

Natural England Commissioned Report NECR108

Identifying best practice in management of activities on Marine Protected Areas

First published 05 December 2012

www.naturalengland.org.uk



Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England. Note, this report was completed in March 2011 and as such, the review covers the information available at that time. Certain information such as legislation and organisational responsibilities may have changed.

Background

The Government is committed to 'creating a UK-wide ecologically coherent network of Marine Protected Areas (MPAs)'. The MPA network is an essential part of the Government's strategy to integrate marine nature conservation and other marine activities in pursuing its vision for 'clean healthy, safe, productive and biologically diverse oceans and seas'.

Effective management of activities is essential to ensure the delivery of the conservation objectives of an MPA and thereby ensure the site's contribution to the MPA network. Existing UK MPAs, for example, marine Natura 2000 sites (Marine Special Areas of Conservation and Special Protection Areas), are generally multiple-use sites where activities are only restricted if they pose a significant risk to designated features. For these sites, Natural England produces advice packages detailing both the conservation objectives for the designated features, and advice on operations which may cause deterioration of natural habitats or the habitats of species, or disturbance of species, for which the site has been designated. Relevant management authorities, informed by this advice, use a variety of tools to implement any necessary management measures.

This report was commissioned in October 2010 to review how certain activities are being controlled to mitigate impact to protected habitats and species,

and to identify examples of best practice. The five activities studied were:

- anchoring;
- recreational disturbance to habitats and species;
- non-natives and ballast water;
- by-catch of cetaceans and birds; and
- dredging and disposal of sediment.

The aim for this report is to better inform Natural England and other relevant (or management) authorities on activities which may cause damage to MPA interests (both Natura 2000 sites and MCZs) and the potential management options available. The Marine Management Organisation has management responsibilities for unregulated/recreational activities in MPAs and has reviewed this report. Other bodies that may use this report include Inshore Fisheries and Conservation Associations, European Marine Site project officers and NGOs.

This report should be cited as:

LILEY, D., MORRIS, R.K.A., CRUICKSHANKS, K., MACLEOD, C., UNDERHILL-DAY, J., BRERETON, T. & MITCHELL, J. 2012. *Identifying best practice in management of activities on Marine Protected Areas*. Footprint Ecology/Bright Angel Consultants/MARINElife. Natural England Commissioned Reports, Number 108.

Natural England Project Officer - Jan Maclennan, York - 4th Floor, Foss House, Kings Pool, 1-2 Peasholme Green, York, YO1 7PX jan.maclennan@naturalengland.org.uk

Contractor - Footprint Ecology, Forest Office, Cold Harbour, Wareham, Dorset, BH20 7PA www.footprint-ecology.co.uk

Keywords - management measures, managing activities, coastal management, European Marine Sites, Marine Protected Areas (MPA), risk management

Further information

This report can be downloaded from the Natural England website: www.naturalengland.org.uk. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail enquiries@naturalengland.org.uk.

This report is published by Natural England under the Open Government Licence for public sector information. You are encouraged to use, and re-use, information subject to certain conditions. For details of the licence visit www.naturalengland.org.uk/copyright. If any information such as maps or data cannot be used commercially this will be made clear within the report.

ISSN 2040-5545

© Natural England and other parties 2012



Summary

This report identifies examples and case study material to highlight the range of management options to address five different issues that take place within marine sites. These five issues are:

- Anchoring and damage to substrate and vegetation;
- Disturbance to birds/animals and damage to habitats from recreational activities;
- Non-natives and ballast water;
- Bycatch of cetaceans and birds; and
- Dredging and disposal of sediment.

Each of these issues forms a discrete chapter within the report. We consider the current range of management measures and highlight examples (from both coastal and non-coastal sites, and from the UK and further afield, as relevant) that illustrate how measures have worked and how they have been implemented. We draw on questionnaires circulated to Natural England staff, direct contact with site managers and published literature to collate information on the relative merits of different management approaches.

Acknowledgements

This report was commissioned by Natural England. Our thanks to Michael Coyle and Aisling Lannin, who managed the contract, for his support, advice and steer through the contract. Comments on an initial draft were gratefully received from Michael, Aisling and other colleagues at Natural England, we thank them for their comments.

Our thanks to the following for useful additional information, reference sourcing and discussion:

- Dawlish Warren LNR: Phil Chambers
- Footprint Ecology: Sophie Lake, Sarah Atkinson
- Natural England: Aly Flowers, Sarah Wiggins, Mike Rooney, Mike Quigley
- Norfolk Wildlife Trust: Chris Joel
- Pagham Harbour LNR: Ivan Lang and Rob Carver
- RSPB: Dave Flumm
- State University of New Jersey: Brooke Maslo
- University College Cork: Cathal O'Mahoney
- University of Minnesota: Olivia Ledee

Thanks also to Rachel Hoskin (Natural England) for advice and help with the section on the Habitat Regulations within the disturbance section. The main table in the disturbance section draws in part from a workshop organised by the Solent Forum and held in Fareham in November 2010. The workshop was not directly linked to this piece of work, but we acknowledge the usefulness of the various discussions. Our thanks to all the participants for suggestions and approaches to managing access on the Solent.

All images in the disturbance section are © Footprint Ecology (Durwyn Liley), apart from the Cape Town Penguin colony image (Nigel Bourn). All images in the dredging section are © Roger Morris.

