: oystercatcher (24,576), grey plover (4,125), knot (38,041), dunlin (96,801) and redshank (11,729).

Ref Number 60 Ref: Northridge, S., di Natale, A., Kinze, C., Lankester, K., Ortiz de Zarate, V. & Sequeira, M., 1991. Gill net fisheries in the European Community and their impacts on the marine environment. Location: European Community waters Reviewed by: Gubbay & Knapman, 1999,	Description: Report on the nature and scale of European gill net fisheries and review of accidental catches of non-target species. Incidental catches reported for common dolphins, bottlenose dolphin, striped dolphin, harbour porpoise, common seal, grey seal, sharks (especially blue sharks), loggerhead turtles, guillemot, razorbill, shag and loon. Community effects: Around the UK catches of grey seals in tangle net fisheries high in the Barra fishery and for Cornwall appeared to be higher than other areas. Catches of common dolphins often reported in southwest fisheries amounting to perhaps some hundreds per year. Bottlenose dolphins rarely recorded but porpoises fairly frequently found in gill net fisheries especially in the North Sea. Drift net fisheries catch most but most of these are released alive. Total drownings in gill nets throughout the country may be in high tens to low hundreds. Impact on porpoise population not known. Bird catches widely reported but little studied. Catches of non-target fish poorly known but crabs are taken in very large numbers. Regarding impact on marine mammals the study clarified importance of North Sea cod fishery and Atlantic hake fishery both already suspected of taking significant number of harbour porpoises and common dolphins respectively. With no populations studies on this species in Europe the impacts of these fisheries and the recently implemented tuna drift net fishery, remain speculative. There are apparently significant catches of birds in the salmon driftnet fisheries in Ireland and Denmark and catches in coastal and lagoon fisheries in Portugal and Italy. It has been estimated that breeding populations of guillemots at two sites in northern Norway have declined by 95 percent from the early 1960's to 1989 and that this decline could be explained entirely by gill net mortalities based on observed catch rates. Impacts on non-target fish poorly documented, but where examined a wide variety of species recorded. Probably most acutely seen in the swordfish driftnet fishery. May be an impact on benthic communities because of cumulative effect of exposure to netting (including lost netting) on certain seaweeds, seagrass or pedunculate invertebrate communities may be important but little investigated.
Ref Number 61 Ref: Harrison, N. & Robins, M., 1992. The threat from nets to seabirds. *RSPB Conservation Review,* 6, 51-56. Reviewed by: Gubbay & Knapman, 1999,	Description: Review paper. Coastal net fisheries have been implicated in declines of numerous seabird populations but there are substantial difficulties in establishing cause of a population decline. Synthetic nets have been implicated as a major contributor to the decline of several auk populations. Community effects: Diving seabirds more vulnerable to entanglement in set nets. Number of birds killed depends on their abundance, diving habits and distribution within the fishery area. Incidental catch of seabirds can be very high around colony sites. Large numbers of shearwaters have been caught in nets. Species of particular importance in European terms known to be caught in nets include: red-throated divers, Leach's petrel, gannet, shag, Brunnich's guillemot and razorbill. In Britain Great northern diver, Slavonian grebe, scaup, common scoter, long-tailed duck and guillemot can be added to the list. Threat to wildlife depends on netting effort and wildlife concentrations. There is temporal and spatial variation in these threats which may be reduced by manipulating where and when fishing takes place.
Ref Number 62 Ref: Dayton, P.K., Thrust, D.F., Agardi, M.T. & Hofman, R.J., 1995. Environmental effects of marine fishing. *Aquatic conservation: marine and freshwater ecosystems,* 5, 205-232. Reviewed by: Gubbay & Knapman, 1999,	Description: Review paper covering many fishing techniques. Habitat effects: Subtidal rocky habitats characterised by encrusting communities that are resilient to predation and invasion are extremely vulnerable to mussel dredging as these organisms often have poor dispersal mechanisms and slow growth rates. Desertification of such habitats recorded in Italy following intensive and destructive mussel dredging. Reefs extremely vulnerable to fishing as they often represent islands in seas of soft sediments making recolonisation from surrounding areas unlikely. Intertidal and subtidal soft sediment communities are vulnerable to fishing and as they are often close to areas of population density, heavily fished. Bottom fisheries have resulted in the destruction of *Zostera* beds and saltmarsh vegetation. Calcareous algal bed of maerl destroyed by 8 passes of a dredge in Scotland. Reef building polychaetes *Sabellaria spinulosa*, seagrass *Zostera marina* and oyster beds *Ostrea edulis* destroyed by trawling. Hydroid and brozoan habitats lost in English Channel.

	Zostera marina indirectly impacted by increased turbidity, replaced by deposit feeding polychaetes, community composition shifts such as these may resist the recovery of suspension feeding species. Epifauna often play key roles in influencing the structure and stability of benthic communities, modifying benthic boundary flow which further influences sediment characteristics and so the settlement of larvae. Epifauna may also provide a refuge for juvenile species from predators. Organisms which stabilise the seabed can also mitigate the effects of natural disturbances such as storms. Modification of microbial activity induced by bottom fishing, resuspension of pollutants, increased benthic/pelagic nutrient flux. With repeated trawling the intense disturbance may select for species with the appropriate facultative responses, communities will become dominated by juvenile stages, mobile species and rapid colonists. Large amounts of discards falling to the seabed cause anoxia in bottom sediments the discards decay using up oxygen, kills scavenging organism attracted by the discards. Decaying discards may also harbour disease and have caused the elimination of a scallop fishery in Australia. Community effects: Diving seabirds more vulnerable to entanglement in set nets. Number of birds killed depends on their abundance, diving habits and distribution within the fishery area. Incidental catch of seabirds can be very high around colony sites. Large numbers of shearwaters have been caught in nets. Species of particular importance in European terms known to be caught in nets include: red-throated divers, Leach's petrel, gannet, shag, Brunnich's guillemot and razorbill. In Britain great northern diver, Slavonian grebe, scaup, common scoter, long-tailed duck and guillemot can be added to the list. Threat to wildlife depends on netting effort and wildlife concentrations. There is temporal and spatial variation in these threats which may be reduced by manipulating where and when fishing takes place. Longline: Swordfish fishery North Western Atlantic took several times more shark than swordfish resulting in grey seal population rising from 3000 to 45000. Grey seals *Halichoerus grupus* acted as a primary host for parasites which then infected cod. Population density may have increased stress in seals causing a population decline. Gill nets implicated in the extinction of several species. Adult survivorship is extremely important for marine mammals and birds as they have slow reproductive capacity and low fecundity therefore they are high vulnerable to even moderately increased mortality. Incidental bycatch of highly mobile predatory marine mammals likely to be higher than less mobile species as they are efficient foragers and are likely to be attracted to nets laden with fish. Approximately 500-1000 harbour porpoise caught annually in Danish waters. Catch rate of harbour porpoise approximately 0.1 individuals/km of net/day probably an underestimate. Porpoise populations substantially reduced by the Pacific tuna purse seine fishery. Ghost fishing by discarded and lost netting may be significant and persistent, impacting not only on non-target species such as birds and marine mammals but also on fisheries themselves. Complete loss of sessile fauna on rocks and cobbles caused by the action of fishing gear on the seabed. Hydraulic dredging causes complete loss of sessile benthic fauna which are killed by the heat. Otter trawling causes massive amount of bycatch including crab, scallops, starfish. Mortality for some species can range from 10 percent in starfish to 90 percent in *Arctica islandica* after a single trawl this may increase drastically with increased trawling intensity. Further notes: Fishing types: Longline, Gill nets, Scallop dredging, Mussel dredging, Purse seine, Hydraulic dredging, Otter trawling

Ref Number 63 Ref: Bourne, W.R.P., 1989. New evidence for bird losses in fishing nets. *Marine Pollution Bulletin,* 10, 482. Location: Cruden Bay, NE Scotland Reviewed by: Gubbay & Knapman, 1999,	Description: Investigations by the author into numbers of dead seabirds on the shore in early 1970s at Cruden Bay in NE Scotland in mid summer. Community effects: Study led to conclusion that seabirds must have been killed in some of the numerous local fixed salmon nets which were often seen holding dead birds. Most were auks which are known to be killed in fixed salmon nets on a considerable scale around the seabirds colonies on St. Abbs Head and Troup Head in the Moray Firth. Some shags also reported killed in nets set near a roost on the Summer Islands. Off the Scottish Wildlife Trust reserves at Longhaven and on the Dunbuy Rock to the south up to 17 bodies per net were recorded on the 12 or so occasions they were examined during the breeding season over the previous four years.
Ref Number 64 Ref: Thomas, D., 1993. *Marine wildlife and net fisheries in Cardigan Bay.* 55pp. Location: Cardigan Bay Reviewed by: Gubbay & Knapman, 1999,	Description: Notes on recorded entanglement casualties in Cardigan Bay. Community effects: Potential threat to red-throated divers from gill and tangle nets high. May have knock on effects at the birds breeding grounds. During 14 inspections of beach set nets between September 1991 and December 1992 no seabird bycatch was noted despite red-throated divers observed diving within 20m of nets. Ten harbour porpoises *Phoecoena phocoena* reported as casualties of gill nets in 1991. Author considers that Harbour porpoise is the only cetacean under severe threat of extinction from static fishing gear in Cardigan Bay. 24 percent of UK deaths of harbour porpoises caused by entanglement in fishing gear. One Grey Seal *Halichoerus grupus*found stranded in 1991 with injuries consummate with gill net entanglement. Net inspected in September 1992 no bycatch recorded despite close proximity of grey seal. Young seals more likely to suffer from entanglement. Juvenile dolphin recorded tangled in net. Author concludes no major entanglement problem in Cardigan Bay. Further notes: other species: Red throated diver
Ref Number 65 Dunn, E. & Steel, C., 2001. *The impact of longline fishing on seabirds in the north-east Atlantic: recommendations for reducing mortality*. RSPB, NOF, JNCC, BirdLife International. Reviewed by: Sewell *et al.,* 2007	Report describes an on-board observer study of the seabird bycatch taken by Norwegian offshore longline fishing vessels in the Norwegian Sea in 1997 and 1998. Report details the significant level of seabird by-catch in the industry and mitigation methods are suggested.

Ref Number 66 Ref: Løkkeborg, S., 2003. Review and evaluation measures of three mitigation measures: bird-scaring line, underwater setting and line shooter, to reduce seabird bycatch in the north Atlantic longline fishery. *Fisheries Research,* 60, 11-16. Study date: 1992-1999 Location: Off the coast of Norway Reviewed by: Sewell *et al.,* 2007	Description: Four experiments were carried out in the north Atlantic to assess the effectiveness of three mitigation measures during longline setting in a commercial longlining fishery. The measures assessed in reducing seabird bycatch were: bird-scaring line, underwater setting and a shooter. During each haul the number of marketable species and seabirds taken by each fleet were counted. Community effects: Bycatch of seabirds was reduced by all three methods, although the difference for the line shooter was not significantly different. The clearest difference was using the bird-scaring line. During the course of the experiments 185,000 hooks were set using the bird-scaring line and only 2 birds were caught, whereas when the control line were set with a similar number of hooks 205 birds were caught. The bird-scaring line was also the most effective a reducing bait loss when the lines were set when compared with both the control and other two methods. Catch rates of the target species was also higher when using one of the mitigation measures than using no measures.
Ref Number 67 Ref: Melvin, E.F., Parrish, J,K. & Conquest, L.L., 1999. Novel Tools to Reduce Seabird Bycatch in Coastal Gillnet Fisheries. *Conservation Biology,* 13, 1386-1397. Study date: 28th July to 29th August 1996. Location: Puget Sound, Washington, USA. Reviewed by: Sewell *et al.,* 2007	Description: Several strategies to reduce the bycatch of seabirds in a salmon drift gillnet fishery in Puget Sound were examined, with the aim of reducing bycatch without causing a decline in fishing efficiency or causing an increase in bycatch of other species. Eight fishing vessels were contacted and divided into two groups; four experimental net types (i. traditional monofilament net, ii. visual alerts, 20 mesh, iii. Visual alert, 50 mesh, and iv. Acoustic alerts, pingers) were rotated around the four vessels each week. Each team completed 17 trips (in total 642 sets) during the experimental fishing. For seabird observations experienced observers on board the vessels recorded marine mammal and seabird abundance and entanglement per set as well as a range of physical variables (i.e. time, tide, visibility etc.) Community effects: During the experimental fishing the target species sockeye was caught in 71% of the sets and seabirds in 25%. The capture of both sockeye and the entanglement of seabirds varied significantly with the gear type used, but were greatest in the monofilament nets. The 50 mesh nets caught the lowest numbers of sockeye and also entangled the lowest number of auklets when compared to the other methods. For the common murres all modified nets entangled a significantly lower number than the monofilament nets. The effect on marine mammals was also considered; pinger nets attracted a significantly greater number of seals than any of the other three methods. The affect of this modified gear had no effect on the incidental catch of other species in the fishery (e.g. dogfish). When compared with the monofilament nets the 50 mesh reduced common murre bycatch by 40% and the 20 mesh by 45%. For the auklet bycatch was only reduced by the 50 mesh (42%). As a result of this study three complementary tools to enable seabird bycatch to be reduced in the Puget Sound were identified: gear modification, abundance-based fishery openings and time-of-day restrictions. Further notes: Time-of-day restrictions, 60% of auklet and 30% of murre entanglement could be reduced by not fishing at sunrise, this only result in an overall loss of 5% in fishing efficiency.
Ref Number 68 Dugan, P.J., Evans, P.R., Goodyear, L.R. & Davidson, N.C., 1981. Winter fat reserves in shorebirds: disturbance of regulated levels by severe weather conditions. *Ibis*, 123, 359-363.	Paper examining the loss of winter fat reserves amongst over-wintering waders. Observations on weight changes in Grey Plover *Pluvialis squatarola* wintering on the Tees estuary over a severe winter.

Reviewed by: Sewell *et al.,* 2007	
Ref Number 69 Ref: Davidson, N.C. & Evans, P.R., 1982. Mortality of Redshanks and Oystercatchers from starvation during severe weather. *Bird Study,* 29, 183-188. Study date: January/February 1979 and January 1982 Location: Ythan Estuary (Grampia) and Montrose Basin (Tayside) Reviewed by: Sewell *et al.,* 2007	Description: The paper examines the mortality of both Redshanks and Oystercatchers that were found dead after a severe winter (for Redshanks the data could be compared to that of normal samples taken in October and November 1978). The collected carcasses were weighed and measured and then deep frozen till analysis. In order to measure the fat and protein reserves the carcasses were dried in a vacuum oven and the fat was extracted using petroleum ether in a Soxhlet apparatus. Fat was expressed as a lipid index and protein reserves were measured as indices of pectoral muscle size. Community effects: The results indicated that level of fat and muscle in the Redshanks found dead both in 1979 and 1982 showed extensive use when compared with those in a normal condition, indicating that the birds died in severe whether after using almost all of their fat and protein stores. The small amount that was left is likely to be structural and not available as a reserve. The results from the Oystercatchers founds dead indicated the same situation as they had very small fat and muscle reserves (were able to compared with one bird found in a normal condition). Samples from the Ythan estuary (windy and moderately cold weather, Jan/Feb 1979) were compared with samples from the Montorse Basin (prolonged cold, but calm weather, Jan 1982) to determine if the mortality of Redshanks and Oystercatchers was caused by an inability to mobilize reserves as opposed to resulting from the exhaustion of body reserves. The results indicated that the fat reserves could be mobilized fast enough, however once the fat reserves had been exhausted then the energy requirements had to be supplied by the breakdown of proteins. The cause of death in 1982 was likely to be due to an inability to breakdown the proteins fast enough to balance the rate of heat loss, rather than the exhaustion of protein followed by starvation.
Ref Number 70 Ref: Campredon,P., 1979. Data on the wintering of waders in the Arcachon basin (Gironde). *Oiseau Rev. Fr. Ornithol.,* 49, 113-131. Study date: 1974 to 1977 Location: Bay of Arcachon (southwest France) Reviewed by: Sewell *et al.,* 2007	Description: Preliminary observations of wintering waders, following the creation of the Banc d'Arguin (Arguin Shoal) Reserve, a sandy oceanic islet. Community effects: wader population increased from 20,000 to 220,000 individuals, approximately 200,000 of these being dunlin. Dunlin, grey plover and oystercatcher adopt a tidal activity cycle, feeding at low tide and resting at high tide. Curlew, bar-tailed godwit and snipe adopt a nycthemeral activity cycle, feeding preferably at night. It appears that the possibility of recuperating and resting on a site emerged at high tide (preferably an islet) which has absolute tranquility is a primordial necessity for a durable stationing for waders. The role of the Reserve is important due to disturbance caused in the Bay of Arcachon by oyster-culture, hunting, etc.
Ref Number 71 Ref: West, A.D., Goss-Custard, J.D., McGrorty, S., Stillman, R.A., Le V. dit Durell, S.E.A, Stewart, B., Walker, P., Palmer, D.W. & Coates, P.J., 2003. The Burry Inlet shellfishery and oystercatchers: using a behaviour-based model	Description: In recent years mussels have begun to settle over the cockle beds causing problems for the cockle fishery, resulting in a request for the mussels to be removed. As a result conservation managers are concerned that the mussels may be providing a high-quality food source for oystercatchers and the removal of these beds could cause problems. Behaviour-based model was used to assess oystercatcher feeding on cockles and mussels in Burry Inlet and its predictions tested against their distribution across the beds and the amount of time spent feeding. The possible effect caused by mussel removal in terms of mortality rate and body condition was also explored. Community effects: Observations indicated that 75% of the birds fed on cockles, 18.75% fed on mussels and 6.25% fed on crumble, the model predicted

to advise on shellfishery management policy. *Marine Ecology Progress Series,* 248, 279-292. Location: Burry Inlet Reviewed by: Sewell *et al.,* 2007	values within a 95% confidence interval of these observed values. The model also predicted the amount of time spent feeding on cockles and mussels with similar precision, when compared to the observed times (model over predicted by 40 minutes across 4 comparisons). At current bird population sizes it was predicted that the shellfish stock would have to be reduced by 50% (from 2000/01 levels) to cause noticeable mortality or emigration. It was also shown that at current stock levels the removal of mussel crumble would have little to no effect on mortality (increase by less then 0.5%). However, if cockle and mussel stocks were to be reduced (by 25%) the reduction in crumble would be more important, between 5 & 7% of oystercatcher populations were predicted to die. Further notes: Models predictions matched the observed behaviour well, particularly for the proportion of the population feeding on cockle as opposed to mussel stocks.
Ref Number 72 Ref: Camhuysen, C.J., Berrevoets, C.M., Cremers, H.J.W.M., Dekinga, A., Dekker, R., Ens, B.J., van der Have, T.M., Kats, R.K.H., Kuiken, T., Leopold, M.F., van der Meer, J. & Piersema, T., 2002. Mass mortality of common eiders (*Somateria mollissima*) in the Dutch Wadden Sea, winter 1999/2000: starvation in a commercially expoited wetland of international importance. *Biological Conservation,* 106, 303-317. Location: Dutch Wadden Sea Reviewed by: Sewell & Hiscock, 2005	Description: The study was carried out following unusually high mortality of common eiders in 1999/2000 (approximately 21, 000 birds died). The area surveyed was home to an intense cockle fishery and mussel culture, both reducing the principal food source for the common eider. Dissected eiders showed signs of starvation. Community effects: Cockle biomass was extremely low during the winter of 1999/2000 , however fishing continued. The remaining cockles were low quality. Stocks of *Spisula* clams in the North Sea (a secondary food source for the common eider) were heavily fished during the end of the summer of 1999 resulting in a loss of 85 percent of stock in some areas. The authors conclude that the likely cause of death of the eiders was starvation, resulting in a lack of food caused by overfishing of the eider's principal and secondary food sources.

Ref Number 73 Ref: Beukema, J.J. & Dekker, R., 2006. Annual cockle *Cerastoderma edule* production in the Wadden Sea usually fails to sustain both wintering birds and a commercially fishery. *Marine Ecology Progress Series,* 309, 189-204. Study date: 1973-2003 (longterm data) Location: Dutch Wadden Sea Reviewed by: Sewell *et al.,* 2007	Description: The study aimed to assess the variability of cockle production and the extend to which contributing factors affect the annual and local production values. Finally, annual estimates of cockle production and biomass were considered against the food requirements of the oystercatcher to determine whether or not a sustainable fishery is possible on the tidal flats of the Dutch Wadden Sea. Community effects: The production of cockles on the tidal flat has been variable during the period of observation. The variability of recruitment seems to be governed by factors relating to the character of the foregoing winter, in particular the presence of epibentic predators (shrimps) on the tidal flat during the early benthic stages of cockles. Future prospects for high cockle production and biomass in the Wadden Sea appear to be poor. This will have consequences for wintering birds in the Wadden Sea that have a specialized diet dominated by large bivalves like cockles and mussels. Due to the low levels of cockle recruitment success during the last 15 years and the poor prospect for the development of future strong cohorts any cockle fishery in the Wadden Sea may be considered harmful to wintering birds. Further notes: In nearly all of the last 15 years, cockles in the western Wadden Sea have been too scarce to sustain both a commercial fishery and populations of wintering birds.
Ref Number 74 Ref: Hall, S.J. & Harding, M.J.C., 1997. Physical disturbance and marine benthic communities: the effects of mechanical harvesting of cockles on non-target benthic infauna. *Journal of Applied Ecology,* 34, 497-517. Location: Auchencairn Bay, Solway Firth Reviewed by: Gubbay & Knapman, 1999,	Description: Three year study into impact and recovery of habitat and marine benthic communities from suction and tractor dredging to harvest cockles. Community effects: Suction dredging had a statistically significant effect on infauna leading to up to a 30 percent reduction in number of species and 50 percent reduction in number of individuals. These effects were not seen with tractor dredging Further notes: Authors suggest difference between methods may be due to experimental design and different times of year in which the experiments were done. By day 56 much of the difference between area where suction dredging was used compared to control site was lost but some effects remained.

Ref Number 75 Ref: Ferns, P.N., 1995. The effects of mechanised cockle harvesting on bird feeding in the Burry Inlet. *Burry Inlet & Loughor Estuary Symposium, March 1995. Part 1.* Nov-18. Location: Burry Inlet Reviewed by: Gubbay & Knapman, 1999,	Description: Experimental dredging using tractor towed cockle harvester at Burry Inlet (east of Whiteford Point and northern edge of Llanrhidian Marsh). Habitat effects: Vehicle tracks and dredging furrows created. Community effects: Dredging attracted black-headed and common gulls which fed on very small prey items lying on the surface of harvested furrows including *Crangon*, *Corophium*, broken cockles, intact small cockles which pass through the drum, and polychaetes. The number of birds attracted and the places they fed depended on the abundance of prey items revealed by harvesting and presence of people. Peak count at Llanrhidian was 200 black-headed gulls and 55 common gulls, mostly adults which fed preferentially in the most recently harvested furrows. Other species present were curlew, dunlin and oyster catchers. The increased feeding activity of birds was short lived, 14 days for oystercatchers and 7 days for gulls and small waders. Significant reduction in bird feeding activity apparent thereafter and still detectable after four months. Oystercatchers responded more quickly to changes suggesting harvesting may have been less disruptive or recovery quicker. Overall the short term increase in the number of gulls and waders in the harvesting area was followed by a long term significant reduction in feeding opportunities for bird species. Birds may then leave to find food elsewhere, leading to the considerable alteration in normal seasonal distribution pattern of shorebird populations. Average density of birds were reduced in this trial by between 15 and 75 percent in harvested area.
Ref Number 76 Ref: Rees, E.I.S., 1996. Environmental effects of mechanised cockle fisheries: a review of research data. 42pp. Location: Various UK sites Reviewed by: Gubbay & Knapman, 1999,	Description: Review. Environmental effects fall into several broad categories the most obvious being (a) direct impacts, mainly on the benthic biotopes and on the discarded undersize bycatch (b) indirect interactions with predators and scavengers, including shorebirds, (c) ancillary disturbance from the vessels and vehicles, including effects at the shore access points. Habitat effects: Hydraulic dredge tracks can be seen at low tide days or weeks later, persistence depending on the stability of the sediment surface and the prevailing tide or wave conditions. On areas of cohesive sediment the tracks appeared to act as lines from which erosion of the surface layer spread out therefore appearing to accelerate the erosion phase of a natural cycle of cohesion of the surface sediment by worm tube mats. Where dredging has been carried out in a sheltered area with eel grass (Auchencairn Bay) breaking the sward allowed erosion that produced clearly visible grooves down the shore. Long-term effects on benthic diatoms on and in the surface of intertidal flats were considered unlikely. Community effects: Shell breakage occurs with overall damage rates to cockles and *Macoma baltica* in screen rejects from hydraulic dredgers 12.6 percent and 5.3 percent respectively. In experimental plots where damage rates from tractor dredging were determined these were 9.3 percent in an area of muddy sand and 8.2 percent in a sandy area but only impinged directly on about 80-85 percent of the area of the plots. Dredged areas often had a lot more dead shell scattered on the surface, an effect which can persist for several months whereas in undisturbed beds most dead shell is normally under the surface which can create a shell layer limiting the depth to which small drainage channels can normally erode into a cockle flat. Observation on other species include the tendency for some motile species, like the amphipod *Bathyporeia sarsi* to temporarily leave disturbed areas, lugworms producing normal casts in dredge tracks as soon as the tide falls, tubes of the sand mason worm *L. conchilega* still standing, apparently to nearly their full extent in the hydraulic dredge tracks. Results from a study of tractor dredging in the Burry Inlet recorded declines in other invertebrates (particularly *H. ulvae*, *P. elegans* and *N. hombergii*), the greatest fall being 14 days after dredging for the less mobile species in the muddy areas, and increases in some species *Urotho*e sp., *M. balthica*, *A. tenuis*. Localised additional bird activity has also been reported in some areas following dredging. In a study on the Solway Firth it was concluded that because natural changes are very large the fishery may not have a significant effect on bird numbers unless a high proportion of the cockles are harvested. On sandy areas the effect on most invertebrate populations was considered to be causing some thinning of stocks rather than persistent patchy defaunation. In muddier, more cohesive sediments tracts may persist for months. Persistent hydraulic

	dredging has in some cases been reported to have changed the sediment structure which may have medium term consequences for deposit feeding benthic species. The most undesirable effects are where the surface is bound by swards of eel-grasses.
Ref Number 77 Ref: Stillman, R.A., Goss-Custard, J.D., McGrorty, S., West, A.D., Durell, S.E.A., le V. dit, Clarke, R.T., Caldow, R.W.G., Norris, K.J., Johnstone, I.G., Ens, B.J., Bunskoeke, E.J., v.d Merwe, A., van der Meer, J., Triplet, P., Odoni, N., Swinfen, R. & Cayfor., 1996. Models of Shellfish Populations and Shorebirds: Final Report. Location: Model tested on Exe estuary Reviewed by: Gubbay & Knapman, 1999,	Description: Report develops a predictive model to explore the effect of different shellfishery management options on the mortality rates of the migratory shorebirds that feed on shellfish on intertidal wintering grounds in Europe. Effects incorporated include disturbance and reduction of abundance of the shellfish stocks. Application to the Exe estuary was successful in predicting levels of oystercatcher winter mortality in previous years Community effects: Main conclusions were: Given a number of conditions it is possible to exploit shellfish stocks without increasing the winter mortality of shorebirds. Effects of a given intensity of shellfishing depends crucially on local conditions of the climate and the general abundance of food. Methods of shellfishing which disturb birds can be significantly more damaging to the bird's chances of survival. Numbers of birds using alternative food sources is an early warning that a change in shellfishery practice is beginning to have an effect on the birds. Key factor in determining the impact is the proportion of the shellfish stock that is affected. Cumulative effects of small increases in shorebird morality in winter can over a period of years greatly affect stable population size. As fishing effort increases, shorebird mortality may be hardly affected initially but then may suddenly increase dramatically once a threshold level of fishing effort has been reached. Further notes: Study into the management of intertidal shellfisheries
Ref Number 78 Ref: Bell, C.M. & Walker, P., 2005. Desk study to assess the impact of cockle suction dredging on The Wash and North Norfolk Coast European Marine Sites. *English Nature Research Reports,* No 670. Location: The Wash (SPA and SAC) Reviewed by: Sewell *et al.,* 2007	Description: Review of evidence of the impacts of cockle dredging on the target species, their environment and non-target species. Including possible mitigation methods that can reduce the impact of suction dredging and the identification of gaps in current knowledge requiring future research. Habitat effects: As a result of cockle suction dredging various studies have indicated that the sediment has become unstable due to a loss of fine sediment and an increase in medium grain size. The direct removal of cockles and other bivalves has also led to sediment becoming unstable, since bivalve pseudofaeces play an important role in the binding of sediment. Community effects: Suction dredging for cockles in the Wash is unlikely to impact on populations of knot, however may contribute to effects on oystercatcher populations, due to a link between oystercatcher mortality and the supply of cockles and mussels. A number of non-target species share the same community as cockles and are therefore likely to be affected by suction dredging, these include: polychaetes, the amphipod *Bathyporeia sarsi*, the snail *Hydrobia ulvae* and the bivalve *Macoma balthica*. Further notes: Recovery times – Evidence from one study (Piersma *et al* 2001) in an area the Wadden Sea indicating in took 8 years for the sediment to return to its pre-dredged state. However, in parts of Traeth Lafan sediment return to normal within 4 months (Cook 1991). A lack of evidence for sediment change suggests that recovery time for the Wash is more likely to be on a shorter time scale. However, this suggest be tested in an experimental context.