Contents

Summary	ii
Acknowledgements	ii
1 Introduction	1
Overview	1
General introduction to the management of Marine Protected Areas	1
Methods and approach	2
Spreadsheet of examples	3
2 Anchoring	4
Overview of the issue	4
Solutions	5
Use of least damaging anchoring equipment and methods	5
Use of permanent mooring	5
Guidance and education	7
Case studies	8
Torbay – South Devon	8
Marine Conservation Society Seychelles mooring buoy programme	8
3 Disturbance and damage from recreational activities	10
Overview of issues	10
Disturbance: activities and impacts	10
Damage	11
Options to manage	13
Habitat management	22
Planning & off-site management measures	22
On-site access management measures	23
Communication to public and site users	26
Enforcement	27
Wardening	31
Implementation of control measures	32
Case studies	33
Water sports	33
Motorboats and personal watercraft	34
Footfall on coastal habitats	35
Bait digging and similar activities	36
Dogs	37
Initiatives across multiple sites	38
Monitoring and research	38

Recommendations: Choice of management measures implemented at different sites	39
Benefits of a range of measures	40
4 Potential strategies for the mitigation and reduction of the bycatch of cetaceans and seabirds in fisheries in UK Marine Protected Areas (MPAs)	48
Overview of issue	48
Options to manage	49
Examples of management	57
Evidence used to underpin management decisions	57
Recommendations	60
5 Non-natives and ballast water	65
Overview of issue	65
Policy context	65
Characteristics of INNS and their management	66
Options to manage	67
Ballast water management	67
Prevention through controls on aquaculture and biofouling	71
Control of existing non-native populations	72
Eradication of species	72
Awareness raising programmes	73
Case studies	82
Strategic approach	82
Ballast water management	82
Control	84
Eradication	85
Recommendations	86
Prevention	86
Control and eradication	86
6 Dredging	88
Overview of issue	88
Why is dredging undertaken?	88
Definitions of dredging	89
Where does dredging occur?	90
Who undertakes dredging?	90
Types of dredger and their uses	91
Backhoe dredger	91
Bucket ladder dredger	92
Cutter suction dredger	92
Grab dredger	92
Plough dredging	92

Trailer suction hopper dredger	93
Water injection dredger	93
Who consents dredging?	93
Port authorities – own legislation	93
Marine Management Organisation	94
Sediment quality – chemical analysis	95
Dredge disposal sites	95
Understanding the impacts of dredging	95
Geographical variation	96
Dredging and physical processes	97
Sediment plumes	99
Loss of habitat	101
Smothering	102
Contaminated sediments	103
Water quality	104
Noise	104
Disposal sites	105
Commercial issues	107
Timing	107
Navigation responsibility	107
Mobilisation and deployment costs	108
Principles underpinning good nature conservation outcomes: sediment management	108
Inter-tidal sedimentation	108
Sediment budgets	109
Offsetting measures – sediment husbandry	110
Offsetting measures – habitat replacement	113
Beneficial use of dredged sediment	113
Overspilling	114
Tidal cycle	114
Disposal sites – policy implications	114
Case studies	115
Chichester harbour (beneficial use of dredged materials)	115
Ems Estuary channel deepening (severely elevated tidal propagation)	116
Harwich Haven capital dredge (1998/1999) (compensation and mitigation)	117
Humber Estuary: Sunk Dredged Channel (incidental beneficial use)	118
Port of Rotterdam (landside disposal of contaminated sediment)	119
Port of Tyne (trial burying of contaminated sediment)	119
Seaforth Container Terminal, Port of Liverpool (sediment feeding)	120

Southampton Water capital dredge (1996/1997) (sediment mobilisation by spring tides)	121
Wallasea Island managed realignment (beneficial use of maintenance dredged material)	122
Regulatory controls	123
Maintenance dredging protocol	123
Water Framework Directive	125
Good practice matrix	126
7 References	127

List of tables

Table 1 Summary of management options	15
Table 2 Summary of management options and when to implement	42
Table 3 Summary of management options available to reduce bycatch of seabirds and cetaceans in UK fisheries	52
Table 4 Summary of management recommendations and when to implement	62
Table 5 Summary table of examples of management approaches	74
Table 6 Descriptions of sediment regimes in proposed dredging sediment zones	96
Table 7 Sediment budget for Southampton Water, reproduced from online estuaries guide	110
Table 8 Principles of good practice to be employed in considering the management of dredging activities	126

List of figures

Figure 1 A fluke style anchor (left) and a grapnel anchor (right)	5
Figure 2 Examples of different management: a) Viewing facilities for Penguin colony, Cape Town, South Africa; b) reed screen, Slapton, UK; c) & d) signs and fencing around Least Tern/Piping Plover enclosure, Cape Cod, U.S.A; e) board walk, Pagham Harbour; f) Kite Surfer code of conduct sign, Exe Estuary; g) Exclosure to protect shingle vegetation, Browdown SSSI	21
Figure 3 Sediment zones relating to Marine Protected Areas	97
Figure 4 Differences in sediment plumes, with and without tidal influences. Left - no tidal or wind influences leading to outward passage similar to ripples on a pond. Right - the plume is drawn into a cigar shape by tidal influences within an estuary	100
Figure 5 Rushenden dredge disposal site, 1993. This is the point where sediment arrives in barges and is pumped ashore	106
Figure 6 Rushenden disposal site, 1993. This shows settled material, which includes a high proportion of aggregate that is now being mined to yield commercial aggregate supplies	106
Figure 7 Techniques to augment sediment supplies to saltmarshes and mudflats. a) inter-tidal placement; b) sub-tidal placement; and c) rainbowing	112
Figure 8 Erosion of the lateral edge of a saltmarsh may also be accompanied by vertical accretion with some of the sediment released by erosion feeding the process of accretion	115
Figure 9 Conceptualised illustration of sediment movement in the mouth of Chichester Harbour	116
Figure 10 Maintenance dredging (cubic metres) from the Sunk Dredged Channel, Humber Estuary [after ABP (2008)]	118
Figure 11 Newly developing <i>Salicornia</i> saltmarsh at Wallasea Island, 2008. Note that the main growth is as a band closest to the new sea wall	122
Figure 12 Saltmarsh cover at Wallasea Island spring 2009. Local topographic variation is clear from the patchy nature of the distribution of plants	123

1 Introduction

Overview

- 1.1 This report was commissioned by Natural England in October 2010 and completed in March 2011 to identify examples and case study material to highlight the range of management options and opportunities for five different types of activity that take place within marine sites. These five activities are:
 - Anchoring;
 - Recreational disturbance to habitats and species;
 - Non-natives and ballast water;
 - Bycatch of cetaceans and birds; and
 - Dredging and disposal of sediment.
- 1.2 These activities form the main chapter headings within this report. For each activity we research current management measures, setting out the range of different options for management. We highlight examples (from both coastal and non-coastal sites, and from the UK and further afield, as relevant) that illustrate how measures have worked and how they have been implemented.
- 1.3 Our aim has not been to repeat existing management handbooks, nor to produce a detailed literature review of impacts of particular activities. Instead our approach is to draw on existing material and a selection of examples to highlight key points regarding management of Marine Protected Areas.
- 1.4 Natural England undertook a risk assessment of activities in marine Natura 2000 sites and relevant authorities have been identifying additional management where it is deemed necessary to further mitigate risks. Through this work, there were some activities/issues where Natural England would like to further understand the availability and efficacy of management options. These activities do not necessarily represent those which pose greatest risk, but they can pose complex challenges for relevant authorities to ensure they are controlled in order to protect MPAs.

General introduction to the management of Marine Protected Areas

- 1.5 Management of the marine environment is complex, with a variety of organisations involved in consents and measures to manage development pressures, extractive or recreational use. The Marine and Coastal Access Act, 2009 establishes two new bodies: the Marine Management Organisation, and Inshore Fisheries and Conservation Authorities (IFCAs). It includes provisions for new powers vested in both the MMO and in IFCAs, together with Natural England, that extend the range of controls that can be exerted to safeguard marine biodiversity. These powers, combined with those already available through the various other relevant and competent authorities, mean that conservation of marine wildlife and habitats should be greatly improved.
- 1.6 The Marine and Coastal Access Act, 2009 is particularly important because it sets out for the first time a mechanism for the development of a coherent network of Marine Protected Areas (MPAs) using a variety of statutory designations. Several designations are already familiar: Special Areas of Conservation (SAC) under the Habitats Directive (1992), Special Protection Areas (Under the Birds Directive 1979), Ramsar Sites and Sites of Special Scientific Interest (SSSI). A new designation, Marine Conservation Zones (MCZs), has also been introduced. MCZs will be selected to encompass a broader suite of objectives and offer an important opportunity to identify

and manage a broader spectrum of marine wildlife apart from specific rare and threatened attributes.

- 1.7 It is anticipated that the overall suite of MPAs will draw upon a broad range of mechanisms to make sure that wildlife assets are maintained or enhanced. Many of the ways in which these objectives are met will be delivered through existing or revised consents regimes. Where such consents are determined in accordance with existing statutory powers many of the critical issues will already have been identified. Good practice can range from the way in which applicants, consenting bodies and advisory bodies engage, through to the ways in which remedial measures are introduced to make sure that the marine environment suffers no further degradation or indeed is enhanced.
- 1.8 The establishment of Management Schemes in accordance with Regulation 34 of the Conservation (Natural Habitats &c.) Regulations, 1994¹ (The Habitats Regulations) provided an early opportunity to develop new management techniques for the marine environment. Such Schemes have drawn together all of those bodies with specific powers to manage the marine environment. These Regulations also introduced the concept of Special Nature Conservation Orders² which could be made to prevent damage to critical habitats and species within sites designated as SAC and SPA.
- 1.9 The Marine and Coastal Access Act, 2009, extends and complements the powers established by the Habitats Regulations. In particular, it strengthens the role of the former Sea Fisheries Committees with the establishment of IFCA's whose remit extends beyond management of fish and shellfish stocks and now includes a significant responsibility for conservation of wildlife assets. The Act also places a duty on Natural England to establish access to the majority of the English coast, which brings a variety of new management issues into the frame. Experience in relation to management of access to common land and to the uplands provides an obvious example of the learning process that has already been followed.
- 1.10 Finally, the Marine and Coastal Access Act, 2009 establishes the concept of marine planning. Marine planning is expected to reduce conflict of multiple use and to improve assessment of environmental effects, including cumulative impact assessment. This is a new concept which has yet to be fully explored. Development of appropriate policies in the context of the suite of Marine Protected Areas is in its infancy, but can be expected to call upon a wide variety of evidence bases.
- 1.11 The combination of issues raised through the introduction of the Marine and Coastal Access Act, 2009 means that it is apposite to develop a fuller understanding of the activities that can have a significant bearing on the welfare and condition of organisms within the marine environment. This review investigates the issues relating to anchoring, recreational disturbance to habitats and species; non-natives and ballast water; dredging and disposal of sediment and bycatch of cetaceans and birds.

Methods and approach

- 1.12 Each of the five activities forms a discrete chapter of the report and they have been written by different authors. The authors have drawn from their own knowledge of the issues. This has been supplemented with:
 - A questionnaire circulated to a selection of Natural England staff asking for examples of different management for each of the five activities.

¹ Now Regulation 36 of the Conservation of Habitats and Species Regulations 2010

² Regulation 25 of the Conservation of Habitats and Species Regulations 2010 vest powers in "appropriate authorities" to make Special Nature Conservation Orders after consultation with the relevant nature conservation body

- Literature searches on the internet using a range of search engines and key words. While we draw widely from academic sources much of the information on management has come from internet forums, websites of management bodies etc.
- Direct contact with site managers and researchers as relevant.

1.13 Each of the five activities addressed within the report is different in scale and the range of different management options available. Each section is therefore different in structure and presentation, to allow the authors the opportunity to focus on the key issues relevant to each issue.