Ref Number 79 Ref: Piersma, T., Koolhaas, A., Dekinga, A., Beukema, J.J., Dekker, R. & Essink, K., 2001. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. *Journal of Applied Ecology,* 38, 976-990. Study date: 1988-1998 Location: Wadden Sea Reviewed by: Sewell *et al.,* 2007	Description: Study compared the changes in sediment characteristics and the abundance of three bivalve species in the Dutch Wadden Sea as a result of mechanical cockle dredging. Sediment samples were taken before the cockle fishery took place (Sept. 1988) and again in 1992, core samples for benthos and sediment were taken at 500m intervals along transects around Griend. The activities of the fishing vessels during the study period were recorded along with stock size and settlement densities. Habitat effects: From 1988 to 1994 silt was lost from the sediments near the Griend that were dredged for cockles and the median sediment grain size increased. By 1996 the initial characteristics of the sediment were re-attained. Community effects: The abundance of *Macoma balthica* declined for 8yrs after the removal of all *Mytilus edulis* and most of the *Cerastoderma edule*. From 1989 to 1998 the stock levels of *Macoma balthica*, *Mya arenaria* and *Cerastoderma edule* declined and did not recover to the levels in 1988. The declines were not helped by the fact that there were low rates of settlement until 1996 in the fished areas. A comparison of settlement both in the short and medium term in several areas that had be dredged for cockles and areas that hadn't been dredged showed that dredging had a significant negative effect on subsequent settlement of *Cerastoderma edule*, (*Macoma balthica* declined but not significantly). The loss of both *Cerastoderma edule* and *Macoma balthica* was the most evident in areas that were dredged for cockles. The study concluded that suction dredging for *Cerastoderma edule* had long-lasting negative effects on the recruitment of bivalves, especially the target species. Further notes: Site was assessed before suction dredging autumn (August – September) 1988 and after suction dredging autumn (August – September) 1989 – 1998. The three bivalve species assessed were: Baltic tellin *Macoma balthica*, soft-shelled clam *Mya arenaria* and edible cockle *Cerastoderma edule*.
Ref Number 80 Ref: van Gils, J.A., Piersma, T., Dekinga, A., Spaans, B. & Kraan, C., 2006. Shellfish dredging pushes a flexible avian top predator out of a marine protected area. *PLoS Biology,* 4, 2399-2404. Study date: 1998-2002 Location: Dutch Wadden Sea Reviewed by: Sewell *et al.,* 2007	Description: Study looks at the changes that mechanical cockle dredging has on the quality and quantity of food for the red knots and how these changes effect the survival of these birds. The prey available was sampled from late July to early September each year (1998-2002). At each station (in total 2,846 stations of which 75% were sampled every year) a core sample was taken and the contents sieved over a 1mm mesh, all potential prey items were frozen and taken to the laboratory for identification. Dredging took place from September to December and the effects on cockles that were actually available to the knots were analysed. The diets of the red knots were assessed through fecal analysis. Community effects: Effects on target species: Within the dredged areas the density of small cockles remained stable however in the undredged sites the density of small cockles increased by 2.6%. There were also differences in the quality of the cockles between dredged and undredged sites. In the undredged areas the quality of the cockles remained stable, but in the dredged areas the quality declined by 11.3%. Effects on non-target species: As a result of decreases in the quality of the cockle stocks the red knots were shown to increase their gizzard mass to compensate for this decline. However, this was not sufficient and resulted in a decrease in local survival rates, indicating the effect that fishing can have on bird populations.

Ref Number 82 Ref: Atkinson, P.W., Clark, N.A., Dodd, S.G. & Moss, D., 2005. Changes in fisheries practices and oysterculture survival, recruitment and body mass in a marginal Cockle fishery. *Adrea*, 93, 199-212. Study date: 1980/1981 and 2002/2003 Location: Traeth Lafan, north Wales Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at changes in oystercatcher numbers, survival, recruitment of juveniles to the winter population and body condition. Oystercatchers were caught using cannon nets between 1980 and 2003, where they were ringed, aged (divided into two age classes' juveniles < 1 yr, adults > 1 yr), measured, weighed and released. The study period was divided into periods of high and low mussel stock; this was because cockle stock were unknown for most of the years due to the changing mussel stocks. Community effects: The number of oystercatchers has fluctuated over the years, with declines in 1983/84 to a low in 1990/91, since than a recovery has been seen reaching a peak in 2001/02 after which there is no data available. This lowest count coincided with two consecutive years of suction dredging for cockles (1989 & 1990) and low mussel stocks. It seems that shellfishing and food supply does have an impact on birds, as a result of overfishing in the 1980s and 1990s the cockle and mussel stocks collapsed. During this period oystercatcher populations fell from 40,000 to 11,000 birds, as food supplies became low instead of moving elsewhere large numbers of birds died in three winters.
Ref Number 83 Ref: Norris, K., Bannister, R.C.A. & Walker, P., 1998. Seasonal changes in the number of oystercatchers *Haematopus ostralgus* wintering on the Burry Inlet in relation to the biomass of cockles *Cerastoderma edule* and its commercial exploitation. *Journal of Applied Ecology,* 35, 75-85. Study date: 1982/83 - 1992/93 Location: Burry Inlet, South Wales Reviewed by: Sewell & Hiscock, 2005	Description: Study examining the relationship between biomass of cockles taken by a small scale, hand gathering fishery, cockle biomass and oyster catcher abundance. The study is based on data covering 11 winters. Community effects: Winter oystercatcher numbers were not correlated with cockle biomass nor biomass taken by the fishery but with the total number of overwintering oystercatchers in the UK overall. Spring oystercatcher numbers were however positively correlated with cockle biomass and negatively correlated with cockle biomass extracted by the fishery. The authors believe that the reason for this is that oystercatchers leave the area earlier in spring when biomass at the start of the winter is small and/or the biomass extracted by the fishery is large. Further notes: The authors note that the current scale of the cockle fishery is very small, extracting less than 25 percent of available stock, using traditional methods such as hand gathering. Even at this level, oystercatcher numbers in spring time were reduced. If more efficient methods of cockle harvesting are employed in the future, resulting in higher catch rates, effects may be even more severe.

Ref Number 84 Ref: Andrews, J., 2003. Sands of change. Portrait of the cockle fishery in Morecombe Bay: November 2002 - October 2003. *Shellfish News,* **16**, 21-24. Location: Morecombe Bay, northwest England. Reviewed by: Sewell & Hiscock, 2005	Description: Description of cockle fishing practices in Morecombe Bay. The author describes his observations of changes to the cockle industry, also management response and social issues related to the changing cockle fishery. The report describes how the cockle fishing industry changed from a relatively small scale fishery prior to 2002 to a large scale fishery with over 400 hand gatherers working beds at the peak of activity. Large vessels, usually used for suction dredging were dried out on cockle beds and used to collect and transport large tonne bags of cockles gathered by large numbers of people from the shore. At times, up to four vessels were operating at a time. Community effects: Although no environmental effects are described in this article, the author notes that the area is designated as an SPA for its important bird life and an SAC for other wildlife and effects that the fishing activity has on these features have implications for fisheries management.
Ref Number 85 Ref: Black, K.D. 1996. Aquaculture and sea lochs Location: Principally Scottish sea lochs Reviewed by: Gubbay & Knapman, 1999,	Description: Symposium report with papers dealing with the physical environment, input of nutrients and chemicals, benthic enrichment, interactions between sea trout and other fish species, seabirds and mammals and aquaculture, the use of wrasse, the consequences of nitrogen enrichment and the possible effects of escapees on wild fish.
Ref Number 86 Ref: Atkinson, P.W., Clark, N.A., Bell, M.C., Dare, P.J., Clark, J.A. & Ireland, P.L., 2003. Changes in commercially fished shellfish stocks and shorebird populations in the Wash, England. *Biological Conservation,* **114**, 127-141. Study date: 1970 to 1988 Location: The Wash, eastern England.	Description: Looking at the changes in population numbers of oystercatchers and knots in the Wash and if these changes were linked to changes in shellfish stocks and winter weather. Bird counts have been carried out monthly since 1970; indices of population size were calculated using the Underhill method for December to February counts. Estimates of cockle and mussel stock and spat abundances were obtained from CEFAS and ESFJC (quantitative estimates available for mussels stocks from 1982 onwards and cockles from 1990 onwards). Community effects: Oystercatcher – Population numbers increased rapidly in the 1980s reaching a peak of 40,000 in 1988/89, before crashing by 1998/99 the population of wintering birds was 25% of its population 10 years earlier. Knot – Population numbers declined between 1970/71 dropping from 70,000 to 20,000, before recovering in the mid-1980s to 80,000. Numbers remained steady reaching a peak between 1990/1992 of 110,000 before dropping to 40,000 by 1998/99. Cockle spat levels have shown declines since 1987, stock levels despite showing no trend since 1970 have shown declines in recent years. Spat indices

Reviewed by: Sewell *et al.,* 2007	showed poor recruitment for mussel larvae since 1987 and a rapid decline in stock abundances in 1982 (20,000t to 2,000-4,000t). Results indicated that cockle or mussel spat abundance or winter weather had no effect on the survival rate of the knot. However, in poor cockle years and with declines in mussel stocks as a result of overfishing the vulnerability of oystercatchers to mass mortality was increased. Therefore to prevent further declines in the oystercatcher populations it is important that mussels are available in years when the cockle stocks are poor. The introduction of mussel cultivation is beneficial and an important tool for maintaining bird populations. Further notes: Population counts for birds carried out from Gibraltar Point (53º05' N, 0º20' E) to Holme (52º51' N, 0º34' E) in an unbroken line. N.B During the summer of 1997 1680t of mussels were re-laid in the intertidal zone, meaning they would be come available to birds from this time.
Ref Number 87 Ref: Fahy, E., Carroll, J. & Murran, S., 2005. The Dundalk Cockle *Cerastoderma edule* fishery in 2003-2004. *Irish Fisheries Investigations,* 14. Study date: 2003-2004 Location: Dundalk Reviewed by: Sewell *et al.,* 2007	Description: The study was undertaken to assess the cockle resource in Dundalk Bay as the area is both an SPA for overwintering birds and a cSAC (candidate Special Area of Conservation). 14 samples were collected between October 2003 and October 2004 using a continuous delivery dredge. A survey of cockle densities were also collected on the North Bull (March 25th to April 2nd 2004) and South Bull (April 29th to June 10th 2004) by raking a 1m2 randomly-chosen quadrat over the extent of mud and sand. Habitat effects: Consequences of mechanical dredging other that the amount of damage caused to the target species were not investigated. Community effects: The cockle population in the Dundalk makes up 99% of the biomass of bivalves on the mud and sand flats. The population was shown to be short lived, with 7.42% of the discarded cockles showing signs of damage. Although the population density was shown to be lower than that of the Wash or Burry Inlet, the current fishery in Dundalk may be the largest in the area since 1970. The Dundalk was designated an EMS based on primarily the presence of oystercatchers, although population counts may vary it was calculated that oystercatchers in Dundalk might consume 1,400 tonnes of cockles between October and March, in spring 2004 the biomass in Dundalk Bay was estimated at 1,645 tonnes. Further notes: As the surveys were conducted in the spring after a seasons fishing and after the wintering birds had left, the report concluded that there would probably be a small surplus for harvest the following autumn once the requirements of the EMS had been met, therefore eliminating the possible problem of competition for resources.
Ref Number 88 Ref: Goss-Custard, J.D., Stillman, R.A., West, A.D., Caldow, R.W.G., Triplet, P., le V. dit Durell, S.E.A. & McGrorty, S., 2004. When enough is not enough: shorebirds and shellfishing. *Proceedings of the Royal Society of London B,* 271, 233-237. Study date: 1998-2004 Location: Exe estuary, Bangor flats, Burry Inlet, Wash, Baie de Somme. Reviewed by: Sewell *et al.,* 2007	Description: Simulations with behaviour-based model for oystercatchers in five areas to assess the amount of shellfish that must remain after harvesting for the oystercatcher populations to be maintained. The model incorporates aspects of shellfishing that effects oystercatchers. Community effects: Based on the five estuaries modeled so far for oystercatchers to survive from autumn through to spring between 2.5 & 7.7 times the shellfish biomass that will be consumed by oystercatchers must be available in the autumn.

Ref Number 90 Ref: Rimington, N, 2002. The relationship between mussel and oystercatcher populations in the Burry Inlet, Part 2. *CCW Contract Science* Report No 491 Location: Burry Inlet, Wales Reviewed by: Sewell & Hiscock, 2005	Description: Study using a modelling approach to identify how the removal of 'mussel crumble' from a cockle bed in the Burry Inlet would affect overwintering populations of the oystercatcher *Haematopus ostralegus*. The study aimed to identify whether birds in the inlet are food limited under current conditions and to predict any ornithological implications of changes in shellfishing activity. Community effects: The simulations indicated that removal of 'mussel crumble' and a change to a cockle fishing regime would be unlikely to effect oystercatcher numbers. It was also suggested that fishing practices that reduce shellfish numbers, but do not reduce the area covered by shellfish beds are less likely to have a negative effect on bird populations than fishing practices that reduce the area covered by shellfish. This is due to the increased bird density and interference competition that may occur as a result of reduced shellfish-bed area. Further notes: The study was undertaken in response to a request by the cockle fishing industry to remove 'mussel crumble' as it was likely to be reducing their fishing resource by smothering cockle beds.
Ref Number 91 Ref: Verhulst, S., Oosterbeek, K., Rutten, A.L. & Ens, B.J., 2004. Shellfish Fishery Severely Reduces Condition and Survival of Oystercatchers Despite Creation of Large Marine Protected Areas. *Ecology and Society,* 9. Study date: January and February 2001 (see further notes). Location: Dutch Wadden Sea. Reviewed by: Sewell *et al.,* 2007	Description: The effectiveness of MPAs for protecting oystercatcher populations was investigated in the Dutch Wadden Sea. 520 oystercatchers at 7 sites were captured with cannon nets or mist nets where biometric parameters were measured following standard techniques these included bill tip shape, sex, age as well as blood samples being taken. Community effects: There has been a decrease in the number of wintering oystercatchers in the Dutch Wadden Sea over recent years (250,000 to 150,000). It was thought that with the introduction of MPAs to protect the oystercatchers' food source this species would redistribute itself in relation to food supply. However, there has been no indication that this has occurred and oystercatchers have not increased in numbers within the MPA. There was no difference in the body size or age of oystercatchers between the protected and protected areas. The bill tip shape however did indicate differences; the number of oystercatchers inside the protected areas with a 'shellfish tip' was much higher when compared to the number outside the protected areas (40.3% $n = 4$ sites, vs. 24.5% $n = 3$; $p < 0.02$). These differences were similar between males and females; the number of oystercatchers eating shellfish was much higher in male populations. This indicates that male populations are more vulnerable than females to low shellfish stocks. Oystercatchers in the unprotected sites were found to have a much lower level of shellfish within their diets and the estimated mortality was 43% higher. For this reason it is therefore likely that shelfish fishing can explain or at least partly explain the 40% decline in oystercatcher numbers over recent years. Further notes: Bird counts have been conducted annually in the Dutch Wadden Sea since 1972, only counts conducted in January were included in the study.

Ref Number 92 Ref: Le V. dit Durell, S.E.A., Stillman, R.A., Triplet, P., Aulert, C., Ono dit Biot, D., Bouchet, A., Duhamel, S., Mayot, S. & Goss-Custard, J.D., 2005. Modelling the efficacy of proposed mitigation areas for shorebirds: a case sudy on the Seine estuary, France. *Biological Conservation,* 123, 67-77. Location: Seine estuary, France Reviewed by: Sewell *et al.,* 2007	Description: The study uses a behaviour based model to assess the body condition and mortality of three shorebirds, i) curlew *Numenius arquata*, ii) dunlin *Calidris alpina* and iii) oystercatcher *Haematopus ostralegus* which may result due to an extension of the port at Le Harve and the potential mitigation measures put in place. Habitat effects: With a 20% reduction in habitat the body condition and mortality of the curlew was unaffected, however there was significant decrease in the body condition and increase in mortality in both the oystercatcher and dunlin. Community effects: Two mitigation measures were assessed, i) the introduction of a buffer zone in order to reduce disturbance to feeding birds and ii) the introduction of a new mudflat in order reduce the effects of habitat loss. The introduction of a buffer zone restored both body condition and mortality to pre-disturbance levels across all three species of shorebird. Only the dunlin and oystercatcher were affected by a reduction in habitat loss. In order to restore body condition and mortality of the oystercatcher to baseline levels a 50 ha mitigation area of the same quality as the adjacent mudflat would be required. In order to restore body condition and mortality of the dunlin to baseline levels a 100 ha mitigation area of the same quality as the adjacent mudflat would be required. Further notes: The paper has shown that behaviour based models can predict the effects of both detrimental and beneficial environmental changes. Also, that a reduction in habitat as a result of development can be very detrimental to shorebirds, especially if measures are not put in place to reduce the effects.
Ref Number 94 Ref: Fahy, E., Norman, M., Browne, R., Roantree, V., Pfeiffer, N., Stokes, D., Carroll, J. & Hannafy, O., 2001. Distribution, population structure, growth and reproduction of the razor clam *Ensis arcuatus* (Jeffreys) (Solenaceae) in coastal waters of western Ireland. *Irish Fisheries Investigation,* 10, 24pp. Study date: January 2000 to January 2001 Reviewed by: Sewell *et al.,* 2007	Description: The study was conducted to clarify the biology of *Ensis arcuatus* and to provide evidence as to how the population might be exploited in a sustainable way. Samples were collected by diver surveys to quantify the razor clam population. At each station a quadrat was placed on the seabed and 1 litre of granular salt was poured over the substratum, after 10 minutes any clams that appeared were collected by hand. Samples were also collected from the commercial fishery. All harvested clams (diver and commercial collection) were taken back to the laboratory where they were measured and weighed. Around 30 clams were split lengthways and a section of the gonadal tissue was extracted, this was used to assess gonad development. Habitat effects: Large concentrations of *Ensis siliqua* were associated with fine sand, whereas *Ensis arcuatus* occurred in algal gravel (including maerl) and shell sand. The highest densities of *Ensis arcuatus* occurred on a sand substratum with concentrations of *Zostera*. Further notes: Although the exact consequences of hydraulic dredging on habitats are not mentioned, the habitats that provide favorable conditions for *Ensis arcuatus* are shown to be those listed on the EU Habitats Directive.
Ref Number 95 Ref: Meyer, T.L., Cooper, R.A. & Pecci, K.J., 1981. The Performance and Environmental Effects of a Hydraulic Clam Dredge. *Marine Fisheries Review,* 43, 14-22. Study date: August 1977 Location: Rockaway Beach, southwestern Long	Description: Paper looks at the results from surveys conducted by divers to estimate the dredge efficiency of the Northeast Fisheries Center (NEFC) 1.2m hydraulic clam dredge and to assess the effect that dredging had on the bottom substrate and fauna. Habitat effects: During the tow a cloud of silt (0.5-1.5m in height) was created, which settled within four minutes of the tow leaving a 75mm thick layer of silt over the fine to medium sand in the study area. The dredge track was clearly visible with a flat floor and smooth, sharply angled walls (depth of the track remained relatively constant at 23cm). During the tow sediment was pushed off to the sides by the dredge, these mounds of sediment are referred to as the track shoulder. The track shoulders were initially 15-35cm wide and 5-15cm high when measured against the undisturbed sediment. After 2 hours the walls had began to slump creating a rounded depression in the seafloor, the track shoulders had also begun to decrease (10-25cm wide, 5-10cm high). After 24 hours the track shoulders were no longer visible and the dredged path looked like a series of shallow depressions, it blended in with

Island, N.Y Reviewed by: Sewell *et al.,* 2007	the general bottom features and was difficult to recognize. Community effects: A negative effect on the target species (clams) was mortality seen as a result of cut clams or crushed clams. The cut clams were observed by divers whenever the dredge blade did not penetrate into the seabed by at least 20cm, large clams that burrowed deep into the sediment suffered the greatest amount of damage. A number of crushed clams were found after the dredge had been filled, mortality as a result of crushing was highest amongst larger clams. Predation was another cause of mortality to the target species. The greatest numbers of predators occurred inside the dredge track and were divided into two groups depending on whether they fed on the remains of damaged clams or preyed on undamaged clams. Further notes: In particular hydraulic clam dredge.
Ref Number 96 Ref: Hauton, C., Hall-Spencer, J.M. & Moore, P.G., 2003. An experimental study of the ecological impacts of hydraulic bivalve dredging on maerl. *ICES Journal of Marine Science,* 60, 381-392 Location: Stravanan Bay, Clyde Sea, Scotland Reviewed by: Sewell & Hiscock, 2005	Description: This study examined the potential effects of hydraulic dredging on maerl beds. A flourescent sediment tracer was used to mark dead maerl, that was laid over the area to be trawled. The maerl was laid on the seabed in a way, that represented the natural maerl bed typical of the area. Following the passage of the hydraulic dredge, dredge track observations, catch analysis, and assessment of maerl catch and sediment resuspension were carried out. Habitat effects: Large quantities of dead maerl were caught by the dredge. Only a relatively small proportion of dyed maerl was captured, as the majority was dragged along the dredge track and reburied. A large amount of fine sediment was resuspended by the trawl, when it settled, maerl around the dredged path was blanketed by newly settled silt. This blanketing effect was easily discernable at least 21 m away from the dredged path. Community effects: A large number and high diversity of benthic organisms were captured in the dredge, including many large, long-lived, deep burying animals. Many larger, more fragile organisms were killed, whilst smaller more robust organisms were largely unharmed. Very few active species were captured, reflecting the slow speed of the dredge. Some live maerl thalli were also caught in the dredge.
Ref Number 97 Ref: Addison, J., Palmer, D., Lart, W., Misson, T. & Swarbick, J, 2006. Development of a suitable dredge for exploitation of razorfish (*Ensis directus*) in The Wash. Cefas Contract No. C2323 Location: The Wash & North Norfolk Coast Reviewed by: Sewell *et al.,* 2007	Description: The main aims of the project were to firstly review the current design and operation of razorfish dredges in other European fisheries and identify a suitable design for The Wash. Secondly, field experiments were conducted in The Wash using an appropriate dredge to assess the impact of the dredge on the interest features and evaluate how efficient the dredge was at collecting the razorfish and assess the damage rate of the razorfish. To assess the damage to the seabed two sites were tested with a different pressure level at each site; i) Seal Sand, pressure level increased slowly with approximately 1 minute at each level to a maximum of 3.5-3.7 bar and ii) Sunk Sand, pressure was kept at the maximum pressure for the entire haul. Habitat effects: A key environmental effect was the mechanical action of the dredge on the seabed; this was investigated by examining the excavation depth of dredge. At the Seal Sand site the speed of the vessel was 0.6 knots, with a starting pressure of 1.63bar (mean) this resulted in an excavation depth of about 86mm. As the pressure was increased to 2.47bar (mean) the excavation depth increased to about 192mm and increased again to about 240mm when the pressure was increased to 3.7-3.74bar (mean). At the Sunk Sand site the speed of the vessel was reduced to 0.3-0.4 knots and the pressure was increased to its working maximum of 3.57bar, during the haul this resulted in an average of 163mm of seabed excavated. The results also suggested that the excavation depth may be limited the composition of the sediment, in areas where the sediment appeared to be denser the excavation appeared to be reduced. Community effects: Target species: there was a positive relationship between the speed at which the dredge was towed and the damage rate observed, the faster the speed of the vessel the greater the damage rate of *Ensis directus* that was observed. At faster speeds up to 35% of the catch were damaged this was considered to be unacceptably high.