Spreadsheet of examples

1.14 In addition to this report, a spreadsheet has been created listing the main examples cited in the report. The spreadsheet provides a simple list of examples of management. Natural England requested that examples be listed in this fashion to allow the potential for a database or similar to be developed in the future. We can see the potential of such an approach. The spreadsheet could provide the foundation for a database, for example using Microsoft Access or on-line. Ideally the database will allow users to search using different terms (such as “disturbance”, “birds”, “dogs”), and provide the user with details of the management. Ideally such details would be presented in a standard format, setting out the details of management, the cost, any indications of effectiveness and could be accompanied by photographs and links to reports, papers etc. The approach used by the Conservation Evidence website³ provides a useful template. The writing of these individual examples would be the most time consuming part to building the database. In the long-term these individual write-ups would be best written by site managers or organisations involved in the management, but initially it may be necessary to commission a series of write-ups to ‘seed’ the database. For more information about this spreadsheet please contact the Marine Operations and Advice Team at Natural England by contacting enquiries@naturalengland.org.uk.

³ <http://conservationevidence.regulus.titaninternet.co.uk/Default.aspx>

2 Anchoring

Overview of the issue

- 2.1 There is considerable evidence that boat anchors can cause damage to seabed plant and animal communities. Most studies have examined damage to coral reefs and seagrass beds but maerl and *Sabellaria* beds and infaunal and epifaunal invertebrate communities and biogenic reefs are also vulnerable.
- 2.2 A number of studies from outside the UK have attempted to quantify the damage from boat anchoring and assess which operations are most damaging. Boat anchoring has been found to damage *Posidonia oceanica* seagrass beds from anchor fall, lock-in and weighing, from anchor drag and from the scouring effect of a chain or rope attached to the anchor moving across the seabed as the boat swings round the anchorage (Francour, Ganteaume, & Poulain 1999). Damage can also be caused by hull grounding and propeller wash in shallow water. Damage ranges from removal or abrasion of foliage to dislodgement of rhizomes and complete removal of plants. Seagrass beds are composed of light demanding species and there can be additional effects from shading by boat docks or smothering from increased turbidity including clouds of particles in suspension from the scouring actions of ropes or chains (Loflin 1995).
- 2.3 The extent of the damage can depend on the type of anchor used, the size of the anchor and the design of the mooring, as well as on the strength and direction of tides and currents and whether the anchoring site is erosional or depositional (Hastings, Hesp, & Kendrick 1995; Francour *et al.* 1999; Milazzo *et al.* 2004). Traditional block and tackle and heavy chains can be most damaging. Circular scour damage to seagrass beds from continual sawing of the anchor rope or chain can create bare areas of up to 1000 m², with anchor scars of up to 0.16 m². Loss of seagrass areas has been variously described as small to devastating with estimates of loss due to moorings extending up to 30% over 50 years and up to 0.5% per annum, associated with increases in exposed edge, interference with the physical integrity of the seagrass meadow and a reduction in plant density (Walker *et al.* 1989; Hastings *et al.* 1995; Creed & Amado Filho 1999).
- 2.4 Recovery times of damaged seagrass beds vary, depending on the size of scoured areas, physical conditions and the species making up the beds. Some studies have recorded complete recovery within a year and others have estimated 50 years or more, depending on the size of the holes in the seagrass beds and the species concerned; there seems to be general agreement however that recovery is mostly due to rhizome spread rather the seed germination from the seed bank or from fresh seed (Vermaat *et al.* 1995; Rasheed 1999; Meehan & West 2000). Although factors influencing regeneration have been identified for UK *Zostera* species (for example, Davison & Hughes 1998), there is little information on recovery time specific to particular factors. There appears to be little information on recovery of associated fauna, but seagrass beds are habitat to many important species including shellfish, crustaceans and seahorses as well as providing nurseries for small fish.
- 2.5 Damage to coral reefs and seagrass beds from anchoring boats have been recorded across the world with concerns expressed in Europe, the Mediterranean, the United States and South America, Asia and Australasia. There is little information on damage to other fauna and flora, possibly as boat anchoring in the deeper water where these can be found is less common and most studies in such conditions have concentrated on damage caused by fishing gear used by commercial fishermen.

Solutions

2.6 Solutions to anchoring damage can be categorised under the following headings:

- Use of least damaging anchoring equipment and methods;
- Restrictions on anchoring in sensitive locations;
- Use of fixed moorings; and
- Guidance and education to inform the above points.

2.7 In particularly sensitive locations where the use of least damaging anchoring equipment and methods is not considered adequate, and alternative anchoring sites in less sensitive locations are not available, then provision of appropriate permanent moorings may be necessary. Guidance and education will be important to ensure the success of whichever solution, or combination of solutions is used for any given situation.

Use of least damaging anchoring equipment and methods

2.8 A study of types of anchor showed that the Hall anchor, which is a stockless bow anchor type with fixed flukes is less damaging when used in seagrass beds than a Danforth anchor with movable flukes, but that the most damaging type of small anchor in this situation is a grapnel with tines facing in all directions. None of these anchors caused significant damage from dropping or digging in, but the grapnel caused significantly more damage when being weighed than the other two types with the Hall anchor being least damaging (Milazzo *et al.* 2004). As the tines on a grapnel anchor are much thinner than the flukes on a more conventional anchor they have less hold in sandy or clay seabeds and can be more liable to drag in strong winds or currents which can increase damage to seagrass or maerl beds. The same effects will be seen where the boat operator pulls the anchor across the seabed to a boat. Small boats should therefore use a fixed fluke anchor where possible and always take the boat up to the anchor before weighing, so that the anchor is lifted vertically off the seabed to minimise drag.



Figure 1 A fluke style anchor (left) and a grapnel anchor (right)

2.9 When anchored to a single point, a boat will swing around the anchor point as it is subject to winds and tides. In many cases the boat will describe a 360° circle with the anchor chain or rope causing a circular scour. To avoid this, either a buoyant rope should be used or a buoy should be fixed to the rope to hold it off the seabed about 1m from the anchor. Results of studies on three chained cyclone moorings (a mooring with three anchors and a swivel) are contradictory with one study asserting that such systems are less damaging than a single anchor (Walker *et al.* 1989) and another that such a system results in three circular scours instead of one. Another alternative is to anchor fore and aft to prevent the boat swinging (Hastings *et al.* 1995).

Use of permanent mooring

2.10 Where anchor damage is unacceptable but alternative anchorages in less damaging situations are not available, then permanent moorings may need to be considered.

- 2.11 In these circumstances, in one widely used system, a permanent mooring point is fixed to the seabed from which a mooring line runs to the surface and is attached to a polypropylene or polyethylene buoy (with ultraviolet stabilisers to reduce sunlight damage) and with a 12-15ft floating pick up line attached to the top of the buoy with an eye splice at the other end. To minimise chafing, protective sheaths, thimbles and shackles are used at all attachment points. The mooring line is kept off the seabed with an attached float and drops vertically from the buoy with an attached weight to prevent entanglement with boat gear.
- 2.12 In many private or older systems the buoy is attached to a heavy weight, usually a lump of concrete or stone, an old engine block or similar scrap metal, sitting on the seabed.
- 2.13 Such systems are not recommended as the weight can be dragged along the seabed by a larger boat in strong tides or strong winds, and if this happens the weight can create more damage than the temporary anchoring that this system was installed to avoid. Furthermore, the use of second-hand engine blocks or similar can introduce pollutants into the sea and cause further damage to flora and fauna.
- 2.14 The recommended mooring system is one which has been designed for the task and usually involves a purpose made eyebolt cemented into the rock using marine cement or epoxy resin, or an augur fixed to a sandy or clay substrate or a manta ray anchor screwed into rubble or sand. Manta ray anchors are essentially long toggle bolts driven into the seabed by a hydraulic jack hammer and then the toggle is locked into place by a hydraulic load-locker which at the same time strain tests the installation. A manta ray anchor, once installed is ready for immediate use. On rock surfaces a modified hammer drill is used to drill a hole for a pin to be cemented into the rock and on softer limestone or coral a corer is used to create a larger diameter hole for t-bar pins to be inserted. Where pins are used they have to be left for several days to let the cement set, before use.
- 2.15 All these installations require specialists to install them (and to remove them) or specialist training of local contractors or marine staff. They should be installed and the position recorded using GPS with each mooring numbered and certified as satisfactory before use. They are also expensive to install and require a regular maintenance programme with checks and cleaning at regular intervals.
- 2.16 To work satisfactorily, permanent moorings need to be installed using standardised buoy colours and shapes for different boat sizes and to indicate overnight or more permanent stay locations. Mooring buoys must appear clean and well maintained otherwise boat owners will not view them as safe and reliable and will not use them. Each buoy should be clearly numbered and a record of maintenance kept.
- 2.17 Mooring guidelines to follow:
- Carefully located for comfort, convenience and safety of boat users as well as in locations to minimise seabed damage.
 - Each installed mooring should be recorded with the type of buoy, the manufacturer, the serial number, the installer and date of installation, and how it was emplaced.
 - Only proven mooring designs should be used.
 - Where possible a representative of the mooring authority should be present when new moorings are installed.
 - A maintenance programme should be agreed for all new moorings before they are installed and the records checked at regular intervals.
 - Maintenance records should include the name of inspector, description of condition and records of any repairs or maintenance carried out.
 - Maintenance should include regular replacement of mooring lines and other hardware subject to corrosion.

- No part of a mooring should be within at least fifteen meters of sensitive features to avoid shading.
- Where moorings are located, there can be littering, disposal of sewage or waste and noise and disturbance from boats using the facility - this should be recognised in deciding mooring locations. Clothing or towels can smother marine life, plastic items can trap and kill animals, and discarded fishing line can injure marine mammals and birds.
- Water depth over moorings should be deep enough to avoid hull or propeller wash damage at all states of the tide.
- Surface flotation devices must be clearly visible, light and radar reflective.
- No use should be made on mooring equipment of anti-fouling agents, toxic substances or metal components.
- Care needs to be taken to cause no damage by maintenance or maintenance vessels to seabed flora and fauna.
- Boat users should be warned that it is their responsibility to check the condition and suitability of the mooring, and to use it correctly.

2.18 Prior to consideration of permanent moorings where boats regularly anchor, a survey should be undertaken to estimate use. Moorings are an expensive option to install and maintain, and unnecessary moorings which are subsequently not or only lightly used will be an unnecessary cost. It may be necessary to defray the cost of moorings provision by charging for their use. This presupposes that staff are available to collect mooring fees and carry out regular maintenance.

2.19 In England, applications for fixed moorings are dealt with by the Marine Management Organisation through the marine consents process. Natural England must be consulted on moorings proposed in designated sites which may require an environmental impact assessment. Care should be taken to avoid placing moorings on sites which may have archaeological interest, and local fishing interests, (including shell and crustacean fishing), should also be consulted.

Guidance and education

2.20 Another alternative is to educate boat users in anchoring practices and locations to minimise seafloor damage.

2.21 Seabed features can be protected by buoy markers, and this has worked well in some areas in the protection of coral reefs⁴. However, to be effective, marker buoys must be clearly visible and their colours and shapes standardised with a clear message which is widely understood by boat users. Marker buoys that do not meet these requirements will be ignored by boat users who may believe them to be markers for lobster pots or local moorings.