	Further notes: Paper concludes that if an experimental fishery were to take place it would need to be monitored to assess the impact of the fishery has on the stock itself and also the interest features of the cSAC. Monitoring of the substrate and benthic community would need conducted before and after the fishery takes place.
Ref Number 98 Ref: Fahy, E. & Gaffney, J., 2001. Growth statistics of an exploited razor clam (*Ensis siliqua*) bed at Gormanstown, Co Meath, Ireland. *Hydrobiologia,* 465, 139-151. Study date: July 1998-July 1999 Location: Gormanstown, Co Meath, Ireland Reviewed by: Sewell *et al.,* 2007	Description: Study aimed to assess and monitor the progress of the razor clam fishery in Gormanstown that started in 1997. During the year long study (1998/99) 25 samples were collected, 10 were obtained by boarding the commercial vessels and collecting a fraction of the dredge contents and 15 were provider by the fishermen themselves. Once in the laboratory the dredge contents was identified and weighed, the clams that were intact were measured and any breakages were recorded. Community effects: The dredge samples contained a variety of animal species and sediment; the sediment consisted of fine sand to coarse shelly material. The species that were occasionally found in large numbers were *Lanice conchilega*, *Pharus legumen* and *Donax vittatus* the abundance of these species was often associated with very small razor clams (<6 cm). Hydraulic dredging was shown to have short term effects; however the physical consequences were not visible after 40 days. It was long-lived species that were likely to take much longer to recover.
Ref Number 99 Ref: Hiddink, J.G., 2003. Effects of suction-dredging for cockles on non-target fauna in the Wadden sea. *Journal of Sea Research,* 50, 315-323. Study date: 2000 - 2001 Location: Groninger Wad, Dutch Wadden Sea. Reviewed by: Sewell & Hiscock, 2005	Description: An oportunistic survey examining how suction dredging for cockles *Cerastoderma edule* effects non-target fauna. Non-dredged locations were compared to heavily commercially fished areas. Habitat effects: Dredging tracks were formed and stayed for several months. Sediment was physically removed and dominant sediment type was altered to make it unsuitable for the settlement of mussels *Mytilus edulis*. Community effects: No significant effect of fishing was found for densities of *Hydrobia ulvae* or 0 - 1 year class *Cerastoderma edule*. No *Mytilus edulis* were found in heavily trawled areas and this was considered to be a direct result of the physical effects of trawling. There was a signifiant negative effect of fishing on young (2000 year class) *Macoma balthica*, but the effects on older individuals could not be tested. Further notes: The author concludes that the effects of bottom disturbance by cockle dredging can last more than a year, even in a dynamic ecosystem.

Ref Number 100	
Ref: Hauton, C., Atkinson, R.J.A. & Moore, P.G., 2003. The impact of hydraulic blade dredging on a benthic megafaunal community in the Clyde Sea area, Scotland. *Journal of Sea Research,* 50, 45-56. Location: Clyde Sea, Scotland Reviewed by: Sewell & Hiscock, 2005	Description: Study to quantify impacts of hydraulic blade dredging for razor clams. The study focused on discard generation, damaged caused to the catch and the ability of disturbed organisms to rebury following disturbance. Community effects: Dredge contents and dislodged fauna were dominated by the heart urchin *Echinocardium cordatum*. Approximately 80 percent of these survived the dredge proccess. The majority of heart urchins left in the dredge track that were undamaged were able to rebury following the disturbance. However, none that were brought to the surface after dredging were unable to succesfully rebury within three hours of being returned. The second most common species were the target razor clams *Ensis siliqua* and *Ensis arcuatus*, as well as the otter shell *Lutraria lutraria*. Of these, between 20 and 100 percent of those caught suffered severe damage in any one haul. Approximately 85 percent of razor clams were able to rebury following disturbance. Further notes: The authors calculate that for every 10 kg of marketable razor clams caught by this method, 29 kg of heart urchins would be disturbed, 23.5 kg of which would be brought to the surface and discarded and would be unlikely to rebury.
101 Ref: Rostron, D.M., 1995. The effects of mechanised cockle harvesting on the invertebrate fauna of Llanrhidian sands. *Burry Inlet & Loughor Estuary Symposium, March 1995. Part 2.* 111-117 Location: Llanrhidian Sands, Burry Inlet. Reviewed by: Gubbay & Knapman, 1999,	Description: Experimental dredging of sandflats with mechanical cockle dredge. Two distinct sites sampled. Site A: Poorly sorted fine sand with small pools and *Arenicola marina* casts with some algal growth. Site B: Well sorted fairly coarse sand, surface sediment well drained and rippled as a result of wave activity. Habitat effects: Dredge track visible after 6 months at Site A (stable sediments). No alteration in sediment parameters by dredging at Site B (mobile sediments). Community effects: Effects of dredging on biota apparent at Site A after 3 months may be attributed to destruction of seabed algal covering, destruction of permanent tube dwellings, mortality of eggs/broods, interference with predator prey relationships or changes in sediment characteristic. Seasonal perturbation e.g. produced by winter storms produce community changes of greater magnitude than those caused by dredging in unstable high energy environments such as Site B. Site A (stable sediments): Decreased number of *Pygospio elegan* no recovery to pre-dredging numbers by six months. Disappearance of *Scoloplos armiger* from some dredged plots. Distribution of *Nephtys hombergii* disturbed by dredging recovery after six months. Large decline in numbers of *Hydrobia ulvae*, statistical difference between dredged sites and control sites up to six months post-dredging. *Cerastoderma edule* numbers reduced by dredging, significant reduction in numbers compared with the control still apparent up to six months post-dredging. Site B (mobile sediments): Populations of *Bathyporeia pilosa* exhibit greater fluctuations in numbers of individuals post-dredging. Initial reduction in the population densities of *Hydrobia ulvae*, *Pygospio elegans*, *Cerastoderma edule*, *Nematoda* spp. and *Psammodrilaida* after dredging followed by rapid recovery (no difference between control and experimental plots after 14 days). Increase numbers of Nematode attributable to dredging.

Ref Number 102 Ref: Jennings, S. & Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology,* 34, 201-352. Reviewed by: Gubbay & Knapman, 1999,	Description: Review paper describing direct and indirect effects of fishing gears on benthic fauna and habitat, fish community structure and trophic interactions. Habitat effects: Effects on habitats and benthic communities most readily identified and last longest in those areas that experience infrequent natural disturbance. Initial effects can be dramatic, additional effects more difficult to detect. Authors concluded that once an ecosystem enters the fished state, diversity, structure and fish production tend to remain relatively stable across a wide range of fishing intensities. Fishing has accelerated and magnified natural declines in abundance of many forage fishes and this has led to reduced reproductive success and abundance in birds and marine mammals. Dramatic and apparently compensatory shifts in the biomass of different species in many fished ecosystems are considered to often be driven by environmental change rather than indirect effects of fishing. When predator or prey fill a key role, fishing can have dramatic indirect effects on community structure Further notes: Authors conclude that many marine ecosystems are overfished and that better management is needed. Population-based management, management which minimises the direct and indirect effects of fishing and the case for marine reserves as an adjunct to other management methods are discussed.
Ref Number 103 Ref: Hall, S.J., Basford, D.J. & Roberts, M.R., 1990. The impact of hydraulic dredging for razor clams *Ensis* sp. on an infaunal community. *Netherlands Journal of Sea Research,* 27, 119-125. Location: Loch Gairloch, Scotland Reviewed by: Gubbay & Knapman, 1999,	Description: Field experiment of impact of fishing for razor clams Ensis sp. by hydraulic dredging on the associated infaunal community, 7m depth. Community effects: Infaunal samples were examined at 1 and 40 days from fished and unfished plots. There were differences in mean number of species and individuals for control and fished sites 1 and 40 days later but only total numbers of individuals significantly lower. After 40 days no detectable difference. No statistically significant differences in the 10 most abundant species *Bathyporeia elegans*, *Siphonoecetes kroyeranus*, *Exogene hebes*, *Spio filicornis*, *Corophium crassicorne*, *Streptosyllis websteri*, *Cochlodesma praetenue*, *Nephtys cirrosa*, *Megalorupus agilis* and *Perioculodes longimanus* between treatments after either 1 or 40 days. Suction dredging for *Ensis* had profound immediate effects on benthic community structure with consistent reductions in the numbers of many macrofaunal species and the target species. However, despite the relatively large scale nature of the disturbance, these effects appear to persist for only a short period. After 40 days no detectable difference - visually or from macrobenthic community analysis, effects on long-lived bivalves could however be more serious, and action of the dredge is violent enough to often crack shells of adult *Arctica islandica*. Larger polychaetes and crustaceans are also often retained on the conveyer, crushed in the mechanism or fall off the end to fall at random on the seabed. No estimate was made of survivorship of these individuals but many scavenging hermit crabs were active immediately after dredging. Migration and passive translocation play a part in returning the abundance of species to pre-impact levels. Authors suggest that local population reductions due to dredging are only likely to persist in a habitat if one of two conditions are met: (a) macrobenthic populations themselves, or the sediments in which they live, are immobile or (b) the affected area is large relative to the remainder of the habitat such that dilution effect cannot occur. For most habitats where *Ensis* could be fished authors believe that neither of these conditions likely to hold. Current technology restricts this type of fishing to approximately 7m therefore likely to be strongly influenced by wind and tide-induced currents in these areas. Sediments are probably mobile and effects will be diluted rapidly. However they note there is little knowledge of the relative importance of the various processes which contribute to animal movement and whether certain habitats may be more susceptible to persistent damage than others. At most sites the authors believe there will be adequate areas to dilute effects but prior examination of potential fishery sites is warranted. Target species removed in great numbers, long-lived bivalve species often damaged or killed and smaller-bodied infauna either displaced or killed. With the exception of large bivalves, it would appear that effects on macrofaunal community in general are not locally persistent, although in calmer seasons

	effects may persist for longer than observed here. Another consideration is that if *Ensis* and other large bivalves play an important role in structure of benthic communities, their removal would result in cascading effects over long time scales. But in the high levels of sediment mobility at the study site, this hypothesis was considered unlikely.
Ref Number 104 Ref: Tuck, I.D., Bailey, N., Harding, M., Sangster, G., Howell, T., Graham, N. & Breen, M., 2000. The impact of water jet dredging for razor clams, *Ensis* spp., in a shallow sandy subtidal environment. *Journal of Sea Research,* 43, 65-81. Study date: Mar-98 Location: Sound of Ronay, near Grimsay, Outer Hebrides Reviewed by: Sewell & Hiscock, 2005	Description: Experimental dredges were carried out by a commercial water jet, dredging vessel, targetting razor clams (*Ensis* spp.) fishing was conducted for 10min periods. 6 tracks were intensively studied by divers, who observed sites during dredging, collected cores for analysis, made measurements of physical impacts and made observations of epifauna. Video footage of trawls sites was also used. Habitat effects: A flat-bottomed 'V' shaped Trench was left, measuring 1.2 m surface width, 0.5 m base width and 0.15 m depth. Track lengths varied between 26 and 122 m. Tracks were still visible but less pronounced after five days. After 11 weeks tracks were no longer visible. However, sediment was still in a state of fluidisation to a depth of 0.2 m. Community effects: Some short term changes were recorded between infaunal assemblages immediately after and five days after the trawl, but no difference was apparent after 11weeks. Within a day of fishing, the number of infaunal species and number of individuals within trawl tracks had significantly decreased, but no difference was recorded after five days. A reduced biomass in fished areas, compared to control sites was still evident after five days. None of the diversity parameters studied showed significant effects of fishing. Due to the mobile nature of the sediment, epifauna was limited, but there was an increase in large scavangers in trawled areas imediately after each trawl. Several larger organisms where captured as bycatch and many of these showed signs of damage. Further notes: Sediment consisted of moderately well-sorted medium or fine sand. The area was swept by strong tidal flow and sediment was mobile. The authors note that in this study, the trawl was only passed through each site once. Commercial vessels would be likely to cross over the area a number of times, with pottentially more profound effects.
Ref Number 105 Ref: Robinson, R.F. & Richardson, C.A., 1998. The direct and indirect effects of suction dredging on a razor clam (*Ensis arcuatus*) population. *ICES Journal of Marine Science,* 55, 970-977. Location: Orphir Bay and Bay of Ireland, Orkney Islands Reviewed by: Gubbay & Knapman, 1999,	Description: Comparative study of dredged and undredged sites to investigate effects of suction dredging on razor clam. Community effects: Undredged site was characterised by an absence of small razor clams, contained the largest individuals, and a higher density of razor clams. At the dredged site the population had changed considerable in the 7 years of spasmodic dredging. The most notable differences were the absence of a middle size range of clams and a decline in the number of large razor clams. Shells from the dredged site hand considerably more disturbance marks/damage to the outer shell layer than at the control site with 70 percent showing the highest level ie. Deep clefts in the outer shell layer embedded with sand grains. Observations of the reburying of razor clams collected by airlift and subsequently released onto the surface of the sediment suggested that they are highly vulnerable to attack from predatory crabs and will experience a high level of mortality after removal.

Ref Number 106 Ref: Fisheries Research Services, 1998. A Study of the effects of water jet dredging for razor clams and a stock survey of the target species in some Western Isles populations. Report No. 8/98. Location: Western Isles Reviewed by: Gubbay & Knapman, 1999,	Description: Experimental dredging in sandy areas swept by strong tidal flow with a paucity of epifauna but openings of numerous larger infaunal animals such as various bivalve species.Tests conducted using single fishing events rather than repeat fishing. Habitat effects: Trenches up to 2m wide and 0.15 deep at centre were observed. These started to fill after 5 days and were no-longer visible after 11 weeks but sediment in the tracks remained fluidised under a thin crust of firm sediment. Long term physical effects are less well understood and may be exacerbated by repeated fishing of the same area. Community effects: Immediate reduction in number of species, individuals and biomass in fished tracks but measures of diversity showed no effects. Abundance of polychaetes reduce and of amphipods increase. Crab species moved into the region to scavenge of material disturbed by the dredge.The results suggest biological effects are only short term. No effects were recorded after 11 weeks. Species likely to be damaged (eg.heart urchins and large bivalves) were rare in the samples but present in dredge catches where damage was noted. Most of the animals in the sediments are adapted to a mobile environment so other than being removed or displaced they were not thought to be greatly affected by the dredging. On the basis of this work difficult to comment on areas with more obvious and diverse epifauna. Authors conclude there is little difference between the biological impact of water jet dredges and suction dredging although the latter may have a greater physical effect and fish less selectively.
Ref Number 107 Ref: Kaiser, M.J., Edwards, D.B. & Spencer, B.E., 1994. Infaunal community changes as a result of commercial clam cultivation and harvesting. *Aquatic Living Resources,* 9, 57-63. Location: Whitstable, Kent, England Reviewed by: Gubbay & Knapman, 1999,	Description: Survey of intertidal benthic community and physical characteristics at a site of commercial clam cultivation on a shallow shelving mudflat during clam growth and post harvesting. Underlying sediment composed of London clay interspersed with shell debris and lignin deposits. Surface sediment of fine silt and sand with patches of clay. Habitat effects: During clam growth no significant difference in particle size, organic content or photosynthetic pigment between control and clam lay sites. Harvesting by suction dredging removed upper sediment layers exposing clay which is unsuitable for larval settlement. Seven months post harvesting sedimentation had nearly restored the sediment structure. Community effects: During clam growth no significant increase in faunal diversity under clam lay but density of benthic species individuals much greater. Community under clam lay significantly different from the control areas. Control area dominated by polychaete *Nephtys hombergii*, area under clam lay dominated by deposit feeding worms *Lanice concilega* and the bivalve *Mysella bidentata*. Nets may change hydrography reducing water flow and increasing sedimentation. This increases food supply and so may promote larval settlement. Adjacent areas may be influenced by commercial clam operation. Suction dredge harvesting had a profound effect on the community structure. Large amounts of sediment and associated animal community (particularly crustaceans and bivalves) removed. Seven months post harvesting density of individuals decreased significantly to the point where there was no difference between control and harvested sites, with *Neptys hombergii* responsible for the similarity between treatment and control. The effect of clam harvesting barely detectable after 7 months. Clam cultivation increases productivity as the netting reduces wave action and other disturbances. Further notes: Authors conclude that clam cultivation does not have long-term effects on the environment or benthic community at the study site.

Ref Number 108 Ref: Morello, E.B., Froglia, C., Atkinson, R.J.A. & Moore, P.G., 2005. Impacts of hydraulic dredging on a macrobenthic community of the Adriatic Sea, Italy. *Can. J. Fish. Aquat. Sci.,* 62, 2076–2087. Study date: June - July 2001 Location: Ancona Maritime District, Central Adriatic Sea, Italy Reviewed by: Sewell *et al.,* 2007	Description: Examining impacts of Hydraulic dredging, Chamelea gallina fishery. Study took place in area of fine, well sorted sands. The commercial hydraulic dredge used comprises a 2.4-3 m wide rectangular cage weighing 0.6-0.8 tonnes, mounted on two sledge runners to prevent it from digging into the substratum to a depth of more than 4-6 cm. Single tow. Sampling 4 times before (14th June-7th July) and 4 times after (11th -25th July) dredging Community effects: Measured 1 day peak in scavenging species. When all species groups were studied together, no discernable impacts from Hydraulic suction dredging were recorded. Where Bivalves, polychates and deposit feeders were studied separately, a discernable affect was noted. Further notes: Suggest that Abra alba would be a good indicator species of community effects because it has intermediate sensitivity to dredging activities.
Ref Number 109 Ref: Oro, D. & Ruix, X., 1997. Exploitation of trawler discards by breeding seabirds in the north-western Mediterranean: differences between the Ebro Delta and the Balearic Islands areas. *ICES Journal of Marine Science,* 54, 695-707. Study date: April to June from 1992 to 1996 Location: Ebro Delta and Majorca Reviewed by: Sewell *et al.,* 2007, 2007	Description: The aim was 'to assess the utilization of discarded fish by scavenging seabirds behind trawlers in both areas'. Within the study areas data from 28 commercial trawls was collected, 15 from the Ebro Delta and 13 from Majorca. Stern counts were carried out in a 360º scan around the ship; species that followed the vessel every 15 minutes from the beginning of the haul to the end of discarding were recorded. Of the fish discarded, species, length, whether it sank or was picked up by a bird was recorded. Community effects: Gulls and terns followed behind the trawlers, Procellariiformes were noted away from the stern Skus moved around the trawlers, but often kept away from them. Results suggest that discards from trawler fleets readily support all scavenging seabirds breeding at Ebro Delta, but not at the Balearic Archipelago. As discards from the Balearic Archipelago are unable to support the energy requirements of scavenging seabird populations, as a result of the competition for resources and suitable breeding sites it may explain why populations of the Audouin's gull increase at a much lower rate in the Balearic Archipelago than the Ebro Delta. Further notes: Number of seabirds recorded during the discarding was significantly higher at Ebro Delta than at Majorca.
Ref Number 110 Ref: Peterson, C.H., Summerson, H.C. & Fegley, S.R., 1987. Ecological consequences of mechanical harvesting of clams. *Fishery Bulletin N.O.A.A,* 85, 281-298. Study date: 1980-1984	Description: Field experiments were carried out to assess the impact that mechanical clam harvesting can have on a large scale, with aim of providing data to resource mangers and increase the scope of benthic ecology. To see what effect this physical disturbance has four things were considered: i) recruitment success, ii) biomass of seagrasses, iii) density of bay scallops and iv) density of other benthic macrofauna. Two sites within an estuarine habitat were selected, seagrasses and sand flats with 6 plots in each site. Each plot was sampled before harvesting to estimate the abundance of bay scallops, hard clams and seagrasses. The harvesting was applied on two occasions and then sampled on 5 subsequent occasions to test for any effects. Of the 6 plots 2 were left untouched in each site, 1 was as a control and the other was subjected to low intensity harvesting. Habitat effects: As a result of raking and light intensity clam-kicking the biomass of seagrass beds was reduced straight away by ~25% of the control

Location: Back Sound, North Carolina (USA) Reviewed by: Sewell *et al.,* 2007	levels and a full recovery of the site occurred within a year. As a result of high intensity clam-kicking the biomass of seagrass beds was reduced straight away by ~65% of the control levels. Recovery didn't begin until 2 years later and even 4 years later the biomass was still ~35% lower than the control levels. Community effects: Effect on target species: the recruitment of clams varied between the two habitat types. Although there was no clear difference in recruitment on seagrass beds as a result of different intensities of harvesting, there was a difference on the sand flats. The recruitment was lower on the plots that were intensively harvested when compared to the control plot. Effect on other species: the density of the bay scallop decreased as the seagrass beds decreased, this occurred across all intensities of harvesting. Clam harvesting did not affect the species composition or density of small benthic macroinvertebrates across any of the harvesting intensities. Further notes: As the density of benthic macroinvertebrates did not respond to different intensities of harvesting it suggests that polychaetes (which were the dominant species) can recover quickly and are not adversely affected by clam harvesting. The harvesting technique mentioned refers to "clam-kicking" which involves directing the prop wash downwards and dislodging the calms and causing the sediment to be re-suspended, a heavily chained trawl is then dragged across the seabed behind the boat to gather the calms. The dragging of trawl across the seabed may have similar impacts to that of scallop dredging and the use of water pressure to dislodge the sediment and loosen clams may have similar impacts to that of suction dredging.
Ref Number 111 Ref: Moore, J, 1991. Studies on the Impact of Hydraulic Cockle Dredging on Intertidal Sediment Flat Communities: Final Report, CSD Report, no. 1256, Peterborough, 46 pp. Location: Lavan Sands, Wales & Blackshaw Flats, Solway Firth Reviewed by: Gubbay & Knapman, 1999,	Description: Control and treatment type experimental investigation with pre and post dredge comparisons. Two spatially separated sites exposed to a single dredge with subsequent benthic sampling. Site A, Lavan Sands NW Wales 3m above chart datum substrate very fine sand, extensively rippled, compact and firm, well oxygenated sediment. Site B, Blackshaw Flats, Solway Firth 5m above chart datum well sorted very fine sand, extensively rippled, compact and firm, well oxygenated sediment. Two experimental regimes. Experiment 1: Effects of a single dredging activity. Experiment 2 at Lavan Sands 80 sampling stations over an area of 400x300m used to assess the effects of a 3 month licensed commercial dredging operation using pre and post dredging data. Habitat effects: Experiment 1 - Dredging had no significant impact on the measured sediment characteristics due to the small percentage of fine material and the high degree of sorting.Experiment 2 - No severe erosion of sediments occurred. Community effects: Experiment 1 - Rapid recovery of benthic infaunal communities as sediment exposed to regular disturbance from water movement - community already adapted to disturbance. *Hydrobia ulvae*, surface grazing gastropod, significantly affected by dredging. Experiment 2 - Impacts appear to be small and for the most part not statistically significant. Significant decrease in the population of tube dwelling polychaete *Pygospio elegans* whose tubes may be destroyed by dredging. *Lanice conchilega* has tough tubes apparently not greatly affected by the dredging operation. Also they can retract into tubes below the maximum depth disturbed by the dredge and can regrow head tentacles. Numbers of *Cerastoderma edule* and *Macoma balthica* reduced significantly resulting in a significant reduction in the total macrofaunal biomass (these molluscs contribute to about 70 percent of the biomass wet weight). Author concludes hydraulic cockle dredging unlikely to have a significant impact on non-target infaunal species at the site as the sediments are moderately mobile with a low silt content.

Ref Number 112 Ref: Rose, C., Carr, A., Ferro, D., Fonteyne, R. & MacMullen, P, 2000. Using gear technology to understand and reduce unintended effects of fishing on the seabed and associated communities: background and potential directions. *ICES Working Group on Fishing Technology and Fish Behaviour.* Reviewed by: Sewell *et al.,* 2007	Description: Study looks at the effects of different fishing gears, indicating which components of the gear are likely to cause the most severe effects and also how these gears affect community structure. Habitat effects: Observations by divers and ROV have shown that trenches have formed after the passage of dredges over the substrate, with visible sediment rings being deposited on each side of the track. Effects of dredging can include: bringing stones to the surface after repeated dredging, damage to reefs and chemical changes & sediment compaction. The effects of hydraulic suction dredging can also be seen immediately with visible trenches being left in the seabed. Although these trenches started to fill after 5 days and were not visible after 11 weeks the sediment in the tracks that had been fished remained fluidized for a much longer period of time. Community effects: Effects on non-target species can range from none to displacement or injury including mortality depending on vulnerability of the organisms. Mobile epifauna may be capable of avoid capture depending upon the gear type; where as sessile organisms may be more vulnerable. Some species that provide a habitat for other organisms may be caught and removed. A result of hydraulic suction dredging is that non-target species can become distributed much further away from the dredging location. Further notes: How long the effects of fishing last are related to the rate at which the seabed features are produced. In high energy environments the features are constantly being renewed and the effects of fishing will be less persistent.
Ref Number 113 Ref: Cook, W, 1991. Studies on the effects of hydraulic dredging on cockle and other macroinvertebrate populations 1989-1990. *North Western and North Wales Sea Fisheries Committee.* Study date: 1989-1990 Location: Traeth Lafan Reviewed by: Sewell *et al.,* 2007	Description: In 1989 a 3 month experimental study of the impacts of hydraulic suction dredging for cockles was carried out. As this was the first large scale use of the method the impact on both the cockles and other macroinvertebrate populations were considered. A second 3 month study was also conducted in 1990 again looking at both cockles and non-target species. Stock surveys were carried out before, during and after both studies. 5 transects were established with 55 sampling sites along each transect, at each site a 0.1m2 quadrat was laid and sediment within was dug out to a depth of about 7cm, the contents was sieved and retained for analysis. Habitat effects: The habitat type varied across the survey area. For the areas that appeared to have a muddy composition dredge tracks remained for several weeks after dredging had finished. However the sediment appeared mobile and quickly filled in the gaps back up to bed level. In areas where the bed substrate was harder, dredge blades were set so they would dig deeper into the sediment; this led to localized erosion of the bed surface. When dredging finished in October 1989 a number of hollows and hummocks could be seen across the seabed. However, by the end of January 1990 after are some strong winds the seabed had started to flatten out and return to a more normal appearance.
Ref Number 114 Ref: Hauton, C; Paterson, D.M., 2003. A novel shear vane used to determine the evolution of hydraulic dredge tracks in sub-tidal marine sediments. *Estuarine, Coastal and Shelf Science,* 57, 1151-1158.	Description: Study to test a novel shear vane for the analysis of Hydraulic dredge tracks. Used to analyse sediment characteristics following dredging activity. Test study undertaken in on a razor clam (Ensis) bed in a sheltered harbour area, with low tidal flow, in water depth - 4-6m below Chart datum. 2 sites subjected to a single tow using a UMBSM Hydraulic suction dredge. 2 undredged control sites. Diver measurements and core analysis used to assess recovery in addition to shear vane analysis. Habitat effects: After 100 days, track depth decreased from 13.9 cm to 2.9cm and width increased from 100 – 110 cm due to bank erosion. Vertically

Study date: 2000 - 2001 Location: Lamlash Harbour on the Isle of Arran, Scotland Reviewed by: Sewell *et al.,* 2007	homogenised sediment reduced stratification for depths exceeding 20cm. Impact remained apparent for more than 100 days, probably due to the sheltered (tidal flow did not exceed 0.5ms –1) nature of the study site. This was compared to a recovery time of only 40 days from a previous study in a more exposed area in the Sound of Ronay, Scotland (tidal flow exeded 1.5ms-1). Community effects: Authors suggest that repeated passes by Hydraulic dredges in sheltered areas could have a serious impact on biological community structure and the persistence and ultimate consequence of these activities should be carefully assessed. Further notes: The novel Shear vane has great potential for monitoring the impact and recovery of hydraulic dredging on the seabed.
Ref Number 115 Ref: Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield. P.J. & Karakassis, I., 2006. Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series,* 311, 1-14. Location: See additional information Reviewed by: Sewell *et al.,* 2007	Description: Study was a meta-analysis of 101 different fishing impact manipulations, for this 101 different experimental manipulations /observations were examined for the effects of fishing disturbance on benthic fauna and communities. To classify the experimental studies a number of different variables were considered that might affect the degree of fishing impact, these included: fishing gear type, water depth (m), disturbance regime, habitat type (e.g. mud, sand, biogenic habitat), taxonomic grouping (e.g. by phylum) and minimum dimension of the reported scale of disturbance (e.g. width of trawl). Studies that also considered recovery rates were also important. Habitat effects: Intertidal habitats: the impact of intertidal dredging was shown to be much more severe than that of intertidal raking. With intertidal raking the sediment was left in situ, only the upper few cm were disturbed by the gear, however intertidal dredging resulted in the removal and resuspension of sediment in the water column. Subtidal habitats: Both beam trawling and scallop dredging had short-term negative impacts on muddy-sand and sand habitats. Otter trawling had a significant initial impact on mud and muddy-sand habitats, but the effects appeared to be short and the long-term outcome was positive. The studied showed that otter trawling on biogenic habitats caused negative impacts, but these were not as severe as those caused by scallop dredging. The scallop dredging on biogenic habitats gave the greatest initial negative impact and these effects were predicted to last from 972 to 1175 days after the dredging stopped. Community effects: Both deposit and suspension feeders were vulnerable to scallop dredging across gravel, sand and mud habitats. For recovery, slow growing large-biomass biota (e.g. sponges and soft corals) took much longer to recover from the effects of fishing, up to 8 years. Biota with short life-spans (e.g. polychaetes) recovered much quicker, less than 1 year. Biota of soft-sediment habitats, especially muddy sands, also had recovery periods predicted to be in years. Further notes: Most of the studies were from Northern Europe (46) and Eastern North America (30), the following indicates where the remaining studies were conducted: Southern Europe (8), Western North USA (1), Australia/New Zealand (15) and South Africa (1).Fishing types considered were: otter trawling, scallop dredging, beam trawling, inter-tidal dredging, inter-tidal raking.

Ref Number 116 Ref: FOC. 2006. Pacific region, Council of the Haida Nation/Fisheries and Ocean Canada. Joint Management Plan Razor Clam January 1 to December 31, 2007 Location: Pacific Region, Canada Reviewed by: Sewell *et al.,* 2007	Description: Report assesses the status of the current stock and current management issues as well as looking at the management changes for 2007. Further notes: Restrictions implemented include: Catch ceiling for 2007 is 142.9 tonnes, Fishermen must have a designation card (non-transferable), ID and designation cards must be carried at all times, Razor clams must exceed 90mm, Set areas where activity can take place, All harvesting is restricted to hand digging, Fishery closed during January, February, March, July and August 2007, During opening months fishing can only take place on set days.
Ref Number 117 Ref: FOC. 2006. Pacific region, Heiltsuk Tribal Council/Fisheries and Ocean Canada. Intertidal Clam Joint Management Plan November 15, to March 31, 2007. Reviewed by: Sewell *et al.,* 2007	Description: Report assesses the status of the current stock and current management issues as well as looking at the management changes for 2007. Further notes: Restrictions implemented include: Open season from November 14th 2006 to March 31st 2007, Set areas where fishing is allowed, All Manila or little neck clams must exceed 38mm, TAC for Manila clams is set at 102,056 pounds, Harvesting is restricted to hand picking/digging, ID and proof of designation must be carried at all times.
Ref Number 118 Ref: Rambaldi, E., Bianchini, M., Priore, G., Prioli, G., Mietti, N., & Pagliani,T., 2001. Preliminary appraisal of an innovative hydraulic dredge with vibrating and sorting bottom on clam beds (Chamelea gallina). *Hydrobiologia,* 465, 169-173. Reviewed by: Sewell *et al.,* 2007	Description: Examining selectivitiy of a novel hydraulic dredge, incorporating a vibrating, sorting bottom. Community effects: Undersized indivivuals and some non-target species were sieved out and dropped in situ, reducing the potential impact of being removed entirely from the sediment and being dispersed elsewhere. More damage to captured individuals was recorded than standard gear. Gear was selective for associated fauna, resulting in high weight of bycatch in experimental gear. Further notes: Authors consider the results to be positive and suggest real benefits of the novel gear, particularly for stock management.

Ref Number 119 Ref: McDonough, N.A; Patino, D.M., 2005. Developing stock enhancement techniques for two razor clam species in the European Atlantic Area. *Journal of Shellfish Research,* 24, (1) 329. Reviewed by: Sewell *et al.,* 2007	Description: The Sustainable Harvesting of Ensis (SHARE) project, funded by the European Interreg IIIB Atlantic Area Programme, aims to developsustainable production strategies for two commercially important species of razor clams that form the basis of a declining wild fishery in parts of the Atlantic coast of Europe. Partners from the UK, Ireland, Portugal, and Spain are collaborating on this three-year project (2004 to 2007), which will take a "seed to market" approach to the production two European razor clam species, Ensis siliqua and Ensis arcuatus. At present, dredging for razor clams is prohibited in the UK (stocks are fished by diver harvesting and collecting on the low intertidal). However, the use of dredges is permitted in Ireland, and a large bed discovered off the east coast in 1997 has been heavily fished since then using hydraulic dredges. There is currently little or no management of this fishery and concerns exist regarding the environmental impact of heavy fishing activity that may result in the classic boom/bust scenario. The Centre for Marine Resources and Mariculture at Queen's University Belfast will work closely withCentro de Investigacions Marinas (CIMA) in NW Spain to develop hatchery, nursery, and restocking techniques for E. arcuatus and E. siliqua. Although it is unlikely in the long-term that stock enhancement will provide an economically viable basis for a sustainable fishery, it will be necessary to develop technical measures to achieve restoration of the depleted stocks in the short-term until a suitable fisheries management regime is in place.
Ref Number 120 Ref: ICES, 2006. Report of the Working Group of Ecosystem Effects of Fishing Activities (WGECO), 5-12 April 2006, 174pp. Location: North Sea Reviewed by: Sewell *et al.,* 2007	Description: The working group reviewed the impact that fishing gear had on all components of the ecosystem and described the distribution of the following fishing efforts: beam trawls, otter trawls and small-meshed fisheries. Habitat effects: Dredging, otter trawling and beam trawling all involve contact with the seafloor and therefore causing the removal of large physical features as well as altering both structural biota and habitat complexity. The impact of otter trawling is considered to be less than that of beam trawling, with dredging being the most disruptive to both benthic habitats and processes. Community effects: Dredging: no evidence of concern was presented over the bycatch of commercial and non-target fish species and no impact on marine mammals or seabirds was presented. Otter trawling: there have been a few records of seabirds and marine mammals becoming caught in otter trawls as bycatch, these species have been recorded feeding in the nets and on fish that escape through the mesh. Beam trawling: no evidence of concern was presented over the bycatch of marine mammals or seabirds.

Ref Number 121 Ref: Collie, J.S., Hall, S.J., Kaiser, M.J. & Poiner, I.R., 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *Journal of Animal Ecology,* 69, 785-798. Location: See further notes Reviewed by: Sewell *et al.,* 2007	Description: A meta-analysis of 39 published fishing impact studies was undertaken, with the aim of identifying whether there was sufficient data on the impacts of fishing activities on benthos to answer the following questions: 1. Are there consistent patterns in the responses of benthic organisms to fishing disturbance? 2. How does the magnitude of this response vary with habitat, death, disturbance type and among taxa? 3. How does the recovery rate of organisms vary with these factors? Any gaps in the data were also identified. Habitat effects: The largest negative impact occurred on biogenic reef and muddy sand and gravel habitats. The recovery of habitats was quickest within sand habitats, which tended to be less physically stable and also contained more opportunistic species, as opposed to any other habitat type. Community effects: Within the disturbed plots the total number of individuals decreased by 46% and the total number of species decreased by 27%. Results also indicated that inter-tidal dredging and scallop dredging had the largest initial impact on benthic biota and trawling had the least impact. Further notes: The impacts of the following fishing activities were studied; beam trawls, hydraulic dredging, inter-tidal dredging, inter-tidal raking, otter trawls and scallop dredging. The areas considered within the study were: Northern Europe, Southern Europe, East North America, West North America, South Africa, East Australia, North-western Australia, South Australia and New Zealand. The study also indicated that the data available on impacts and recovery rates epifaunal structure-forming benthic communities was limited and more studies in this area were required.
Ref Number 122 Ref: Department of Fisheries and Oceans, 2006. Impacts of Trawl Gears and Scallop Dredges on Benthic Habitats, Populations and Communities. *DFO Canadian Science Advisory Secretariat.* Science Advisory Report 2006/025 Location: Canada Reviewed by: Sewell *et al.,* 2007	Description: Study examined the effects of specific fishing gear used in Canadian waters, this included otter trawls, scallop dredges and hydraulic clam dredges and their effects on seafloor habitats and on populations and communities of benthic species. Habitat effects: The main points from the study indicated that bottom gear can damage or reduce habitat complexity and structural biota, as well as altering the structure of the seafloor and large habitat features (could have positive or negative consequences). The initial impact tends to be greater on sandy and muddy bottoms than on hard, complex bottoms; however, the duration of impacts tends to be greater on hard complex bottoms. Dredges and bottom trawls are also considered to cause the most damage to benthic populations, communities and habitats per unit effort. Community effects: Bottom gear can impact benthic populations and communities by changing the relative abundance of benthic species, which in turn can alter the composition of benthic communities. Bottom gear can decrease the abundance of long-lived species and increase the abundance of short-lived species. Further notes: Recovery times from bottom gear disturbance can take from days to centuries and for some specialized biogenic features and some physical features recovery may not be possible. Recovery times will also depend on the following: i) specific features of the seafloor, ii) species present, iii) gear used, methods, frequency at the impacted site ad iv) history of human activities (past fishing activities).

Ref Number 123 Ref: Broadhurst, M.K., Suuronen, P. & Hulme, A., 2006. Estimating collateral mortality from towed fishing gear. *Fish and Fisheries,* 7, 180-218. Study date: 1890 - 2006 Reviewed by: Sewell *et al.,* 2007	Description: Paper reviews primary literature that has estimated collateral and unaccounted fishing mortalities and identifies the key reason behind them. Collateral and unrecorded mortality can include can include: i) avoiding, ii) escaping, iii) dropping out of the gear during fishing, iv) discarding from the vessel, v) ghost fishing of lost gear, vi) habitat destruction (& subsequent), vii) predation, viii) infection from any of the above. The review then aimed to develop a way of reducing the unwanted exploitation and suggest possible mitigation methods. Further notes: To reduce this collateral mortality different measures can be implemented including modifications to gears to improve selection this may involve changes rigging, netting materials and overall gear design (has been done with otter trawls). Management tools include restricting fishing to specific times and locations or prohibiting fishing in some areas completely. Whichever mechanisms are considered there is a need to consider the key biological, environmental and technical factors.
Ref Number 124 Ref: Bergman, M.J.N. & Van Santbrink, J.W., 2000. Fishing mortality of populations of megafauna in sandy sediments. In *The Effects of Fishing on Non-target Species and Habitats: Biological, conservation and socio-economic issues* (ed. M.J. Kaiser & S.J. de Groot), pp. 49-78. Location: South Eastern North Sea Reviewed by: Sewell & Hiscock, 2005	Description: For full details of this study, see also: Bergman, M.J.N. & van Santbrink, J.W. 2000. Mortality in megafaunal benthic population caused by trawl fisheries on the Dutch continental shelf in the North Sea.

Ref Number 125 Ref: Bergman, M.J.N. & van Santbrink, J.W., 2000. Mortality in megafaunal benthic population caused by trawl fisheries on the Dutch continental shelf in the North Sea. *ICES Journal of Marine Science,* 57, 1321-1331. Location: South Eastern North Sea Reviewed by: Sewell & Hiscock, 2005	Description: Study to calculate direct mortality of infaunal and epifaunal species of invertebrates, following otter and beam trawls. The annual fishing mortality for megafaunal invertebrate populations in the Dutch sector of the North Sea was also estimated based on the results of this field study.Three types of commercial beam trawls were tested (12 m wide and 4 m wide with tickler chains and 4 m wide with chain matrices) as well as an otter trawl with a 20 m net width. Mortality was determined by measuring species density before and comparing this with density 12-24 hours after trawling. Community effects: Single tows of 4 m and 12 m beam trawls, resulted in direct mortality of a number of species, ranging from 5 percent to 50 percent and up to 68 percent for some bivalve species. There were lower levels of mortality associated with otter trawls than beam trawls of all sizes. Mortaliy of organisms was greater in silty sediment than sandy sediment. Most direct mortality took place either as a result of impact by the trawl or disturbance and exposure leading to predation. Only a relatively small percentage of mortality was due to organisms being caught in trawls and discarded.
Ref Number 126 Ref: Moran, M.J. & Stephenson, P.C., 2000. Effects of otter trawling on macrobenthos of demersal scalefish fisheries on the continental shelf of north-western Australia. *ICES Journal of Marine Science,* 57, 510-516. Location: north-western Australia Reviewed by: Sewell & Hiscock, 2005	Description: A study comparing the impact of a benthic otter trawl with a semi-pelagic otter trawl, fished approximately 15 cms above the seabed. Repeated trawls were undertaken in marked areas and the effects on macrobenthos (mainly sponges, soft corals and gorgonians) were recorded, by measuring bycatch and using video survey. Community effects: No measurable effects were recorded following semi-pelagic trawls, whereas demersal trawls resulted in reductions to the density of benthic organisms growing higher than 20 cm from the seabed of 15.5 percent on each tow through the site. Further notes: Only four percent of the benthos detached by trawls was retained in the net. The semi-pelagic trawl took lower levels of benthos, but also took far less fish.

Ref Number 127 Ref: Jenkins, S.R., Beukers-Stewart, B.D. & Brand, A.R., 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. *Marine Ecology Progress Series,* 215, 287-301. Study date: July 12 - July 21 2000 Location: West coast of the Isle of Man. Reviewed by: Sewell & Hiscock, 2005	Description: Study examining the effects of dredging for scallops on megafauna by direct observations of damage in bycatch and in dredge tracks (individuals encountering dredges, but not captured). Authors used two gangs of four 'Newhaven' spring toothed dredges. An identical damage score was used by divers, surveying dredge tracks and scientists on board vessels examining bycatch. The abundance and damage score was recorded for all megafauna. Community effects: *Asterias rubens* and *Neptunea antiqua* were more severely damaged in bycatch than dredge tracks. *Cancer pagurus* was more severely damaged in the dredge track. For *Cancer pagurus* and *Liocarcinus* spp. nearly twice as many crushed or damaged animals were left on the sea bed than were found in bycatch. Some species were little affected by dredging, including *Porania pulvillus* and *Asterias rubens*. The study showed that the majority of fauna to come into contact with the dredge remains on the seafloor and that the majority of megafauna mortality associated with scallop dredges of this type occurs in dredge tracks and not in discarded bycatch. Further notes: Sediment ranged from pure sand to gravelly sediments containing mud, sand, shell material and stones.
Ref Number 128 Ref: Garcia, E.G., Ragnarsson, S.A. & Eiriksson, H., 2006. Effects of scallop dredging on macrobenthic communities in west Iceland. *ICES Journal of Marine Science,* 63, 434-443. Study date: 1993-2001 Location: Breidafjordur, west Iceland Reviewed by: Sewell *et al.,* 2007	Description: Assessment was conducted into the effects of scallop dredging on the spatial and temporal trends of non-target species caught as bycatch. Bycatch data was collected during the annual scallop stock surveys conducted in April (108-130 samples collected annually). Total catch from each tow was weighed and a random 25kg subsample was taken, all scallops and bycatch species were counted and weighed and abundance and biomass was estimated. Catch and fishing data was obtained from log books from 1972-2001, fishing effort was recorded as dredging time (the time elapsed between the first and last haul of each fishing day). Community effects: The data from the annual stock assessment showed that 42 bycatch species were recorded, 22 taxa were excluded as the dredge sampled them inadequately (19 demersal fish species, 2 pelagic invertebrates and 1 bivalve mollusc). Of the taxa that remained only 8 were present in more than 60% of the tows. The biomass of the 10 most abundant bycatch species accounted for 98.8% of the total biomass bycatch, of this *Modiolus modiolus* accounted for 32.3% and *Cucumaria frondosa* accounted for 25.3% of the benthic bycatch. The macrobenthic community showed similar aspects of disturbed communities elsewhere, diversity and species richness was generally low and the dominant taxa included starfish, crabs, hard-shell gastropods and large bivalves. However, there were no evidence of any major impacts of scallop dredging on the abundance and distribution of bycatch taxa. Scallop dredging started in 1972 and bycatch data is only available from 1993 onwards and data for no dredged areas is limited. For this reason it is likely that scallop dredging had already altered the community structure and removed sensitive species before the bycatch data started. Further notes: Sledge dredge was used from 1993 and substituted for a roller dredge (of Icelandic design) in 1998. The catchability of scallops was significantly higher when the roller dredge was used compared to the sledge dredge, only three bycatch species were significantly different between the two dredge types.

Ref Number 129	Description: Large scale investigations on soft sediment communities depth between 12-15m, 2km offshore. Six vessels towing 3m wide commercial Peninsula dredge with scraper/cutter bars not extending below the dredge skids. Site dredged for 3hrs day-1 over 3 days covering the dredge area at least twice. Dredging intensity was typical of local commercial fishing intensity.
Ref: Currie, D.R. & Parry, G.D., 1996. Effects of scallop dredging on a soft sediment community: a large scale experimental study. *Marine Ecology Progress Series,* 134, 131-150 Location: Port Phillip Bay, Australia Reviewed by: Gubbay & Knapman, 1999,	Habitat effects: Typically top 2cm of surface sediment disturbed but up to 6cm. Observations 8 days after dredging revealed seabed formations such as pits and depressions filled in and mounds formed by burrowing shrimps removed. Parallel tracks from dredge skids apparent after dredging. Physical changes in the seabed still apparent one month post-dredging. Six months post dredging most physical features reformed (abundance and size of callianassid mounds similar to those present before dredging) however some flattened areas still apparent. No physical differences between dredged and control sites after 11 months. Community effects: Ther number of species in dredged areas decreased significantly. Maximum impact did not occur immediately after dredging suggesting some indirect ecological changes such as uncovered organisms becoming more vulnerable to predation by invertebrates and demersal fish. Most species decreased in abundance by approximately 20-30 percent in the 3.5 months after dredging. The duration of the decrease in abundance species varied, with effects still apparent in some species after 8 months and in two species up to 14 months although this was possibly due to undersampling in the pre-impact period. 11 animals were not found in the sample area after dredging, mostly sedentary and therefore unable to re-establish except by larval recruitment. Susceptibility to dredging not correlated to feeding type or rarity. Fragile groups such as nemerteans were greatly damaged by dredging, polychaetes probably cut and killed by passing dredge. Other species may have been affected by high rates of dredging induced sedimentation, which may be 2-3 orders of magnitude greater than storm produced sedimentation, or buried when depressions filled in. Two species showed significant increase in abundance following dredging (*Diamorphostylis cottoni* and *Oedicerotid* sp.) whereas the isopod *Natalolona carppulenta* decreased sharply and then increased to be consistently higher on the dredged plot for 8 months possibly due to greater availability of prey. Seasonal and interannual changes in community structure much greater than those caused by dredging. Long-lived and slow recruiting epifaunal species (eg sponges and ascidians) likely to be particularly vulnerable to dredging. Long-term effects may be different to the short and medium-term effects. Needs to be studied over longevity of longest lived component species.

Ref Number 130 Ref: Watling, L., Findlay, R.H., Mayer, L.M. & Schink, D.F., 2001. Impact of a scallop drag on the sediment chemistry, microbiota and faunal assemblages of a shallow subtidal marine benthic community. *Journal of Sea Reasearch,* 46, 309-324. Location: Damariscotta River estuary, Maine, USA. Reviewed by: Sewell & Hiscock, 2005	Description: Experimental study examining the effects of scallop dredging on the fauna and sedimentary characteristics of a silty sand community. A 2 m wide Bedford-style scallop dredge was dragged 23 times across the study site and this area was compared to an a undisturbed, adjacent site. The two areas were sampled four and five months before, immediately before and after and four and six months after dredging. Habitat effects: Passing the dredge over the site removed the surface few centimetres of sediment. Food quality of the sediment was reduced, as was calculated by measuring microbial populations, enzyme hydrolysable amino acids and chlorophyll a levels. This reduced food quality showed relatively complete recovery within four to six months. Community effects: Immediately after dredging, macrofauna were significantly decreased in overall abundance and assemblage structure was altered at the dredged site. Macrofaunal abundance and assemblage structure at the dredged site did not recover to levels equivilent to the undredged site before six months. Further notes: Sediment was characterised by silty sand and the depth was 25 m below mean low water.
Ref Number 131 Ref: Thrush, S.F., Hewitt, J. E., Cummings, V. J. & Dayton, P.K. 1995. The impact of habitat disturbance by scallop dredging on marine benthic communities; what can be predicted from the results of experiments? *Marine Ecology Progress Series,* 129, 141-150. Location: Mercury Bay, New Zealand Reviewed by: Gubbay & Knapman, 1999,	Description: Experimental dredging at two subtidal sandflats (depth around 24m) to identify short-term impacts on macrobenthic communities. Comparison with adjacent reference plots. Habitat effects: Natural surface features broken down (eg.emergent tubes, sediment ripples) and teeth on dredge created grooves 2-3cm deep. Community effects: Density of common macrofauna decreased at dredged sites and some significant differences still apparent after 3 months. At both sites more than 50 percent of the common taxa showed significant effects. Differences in recovery process likely to relate to differences in initial community composition and to differences in environmental characteristics. Authors consider the effects recorded were conservative as commercial fishermen work over much larger areas and repeatedly dredge the same area in any one fishing trip.