2.22 The same strictures apply to sensitive marine habitats, where anchorages or moorings are installed, and boat owners should be informed through information on charts (and particularly electronic charts) and pilot books.

2.23 To address problems of careless anchoring, littering, disposal of fishing gear and other issues, written guidelines can be issued and widely publicised and for local boat owners, workshops can be a useful means of conveying information. Information in boat hiring and marine equipment shops, diving and fishing shops and marinas, boatyards and other hire and equipment suppliers as well as yacht clubs will also help to inform. Local boat owners and users are usually caring about their local marine environment and if well informed, can help to encourage others to follow suitable codes of behaviour.

2.24 Websites are also widely used by boat owners and others seeking information, and leaflets and guidance sheets are produced by a number of national organisations including the Royal

⁴ Great Barrier Reef Park Authority 1999

Yachting Association⁵, The Green Blue (sponsored by the RYA and The British Marine Federation)⁶ and Project Aware⁷, which promotes divers conserving underwater environments and is sponsored by the scuba divers organisation PADI and the Crown Estate⁸. Links to their websites are given at the end of this section.

Case studies

Torbay – South Devon

- 2.25 This area has long been known for its important marine habitats and species. In 2000 the Coastal Forum set up under the marine ecotourism project, issued a report identifying that there was disturbance to habitats and species from recreational users including to the important eel grass beds, that enforcement of existing rules was inadequate, that byelaws were outdated and there was limited cooperation between conservation bodies to address these problems.
- 2.26 Recognising the legitimate rights of people to enjoy leisure facilities, the need to protect the environment, the need for flexibility and the importance of cooperation and partnership working, the following actions were recommended in relation to boat users:
- Establish zoning to reduce disturbance to sensitive species and habitats;
 - Encourage effective training of powerboat users;
 - Improve information and education of the general public on coastal zone issues;
 - Prepare and publicise a code of practice; and
 - Provide specific training to commercial operators.
- 2.27 As part of the actions to implement these proposals, Tor Bay Marine Habitats and Marine Biodiversity Action Plans were produced with recommendations for habitat conservation measures, including the institution of a seagrass monitoring programme, creation of protective zones over sea grass beds and the launch of a voluntary code of conduct and a general awareness campaign for seagrass beds. With funding help through the Landfill Communities Fund, surveys of the sea grass beds have been carried out, a map showing the sensitive areas and other features has been produced and a seagrass beds leaflet has been produced that describes the importance of the habitat, shows maps of where the beds are found in Tor Bay, and advises boat users on how to avoid damaging them.
- 2.28 With the help of Torbay Harbour Authority, special white marker buoys have been installed with 'CAUTION SEAGRASS' written on them to identify the location of the most vulnerable seagrass areas within the bay. There are also leaflets and waterproof reference maps available at harbours, marinas and yacht clubs which show where the main beds are and inform people how they can avoid causing damage to the seagrass.

Marine Conservation Society Seychelles mooring buoy programme

- 2.29 In the Seychelles, concerns were raised that there were insufficient moorings and that moorings were being managed by a range of organisations and individuals with differing standards of installation and maintenance.
- 2.30 A study was commissioned of existing practices and problems which found that maintenance practices were not consistent across managers of moorings and poorly maintained moorings were not being used, that there were limited powers to enforce standards, that there were

⁵ www.rya.org.uk/Pages/Home.aspx

⁶ www.thegreenblue.org.uk/

⁷ www.padi.com/scuba/about-padi/padi-partners/project-aware/default.aspx

⁸ www.thecrownestate.co.uk/marine

insufficient moorings in key ecological locations and that shortage of funding for maintenance was limiting.

- 2.31 Following a public and stakeholder workshop to examine these problems, a steering group to oversee the long term process for moorings in the Marine Parks was established including representatives from the Marine Parks Authority (MPA) and the Marine Conservation Society Seychelles (MCSS). The Steering group approves the number and positions of all new moorings in or near marine protected areas, with the MPA taking on routine maintenance and MCSS undertaking inspections and other essential maintenance. Entrance and overnight mooring fees fund these activities.
- 2.32 MCSS has now installed a national mooring buoy system in and adjacent to Marine Protected Areas with 100 moorings with donor funding from The Netherlands using best practice following a training programme for staff. The buoys are now well maintained and provide a much needed facility for tourist boats and yachts whilst giving greater protection to the sensitive marine ecosystems.

3 Disturbance and damage from recreational activities

Overview of issues

- 3.1 In this section we address disturbance to species, such as birds, and also damage to habitats, for example trampling of vegetation or substrates. We focus on impacts from recreation (rather than industrial or other commercial activities), including both shore based and water-based activities.
- 3.2 We therefore address the primary impacts caused by the presence of people undertaking recreation in Marine Protected Areas. Disturbance can be defined as any human activity that influences an animal's behaviour or survival. In terms of habitats, the presence of people and their pets can also result in damage to vegetation and substrates through wear - the cumulative effects of footfall and abrasion from vehicles and boats. Such wear typically initially results in a reduction of vegetation cover, which can be followed by substrate damage. Another way in which damage can occur is through fouling, for example by dogs. The impacts from damage therefore relate primarily to plants and substrates. There can be knock-on consequences for other species.
- 3.3 The section covers a very broad range of topics and issues, we do however exclude the following:
- Impacts from anchors and moorings (these are addressed in section 2);
 - Consequences (i.e. depletion) of harvesting (for example, fishing, shellfishing, bait digging, wildfowling) on the species harvested; and
 - Impacts of fire.
- 3.4 Disturbance and damage from recreation are highly relevant and current issues. Levels of recreational use of the UK countryside are increasing (for example, TNS Research International Travel & Tourism 2010). Visitor surveys undertaken at Marine Sites typically indicate a wide range of different activities and highlight that coastal areas have a wide draw (Fearnley, Clarke, & Liley 2010; Liley & Cruickshanks 2010). Climate change may have implications for access levels and impacts of access (Coombes 2007).

Disturbance: activities and impacts

- 3.5 There are a wide range of studies and a large volume of scientific literature that consider disturbance and its consequences. The impacts and issues are complex and researchers tend to focus on the ecological or theoretical implications of their research and avoid making practical recommendations. There is a large body of scientific and grey literature addressing the impacts of disturbance in coastal environments, and a number of reviews on the effects of access are available (for example see Hockin *et al.* 1992; Hill *et al.* 1997; Nisbet 2000; Saunders *et al.* 2000; Penny Anderson Associates 2001; Kirby *et al.* 2004; Woodfield & Langston 2004; Lowen *et al.* 2008).
- 3.6 By far the majority of the literature and concern relating to disturbance and individual species is focussed on birds. However disturbance impacts at coastal sites are also relevant to mammals such as seals (Lidgard 1996; Lewis & Mathews 2000; Cassini 2001; Westcott & Stringell 2003; Skeate & Perrow 2008) and invertebrates and other fauna (Bonte & Maes; Addressi 1994; Moffett *et al.* 1998; Beauchamp & Gowing 2003a; Arndt, Aydin, & Aydin 2005; Casu *et al.* 2006; Barca-Bravo *et al.* 2008; Ugolini *et al.* 2008; Bally & Griffiths 2008).
- 3.7 Studies of disturbance effects to species have shown disturbance effects for a wide range of activities besides simply people, for example aircraft (Drewitt 1999), traffic (Reijnen, Foppen, &

Meeuwssen 1996; Reijnen, Foppen, & Veenbaas 1997), dogs (Lord *et al.* 2001; Banks & Bryant 2007) and machinery (Delaney *et al.* 1999; Wright, Goodman, & Cameron 2010). There is still relatively little work on the effects of different types of water based craft and the impacts from jet skis, kite surfers, windsurfers etc. (see Kirby 2004 for review)(see Kirby *et al.* 2004b for review). Some types of disturbance are clearly likely to invoke different responses. In very general terms, both distance from the source of disturbance and the scale of the disturbance (noise level, group size) will both influence the response (Beale & Monaghan 2005; Wright *et al.* 2010). On UK estuaries and coastal sites, a review of WeBS data showed that, among the volunteer WeBS surveyors, driving of motor-vehicles and shooting were the two activities most perceived to cause disturbance to birds (Robinson & Pollitt 2002).

- 3.8 Disturbance can have a variety of impacts. There are studies showing impacts to species that include behavioural effects, such as birds changing their feeding behaviour (Fitzpatrick & Bouchez 1998; Verhulst, Oosterbeek, & Ens 2001), taking flight (Burger 1998; Fernandez-Juricic, Jimenez, & Lucas 2001, 2002; Blumstein *et al.* 2003, 2005; Eason *et al.* 2009) or being more vigilant (Riddington 1996; Stevens & Boness 2003; Randler 2006). Other studies have focused on physiological impacts, such as changes in the levels of stress hormones (Remage-Healey & Romero 2000; Tempel & Gutierrez 2003; Walker, Dee Boersma, & Wingfield 2006; Thiel *et al.* 2011) or heart rate (Hubert & Huppopp 1993; Nimon, Schroter, & Oxenham 1996; Weimerskirch *et al.* 2002). Direct mortality resulting from disturbance has been shown in a few circumstances, for example through trampling of eggs or young (Liley 1999; Yasue & Dearden 2006) and many (but not all) studies have shown a reduction in breeding success where disturbance is greater (Murison 2002, 2007; Bolduc & Guillemette 2003; Ruhlen *et al.* 2003; Brambilla, Rubolini, & Guidali 2004; Beale & Monaghan 2005; Arroyo & Razin 2006). There are also many examples of otherwise suitable habitat being under-used as a result of disturbance (Gill 1996; Liley & Clarke 2003; Kaiser *et al.* 2006; Liley & Sutherland 2007), or birds being displaced from one site to another (Cairns, Dibblee, & Daoust 1998)
- 3.9 Despite this large body of work, there is still contention (Gill, Norris, & Sutherland 2001) as it is often difficult to understand whether there is a real issue and whether disturbance is a cause of conservation concern. For example, the fact that a bird takes flight when a person approaches is to be expected and a short flight is unlikely to have a major impact on the individual in question, let alone the population as a whole. However, repeated flushing, over extended periods or in particular circumstances may have consequences for the population as a whole (West *et al.* 2002). Very few studies have actually placed disturbance impacts in a population context, although there are examples where the actual impact of disturbance on population size has been demonstrated (West *et al.* 2002; Liley & Sutherland 2007; Mallord *et al.* 2007; Stillman *et al.* 2007; Kerbiriou *et al.* 2009).
- 3.10 Much of the science rarely provides detailed guidance to inform site management. It is often difficult for conservation practitioners to fully understand the implications of the research in terms of management of a particular site or the measures necessary to avoid adverse effects on the integrity of a site.

Damage

Trampling and abrasion from vehicles etc

- 3.11 Trampling can seriously affect vegetation communities, leading to loss of vegetation cover, damage to the underlying substrate and loss of substrate through erosion (Liddle & Grieg-Smith 1975; Liddle & Greig-Smith 1975; Slatter 1978; Andersen 1995; Christensen & Johnsen 2001; Doody & Randall 2003a; Grunewald 2006; Coombes 2007).
- 3.12 In sand dunes, the more stressed the environment and unstable the substrate, the greater the impact. Thus, fore dunes with marram *Ammophila arenaria* may be very susceptible to trampling, while rank grasses and dune heath are moderately susceptible and short turf and scrub most resilient (Boorman & Fuller 1977). In unmanaged dune grassland, trampling results in a

progressive decline in height of vegetation and less litter; and also some increase in pH associated with compaction (Slatter 1978).