Ref Number 132 Ref: Bradshaw, C., Veale, L.O. & Brand, A.R., 2002. The role of scallop-dredging disturbance in long-term changes in Irish Sea benthic communities: a re-analysis of an historical dataset. *Journal of the Sea Research,* 47, 161-184. Study date: 1938-1950 and resampling 1998-1999 Location: Irish Sea Reviewed by: Sewell *et al.,* 2007	Description: Data on the benthic community in the Irish Sea was collected by N.S. Jones between 1938 & 1950. The aim of this study was to determine whether over the last 40-60 years the benthic communities had changed and if these changes could have been caused as a result of scallop dredging. To achieve this seven of Jones' sites were re-sampled. Habitat effects: Results from the effects of scallop dredging on sediment indicated that during the 40-60 year study period the sediment at four of the sites (for which there was historical data) became finer and possible at another two sites if estimates of the historical data are correct. The decrease in sediment size made no difference whether the seabed was stony, sandy or gravely initially. Community effects: Community composition was shown to change at all seven sites, but to varying degrees, the amount of change was related to how long the site had been dredged for as opposed to the intensity of the dredging. Species that were considered to be robust, mobile and scavenging had increased in abundance, where as in comparison organisms that were fragile, slow-moving or sessile had decreased in abundance. Further notes: The differences between the modern samples and the historical data were greater than could be accounted for by natural variation and therefore indicates a real long-term change.
Ref Number 133 Ref: Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E. & Brand, A.R., 2000. Chronic fishing disturbance has changed shelf sea benthic community structure. *Journal of Animal Ecology,* 69, 494-503. Study date: 1986-1996 Location: Irish Sea Reviewed by: Sewell *et al.,* 2007	Description: Studied aimed to compare the benthic fauna found in areas that had been exposed to different intensities of bottom-fishing (high or low) over a 10 year period. Data on fishing effort was obtained from 1/3 of the dredging fleet via log books. Ten sites were selected (5 high intensity and 5 low intensity), at each site the following data was collected, 3 day grabs for organic content and sediment particle-size analysis, 3 infaunal samples using an anchor dredge (deployed 1 minute on seabed) and 3 epifaunal samples collected using a 2-m wide beam trawl (towed for 5 minutes). In the laboratory faunal samples were identified to species level where possible and biomass and total number of species was quantified. Habitat effects: The study showed that the disturbance as a result of scallop dredging had led to changes in the community structure of both benthic habitats. The removal of organisms that contribute to the complexity of the habitat may result in the degradation of the habitat to a point where it becomes unsuitable for associated species as well as the target species. Community effects: Abundance and biomass data for the epifaunal and infaunal samples was plotted on K-dominance curves. The results for the low intensity fishing areas showed that the biomass curve was above the abundance curve, this indicated that the community was dominated by a small number of large-bodied organisms. For the high intensity fishing areas the two curves converge, this indicates an increase in physical stress; the community was dominated by a high number of small-bodied organisms. Within the high intensity fishing areas the biomass of brittlestars *Ophiura albida* and *Ophiocomina nigra* was highest and the biomass of soft corals *Alcyonium digitatum*, the large sea urchin *Echinus esculensis*, the bivalve *Glycymeris glycymeris* and the gastropod *Buccinum undatum* were lowest. This change in structure indicated that as a result of repeated dredging the large-bodied organisms have been removed and replaced with small-bodied organisms that are less susceptible to disturbance. Further notes: Two distinct soft sediment habitat types were assessed, i) course sand and ii) gravel. Although the habitats are not specifically SAC designated habitats the study clearly shows the impact that scallop dredging can have on benthic communities.
Ref Number 134	Description: Survey was carried out to test the following statements: high fishing effort i) reduces diversity and evenness,

Ref: Blanchard, F., LeLoc'h, F., Hily, C. & Boucher J., 2004. Fishing effects on diversity, size and community structure of the benthic invertebrate and fish maegfauna on the Bay of Biscay coast of France. *Marine Ecology Progress Series,* 280, 249-260, Study date: 2001 Location: Bay of Biscay coast of France. Reviewed by: Sewell *et al.,* 2007	ii) reduces observed maximum body mass, iii) favours a few body mass classes, iv) increases the steepness of the slope of number-size spectra, v) shifts abundance and biomass distributions among species toward those of a disturbed community, vi) changes species composition. The survey was conducted in around 100m of water to over physical disturbances, 4 areas were chosen, with 2 stations in each. A bottom trawl was carried out in late May and early June 2001, a 2m beam trawl was used to collect samples of demersal fish and invertebrate megafauna. Community effects: Species richness was greatest in the moderately exploited areas (B & D) than in the heavily exploited areas (A & C), although this difference was not considered to be significant. Species diversity however showed a significant difference between the areas, diversity was greatest in the moderately exploited areas and than the heavily exploited areas. An abundance-biomass comparison indicated that areas B & D showed an undisturbed pattern with the abundance curve below the biomass curve, for areas A & C the curves crossed indicating a disturbed pattern. The dominant species also varied between areas. Area B was dominated by an opportunistic, commercial species, *Nephrops norvegicus*, area D was dominated by a sensitive echinoderm *Astropecte*n spp., which was only found in this area. In areas A & C opportunistic carnivores were the dominant species, *Liocarcinus depurator* in area A and *Munida bamffia* in area C. Further notes: Although the no specific SAC habitat or species have been mentioned in this study the results do indicate that fragile and sensitive species are less likely to occur in heavily exploited areas, instead opportunistic and scavenging species are likely to dominate. The study concluded that the differences between heavily and moderately exploited areas were consistent with the hypothesis.
Ref Number 135 Ref: Frid, C.L.J., Harwood, K.G., Hall, S.J. & Hall, J.A., 2000. Long-term changes in the benthic communities on North Sea fishing grounds. *ICES Journal of Marine Science,* 57, 1303-1309. Study date: 1930-1990 Location: North Sea Reviewed by: Sewell *et al.,* 2007	Description: The study involved the review of both published and unpublished data to compile a long-term data set to assess the changes within the benthic communities of the North Sea at five fishing grounds over the past 60 years. The five fishing grounds were: i) Dogger Bank, ii) Inner Shoal, iii) Dowsing Shoal, iv) Great Silver Pit & v) Fisher Bank. Community effects: Results indicated differences between the 1920s and post 1985 samples at three of the five sites; this shift in benthos has coincided with an increase in the fishing power of the fleet. Although there were clear differences over time at three of the sites the changes did not appear to be as a result of a decrease or disappearance of sensitive species or an increase in opportunistic species. Instead the changes appeared to be as a result of changes in abundance of many taxa as opposed to a large-scale loss of sensitive organisms. Despite the fact the study did not indicate a loss of sensitive species it does however indicate that increases in fishing effort can alter the benthic community of the seafloor and therefore must be considered by fisheries managers. Further notes: Fishing types were not listed in the study, but were referred to as bottom and trawl gears.
Ref Number 136 Ref: Kaiser, M.J., Armstrong, P.J., Dare, P.J. & Flatt, R.P., 1998. Benthic communities associated with a heavily fished scallop ground in the English Channel. *Journal of the Marine Biological Association,* 78, 1045-1059.	Description: The paper looked at the benthic communities found in the Fowey/Eddystone scallop grounds in the English Channel (these have been heavily dredged for more than 10 years) and also looked at relating the distribution of scallops to water depth, community characteristics and substratum type. Scallop dredge survey: at each site two scallop dredges were towed for 15 minutes, benthic fauna from the dredges were brought aboard for analysis and identification down to the lowest taxonomic level, species that could not be identified were preserved in 70% alcohol and identification in the laboratory (due to time restrictions only fauna from 2 out of the 4 dredges were analysed). Anchor dredge survey: the dredge was deployed from the stern and left to 'anchor' for 1 minute before being retrieved, each sampled was sized and the residue was preserved in 4% buffered formalin in seawater. Once at the laboratory the fauna were identified to the lowest taxonomic level. At each anchor site sediment samples were also collected using

Study date: July 1993 Location: Fowe/Eddystone Ground (English Channel) Reviewed by: Sewell *et al.,* 2007	a 0.1m2 Day grab. Habitat effects: The greatest abundance of scallops were found in sandy sediment, along with the richest communities and largest biomass of structural epifauna. These species can be removed by scallop dredging altering the community structure; a loss of this biogenic epifauna can have implications for juveniles. The problem being that the juveniles of some commercial species gain protection from predation by other species within these structured habitats. Community effects: Within the sandy sediment samples the most important taxa were: *Ophiurs albida*, *Turritella communis*, *Edwardsia* sp., *Photis longicaudata,*/em> and Eunicidae. Within the gravelly sand sediment samples the most important taxa were: *Owenia fusiformis*, Eunicidae, *Hydroides norvegica*, *Glycera* sp. and *Ophiura affinis*. The results suggested that the emergent fauna such as soft corals, sponges and hydroids are vulnerable to removal fishing gear. Effects to target species: Results from both the scallop dredge survey and anchor dredge survey indicated that the greatest abundance of species was found on sandy sediments, the lowest abundance of species was found on gravelly sand sediments. Further notes: Scallop dredge survey: benthic community could be split into three groups: i) samples that occurred on sandy or gravelly sand sediment, ii) samples that occurred on mostly sand sediment and iii) samples that occurred on sandy sediment and gravelly muddy sand.
Ref Number 137 Ref: Auster, P.J., Malatesta, R.J., Langton, R.W., Watling, L., Valentine, P.C., Donaldson, C.L.S., Longton, E.W., Shephard, A.N. & Babb, I.G., 1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (northwest Atlantic): implications for conservation of fish populations. *Reviews in fisheries Science,* 4, 185-202. Location: Gulf of Maine Reviewed by: Gubbay & Knapman, 1999,	Description: Effects of mobile fishing gear at three sites on a variety of bottom types in the Gulf of Maine were investigated. Habitat effects: Habitat complexity was reduced by direct removal of biogenic and sedimentary structures and the organisms that create structure eg. reduction of an extensive sponge community to the occasional small colony on large boulders, absence of previously widely distributed ascidian, reduced density of shrimp, dispersal of shell deposits by mobile gear. Community effects: Authors discuss how this reduction in complexity may lead to increased predation on juveniles of harvested species and ultimately recruitment to harvestable stock especially in the northeast USA, where fish assemblages are part of a system where predation mortality on postlarval and juvenile fishes has a major effect on year-class strength.
Ref Number 138 Ref: Thrush, S.F., Hewitt, J.E., Funnell, G.A., Cummings, V.J., Ellis, J., Schultz, D., Talley, D. & Norkko, A., 2001. Fishing disturbance and marine biodiversity: role of habitat structure in simple soft-sediment systems. *Marine Ecology*	Description: Authors studied the relationship between macrobenthic species diversity and habitat complexity at 10 spatially separate sites. Experiments were carried out in a 10 - 20m deep large embayment, composed mainly of simple, soft-sediment habitats, varying in sediment and structure. Community effects: The findings of the report strongly suggest that biodiversity is directly related to habitat complexity and that human activities (particularly trawling and dredging) that remove epifauna and lead to habitat homogenisation will reduce biodiversity in soft bottomed habitats.

Progress Series, 221, 255-264. Location: Kawau Bay, North Island, New Zealand Reviewed by: Sewell & Hiscock, 2005	
Ref Number 139 Ref: Blyth, R.E., Kaiser, M.J., Edwards-Jones, G., & Hart, P.J.B., 2004. Implications of a zoned fishery management system for marine benthic communities. *Journal of Applied Ecology,* 41, 951-961. Location: South Devon coast, English Channel Reviewed by: Sewell & Hiscock, 2005	Description: Study examining benthic species assemblages, subjected to four different types of commercial fishing pressure. These were: i) Towed gears only, ii) annual, seasonal towed-gear use, iii) temporary towed-gear use but reverting to static gear use 18 - 24 months before sampling, and iv) static gears only. The survey was undertaken in an IPA (Inshore potting agreement) area, where towed gears had been previously banned, but potting was allowed. Video surveys were used, combined with sampling with towed dredges. Community effects: Higher biomass and diversity of species was found in sites that had not been trawled in the year prior to sampling, compared to towed gear sites. Untrawled areas had higher biomass, but lower species diversity than 'ex-trawl sites'. The Authors suggest that the most important finding of the study was that very little difference existed between benthic communities in trawled sites and seasonally trawled sites. It was suggested that this indicated that a six month cessation of trawling is insufficient to allow recover of benthic communities. Significantly greater biomass of attached species were found at untrawled sites than all other sites. The authors note that this is important, as many attached species are known to provide settlement sites for other benthic species and shelter for a number of fish species. Further notes: The substratum at the study site was mixed, coarse sand.
Ref Number 140 Ref: Collie, J.S., Escanero, G.A. & Hunke, L., 1996. Scallop dredging on Georges Bank: Photographic evaluation of effects on benthic epifauna. CM, 1996/Mini: 9. Location: Georges Bank, Canada Reviewed by: Gubbay & Knapman, 1999,	Description: Photographic evaluation of the effects of scallop dredging on Georges Bank. Habitat effects: small differences in sediment type between dredged and undredged sites with dredged sites having a slightly higher frequency of small pebbles, and the undredged sites having slightly more larger pebbles and cobbles. Community effects: Samples of benthic megafauna from disturbed and undisturbed sites showed that disturbed sites had lower density of organisms, biomass, and species diversity than undisturbed sites. Many of the species that were absent or less common in dredge sites were small, fragile polychaetes, shrimps and brittlestars. Most apparent difference was the lack of colonial, epifaunal taxa at the disturbed site. This study aimed to give a quantitative assessment of the impact using still photographs. Comparison of deep sites showed that *Filograna implexa* had a high percentage cover at the undredged site and no epifauna and few animals visible at the dredged site. Significant effect between depth and dredging for both *F. implexa* and plant-like animals with effect on percentage cover greater at the deep sites. For plant-like animals the effect was higher at the shallow sites. *Protula tubularia* was significantly more abundant at undredged than dredged sites. There were no differences in the proportion of photographic sampling cells with bryozoans in them, but dredged sites had a significantly higher proportion of cells with abundant bryozoans than undredged sites. *Spirorbis* was more abundant at the deep sites and was in higher frequencies at the dredged sites than undredged sites. Most likely explanation is that the emergent epifauna at undredged sites concealed encrusting bryozoans and *Spirorbis* from view. Depth had the greatest effect on the frequencies of non-colonial animals. Dredging had a lesser, but still significant effect on the frequencies of non-

	colonial species. Undredged sites had higher frequencies of almost all taxa except burrowing anemones, the earshell *Sinum perspectivum* and hermit crabs. Most of the non-colonial taxa seemed to be negatively affected by dredging but some seemed to profit from dredging. Burrowing anemones were more prevalent at dredged sites for example, perhaps because tentacles easily retracted to safety. Results consistent with the hypothesis that gravel habitats are very sensitive to physical disturbance by bottom fishing and the primary impact is the removal of emergent epifaunal taxa. Further notes: Gravel sediment
Ref Number 141 Ref: ICES, 1996. Report of the Working Group on Ecosystem effects of fishing activities. C.M. 1996/Assess/ Env:1. Ref: G. Location: Northern Georges Bank, NW Atlantic Port Erin, Isle of Man Reviewed by: Gubbay & Knapman, 1999,	Description: Update on studies relating to areas closed to fishing. Community effects: Comparison of community structure in areas of high and low scallop dredging on northern Georges Bank shows undredged sites had higher densities of shallow burrowing and epibenthic species, more abundant *Modiolus modiolus* and more abundant small fish. Hard-shelled molluscs were equally abundant at dredged and undredged sites as well as scavenger species suggesting that scavenger abundance was not food limited. No consistent differences in mean size and weight of species between dredged and undredged sites. Many polychaete species were only abundant at the undredged sites because of the complex habitat there. Habitat complexity was higher at the undredged sites due to present of *Filograna implexa*, bushy bryozoans and hydroids. Closed area (from 1989) of scallop ground off Port Erin, Isle of Man is being used to assess environmental impact of scallop dredging. Benthic community and physical habitat has been compared with adjacent areas since 1994 and two plots within the closed area experimentally dredged at 2 month intervals. Results to date show differences in the epifaunal communities including greater species consistently more abundant in undredged areas. Further analysis shows this was due to absence of dredging and not variations in sediment or depth. Overall higher densities of shallow burrowing and epibenthic species at the undredged sites but particular species noted for their vulnerability to dredging eg *A. digitatum*, *Anseropoda placenta Luidia sarsi*, *Cellaria fistulosa* and *E. esculentus*. There was no evidence of longer-lived benthic species at undredged sites but this was not surprising due to relatively short time since effective closure of the area. Scavenger species were common at both dredged and undredged sites with *A. rubens* consistently more abundant on the dredged sites. Ratio of polychaetes to molluscs was lower at the dredged sites and may be due to greater habitat complexity in the closed area although authors also note that infaunal bivalves were probably not adequately sampled. Further notes: Two studies described here. Other studies reported are trawling experiment on the Grand Banks, North Sea Plaice Box, Loch Gareloch (Scotland) and Gullmar Fjord (Sweden).

Ref Number 142 Ref: Collie, J.S., Escanero, G.A. & Valentine, P.C., 2000. Photographic evidence of the impacts of bottom fishing on benthic epifauna. *ICES Journal of Marine Science,* 57, 987-1001. Location: North edge of Georges Bank, North America. Reviewed by: Sewell & Hiscock, 2005	Description: Video and photographic survey of sites with varying degrees of fishing disturbance along transects during two experimental cruises to the area. Habitat effects: Emergent colonial epifauna provided a complex habitat for a number of invertebrates and small fish at undisturbed sites. Bottom fishing was found to remove this epifauna, thus reducing the structural complexity and species diversity of the benthic community. Community effects: For photographed sites, significant differences between disturbed and undisturbed areas were found for; the percentage of the bottom covered by "bushy, plant-like organisms" and colonial worm tubes and the presence or absence of encrusting bryozoa. Colonial epifauna were conspicuously less abundant at disturbed sites. Further notes: Sediment types included sand, gravelly sand, pebbles, cobbles and boulders.
Ref Number 143 Ref: Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2001. The effect of scallop dredging on Irish Sea benthos: experiments using a closed area. *Hydrobiologia,* 465, 129-138. Study date: 1995 - 2000 Location: South west coast of the Isle of Man Reviewed by: Sewell & Hiscock, 2005	Description: Experimental study using an area closed to scallop dredgers since 1989. Experimental plots were set-up outside the closed area, in an area still exposed to commercial trawling, unfished plots and experimentally trawled plots were also set up inside the closed area. Plots were studied using grab sampling and diver counts of *Pecten maximus*. Community effects: Benthic communities in experimentally dredged plots became less similar to adjacent undredged sites and more like commercially dredged sites. Since 1989, an increase in numbers of and age of *Pecten maximus* occurred in the closed area.
Ref Number 144 Ref: Thrush, S.F., Hewitt, J.E., Cummings, V.J., Dayton, P.K., Cryer, M., Turner, S.J., Funnell., G.A., Budd, R.G., Milburn, C.J. & Wilkinson, M.R., 1998. Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. *Ecological Applications,* 8, 866-879. Location: Inner Hawraki, New Zealand Reviewed by: Sewell *et al.,* 2007	Description: Paper tests priori predictions taken from the literature of changes in population, taxonomic and functional groups, as well as looking at community-level characteristics with changes of fishing pressure. A high resolution side scan sonar was used to survey the seafloor and identify sites with differing levels of fishing activity and environmental conditions. An ROV was used to conduct video transects of the seafloor at each site; this enabled the density of large epifauna to be estimated. At a central area of each site macrofauna was sampled, at muddy sites with was done using a grab and at sandy sites using a suction dredge. 15 core samples were also randomly taken at each site. Habitat effects: Side scan sonar indicated a number of scallop dredge marks in the sediment. One of the most important ecological effects is related to changes in habitat complexity, the removal of organisms that add complexity to benthic habitats can be very destructive as can the homogenization of sediment characteristics by the physical action of both trawls and dredges. Both can cause a reduction in spatial heterogeneity over a range of ecologically important scales. From a theoretical point heterogeneity is an important component of ecological systems which can have implications fro the maintenance of biodiversity and stability at all levels (population, community and ecosystem level). Community effects: Results from the video data indicated that for each site as a whole the density of epifauna produced the results that were predicted, as fishing pressure decreased the density of large epifauna increased. The grab and suction dredge data indicated that density of deposit feeders, total number of individuals and epifauna were all influenced by fishing pressure, although not all were significantly influenced. In each case as fishing pressure decreased the density of deposit feeders, total number of individuals and epifauna increased. The predictions tested have important consequences for

	changes in both sediment structure and function of benthic communities. Further notes: Note the trawling method used was a Danish Seine trawl for snapper. The study area was ranked in terms of potential habitat disturbance as a result of commercial bottom trawling and dredging. During the development of ranking the fisheries, scallop dredging was considered to cause more disturbance than both bottom trawling or Danish seine trawling. The fisheries were ranked based on local legislation and information from fisheries managers. Paper has demonstrated a relationship between habitat disturbance by commercial fishing and regional-scale changes in macrobenthic community structure.
Ref Number 145 Ref: Caddy, J.F., 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. *Journal of the Fisheries Research Board of Canada,* 30, 173-180. Location: Chaleur Bay, Gulf of St Lawrence Reviewed by: Gubbay & Knapman, 1999,	Description: Trials looking at effects of three types of trawling gear on bottom sediments. Shallow traces made by inshore and offshore scallop dredging could be distinguished from each other. Habitat effects: Scallop dredging observed to lift fine sediments into suspension, bury gravel below the sand surface, and overturn large rocks embedded in the sediment, appreciably roughening the bottom. The inshore Alberton dredge was inefficient, dumping its contents back on to the bottom at intervals. Trawl tracks were seen as grooves on the seafloor - considered to be made by otter trawl doors. Suspended sediment in dredge tracks reduced visibility from 4-8m to less than 2m within 20-30m of the track but dispersed within 10-15mins, coating the gravel in the vicinity of the track with a thin layer of fine silt and obscuring *Lithothamnion*. Offshore dredge - gravel fragments overturned. Depressions left by tow bar of the dredge. Gravel less frequent inside the track. Inshore dredge (Alberton) tracks left, gravel sparser inside and dislodged boulders commonly observed. Tooth marks over sandy bottom. Bottom type and hydrographic regime in the Bay probably allowed marks made by fishing gear to remain recognisable for a long time as tidal currents faster than 1km/hr were not encountered. Even a relatively minor fishery may therefore have a significant cumulative effect on bottom microtopography under these conditions. Scallop and otter tracks could be distinguished, scalloping contributing to an appreciable roughening of the bottom, lifting large boulders and overturning many of them, presumably leading to destruction of the epifauna on their upper surfaces. Under strong tidal flow author considers that intensive dredging will lead to erosion of sediment lifted into suspension by the dredge - this aspect needs more study. Community effects: Dredging caused appreciable lethal and sublethal damage to scallops left in the track. Damage greatest on rough bottom. Predatory fish and crabs were attracted to dredge tracks within 1hr, and fish were observed in the tracks at densities 3-30 times those observed outside the tracks. There was a pronounced and rapid aggregation of foraging fish - a natural response which also occurs in the absence of fishing operations.

Ref Number 146 Ref: Chapman, C.J., Mason, J. & Drinkwater, J.A.M., 1977. Diving observations on the efficiency of dredges used in the Scottish fishery for the scallop, *Pecten maximus* (L). *Scottish Fisheries Research,* 10, 16. Reviewed by: Gubbay & Knapman, 1999,	Description: Observation of standard and spring-loaded dredges. Habitat effects: Bottom deposits settled about 20 mins after hauling. Short teeth of these dredges dug in up to Â½ to Â¾ of their length and generated a large mound of sediment in front of the toothed bar. Most was deposited around the sides of the dredge and at times completely filled the dredge opening, particularly when large stones or shells blocked some of the gaps between the teeth. Dredge tracks were distinct, ridges of sediment being deposited each side, but path of the spring-loaded dredge less obvious than standard dredge. Community effects: The dredges caused some damage to benthic organisms. Most hauls had a few crabs *Cancer pagarus* and starfish eg *Marthasterias glacialis* broken up by the gear. The teeth also dug out several sub-surface animals including heart urchins *Spatangus purpureus* and the mollusc *Laevicardium crassum*. These and other organisms raked up by the teeth appeared to attract several fish and invertebrate predators including juvenile cod adult plaice and dogfish, whelks and hermit crabs.
Ref Number 147 Ref: Ramsay. K., Kaiser. M.J. & Hughes, R.N., 1998. Responses of benthic scavangers to fishing disturbance by towed gears in different habitats. *Journal of Experimental Marine Biology and Ecology,* 224, 73-89. Location: Walney Island, Anglesey offshore and Red Wharf Bay. The Irish Sea Reviewed by: Sewell & Hiscock, 2005	Description: Surveys were undertaken of three sites before and after trawling. Site One: Dulas Bay. Sediment was coarse sand with gravel and low commercial fishing activity. Site Two: Red Wharf Bay. Sediment was medium sand, occasionally fished. Site Three: Walney Island. Muddy sediment, heavily fished. 4 m wide beam trawl was used at all sites. Eight 0.75 m wide Newhaven, scallop dredges were used at Site Two only. Community effects: At Site One, numbers of hermit crab *Pagurus bernhardus* increased following trawls. At Site Two, no increase in scavangers was observed immediately after trawling, however 25 hours after fishing, the abundance of some scavanging starfish and brittle stars increased significantly. At Site Three, the abundance of some previously abundant scavanging species decreased following trawling disturbance. Damage to large, fragile organisms was observed by divers, following trawls.
Ref Number 148 Ref: Robinson, S.M.C., Bernier, S.& MacIntyre, A., 2001. The impact of scallop drags on sea urchin populations and benthos in the Bay of Fundy, Canada. *Hydrobiologia,* 465, 103-114. Study date: 1993 Location: Bay of Fundy, Canada. Reviewed by: Sewell & Hiscock, 2005	Description: Study examining the effects of scallop dredging fo sea urchins and scallops on the proportion of sea urchins damaged during the harvesting operation, the impact on and subsequent recovery time of the associated benthic flora and epifauna, and the impacts on the bottom substrate. Diver surveys were carried out immediately before and immediately after and three and six months after the passage of a scallop dredge. Two sites were chosen, with an experimental and control plot at each site. Habitat effects: Boulders of varying sizes were dislodged and overturned by the dredge. Community effects: At both experimental sites, a decrease in urchin numbers and an increase in broken urchin tests was observed following the harvesting operation. There were significant changes in numbers of predators. The breakage rate of kelp was also increased as a result of dredging. Further notes: The observable effects on the bottom from the single dragging event were gone in less than 3 months.

Ref Number 149 Ref: Bullimore, B., 1985. An investigation into the effects of scallop dredging within the Skomer Marine Reserve. Location: Skomer Reviewed by: Gubbay & Knapman, 1999,	Description: Pre-dredging surface followed by qualitative and quantitative assessments (although not at the same stations), photographs and sediment samples. Habitat effects: Conspicuous tracks on the seabed about 4m wide. At each site a ridge of stones, shells and shell fragments approx. 15cm high and 30cm wide. Inside ridges shallow grooves formed by rubber bobbins at the ends of the towing beam. Examination of tubes of the anemone Cerianthus *lloydii* in the dredge paths suggested top 2-4cm had been removed. Passage of dredge created a thick sediment cloud the heaviest constituents of which settle out rapidly and close by. Fine sediments were carried away by the tide. Community effects: Dredge bags contained shells and stones most of which supported sponges, hydroids, small anemones, tube-worms, barnacles, ascidians and bryozoans. Remains of several *P. folicacea* and large numbers of small crustaceans (chiefly *Pilumnus hirtellus*), molluscs (especially *Trivia* spp.) and juvenile echinoderms within the folds of the colonies. Also several sponges (mostly *Suberites*spp.) and a large number of epibenthic echinoderm species in the catch. Predators and tidal currents removed much evidence of killed or injured animals in the 24 hours after dredging but dead or damaged tubeworms, crabs, squat lobsters echinoderms and P. foliacea were found. Large numbers of *C. lloydii* present in dredge path. Broken tops of *l. conchilega* tubes were common in dredge paths but large numbers of intact tubes suggested that the worms had survived and rebuilt their tubes. Large mobile epifauna generally absent from dredge path except for occasional scavenging *A. rubens* although within 48hrs smaller mobile species such as hermit crabs were present. Counts of infauna in and immediately alongside dredge paths showed these species were unaffected by the level of dredging. Sessile species found during presurvey but not seen in dredge paths include shell fauna, *C. celata*, Suberities spp. *A. digitatum* and *P. foliacea*. Further notes: Sediment types: Mixed sediment chiefly sand and shell gravel with varying quantities of silt, shells, gravel, stones and cobbles.
Ref Number 150 Ref: Devon Wildlife Trust, 1993. Lyme Bay: A report on the nature conservation importance of the inshore reefs and the effects of mobile fishing gear. Location: Lyme Bay, England Reviewed by: Gubbay & Knapman, 1999,	Description: Pilot survey of reefs subject to bottom trawling/dredging on a variety of seabed types; flint shards; sand, broken shell and dead maerl; sand, gravel, broken shell and dead maerl overlain with cobbles and small rocks; reef of mudstone ledges. Community effects: Clear differences in epifaunal communities between areas considered to be worked by mobile fishing gear and those not, however different sediment types in these areas is another influence. Reefs highly vulnerable to removal of epifauna and erosion caused by the action of the gear. Reefs with large boulders or severe topography which prohibits the use of fishing gear considered to be self protecting. Complex areas of sandy pockets, cobbles and boulders the size of which do not prohibit the use of rock hopper or spring loaded dredges, which support slow growing and numerous hydroids, anemones and corals, bryozoans, tunicates and echinoderms particularly vulnerable to highly mobile fishing gear. Recolonisation and recovery likely to be slow. . Further notes: Potential loss of productivity, habitat, and food caused by highly mobile fishing gear, may lead to the direct mortality of commerciality exploitable reef dwelling species

Ref Number 151 Ref: Currie, D.R. & Parry, G.D., 1999. Impacts and efficiency of scallop dredging on different soft substrates. *Canadian Journal of Aquatic Science,* 56, 539-550. Location: Port Phillip Bay, southeastern Australia Reviewed by: Sewell *et al.,* 2007	Description: The impacts of scallop dredging were examined through an experimental study at three sites in southeastern Australia (Dromana, St Leonards and Portarlington), which were closed to scallop dredging in 1991. The areas chosen represented a wide range of sediment types in the 10-20m depth zone (depth at which most of the commercial scalloping takes place). Two experimental plots were located in each area. Each plot was dredged for a maximum of 3hrs/day for 2-4 days by a fleet of 5-7 commercial scallop vessel using 3m wide 'Peninsula' dredges. Number of scallops and bycatch species caught were recorded. To assess visual changes caused by the scallop dredge diver-operated video recorded was also carried out at each plot before and after the dredging at various time intervals (at one site Portarlington the site was not videoed before dredging due to poor visibility). Habitat effects: The dredging that occurred flatten all plots, however changes were most apparent at the St Leonards site which was dominated by callianassid mounds before dredging. Community effects: Differences in bycatches species were clearly visible between the different areas. At Dromana the most abundant bycatch species in the sandy sediment were oysters, sea quirts, whelks, hermit crabs and giant spider crabs. In the muddy sediment at Portarlington sea squirts, sea cucumbers and brittle stars were the most abundant species, the bycatch at St Leonards included species from both of the other two sites. Dredges were most efficient on soft, muddy, flat sediment catching 51-56% of commercial sized scallops, where as on firm, sandy sediments with varying topography dredges were less efficient catching only 38-41% of commercial sized scallops. Further notes: Sediment types included: medium sand (at Dromana), fine sand (at St Leonards) and coarse silt (Portarlington).
Ref Number 152 Ref: Schwinghamer, P., Gordon, D.C. Rowell, T.W., Prena, J., McKeown, D., Sonnichson, G. & Guignes, J.Y., 1998. Effects of experimental otter trawling on surficial sediment properties of a sandy-bottom ecosystem on the Grand Banks of Newfoundland. *Conservation Biology,* 12, 1215-1222. Location: Grand Banks Reviewed by: Gubbay & Knapman, 1999,	Description: Three year study into the effects of otter trawling on a sandy-bottom ecosystem of the Grand Banks. Sediment samples, acoustic measurements and video surveys undertaken. Habitat effects: Statistical analysis of seven size fractions gave no evidence that trawling had any immediate effect on sediment grain size. Sidescan sonar showed the persistence of door tracks was variable from several months to a year. Acoustic data suggest that repeated trawling did not affect sediment texture but increased surface relief or roughness. Small-scale biogenic sediment structure down to 4.5cm also changed. Video surveys showed clear differences in the appearance of the seabed. After trawling hummocks were removed or less pronounced, organic floc was either absent or less abundant and mottled appearance of the seabed less pronounced. Sediment grain size data suggest that there may be natural inter-annual changes that are more pronounced than those caused by the experimental trawling. Community effects: Video imagery showed organisms and shell has organised into linear features in the trawled areas. At times high concentrations of *Strongylocentrotus pallidus* were visible and seemed to be scavenging on dead snow crabs. Biological effects have still to be examined.
Ref Number 153 Ref: Kaiser, M.J., Spence, F.E. & Hart, P.J.B., 2000. Fishing-Gear Restrictions and Conservation of Benthic Habitat Complexity. *Conservation Biology,* 14, 1512-1525.	Description: Differences in benthic community structure and habitat complexes in areas exposed to different levels of bottom-fishing activity were assessed. The level of the bottom-fishing activity was dependant upon the restrictions imposed by a voluntary management agreements existing between towed bottom gear fishers and fixed gear fishers. Fishing effort was divided into three groups: 1) low fishing effort with 3 sites, one with no trawling permitted and two where potting only occurred all year, 2) medium fishing effort with 2 sites both with seasonal trawling and 3) high fishing effort with 3 sites where trawling was permitted all year. At each site a grid of 9 sampling stations was established, at each station infaunal samples (using an anchor dredge), epifaunal samples (using a 2m beam trawl), sediment samples (using a Day gab) and acoustic ground-discrimination data was collected. Five

Location: Salcombe, south Devon coast Reviewed by: Sewell *et al.,* 2007	environmental paramteres were quantified: median grain size, water depth, percentage organic content, mass of stone and mass of shell. Habitat effects: The video-transect showed that the rocky outcrops and reefs occurred throughout the closed areas it is known these reefs can support a number of species. The reefs consist of fragile rock that can get caught when sampling gear is misplaced or when the voluntary agreement is broken. The number of stones and rock fragments in the survey samples were much higher in areas that had been exposed to towed fishing gear. Community effects: In the areas closed to fishing activities communities were dominated by higher biomass and emergent fauna that increased the habitat complexity. One species in particular was most abundant in this closed area, *Glycymeris glycymeris*, this species is vulnerable to fishing because it lives close to the sediment surface and reproduces infrequently. In comparison those areas where towed gear was permitted were dominated by scavenging taxa and smaller-bodied fauna. Further notes: Results indicated that management to avoid conflict between fishermen has the added benefit of being able to conserve benthic fauna and habitats that are sensitive to bottom-fishing disturbance.
Ref Number 154 Ref: Sea Fish Industry Authority, 1993. Benthic and ecosystem impacts of dredging for pectinids, (reference 92/3506) Consultancy Report No.71 Location: Lyme Bay (Beer Home Ground and Eastern Heads) Reviewed by: Gubbay & Knapman, 1999,	Description: Single pass of full sized scallop dredge (12 spring-loaded dredges, deployed either side in groups of 6 attached to two beams) along 300m transects. Video recordings before and after and survival studies of specimens in laboratory for 14 days. Habitat effects: Scallop dredging can alter the substrate composition. Stones and boulders (up to 60cm in length) overturned, small boulders piled against larger boulders, fragments of mudstone reef broken off, sand waves in the dredge path completely obliterated, suspension followed by settlement of fine sediments disturbed by the dredge and displacement of substrate (apart from mudstone, loose rocks brought to the surface and shovelled off the deck once the catch had been sorted). Overall there was a markedly changed appearance the most striking being the covering of all boulders and rocks with a fine coating of sediment. Chipping and movement of cobbles and boulders has implications for the habitat of juvenile crabs, particularly *Cancer pagurus*, which appears to inhabit the areas of soft mudstone. Of the habitats studied, area of sand waves was probably the least vulnerable to scallop dredging in the long term. Community effects: Changes in species observed before and after dredging due to various factors; revealed by dredge as substrate overturned, dug out of substrate (eg *Pomatocerus triquiter*, *Pecten maximus*) or dislodged off the interstices eg *Maja squinado*; species hidden *Porifera*, destroyed *Pentapora foliacea*, injured or killed by action of dredge (adult crustaceans) and attracted by injured specimens in wake of the dredge *Pollachus* spp. crustaceans. Survival of dredged specimens in laboratory tanks showed surprising resilience of juvenile *C. pagurus* and *Pholus dactylus* which remained in the honeycomb mudstone, sea squirts died rapidly compared to controls and starfish exhibited comparable survival between experiment and control. No clear cut evidence in the case of *P. foliacea* and *E. verrucosa* but these most likely to suffer from being displaced as unlikely to re-establish themselves so mortality of these species seems likely. Response of the whole system to dredging will depend on resettlement and growth of new stock and whether the substrate is suitable for this. The vulnerability of the system switching to another system would depend on importance of the species affected. If slower growing species with poor recruitment (eg *E. verrucosa* or slow growing but rapidly recruiting (eg *P. foliacea*) hold the system in its present form there is a high risk of complete change. Further notes: Substrate types: Mudstone reefs, cobble and bulder seabed, sandy areas with boulders and sandy substrates.

Ref Number 155 Ref: ICES, 1992. Report of the study group on ecosystem effects of fishing activities. C.M. 1992/G:11. Location: North East Atlantic, North Sea, Irish Sea Reviewed by: Gubbay & Knapman, 1999,	Description: Review report describing direct effects of fishing. Habitat effects: all towed gears which exploit bottom-living species disturb the sediment and may therefore have an impact on the structure and processes at the seabed. Grain size distribution, sediment porosity and chemical exchange process are properties which may be affected. Another direct consequence is displacement of boulders which would otherwise be a surface for epifauna. A direct consequence of disturbance is an increase in suspended sediment load and the possibility of net transport of finer sediments. Resuspension may also influence uptake or release of contaminants, a shift in sediment-water exchange eg of nutrients. Reworking of sediments may result in burial of organic matter. Gears which disrupt the sediment most are beam trawls and shellfish dredges but method of rigging can have a profound effect on the level of disturbance. Community effects: Box cores revealed extensive changes to infauna before and after trawling. Significant reduction in burrowing sea urchin and the density of tube-building polychaetes. Survival rates for infauna and epifauna caught in net of beam trawl were high for starfish, many molluscs and crabs but poor for *Arctica islandica*. Trawl-caught whelks and hermit crabs largely unaffected. These results suggested that a relatively high proportion of some benthic species can be killed in the path of a beam trawling. In relation to scallop dredging epibenthic mortalities can be marked. Effects on seabed and benthos depend on substrate type, hydrographic features and community structure as well as the design and operation characteristics of the gears. Seabirds have been killed in gill and other static nets, no comprehensive studies of entanglement in the North Sea but available evidence indicates that it is likely to occur for diving birds in areas with fixed net fisheries. Gill net fisheries in some places have had a high bycatch of diving birds. Seals may be caught in gill nets, fyke nets and fixed nets for salmon. Gill nets killed the most cetaceans, catch rates varying seasonally. Around the British Isles several species of small cetacean have been reported as incidental catches but in the North Sea reported bycatches of species other than harbour porpoise are rare. As well as catch, fishing operations cause incidental mortality of fish which escape from the gear. Gill nets, tangle nets and traps may continue to fish for some time after being lost of discarded. Length of time depends on factors such as current speed and fouling. On the bottom multifilament nets remain tangled, monofilament nets may, once clear of fish remains and crabs, disentangle, return to an upright position and resume fishing. Over time they build up an encrusting layer of marine organisms and become more visible to fish. Fragments of nets of all types may also entrap seabirds and marine mammals. Direct effects of fishing compared with the effects of other anthropogenic influences and natural processes also discussed, along with long-term effects of fishing activities. In the long term there may be changes in the feeding relationships of organisms, changes in the genetic makeup of populations and other changes such as in the habitat. The mix of direct and indirect effects makes it extremely difficult to establish causal relationships between the amount of fishing and observed long-term population changes. Long-term cascading changes in community structure may occur if 'keystone' populations are adversely affected by fishing, leading to marked changes in the pattern of predation and or competition. One general effect that has been suggested for benthic communities is that overall productivity may increase due to long-lived slow growing taxa being replaced by smaller faster growing taxa whose populations are better able to respond numerically to continued disturbance. Such shifts, it has been suggested, could lead to changes in other community parameters such as species diversity. However, not all levels of disturbance will necessarily result in lower community diversity. Current ecological theory supports the idea that intermediate levels of disturbance would result in an increase in diversity.
Ref Number 156 Ref: Southern Science, 1992. An experimental study on the impact of clam dredging on soft sediment macro invertebrates. Location: Langstone Harbour	Description: Treatment and control type dredging experiment, 2 passes of a modified oyster dredge. Habitat effects: Sediment removed to a depth of between 15-20cm by dredging and gravel fraction reduced. Sediments may become more anoxic after dredging. Dredge tracks most likely to be filled with fine sediment in low energy conditions therefore discrete habitat variation will be created. Resuspended sediment may have serious survival implications for species unable to deal with heavy suspended sediment loads. Community effects: Due to the deep penetration of the dredge all fauna, with the exception of bivalves (eg *Abra tenuis*, *Cerastoderma edule* and *Mya*

Reviewed by: Gubbay & Knapman, 1999,	*arenaria*) were removed completely in the short term. It is likely that these organisms were dislodged and then redeposited by the dredge or that they migrated or were passively dispersed into the area from adjacent undredged areas. Annelids were most badly affected by the dredge with the exception of *Tubificoides benedeni* and a phyllodocid. Abundance of bivalves was also greatly reduced but some found in some dredged samples (small specimens thought to have been disturbed by the dredge and re-deposited afterwards). No clear recovery of fauna evident over the 8 day period of study but opportunistic polychaetes (eg *Capitella capitata* and *Tubificoides benedeni*) likely to be early colonisers of disturbed mudflats along with the surviving bivalves. Authors suggest these will be followed by active polychaete species eg *Eteone longa* and more stable habitat species such as *Cirriformia tentaculata*. Continual disturbance will not favour stable habitat species, high biomass communities may occur but are unlikely to contain individuals of high biomass which may be exploited as a food source by birds.
Ref Number 157 Ref: Langton, R.W. & Robinson, W.E., 1990. Faunal associations on scallop grounds in the western Gulf of Maine. *Journal of Experimental Biology and Ecology,* 144, 157-171. Study date: July 1986 and June 1987 Location: Western Gulf of Maine Reviewed by: Sewell *et al.,* 2007	Description: The paper aimed to asses the factors controlling the distribution and abundance of the sea scallop *Placopecten magellanicus* and evaluate the spatial relationship amongst megafaunal invertebrates that also inhabit the ground at two sites. However, coincidentally one of the sites (Fippennies Ledge) was dredged prior to the second year of data collection, which provided a chance to observe the effect that scallop dredging had on the megafaunal community. Five dives were made in a manned submersible in 1986 (2 at Jeffreys Ledge and 3 at Fippennies Ledge), in 1987 the Fippennies Ledge was revisited and 6 transects were completed. For each dive analysis four data sets were available: i) 35-mm photographs, ii) videotapes, iii) transcript of the driver-scientists' observations and iv) the ships bridge log. Habitat effects: The most obvious difference between the dredged site in 1987 and the pre-dredged site in 1986 was a change in substratum from a more organic-silty sand to a sandy gravelly appearance. This was said to be as a result of disruption to the tube mats produced by the amphipod *Erichthonius* sp., which were abundantly found in box core samples. Since no diving took place at a later date, it was no possible to determine how long the effects would have lasted. Community effects: Three species of megafauna were dominating at both sites, the burrowing certianthid anemone *Cerianthus borealis*, the sabellid worm *Myxicola infundibulum* and the sea scallop Placopecten magellanicus, all three of the species showed a large scale cluster distribution. As a result of the marked increase in scallop dredging between 1986 and 1987 at Fippennies Ledge there was a marked decrease in the density of all three megafaunal species, *Placopecten magellanicus* declined by 70%% , and both *Cerianthus borealis* and *Myxicola infundibulum* declined by 25-27%. Further notes: Based on submersible observations, Jeffreys Ledge had been dredged for scallops quite heavily in 1985 and 1986. The Fippennies Ledge showed little evidence of dredging before 1986, but was heavily dredged between July 1986 and June 1987.

Ref Number 158 Ref: Veale, L.O., Hill, A.S., Hawkins, S.J. & Brand, A.R., 2000. Effects of long-term physical disturbance by commercial scallop fishing on subtidal epifaunal assemblages and habitats. *Marine Biology,* 137, 325-337. Study date: 1995 Location: North Irish Sea, around the Isle of Man. Reviewed by: Sewell & Hiscock, 2005	Description: The paper examines spatial differences in the distribution of bycatch assemblages from scallop fishing grounds. High-resolution fishing effort data was extracted from fishermen's logbooks and used to identify areas with varying levels of disturbance. Species composition of experimental trawls at different sites over time was analysed and compared. Community effects: Species diversity and richness, total number of species and number of individuals all decreased significantly with increased fishing effort, as did total abundance, biomass and production of most major individual taxa investigated. Species dominance increased with fishing effort. Bycatch assemblage structure was more closely related to fishing effort than any other environmental variable examined. Further notes: Substratum was generally coarse sand or gravel
Ref Number 159 Ref: Hall-Spencer, J.M. & Moore,P.G. 2000. Impact of scallop dredging on maerl grounds. In *The Effects of Fishing on Non-target Species and Habitats: Biological, conservation and socio-economic issues* (ed. M.J. Kaiser & S.J. de Groot), pp. 105-117. Location: Clyde Sea, Scotland. Reviewed by: Sewell & Hiscock, 2005	Description: Study examining the effect of dredging for scallops at previously fished and previously unfished maerl beds. Fishing took place using a gang of 3 Newhaven dredges with 77 cm mouth width. The impact on benthic species was measured, as was bycatch in the dredges. The dredge sites were monitored imediately after dredging and four times a year for the following four years. Habitat effects: Direct observations showed profound 2.5 m wide tracks were made through the maerl beds, in which, all natural bottom features were erased. Rocks and boulders were overturned, sediment was brought to the surface and live maerl was buried. Community effects: During the trawl a number of large and fragile species were killed or damaged by the trawl. This included damage to individuals and nests of the file shell *Limaria hians*. Investigations immediately after the dredge revealed littering of animal fragments and damaged animals across the seabed. This was followed by an influx of opportunistic scavanging species, that began to disperse after three days. Different groups of organisms recovered at different rates over the four years of surveying after dregding. Large, slow-growing bivalves such as the horse mussel *Modiolus modiolus* and the file shell and some sponges and anemones had not recovered after four years. File shells, their nests and diverse associated fauna remained absent for the duration of the surveys. Further notes: On each tow, 8-15 kg of bycatch organisms were caught for every 1 kg of scallops.

Ref Number 160 Ref: Hall-Spencer, J.M. & Moore, P.G. 2000. Scallop dredging has profound long-term impacts on maerl habitats. *ICES Journal of Marine Science,* 57, 1407-1415. Location: Clyde Sea area, Scotland. Reviewed by: Sewell & Hiscock, 2005	Description: The work was a comparison between maerl and associated benthos in regularly fished and unfished areas, both before and after dredging with a 77 cm diameter Newhaven scallop dredge. The study included comparison between maerl thalli collected in the late 1800s and the study date from a separate site, which had been extensively dredged for the prior 40 years. Habitat effects: A 2.54 m wide track with three parallel furrows was created at test sites in both areas. All natural, physical bottom features were eliminated and boulders of up to one cubic metre had been dragged along the surface. Sculpted ridges made by the trawl were still apparent after 2.4 years at the previously undredged site and 1.5 years at the previously dredged site. Community effects: The scallops *Pecten maximus* were more abundant at the unfished site. File shells *Limaria hians* and their nests and the scallop *Aquipecten opercularis* were present at unfished sites, but not at fished sites. Immediately following the trawl, live maerl was buried and biogenic structures were crushed and destroyed. There were no signs of recovery of maerl within the four year study. Further notes: Historical comparisons of maerl revealed that in the late 1800s, the average size of maerl thalli was significantly greater and live maerl was far more abundant than following fishing activity.
Ref Number 161 Ref: Kamenos, N.A., Moore, P.G. & Hall-Spencer, J.M., 2003. Substratum heterogeneity of dredged vs un-dredged maerl grounds. *Journal of the Marine Biological Association of the United Kingdom,* 83, 411-413. Location: The Stravanan Bay, Isle of Bute and The Caol Scotnish, Loch Sween. Scotland Reviewed by: Sewell & Hiscock, 2005	Description: Comparison of substratum heterogeneity of a dredged site (Stravanan Bay) and an undredged site (Caol Scotnish). Habitat effects: Structural heterogeneity was far lower in impacted, dead maerl, which had similar heterogeneity to gravel. Unimpacted maerl had higher structural heterogeneity. Further notes: The authors suggest that maerl beds with higher structural heterogeneity will support a wider diversity of associated organisms and will be more important as nursery areas for larger species.

Ref Number 162 Ref: Hall-Spencer, J.M., Grall, J., Moore, P.G. & Atkinson, R.J.A., 2003. Bivalve fishing and maerl-bed conservation in France and the UK-retrospect and prospect. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 13, S33-S41. Location: Bay of Brest (NW France) and Clyde Sea area (SW Scotland) Reviewed by: Sewell *et al.,* 2007	Description: Paper outlines the main findings of work conducted in both the Bay of Brest and the Clyde Sea area to assess the past and future impacts that bivalve fishing can have on maerl beds. A habitat that is highly vulnerable to bivalve dredging. Habitat effects: Evidence was presented for the advantages and disadvantages of the exploitation of maerl beds through scallop dredging. However, the conclusion was that the protection of maerl is more advantageous than its destruction as a result of dredging. The reason for this is that scallop dredging on maerl beds reduces the complexity, biodiversity and long-term viability of these very slow growing habitats. Although the deep burrowing organisms which can make up a large proportion of the infaunal maerl biomass can survive dredging in high numbers, these organisms are still vulnerable when juveniles are present at the surface. Community effects: The target species can also benefit from maerl bed conservation as these grounds can provide broad-stock areas for bivalves, which can in fact enhance the recruitment of juvenile scallops.
Ref Number 163 Ref: Fonseca, M.S., Thayer, G.W., Chester, A.J. & Foltz, C., 1984. Impact of scallop harvesting on eelgrass (*Zostera marina*) meadows:implications for management. *North American Journal of Fisheries Managemen,* 4, 286-293. Location: North Carolina, USA Reviewed by: Gubbay & Knapman, 1999,	Description: Experimental dredging studies on hard sand and a soft mud compared to an area of no dredging. Community effects: Experimental dredging studies on hard sand and a soft mud compared to an area of no dredging showed a significantly reduced level of eelgrass biomass and shoot number on both hard and soft seabed. The seagrass was more susceptible to damage (all shoots removed) in the latter case whereas on hard seabed about 15 percent of the eelgrass per core remained. Further notes: The dredges were pulled by hand rather than boat as sometimes done by commercial workers so excluded any effects of propeller scour. Authors conclude that intensive scallop dredging has the potential for immediate as well as long-term reduction of eelgrass nursery habitat. This was based on observation of biological damage which reduces surfaces for attachment for early stage juvenile scallops and other invertebrates.

Ref Number 164 Ref: Pranovi, F., Raicevich, S., Franceschini, G., Farrace, M.G. & Giovanardi. O., 2000. Rapido trawling in the northern Adriatic Sea: Effects on benthic communities in an experimental area. *ICES Journal of Marine Science,* 57, 517-524. Location: 20 km east of Venice Lagoon, northern Adriatic Sea. Reviewed by: Sewell & Hiscock, 2005	Description: The study examined the effects of a 3m wide, 120 kg box dredge with 5 - 7 cm long teeth and a net bag, on the benthos of an offshore, sandy, seabed community. The study also included a comparison between a control (unfished) ground and a fishing ground. Habitat effects: The upper 6 cm of sediment was disturbed and 50 percent of epifaunal organisms were removed along a flattened track with small heaps of sediment running along each side. Community effects: Experimental trawling induced a modification in the macrobenthic community, that was most evident immediately after the trawl. This included the removal of epifauna and an increase in mobile scavenging species. The authors suggest that recorded changes to the meiobenthic community were probably due to sediment disturbance. These changes were recorded after one week. Comparisons between the control grounds and fishing grounds showed that fishing grounds had significantly fewer species and number of individuals and significantly lower biomass of macrofauna, indicating significant long-term effects of fishing.
Ref Number 165 Ref: Bradshaw, C., Veale, L.O., Hill, A.S. & Brand, A.R., 2000. The effects of scallop dredging on gravelly seabed communities. In *The Effects of Fishing on Non-target Species and Habitats: Biological, Consevation and Socio-economic issues (*eds. Kaiser M.J., & de Groot S.J.), pp. 83-104. Location: Isle of Man, Irish Sea. Reviewed by: Sewell & Hiscock, 2005	Description: The paper reviews the results of a large study, examining the ecological effects of disturbance by scallop dredging at both large and small scales on gravelly seabed communities. Habitat effects: Unfished areas were found to be less homogeneous than dredged areas, supporting more diverse species assemblages. Following the onset of the annual closed season Community effects: Large scale: The composition of species assemblage differed greatly between dredged and un-dredged sites and this was thought to be a direct result of dredging activity. However species diversity and dominance of epifaunal assemblages did not differ greatly between dredged and undredged sites. Dredge disturbance in a previously closed area: Infaunal communities in experimentally dredged sites, within an area that had been closed to fishing for nine years quickly altered and became very similar to survey sites in heavily dredged areas. Further notes: The authors believe that the effects of scallop dredging on a gravel bed differs greatly to the impacts on other soft sediments, owing to the extreme patchiness of animal distribution, sediment stability, greater abundance of epifauna and to the combined effect of the heavy, toothed scallop gear and stones caught in dredges.
Ref Number 166 Ref: Eleftheriou, A., Robertson, M.R., 1992. The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. *Netherlands Journal of Sea Research,* 30, 289-299. Study date: Jul-85 Location: Firemore, Western shore of Loch Ewe on the west coast of Scotland	Description: Experimental scallop dredging over a sandy bottom, using a modified 1.2 m scallop dredge with a fixed tooth bar, bearing nine 12 cm long and 1 cm wide teeth, separated by 8 cm spaces. The dredge net was removed. The dredge was towed over exactly the same 25 m2 area a number of times for nine days. Samples and observations were collected after 2, 4, 12 and 25 dredges, to measure the effect of different levels of fishing disturbance. Habitat effects: Large, visible furrows were created and all previous bottom features (ripples and irregular topography) were wiped out. Large fragments of shell and stone were dislodged. Grooves and furrows created by the dredge were eliminated shortly after dredging. The time taken for this to happen depended on wave action . Community effects: Infauna: The infaunal community consisted of bivalves and peracarid crustaceans, Neither taxa showed any significant decrease with dredging disturbance. The biomass of infaunal amphipoda and polychaeta was reduced in all dredged samples, compared to control samples. Epifauna: Insepections of sites following dredges revealed high levels of damage and mortality to large epifauna, including crabs, large bivalves, urchins and

Reviewed by: Sewell & Hiscock, 2005	sandeels. Overall: The authors conclude that the effect of the dredging experiment was limited to the selective elimination of a fraction of the fragile, sedentary components of the infauna and the destuction of large epifaunal and infaunal organisms. Further notes: Sediment at the study site was fine, well sorted sediment with small amounts of silt clay.
Ref Number 167 Ref: Riemann, B. & Hoffman, E., 1991. Ecological consequences of dredging and bottom trawling in the Limfjord, Denmark. *Marine Ecology Progress Series,* 69, 171-178. Location: Limfjord, Denmark Reviewed by: Gubbay & Knapman, 1999,	Description: Effects of mussel dredging and bottom trawling on particulate material, internal nutrient loads and oxygen balance were investigated. Habitat effects: Sampling 0, 30 and 60 mins after fishing. Immediately after mussel dredging suspended particulate material increased significantly but 30 mins after the differences had decreased and, after 60 mins, had returned to the start level. Oxygen decreased significantly after mussel dredging and average ammonia content increased but large horizontal variation in the ammonia content prevented detailed interpretation of these increases. Changes in other nutrients were small. Changes in particulate matter and nutrients were also observed at some stations following low wind. Particulate matter and total phosphorus were markedly higher on windy days. Most dredging and trawling in the Limfjord takes place in summer when there is little wind, nutrients and oxygen consumption are low and temperature high. During these periods trawling and particularly dredging reduce the water quality by increasing internal nutrient loads, oxygen consumption and possibly phytoplankton primary production. Immediate increase in particulate matter, oxygen consumption and increase in nutrients particularly ammonia and silicate were a further effect of the fishing activities. Physical effects were scraping and pressure of gear the magnitude depending on depth of penetration, frequency of fishing and structure of sediment. Community effects: Trawling and dredging can be expected to cause a number of direct and indirect changes in the ecosystem - direct changes in fished populations and the benthos, but also changes in the nutrient level and oxygen budget in the water column. Phytoplankton primary production may increase if nutrients are the controlling factor. During summer when nutrients are generally low in the fjord mixing of sediments will have important consequences for the nutrient regime. It caused the deterioration of the water quality by increasing oxygen consumption and phytoplankton primary production. It was difficult to demarcate trawling and dredging effects versus wind induced effects at this site.
168 Ref: Dyekjaer, S.M., Jensen, J.K. & Hoffman, E., 1995. Mussel dredging and effects on the marine environment. C.M. 1995/E:13 ref.K. Location: Limfjorden, Denmark Reviewed by: Gubbay & Knapman, 1999,	Description: Experimental work in situ and in laboratory to evaluate the importance of the upwelling of sediment during dredging and, in particular, the amount of sediment particles, nutrients and oxygen consuming substances released during dredging as these factors can effect macrophyte and phytoplankton growth as well as affecting fish and bivalves. Habitat effects: Preliminary results suggest a minimum flux of 2km2, corresponding to about 0.9cm penetration of the gear. The release of particles, nutrients and oxygen-consuming substances seems to have little effect on the overall environmental conditions in the fjord. Where 10-15 boats dredge for several days, authors note that this will alter the local concentrations of nutrients and suspended matter directly, but the effect would probably only be visible or significant, during the dredging operations. Total annual release of suspended particles shown to be relatively unimportant compared with total annual wind-induced resuspension and release of nutrients compared to load from land. Community effects: the effects are probably much more severe on the ecosystem by changing the bottom flora and fauna which may in turn affect water quality. If natural bottom community cannot be established the areas will be characterised by low biodiversity and by opportunistic species dominated by young individuals of small sizes. Overall environmental effects of this disturbance in Limfjorden is not fully understood.

169 Ref: Lindeboom, H.J & de Groot, S.J., 1998. The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems. RIVO-DLO Report C003/98 Reviewed by: Gubbay & Knapman, 1999,	Description: Report on the results of international research project investigating the effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystem. Provides an overview of the effects of bottom trawling on marine communities with chapters on physical impact, direct mortality due to trawling, scavenger response to trawling, comparison of undisturbed and disturbed areas and long term trends in demersal fish and benthic invertebrates. Further notes: Recommendations are made for future studies including approaches to management and fishing methods. For more conclusive evidence on the long-term effects of beam trawling on benthic ecosystem authors call for study of relatively large areas closed to fisheries for many years.
Ref Number 170 Ref: Collie, J.S., Escanero, G.A. & Valentine, P.C., 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. *Marine Ecology Progress Series,* 155, 159-172. Study date: 6th-15th April and 8th-18th November 1994 Location: Georges Bank Reviewed by: Sewell *et al.,* 2007	Description: Studied aimed to look at the effects that both otter trawls and scallop dredging have on benthic megafaunal communities in gravel habitats. Two cruises were carried out in 1994 looking to quantify the differences between disturbed and undisturbed sites. Six sites were surveyed with a side-scan sonar, 15 minute video transect transects (3 transects at each site), 1-3 stations were selected at each site for the benthic fauna sampling using a Naturalists dredge (3 replicate samples were collected at each station). In the laboratory the benthic samples were identified to their lowest taxonomic level. (2 survey sites in the US 17 & 18, 4 survey sites in Canada 10, 11, 13 & 20). Habitat effects: At three of the sites (10, 11 & 20) the seabed was comprised of sediment consisting of pebbles and cobbles with a high percentage cover of the tube-dwelling polychaete *Filograna implexa*, the presence of this species would indicate a lack of disturbance. The area also had a number of boulders which would become obstacles for both trawling and scallop dredging. However, on the side-scan sonar dark lines were visible indicating dredge tracks, this provided evidence of minor disturbance. Two sites (13 & 17) showed evidence of heavy disturbance as a result of dredging; the sediment was comprised of smooth pebbles and was almost devoid of encrusting organism like *Filograna implexa* that were abundant at undisturbed sites. The final site (18) appeared to be undisturbed, even though there were few obstacles that would cause problems for dredges and trawls. This site however may have been previously disturbed. Community effects: When the undisturbed sites (10, 11, 18 & 20) were compared with the disturbed sites (13 & 17), they had a higher number of organisms, biomass was higher as was species richness and species diversity, evenness however was higher at the disturbed sites. At the disturbed sites the species dominating these areas were large, hard-shelled mollusks and scavenging crabs and echinoderms. In contrast to this the dominating species at the undisturbed sites were bryozoans, hydroids, worm tubes, which in turn provided a complex habitat for polychaetes, shrimps, small echinoderms, mussels and brittle stars. This shows a clear difference in the community structure between disturbed and undisturbed sites. Further notes: Dredging effort information was only available from the US site (17 & 18). Effort increased in the 1980s, at site 17 effort was highest in 1993 and at site 18 the effort was lowest.

171 Ref: Roberts, D., 2003. Work Package 2 - The current status of Strangford *Modiolus*. KA 2.1: Diving Survey 2003. Location: Strangford Lough, Northern Ireland Reviewed by: Sewell & Hiscock, 2005	Description: Preliminary results of a dive survey to examine the status of *Modiolus modiolous* beds in Strangford Lough. One focus of the survey was to assess whether any recovery of the reefs had taken place since conservation measures to reduce fishing activity were introduced in 1993. Community effects: The survey found no evidence to suggest recovery of the reefs since 1993. The authors conclude that the reefs are 'no longer in favourable conservation status' and that the use of bottom fished gear poses the most immediate threat to the few remaining clumped *Modiolus* beds within the Lough. In a site zoned for trawling for queenies that had previously contained a *Modiolous* with *Chlamys* biotope, no clumped *Modiolu*s remained. Divers also observed very few queen scallops remaining in the area.
Ref Number 172 Ref: Freiwald, A., Fossa, J.H., Grehan, A., Koslow, T. & Roberts, J.M. 2004. Cold-water coral reefs. . pp. 37 - 39. Location: Deep sea coral reefs, Worldwide Reviewed by: Sewell & Hiscock, 2005	Description: Report on deep sea coral reefs. The relevant section, discusses the main threats to coral reefs, including fisheries. The main types of fisheries that operate over deep-water coral reefs and their impacts are discussed. Habitat effects: The main conclusions from this section of the report are: Bottom trawls: Beam and otter trawls operating over coral reefs can smash, disrupt, tear, break and effectively flatten coral reefs, reducing the structural complexity of the habitat and reducing the number of associated species. Further damage can also be caused by the resuspension of sediments. Dredges: The effects of dredging for bivalves over deep-water corals are similar to those caused by trawls. Bottom-set gillnets: Physical damage can be caused to the reef by anchors and weights and lost nets (ghost fishing) can continue to catch fish for years after they are lost. In Norway, attempts to retrieve these nets have used gear that is damaging to coral reef areas.
Ref Number 173 Ref: Rogers, S.I., Kaiser, M.J. & Jennings, S., 1998. Ecosystem effects of demersal fishing: a European perspective. In *Effects of fishing on the seafloor of New England* (ed. E.M. Dorsey & J. Pederson), pp 68-78. Location: North-western Europe Reviewed by: Sewell *et al.,* 2007	Description: Paper reviews different types of demersal gear and the effect these gears have on the marine ecosystem in the waters of north-western Europe. Community effects: The extent of bycatch can indicate how much benthic communities are being disturbed. The occurrence of the heart urchin *Echinocardium cordatum* and the bivalve *Arctica islandica* indicates that the trawl has penetrated to a depth of at least 6cm into the hard sandy substrate. Fishing activities in areas of fragile or long-lived epibenthic invertebrates will have implications for the diversity of the community, the loss of biogenic reefs and their replacement by small polychaete communities can have implications. The reef building species, for example *Sabellaria spinulosa* and maerl, form microhabitats for other species, so the destruction of the reefs can result in the loss associated species. Scavenging species benefit from trawling activity and are often associated with trawled areas feeding on the remains of both damaged and discarded fauna. In communities that are adapted to physical disturbance the effects of fishing disturbance are likely to be short-lived when compared to communities that are rarely disturbed by natural processes.
Ref Number 174 Ref: UK Biodiversity Group. 1999. Tranche 2	Description: Biodiversity Action Plans for various UK marine habitats and species. Relevant points are briefly sumarised below. Action Plans are either Grouped Species Action Plans, Species Action Plans, Priority Habitat Action Plans or broad habitat action plans.

Action Plans - Volume V: Maritime species and habitats. Location: UK Reviewed by: Sewell & Hiscock, 2005	Community effects: The fan shell *Atrina fragilis* is extremely vulnerable to mobile fishing methods. There is evidence that the bivalve has been wiped out in areas where scallop dredging takes place. Although they can survive some physical damage to the anterior end of the shell by mobile gears, they cannot survive removal from the sea bed. The native oyster *Ostrea edulis* has been severely impacted by the introduction of non-native species and diseases associated with bivalve mariculture. Over fishing has also severely impacted native oyster populations around the UK. Habitat action plans *Sabellaria alveolata* reefs can be damaged by trampling associated with fishing and collection of shore animals. Individual worms are also occasionally extracted and used as fishing bait. Mudflats may be adversly affected by fishing activities and bait collection. Bycatch of juvenille flatfish in shrimp fisheries could be a problem as could bycatch associated with hydraulic dredging for shellfish. Sheltered muddy gravels, found mostly in estuaries, inlets and bays are subjected to bivalve fisheries, which are currently small but may increase in the future. These habitats are also vulnerable to invasion by non-native slipper limpets associated with bivalve mariculture. Dredging for oysters and mussels, trawling for shrimp or fin fish, net fishing and potting can all cause physical damage to erect *Sabellaria spinulosa* reef communities and fisheries are thought to be the most important threat to this type of habitat. In the past, shrimp fishers have been known to actively seek out and fish over reefs for the pink shrimps *Pandalus montagui*. Fishing with mobile gears has been very destructive to horse mussel beds in the past, leading to the destruction of beds in Strangford Lough and of the coast of the Isle of Man. Trawls and dredges can 'flatten' clumps causing fatalities and a loss of associated fauna. Physical disturbance associated with trampling and fishing can be damaging to seagrass beds as can the effects of non native species introduced by bivalve mariculture. Mobile fishing gear, especially scallop dredges can devastate maerl beds by breaking and burying the thin layer of living maerl and have been particularly damaging in the Clyde Sea. Deepwater mud habitats (below 20 - 30 metres deep) are subject to potting and dredging for *Nephrops*. Mobile gears extract non-target organisms and disturb the seabed, whilst pots and creels are far less damaging. Marine fish farms sited above deep mud can affect the seabed by causing smothering and increased biological oxygen demand in mud. The tall sea pen *Funiculina quadrangularis* is susceptible to damage by mobile gears and is not found in *Nephrops* trawling grounds in the North Sea. Serpulid reefs are large and fragile and may be susceptible to damage by mobile fishing gears and anchors. They may also be damaged by direct impact from large pots or creels. Sublittoral sands and gravels are impacted by a wide range of fishing types. Some species occuring in these habitats (e.g scallops) are extracted directly by fisheries, others are removed as bycatch. Large, slow growing species are sensitive to fishing disturbance, whilst species inhabiting already perturbed seabeds are usually more resiliant. The removal of predators and competitors may effect the ecological functions within communities. Demersal trawls can break of larg pieces of *Lophelia* reef and repeated use of heavy 'rock-hopper' gear is known to flatten large areas of reef.

Ref Number 175 Ref: The Centre for Environment, Fisheries and Aquaculture Science. 2002. Framework for evaluating the application of seasonal or rotational scallop fishery closures. MF0228. Study date: 01/01/02-31/03/02 Reviewed by: Sewell *et al.,* 2007	Description: Study aimed to provide a framework to evaluate the closure of scallop fisheries around the British Isles on a rotational, seasonal and permanent basis, aiming to reduce the impacts that commercial scallop dredging has on the scallop stock and benthic communities. A review of available information on rotational, seasonal and permanent closures was also conducted. Habitat effects: Seasonal fishery closures: benefit to long-lived fragile benthos is likely to be limited. Rational fishery closures: sandy seabeds can tolerate a low level of disturbance as they are naturally dynamic environments. Short rotational closures (<5 years) should help enhance diversity of these communities. Permanent closures: as a result areas of a larger habitat may be preserved, this could allow for the re-establishment of broad communities. Biogenic habitats are very vulnerable to disturbance as they are slow-growing, long-lived and recruitment is regular (e.g. horse mussels), as a result of this protection is probably best achieved through permanent closure. Community effects: Seasonal fishery closures: benefit to long-lived fragile benthos is likely to be limited; some fast growing species (erect bryozoans and hydroids) may take advantage of the reduced disturbance. Organisms that have similar life-histories to scallop are the ones that are likely to benefit the most from a seasonal reduction in disturbance. Rational fishery closures: short rotational closures (<5 years) may increase the abundance and size of vulnerable species and habitat-forming organisms. However, once dredging resumes these recovered communities can quickly return to their dredged state. To allow for these organisms to recover longer rotational closures (5-10 years) should be considered. Permanent closures: this type of closure can affect the target species though larval export and spill-over of adults into adjacent grounds, which may increase the sustainability of the fishery. Genetic diversity may also be maintained through a reduction of fishing pressure by preventing the stocks from being dominated by slow-growing genotypes. This type of closure may also be the only way to protect key species that are long-lived or fragile.
Ref Number 176 Ref: Murawski, S.A., Brown, R., Lai, H.-L., Rago, P.J. & Hendrickson, L., 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experiment. *Bulletin of Marine Science,* 66, 775-798. Study date: 1994-1999 Location: Georges Bank, New England Reviewed by: Sewell *et al.,* 2007	Description: Since the 1970s there have been seasonal closures in New England to protect the groundfish stocks, however these seasonal closures have had little impact. In December 1994 three large areas were closed year-round to all types of gear that could retain the groundfish. The studies assessed the changes to both scallop and groundfish stocks as a result of the year-round closures. Community effects: Target species: from 1994 to 1998 the biomass of scallops within the closed area increased 14-fold and in July 1998 the total scallop biomass was 9 times denser and the harvestable biomass was 14 times denser in closed areas than the adjacent open areas. Non-target species: closed areas led to a significant reduction in the fishing mortality of the depleted groundfish stocks. The closed areas provided the greatest protection to shallow-sedentary assemblages of fish species-mainly flounders and skates, less protection was provided to migratory species-Atlantic cod and haddock. Further notes: Closing off areas to scallop dredging not only provided protection to the non-target species (groundfish), but also increased the stock of the target species (scallops).

Ref Number 177 Ref: Drouin, M., 2003. A seabed-friendly scallop trawl. *Pacific Fishing,* 24, 25-26. Reviewed by: Sewell *et al.,* 2007	Description: Review of 'seabed friendly' scallop trawl, which works based on the theory that scallops leave the seabed and swim upwards as a result of disturbance.
Ref Number 178 Ref: Rudders, D.B., Dupaul, W.D. & Kirkley, J.E., 2000. A comparison of size selectivity and relative efficiency of sea scallop *Placopecten magellanicus* (Gmelin, 1791), Trawls and dredges. *Journal of Shellfish Research,* 19, 757-764. Study date: August 1997 to May 1998 Location: Sandy Hook, New Jersey to Virginia/North Carolina boarder, USA Reviewed by: Sewell *et al.,* 2007	Description: The sea scallop fishery has been managed under the Sea Scallop Fishery Management Plan (SSFMP) since 1982, with measures initially focusing on controlling the age at entry into the fishery in an effort to maximize yield per recruit. This method proved to be inadequate and the populations continued to be overexploited, with high levels of capture and mortality of small sea scallops. In 1994 Amendment 4 of the SSFMP was adopted in an attempted to reduce fishing mortality by 70% over a 7 year period. The changes to the gear in theory would allow juvenile sea scallops to escape instead on relying on crew to discard them. The studied assessed the size selectivity and relative efficiency of sea scallop dredges and trawls under Amendment 4, to determine if the gear restrictions of Amendment 4 were effective at controlling the sea scallop age at entry into the fishery. Three fishing cruises were conducted using the trawl and dredge gear by utilizing a parallel fishing method, where the two vessels fished the same ground at the same time and sampled from a single sea scallop population. Community effects: Target species: The results indicated that there was no significant difference between the relative harvest efficiency of the two gear types for shell height between 85 and 95mm. The trawl vessels harvested sea scallops more efficiently when the shell height was less than 85 to 95mm, where as the dredge vessels harvested sea scallops more efficiently when the shell height was more than 85 to 95mm. The abundance of sea scallops caught between the two gear types varied, the differences occurred due to differences in the shell height of the sea scallop. During the May 1998 trip the trawl vessel caught 35.4% more scallops per hectare than the dredge vessels, this was due to the presence of a large number of 70 to 90mm shell height sea scallops. Further notes: Primary measures of the Amendment 4 of the SSFMP included limited access to the fishery and restrictions on the number of days at sea. There were also supplementary measures which included crew size limits, vessel replacement restrictions, catch limits for non-permitted vessels and gear restrictions which included minimum mesh size, mesh orientation and maximum trawl sweep for the otter trawl and specific criteria for the scallop dredge including ring size, chafing gear, twine tops and maximum dredge width. Implementations for management: Controlling the age at which sea scallops enter the fishery is one management strategy that is used to maximize yield per recruit and increase the spawning potential of the managed populations. At 3 years old the shell height of the sea scallop is around 70 to 90mm, at 70 to 75mm shell height the sea scallops start beginning retained by commercial vessels. Studies by Serchuk *et al*. (1979) indicated that the maximum yield per recruit for sea scallops was attained when age of first capture was 8 years; this was considered to be unrealistic. If the sea scallops were first retained when shell height had grown from 73 to 92 mm there would be potential for a 65% increase in yield per recruit. This would be possible using the dredge gear as only the larger sea scallops were retained.

Ref Number 179 Ref: AFMA. 2004. Bass Strait Central Zone Scallop Fishery – A guide to the 2005 Management Arrangements. Location: Bass Strait, Australia Reviewed by: Sewell *et al.,* 2007	Description: Report provides a summary of the management arrangements that will apply from January 1st 2005 in the Bass Strait Central Zone Fishery. Further notes: Restrictions that will apply include: No fishing permits instead access to the fishery will be provided through Statutory Fishing Rights (SFRs) – involves using a number of input and output controls, Fishermen will require a Boat SFR and a number of Quota SFRs, Size of catch will depend on the number of Quota SFRs held and the TAC, Minimum landing size has been increased to 90mm (for commercial scallops), no limit set for doughboy scallop, Open season – May 1st to December 20th, Fishermen use either a scallop harvester (dredge) or trawl nets, There are no restrictions on the size or design of the scallop dredge, but fishermen are restricted to just one dredge, Closed areas all year in the east & west of the fishery – enables protection of scallop broodstock, maintain and protect reproductive potential of scallops and the habitat, Two species can be harvested under TACs – Commercial scallop (Pecten fumatus) and doughboy scallops (Minachlamys asperrimus), No scallops can be processed at sea, Any bycatch species must be reported, Interactions that cause injury or death to protected species listed under the Environment Protection and Biodiversity Conservation Act 1999 must be reported within 7 days.
Ref Number 180 Ref: Maguirea, J. A., Coleman, A., Jenkins, S., Burnella, G.M., 2002. Effects of dredging on undersized scallops. *Fisheries Research,* 56, 155-165. Study date: Location: Valentia Island, Kerry, SW Ireland & the Chickens ground, Isle of Man, North Irish Sea Reviewed by: Sewell *et al.,* 2007	Description: Springloaded dredge (width 75 cm) with a toothed crossbar (tooth spacing 66 mm; tooth length 100 mm), a collecting bag made from case hardened 5mm_ 8mm steel rings (diameter, 70 mm) and a mesh bag (mesh size, 100 mm). Used at 2 sites. Undersized scallops were tested for changes in adenylic energetic charge and ability to re-bury when returned following capture. Combined with simulated laboratory experiments. Community effects: adenylic energetic charge did not fall to fatal levels, however, the authors concluded that the righting and recessing speed was greatly reduced by fishing.

Ref Number 181 Ref: Cotterell, E. & Johnson, D., 2006. Management of commercial scallops in the bass strait central zone scallop Fishery, Australia. *Journal of Shellfish Research,* 25. Location: Bass Strait, Australia Reviewed by: Sewell *et al.,* 2007	Description: Study examining management of scallop fishery from late 1980s until 2002 onwards. Various management methods discussed including complete fishery closures and an agreement between 3 fishery regulators to close at least one area to fishing every season to prevent recruitment over fishing . A minimum of 20% of the stock must be above minimum size before fishery is able to open.
Ref Number 182 Ref: Symes, D. & Ridgway, S, 2003. Inshore fisheries regulation and management in Scotland; Meeting the challenges of Environmental Integration. *Scottish Natural Heritage.* Reviewed by: Sewell *et al.,* 2007	Description: Report aimed to review the current management arrangement for inshore fisheries in Scotland considering the need for environmental protection and make any recommendations necessary to improve the management system. Further notes: Inshore fisheries management overview: Within Scotland the Inshore Fishing (Scotland) Act, 1984 grants the Minister power to regulate fishing activities within the 0-6nm zone, which is exercised through the Inshore Fishing (Prohibition of Fishing and Fishing Methods) (Scotland) Order 1989. There is also the Sea Fisheries (Shellfish) Act 1967 which provides a way to grant Several and Regulating Orders which provides companies or individuals which a public right to fish for a range of shellfish species. The Regulating Order provides management for the nominated fishery including: opening and closing times, bag limits, issuing of licences etc. (currently there is only one Regulating Order in Scotland [Shetland]). Management of scallop fisheries: a range of management tools are available and it is likely that a combination of the following measures may prove most effective – *Measures to increase size at first capture: i) increase minimum landing size, ii) increase dredge selectivity. *Measures to reduce fishing effort: i) closed seasons, ii) limits on vessel size, iii) limited no. of licences, iv) spread of dredges, v) length of fishing time, vi) TAC & individual vessel quotas. *Measures to protect vulnerable habitats: i) closed seasons.

Ref Number 183 Ref: Ministry of Fisheries. 2006. Coromandel scallops fisheries plan 'Proof of Concepts' (Second draft). Location: New Zealand Reviewed by: Sewell *et al.,* 2007	Description: Report addresses the goals of the fishery considering sustainability, the environment, use and management. Strategies were then put forward to meet the various objectives and at the end of 2007 these strategies will be reviewed to see how effective they were at meeting the objectives. Further notes: Restrictions that will apply include have been implemented to maintain sustainability and reduce the impacts on the environment, these measures include: TACs, Commercial season July – December (excluding main period of spatfall – January/February), Commercial size limit 90mm, Future plans involve continued monitoring for TACs, Some scallop beds are reserved for non-commercial fishers to help reduce tension between the sectors, Certain areas are closed to commercial dredging, Dredging generally occurs in the same areas each year so impacts are limited to those areas, Future plans involve monitoring the bycatch from the commercial fishery and the non-commercial fishing methods.
Ref Number 184 Ref: Kaiser, M.J., Laing, I., Utting, S.D. & Burnell, G.M., 1998. Environmental impacts of bivalve mariculture. *Journal of Shellfish research,* 17, 59-66. Reviewed by: Gubbay & Knapman, 1999,updated 2007	Description: Reviews current knowledge of environmental modification or conflicts with other species at seed collection, seed nursery and on-growing, and harvesting stages of the cultivation process. Community effects: Seed collection - subtidal dredging for seed mussels likely to be confined to relatively small areas of seabed because they occur in dense aggregations in discrete areas. UK licensed areas from unstable beds which are likely to be lost anyway. Non-target species probably adapted to large-scale natural disturbance so likely to recolonise rapidly but in extensive heavily exploited fisheries, such as the Wadden Sea, the entire mussel stock was removed in 1990/1 resulting in increased mortalities for eider duck and reduced breeding success for oyster catchers. May be some effects associated with intertidal collection (trampling, disturbance of foraging birds and removal of winter food source). Few impacts likely from spat collectors, continuous relaying of cultch leads to habitat modification which may increase diversity. There are also risks associated with the introduction of alien species. Ongrowing: Effect depends on habitat, type and scale of cultivation. Introduced structures effect local hydrography and provide a settlement surface, high densities increases local oxygen demand and elevates input of organic matter however beds used to be extensive and they fulfil an important role in the retention of phosphorus and nitrogen. May be eutrophication beneath mussel lines if not enough tidal flow to disperse particulate matter. Decreases in abundance of macrofauna and increases in meiofauna beneath oyster trestles been measured. In the USA insecticide is sprayed on intertidal areas and ground may be harrowed prior to cultivation. Addition of gravel or shell, formation of mussel mud and use of protective netting induces localised changes in benthic community composition. Small-scale culture seems to have only very limited effects on local benthic communities. Cultivation sites may conflict with bird feeding or roosting sites but probably only problematic if cultivation areas cover significant part of the feeding grounds. Harvesting: restriction harvesting to early winter could ameliorate site restoration if main mechanism for recolonisation is by larval settlement. Suction dredging or mechanical raking effects the habitats. Recolonisation rates likely to differ between habitat types. Further notes: Management considerations in light of the reported effects are discussed and potential beneficial effects mentioned such as the proposal that integrated fish/bivalve mariculture systems can ameliorate undesiratal impacc ts of nutrient rich effluents from fish farmining, or for restoration of enclosed, polluted water masses.

Ref Number 185 Ref: Kennedy, R.J. & Roberts, D., 1999. A Survey of the current status of the flat oyster Ostrea edulis in Strangford Lough, Northern Ireland, with a view to the restoration of it oyster beds. Biology and Envionment. *Procedings of the Royal Irish Academy,* 99, 79-88. Reviewed by: Sewell *et al.,* 2007	Description: A study to assess the potential for restoring native oyster beds in Strangford Lough. Further notes: The best settlement substrate for oyster spat is mature oysters, subsequently, removal has detrimental effects on spat settlement. Stock restoration could be possible, but would require restoration of suitable substrate as required for the settlement of spat and potentially he introduction of large quantities of cultivated spat.
Ref Number 186 Ref: Eno, N.C., Clark, R.A. & Sanderson, W.G., 1997. Non-native marine species in British waters: a review and directory. Location: Review, British waters Reviewed by: Sewell & Hiscock, 2005	Description: A review of non-native marine species found in British waters, including detailed information on each species. The report indicates that the greatest single source of non-native species in British waters (31.4 percent) have been by associated unintentional introduction with mariculture. 7.8 percent have been introduced by deliberate commercial introduction. Only species introduced by these methods (relevant to this report) and their effects on relevant species and habitats are described. Community effects: It has been suggested that the phytoplankton species *Coscinodiscus wailesii* may have been introduced to UK waters from the Indian and Pacific oceans with imported oysters. When large numbers are reached, skeletons and minerals can 'blanket the seabed. The red algal species, *Asparagopsis armata*, *Bonemaisonia hamifera*, *Grateloupia doryphora*, *Grateloupia filicina*, *Agardhiella subulata* and *Antithamnionella spirographidis*, also the brown algae *Colpomenia peregrina* are all thought to have been possibly introduced to European waters unintentionally with shellfish (most often oysters). The impacts, they are likely to have on the environment are however unknown. Another red algae *Polysiphonia harveyi* is known to have been introduced with oysters. It grows quickly on hard substrates and may displace native species. The brown algae Undaria pinnatifida may cause the displacement of native species on hard substrates and japweed *Sargassum muticum*is known to cause the displacement of native species including eelgrass and rockpool species. Both species are thought to have been introduced with non-native oysters. The green algae *Codium fragile* is thought to have been introduced with shellfish and displaces the native species *Codium tomentosum*. The gastropod *Crepidula fornicata* was introduced with the American oyster. It competes with native, filter feeding invertebrates for food and space and encourages the deposition of mud, rendering the substrate unsuitable for the settling of spat oysters. The American oyster drilll *Urosalpinx cenerea* was also introduced with American oysters. It predates native oysters and can consume up to 40 oyster spat per year. Two species of non-native oyster have been deliberately introduced to British waters *Crassostrea gigas* and *Tiostrea lutaria*, however neither are thought to have had a significant environmental impact. In the USA, *C. gigas* is known to have settled in dense agregations and displace native species. The American Hard-shelled clam *Mercenaria mercenaria* was deliberately introduced and now, fishing for the species can have a negative impact on seagrass beds. It is also likely that the presence of this species prevented the reestablishment of the native species *Mya* following a die of caused by cold weather.

Ref Number 187 Ref: Diederich, S., 2006. High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. *Journal of Experimental Marine Biology and Ecology,* 328, 211-227. Location: Wadden Sea, North Sea, Germany. Reviewed by: Sewell *et al.,* 2007	Description: Study examining potential loss of settlement habitat for Mytilus edulis due to invasion by Crassostrea gigas on mudflats. Community effects: The authors conclude that through competition for space and altering substrate composition, that invasions by C. gigas would be likely to restrict usable habitat for native mussels in the Wadden sea area. Oysters were not selective with regard to settlement substrate, whilst mussels showed significantly higher growth on clear sand flats. High survival rates of oysters will compensate for poor recruitment years, resulting in the successful spread of the species.
Ref Number 188 Ref: Mattson, J. & Linden, O., 1983. Benthic macrofauna succession under mussels, *Mytilus edulis*, cultured on hanging long-lines. *Sarsia,* 68, 97-102. Location: Sweden Reviewed by: Gubbay & Knapman, 1999,	Description: Changes in sediment composition and benthic community structure under cultures studied over 3 years in a narrow sound, 13-15m deep with generally weak currents.. Habitat effects: Faecal material and mussels drop to the seabed. As a consequence a layer of sediment was found to increase at a rate of 10cm/yr. This resulted in the production of H2S in the uppermost layers. Small grain size, high organic content and a negative Redox potential recorded under the cultures and changed with distance from the culture. Community effects: Benthic fauna initially dominated by *Nucula* nitiosa (numerically), *Echinocardium cordatum* and *Ophiura* spp (biomass). After 6-15 months these disappeared and were replaced by opportunistic polychaetes (*Capitella capitata*, *Scolelepis fuliginosa* and *Microphthalmus sczelkowii*). Further notes: Anaerobic sediments and mass occurrence of opportunistic polychaetes localised 5-20m around the cultures. After harvesting only limited recovery was observed after 6 months.

Ref Number 189 Ref: Spencer, B. E., Kaiser, M. J. & Edwards, D. B., 1997. Ecological effects of intertidal Manila clam cultivation: observations at the end of the cultivation phase. *Journal of Applied Ecology,* **34**, 444-452. Location: River Exe Reviewed by: Gubbay & Knapman, 1999,	Description: Study on ecological effects of Manila clam cultivation at the end of the cultivation phase (for all stages see Gubbay & Knapman, 1999 Reference 64) Habitat effects: Organic enrichment in net covered area. Short term sedimentation rates were up to 4 times higher in netted plots than control areas. The increase was localised. Increased organic matter, percentage fines and phaeopigment in the sediment and reduced water flow on the netted plots is likely to have had a major influence on the changes in abundance of some infauna species. Community effects: Netting encouraged settlement of green macro-algae and in turn *Littorina littorea*. In the first 6 months fauna dominated by opportunistic species *P.elegans*. After 1 year the stabilising effect of netting and sedimentation led to establishment of species such as *Ampharete acutifrons* and *Tubificoides benedii*. Further notes: Authors consider biotic and abiotic changes are relatively benign compared to other forms of marine culture.
Ref Number 190 Ref: Leguerrier, D., Niquil, N., Petiau, A. & Bodoy, A., 2004. Modeling the impact of oyster culture on a mudflatfood web in Marennes-Oléron Bay (France). *Marine Ecology Progress Series,* **273**, 147-162. Location: Marennes-Oleron Basin, France Atlantic Coast Reviewed by: Sewell *et al.,* 2007	Description: Carbon-based food web modelling to examine changes to food web structure caused by oyster mariculture. Community effects: Authors found that Oysters are direct trophic competitors of other filter feeders, and their presence modifies benthic–pelagic coupling by forcing a shift from pelagic consumers to benthic consumers. Increasing the surface area of cultivated oysters caused secondary production to increase, providing food for top predators (in particular juvenile nekton), reinforcing the nursery role of the mudflat in the ecosystem, and altering the species composition available to the top predators. Further notes: Study site was relatively flat, tidal mudflat with average flow between 0.2 and 0.6 ms –1. Oysters grown 0.5 m above ground on trestles in plastic netting sacks.

Ref Number 191 Ref: Ruesink, J.L., Lenihan, H.S., Trimble, A.C., Heiman, K.W., Micheli, F., Byers, J.E., Kay, M.C., 2005. Introduction of non-native oysters: ecosystem effects and restoration implications. *Annu. Rev. Ecol. Evol. Syst.,* 36, 643-689. Study date: 2005 Location: Worldwide Reviewed by: Sewell *et al.,* 2007	Description: review of literature describing oyster introductions World-wide and restoration methods. Habitat effects: Eel grass beds: induced oyster reefs can directly reduce growth of zostera marina. Crasosstrea beds are unlikely to encourage the same biodiversity levels as Zostera beds, but both encourage higher levels than nearby clear sand or mud. Rocky shores: Oyster growth may increase habitat heterogeneity on clear rock surfaces and may provide more surface area for the settlement of barnacles. In Argentina, Shore birds have been shown to spend a disproportionate amount of time and higher foraging rates in areas of higher C.gigas settlement. Community effects: Most serious effects include introduction of 'hitchhiking' species. Where non-native species become established, they may out compete with native species. Crassostrea gigas is able to filter feed at a greater rate that Ostrea edulis and grows more quickly, giving it a competitive advantage. The report also suggests areas for further study. Further notes: Discuss the possibility of using The ICES' risk assessment protocol for the assement of marine introductions.
Ref Number 192 Ref: Mallet, A.L., Carver, C.E. & Landry, T., 2006. Impact of suspended and off-bottom Eastern oyster culture on the benthic environment in eastern Canada. *Aquaculture,* 255, 362-373. Location: Shippagan, New Brunswick, Canada Reviewed by: Sewell *et al.,* 2007	Description: Study comparing the impacts of suspended oyster culture with oyster table culture and 2 reference sites. Authors examined sediment characteristics and macroinfauna at all sites. Community effects: the authors conclude that the level of oyster culture (8 kg m-2) currently practiced is not sufficient to negatively impact either the sediment biochemistry or the associated benthic community. But suggest continued environmental monitoring is important to ensure that the overall health of the ecosystem is maintained. Further notes: Site was a shallow inlet, where sediment was regularly resuspended by wave action. The authors considered the site to be relatively dynamic.
Ref Number 193 Ref: Yokoyama, S., 2002. Impact of fish and pearl farming on the benthic environments in Gokasho Bay: Evaluation from seasonal fluctuations of the macrobenthos. *Fisheries Science.* 68. 258 - 268	Description: Comparative study examining the effects of finfish and pearl oyster mariculture on sand/ silt sediment faunal assemblages. Relevant sections examine the effect of pearl oyster (Pinctada martensii) Rafts were suspended over sandy silt in 14.4 m water depth. Monthly surveys and sediment samples conducted for 13 months. Habitat effects: Dissolved oxygen levels were lower than for the control site from April to September. Community effects: Community composition was similar to control sites, although species diversity, and densities were lower below oyster culture areas than at the control site. The author did not find anoxic conditions at the oystrer culture study site during the study and concludes that there were no

Study date: June 1995 - July 1996 Location: Gkasho Bay, Japan Reviewed by: Sewell *et al.,* 2007	conspicuous disturbances at the study site. Further notes: Finfish culture was found to have a severe negative impact on the benthic community, leading to anoxic conditions, decreased species biodiversity, increased nutrient loading and at some times azoic conditions.
Ref Number 194 Ref: Wisehart, L.M., Hacker, S.D., Tallis, H.M., Ruesink, J.L., Oyarzun, F. & Dumbauld, B.R., 2004. The effects of different aquaculture techniques on Zostera marina biomass, density, and growth rates in Willapa Bay, Washington. *Journal of Shellfish Research,* 23. Location: Willapa Bay, Washington, USA Reviewed by: Sewell *et al.,* 2007	Description: Sampled an off-bottom long-line culture area, a dredged ground culture area, a handpicked ground culture area, and an area without aquaculture. measured the standing biomass, percent cover and growth rate of eelgrass, as well as the density of vegetative and flowering shoots. Community effects: Found the largest growth rates in areas with off-bottom culture and those without aquaculture; these areas also had the greatest eelgrass biomass, density, and percent cover. Eelgrass growth and biomass were lower in handpicked and dredged culture areas and didnot significantly differ from one another. There were significant site and culture type interactions for most variables suggesting that site-specific conditions may be as influential as culture technique in determining eelgrass growth.
Ref Number 195 Ref: Crawford, C., 2003. Environmental management of marine aquaculture in Tasmania, Australia. *Aquaculture,* 226, 129-138. Location: Tasmania Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at the effects that marine aquaculture has on benthic communities and the management measures in place to reduce these impacts and long-term monitoring programs. Marine farming is based on two main species: Pacific oyster *Crassostrea gigas* and Atlantic salmon *Salmo salar*. The effect of shellfish farming on benthic environments was investigated at three sites (all long established subtidal mussel and oyster farms) and one control site. Using physical and chemical measures sediment condition was assessed, video recording was conducted under the longlines and benthic invertebrate species composition and abundance were assessed. Habitat effects: Results indicated that shellfish faming within the lease area and no impacts on the area outside the lease boundary. Redox, sulphide levels, organic carbon and rates of decomposition did not vary significantly between the inside and outside of each farm. Community effects: The composition of benthic infauna was not significantly different between the inside and outside of each farm; the differences that did occur were between the different farms. Further notes: As a result of the qualitative assessment shellfish farming activities are suggested as having a low risk of impact. Monitoring of the farms is likely to be minimal, possible photographs of intertidal farms and video of subtidal farms every few years.
Ref Number 196 Ref: Forrest, B.M. & Creese, R.G., 2006. Benthic impacts pf intertidal oyster culture, with	Description: Benthic impacts of oyster cultivation based on physico-chemical and biological parameters and the refinement for monitoring and assessment protocols. Assessment took place in an area that had been farmed for more than 8yrs and where mature oysters were present at the time of the survey. Seabed under the farm assessed in relation to 3 controls and spatial effects considered by sampling at three distances (farm parameter along two transects). In the farm sampling was carried out directly beneath the 1m wide racks. At each of the 11 sites three sediment cores were taken.

consideration of taxonomic sufficiency. *Environmental Monitoring and Assessment,* 112, 159-176. Study date: January to April 1990 Location: Mahurangi Harbour, northern New Zealand Reviewed by: Sewell *et al.,* 2007	Habitat effects: The rate of sedimentation beneath the cultivation racks was twice what was measured at adjacent sites. The silt/clay content of sediment trap samples beneath the racks was 96% compared with 83-89% at other sites. The organic content beneath the rack was higher (11.2%) than all the other sites outside of the farm perimeter which were not elevated (8.3-9.1%). Community effects: For the control and outer transect sites the seabed consisted of a relatively low density assemblage, this included a variety of large-bodied individuals associated with undisturbed areas. However a progression towards the farm indicated that at 5m from the farm edge there was a moderate number of co-dominant species and underneath the racks themselves a high density of capitellid polychaetes. Further notes: No data was available on the benthic conditions prior to oyster farming.
Ref Number 197 Ref: De Grave, S., Moore, S,J, & Burnell, G., 1998. Changes in benthic macrofauna associated with intertidal oyster, *Crassostrea gigas* (Thunberg) culture. *Journal of Shellfish Research,* 17, 1137-1142. Study date: September 1995 Location: Dungarvan Bay, SE Ireland. Reviewed by: Sewell *et al.,* 2007	Description: Assessment of the potential changes to macrofaunal community structure beneath trestles and in access lanes associated with large scale oyster culture. Two different treatments were sampled, the first directly under the oyster trestles (possible subjected to additional organic input from oyster fecal) and the second in access corridors (potentially subjected to heavy vehicles). 300m away a control site was established. 10 samples were collected from each treatment. Community effects: In total 21 macrobenthic species were recorded, but only 9 showed a significant difference between the three sites. At the control site high densities of *Nephtys hombergii*, *Bathyporeia guilliamsoniana*, *Gammarus crinicornis*, *Microprotopus maculatus* and *Tellina tenuis* were recorded when compared with the other two sites. In the Trestle treatment higher densities of *Capitella capitata* were recorded and in the Lane treatment higher densities of *Scoloplos armiger*, *Eteone longa* and *Sigalion mathildae* were recorded. When the lane and trestle treatments were compared to the control treatment, the lane treatment indicated a slightly higher diversity value and the trestle treatment showed a slightly lower diversity value. Composite Abundance Biomass Comparison (ABC) curves (based on mean abundance and biomass values) for both the trestle and control treatment suggested a relatively undisturbed community (biomass curve above abundance curve). However, in the lane treatment the ABC curve suggested a more disturbed community (abundance curve above biomass curve), likely to be caused by heavy vehicle traffic for maintenance and harvesting. Results indicated that the benthic communities underneath the trestles have not undergone any form of organic enrichment as no elevated levels of organic matter or potential enrichment indicator species were recorded.
Ref Number 198 Ref: Laing, I., Walker, P. & Areal, F. 2005. A feasibility study of native oyster (*Ostrea edulis*) stock regeneration in the United Kingdom. CARD Project FC1016. Location: United Kingdom Reviewed by: Sewell *et al.,* 2007	Description: Study looks at the regeneration of native oyster stocks within the United Kingdom, taking into consideration the following: the biological factors, the technical requirements, the framework involved in regulating oyster farms and the economic consequences. The study also considers the current status and various attempts at restoration within the UK and from an international perspective, including Channel Islands, Ireland, France, Spain, Denmark, The Netherlands, Norway, New Zealand and the USA. Further notes: The management of fisheries is generally based a round two concepts; firstly there should be limits which define the condition of the fishery and secondly the definition of targets which define the desirable outcome of the fishery. Within England and Wales measures have been developed in order to maintain an adequate spawning stock, the measures have been introduced through byelaws and regulations. These include; licence entry to fishery, vessel restrictions, gear restrictions, bed closure, closed periods, carriage restrictions, total catch limit, minimum landing size, prohibit cultch removal, return undersize to beds, return bycatch to beds and detailed monitoring. In Scotland there are no active consents to fish for native oysters so there is no active management and in Northern Ireland there are no measures in place in relation to native oyster farming.

	In order to manage and mitigate the fishery there is a regulatory framework, which aims to ensure protection and control over the restored stocks and prevent exploitation. Water quality, conservation of the site, preventing the spread of disease and alien species are also taken into account. Within the United Kingdom the framework consists of Regulating Orders, Several Orders, Hybrid Orders and Private Ownership. Regulating Order: granted by Defra in England, WAG in Wales or SEERAD in Scotland to a responsible body to enable the body to regulate the fishery of a natural stock. Several Order: granted by Defra in England, WAG in Wales or SEERAD in Scotland for a fixed period of time when a cultivator would like additional protection for the stocks that are kept in public waters. Hybrid Order: Regulating Orders with the power to grant leases of Several rights. Private Ownership: prevents the public from fishing in some tidal waters. Within the England the following Fisheries Orders are in place: 12 Several Orders, 4 Regulating Orders and 2 Hybrid Orders, within Wales: 5 Several Orders and 2 Regulating Orders and in Scotland: 9 Several Orders and 1 Regulating Order.
Ref Number 199 Ref: Ismail, N.S., 1985. The effects of hydraulic dredging to control oyster drills on benthic macrofauna of oyster grounds in Delware Bay, New Jersey. *Internationale Revue der Gesamten Hydrobiologie,* 70, 379-395. Study date: 1978-1979 Location: Delware Bay, New Jersey. Reviewed by: Sewell *et al.,* 2007	Description: The failure of methods to control oyster drills led to the development of the hydraulic suction dredge, however the effect of the hydraulic suction dredge had not been evaluated on anything other than the drills and oysters themselves. This study aimed to assess the effect of the hydraulic suction dredge on the oyster community and the sedimentary composition of the bottom. Three sites were selected i) Laboratory Ground, ii) Ground 515 and iii) Ground 154 at each site there were control and test plots with five sampling stations at each. To assess the effects of the hydraulic suction dredge on benthos two techniques were used: Peterson grab for the soft-bottom site (Ground 154) and a suction sampler on the sites where there was an abundance of shells (Laboratory Ground and Ground 515). To assess the effects of the hydraulic suction dredge on sediments two techniques were used: Peterson grab was used at the Ground 154 site and an Orange-Peel sampler was used at both the Laboratory Ground and Ground 515 sites. Samples were collected before and after dredging. Habitat effects: The sediment at the selected oyster sites were a mixture of fine and very fine sand with silt-clay, can be described as muddy sands. Immediately after dredging there was a reduction in median grain size as a result of additional silt-clay being brought up from the subsurface layers on the Ground 154 test plot. In contrast at the Ground 515 test plot there was a slight increase in median grain size as a result of a slight loss in the silt-clay content. Community effects: A total of 289 benthic samples were collected before and after dredging and were examined for benthic fauna. Changes in numbers of oyster drills (target species): On the Laboratory Ground the number of oyster drills was reduced by 85% on the test plot and 34% on the control plot immediately after dredging. After 10 months the number of oyster drills on the test plot had increased by 50% but this was still less than half the number on the control plot. On the Ground 515 site the number of oyster drills on the test plot was reduced by 79% immediately after dredging, but 3 months later the numbers on the test plot had increased 9-fold and were larger when compared to the control plot. Changes in total numbers of animals: At the Laboratory site the average density of animals was significantly reduced immediately after dredging (70.3% at the test plot and 72.4% at the control plot), however the difference came from the high density of mysid *Neomysis americana* present at both sites before dredging. If *Neomysis americana* was excluded there was a decline, but this was not considered to be significant (59.1% reduction at the test plot and 29.4% at the control plot). Recovery was not considered to be rapid either, 10 months after the dredging density was still lower on the test plot than the control plot. The situation was similar at the Ground 154 site, only with a different species (*Polydora ligni*). When included there was a 43.2% reduction, when excluded there was a 16.9% reduction in density at the test site. However, at the Ground 515 site there was a significant increase in the density of animals at the test plots immediately after dredging (increase of 74.6%), this was explained by a heavy larval recruitment of the sand shrimp,

	mysid and spionid poltchaeta. On the control plots there were no density measurements before dredging, but after immediately after dredging the density on the control plot was higher than the test plot. Three months after dredging the density of animals on the control and test plots were similar, which indicated a complete recovery of the animals at this particular site. Further notes: Conclusion: the use of a hydraulic suction dredge did not completely remove any species that were present at the dredged sites, instead decreased their densities. Repopulation to pre-dredged/control levels was apparent three months after dredging at the Ground 515 site and after 10 months at the Laboratory Ground site.
Ref Number 200 Ref: Osamu, K., Tamiji, Y., Osamu, M., Toshiya, H. & Haruyoshi, T., 2004. Artificial midlayer seafloor: simple and new devices to reduce organic loads from oyster rafts to the sediment. *Bulletin of the Japanese Society of Scientific Fisheries,* 70, 722-727. Reviewed by: Sewell *et al.,* 2007	Description: Authors tried to reduce the organic load from the cultured oysters deposited on the seafloor by hanging an artificial midlayer seafloor that traps some of the sinking organic particles before they reach the seafloor. The artificial seafloors are suspended in the midlayer so that the organic matter decomposes in the aerobic condition. Three kinds of artificial seafloor which were made of oyster shell, bamboo,charcoal, and particle-filtering mat were tested. Monitoring for 69 days showed that the number of benthic animals increased and decomposed organic matter along with bacterial decomposition on the artificial seafloors. Habitat effects: Budget analyses of organic matter revealed that the artificial midlayer seafloor made of oyster shell was most efficient to reduce the organic load from the cultured oysters above, showing the highest decomposition rate of 6.6% in 69 days. Authors suggest that the devices proposed in this study will support the future sustainability of oyster culture by accelerating the natural self-purification ability.
Ref Number 201 Ref: Wells, F.E. & Jernakoff, P., 2006. An assessment of the environmental impact of wild harvest pearl aquaculture (*Pinctada maxima*) in Western Australia, *Journal of Shellfish Research,* 25, 141-150. Location: Western Australia Reviewed by: Sewell *et al.,* 2007	Description: Paper looks at the operating procedures of the wild harvest pearl aquaculture system in Western Australia and the potential environmental impacts from the industry. Data from two separate studies were examined and a risk analysis workshop was held with the aim of documenting the main potential ecological and environmental risks that arise from various activities carried out by the industry. Thirteen risks were identified across the industry and entered into a risk matrix of likelihood and consequence. Scores from 1 to 6 (1 = remote, 6 = very likely) were assigned and multiplying to two gave a position on the matrix, a score more than 20 was considered to have a high concern, a score of 7-19 was considered to have a moderate concern and a score below 6 was considered to have a low concern. Community effects: 13 different risks were identified, however none were considered to have a high concern, and 3 risks produced a moderate concern: 1) introduction of disease from seedling, 2) attraction of other fauna and 3) introduction of exotic organisms. The remaining 10 risks were considered to be of low concern: 1) spread of disease, 2) introduction of disease form the hatchery, 3) introduction of disease from translocation, 4) impact to protected and endangered species resulting from entanglement, 5) reduction of primary productivity, 6) potential for litter, 7) perceived change in water quality, 8) nutrient impacts in sediment, 9) impact to protected and endangered species attracted to farm lighting and 10) impact of habitat. The workshop concluded that the environmental impacts of the *Pinctada maxima* industry in Western Australia were small. Further notes: Pearl farms for *Pinctada maxima* are managed by the Department of Fisheries Western Australia under the Pearling Act 1990 and must also be certified as environmentally sustainable by the Commonwealth Department of Environment and Heritage under the Australian Commonwealth government's Environmental Protection and Biodiversity Conservation Act 1999. The wild stock of pearl oysters has been the basis for the industry as wild stock are seeded within the laboratory type conditions, to ensure a continual supply, the taking of oysters for seeding has been controlled by a quota system, size limits and the oysters must be collected from specific areas from within the farm.

Ref Number 206	Description: Brief summarises the current situation of the fishery under three headings: i) biological information, ii) social, cultural and economic information and iii) management and service. The brief also supports the development of a management plan for the Foveaux Strait dredge oyster fishery with various management measures.
Ref: Ministry of Fisheries. 2006. Foveaux Strait dredge oyster information brief 'Proof of Concepts' (Second draft). . Location: New Zealand Reviewed by: Sewell *et al.,* 2007	Further notes: Restrictions that will apply include: Fishery is in the Quota Management System (QMS), All commercial fishers must hold a permit, TACs are enforced, The fishing year runs from October 1st to September 30th, All dredge oysters taken must be reported and any undersized oysters returned to the sea, Closed areas, Minimum legal size of 58mm, Restrictions on the size of the oyster dredge – 2 x 3.35m wide dredges per vessel), Recreational fishery is regulated by a daily bag limit of 50 dredge oysters, Seasonal closure March 1st to August 31st - applies to most dredge oyster stocks, Species taken as bycatch must be reported, Future plans include: minimizing the impact of Bonamia, continue stock surveys, evaluate dredge design to minimize impact on the environment and develop a compliance strategy to reduce illegal fishing.