- 3.13 In some dune systems some light trampling in otherwise unmanaged dune grassland may benefit less competitive plants such as some annual plants, but the habitat is very prone to erosion and the creation of increasingly wide, bare pathways. It is generally accepted that recreational pressure results in a decrease in species diversity within dunes (Bonte & Hoffman 2005), and that a threshold can be reached where irreversible damage can occur (Curr *et al.* 2000; Ritchie 2001; Covey & Laffoley 2002), although it is often difficult to identify at what point this threshold may occur.
- 3.14 Whereas for sand dune vegetation some degree of light trampling can be beneficial for some plants and invertebrates, this appears virtually never to be the case for shingle habitats. The shingle survey of Great Britain covered a number of sites at many of which, trampling was noted as an activity causing damage to shingle vegetation (Sneddon & Randall 1993). Damage to ridge structures is also an issue. One of the main causes of damage is the breaking up of the surface layers of vegetation and the fine humic layer that may take many years to be deposited. As a result, damage to vegetation may not be possible to reverse. Spokes (1997) studied shingle vegetation and trampling and compared data from 1991 with that collected in 1997 on a shingle habitat at Slapton in Devon. The results indicated that untrampled areas were more diverse than the trampled areas. Hewitt (Hewitt 1973) came to the same conclusion on Chesil Beach in Dorset. Communities with abundant lichens are susceptible to trampling, again particularly during dry weather. A single pass may be sufficient to cause irreparable damage (Doody & Randall 2003b).
- 3.15 Access can affect the composition of vegetation in addition to causing the replacement of vegetation with bare ground. Natural England's Access and Nature Conservation Reconciliation Guidance (Lowen *et al.*, 2008) highlights the impacts of trampling, citing a range of studies. The guidance notes that experimental work has demonstrated that light levels of trampling can increase plant diversity, but moderate to high trampling can lead to increased bare ground, soil compaction, loss of plant species diversity and changes in vegetation height.
- 3.16 A number of studies, from various locations across the world have investigated the effects of trampling on rocky shores. These generally have shown that trampling causes a reduction in cover of a range of algae species. The extent of damage increases with the intensity of trampling. Increased intensity of trampling leads to increases in the amount of ephemeral algal species and extends recovery times from months to years (Fletcher & Frid 1996; Keough & Quinn 1998; Schiel & Taylor 1999; Milazzo *et al.* 2002; Beauchamp & Gowing 2003b; Irvine 2005). The extent of damage and removal does not seem to be affected by the hydration state of the algal mat. Where the plant cover is not completely removed, effects of trampling can cause loss of vesicles or air bladders and reproductive structures (Keough & Quinn 1998; Denis 2003). Trampling can also cause changes in species diversity (Fletcher & Frid 1996; Pinn & Rodgers 2005; Van de Werfhorst & Pearse 2007).
- 3.17 Saltmarshes and particularly mudflats do not lend themselves to easy access and therefore have a degree of self-protection from trampling damage. Comparative studies of trampling impacts on different coastal habitats indicate that saltmarsh is the most resilient habitat relative to other coastal habitats such as sand dunes (Andersen 1995; Coombes 2007). However, where trampling does occur it may still have significant effects, leading to vegetation loss (for example, Chandrasekara & Frid 1996), which potentially can leave the marsh more vulnerable to erosion. Even annual visits to fixed sample points can cause visible changes to the vegetation (Boorman 2003). In Australia, loss of saltmarsh has been linked to access (Laegdsgaard 2006).

Eutrophication, for example, from dog fouling

- 3.18 A further impact of damage to habitats occurs through nutrient enrichment. The main issue is from dog faeces, which are particularly nutrient-rich. Fouling from horses (Newsome *et al.* 2002) and even people (Liley *et al.* 2010) may also be issues.

- 3.19 A number of reviews have addressed the impacts of dog fouling (Bull 1998; Taylor *et al.* 2005a; Liley *et al.* 2010). Dogs will typically defecate within 10 minutes of a walk starting, and as a consequence most (but not all) deposition tends to occur within 400m of a site entrance (Taylor *et al.* 2005a). In addition most faeces are deposited close to the path, with a peak at approximately 1m from the path edge (Shaw, Lankey, & Hollingham 1995). At Burnham Beeches NNR over one year, Barnard (2003) estimated the total amounts of urine as 30,000 litres and 60 tonnes of faeces from dogs. Limited information on the chemical composition of dog faeces indicates that they are particularly rich in nitrogen and that modern dog food contains an excess of nutrients to improve flavour and any excess is excreted (Taylor *et al.* 2005a).
- 3.20 Nutrient levels in soil (particularly nitrogen and phosphorous) are important factors determining plant species composition and for some habitats the typical effect will be equivalent to applying a high level of fertilizer, resulting in a reduction in species richness and the presence of species typically associated with more improved habitats. Consequently a lush green strip is often evident alongside paths as nutrient enrichment can also lead to more vigorous growth and flowering (Taylor *et al.* 2006).
- 3.21 The persistence of dog faeces and nutrients in the soil will be subject to a number of factors, but primarily the soil type, soil water, weather and temperature. Dog faeces can take up to two months to break down, however if the weather is cold and dry this is likely to take longer, whereas if it is warm and wet it is likely to take less time (Taylor *et al.* 2005a). The persistence of these nutrients in the soil is strongly influenced by the soil type, with nutrients more likely to leach from free draining sandy soils (Gough & Marrs 1990).
- 3.22 There is very little evidence to the extent of the problem of human fouling or the nutrient persistence in the natural environment. Problems, however, are likely to be highly localised. It is reasonable to assume that the visual and nutrient persistence of human faeces is similar to that of dogs, however there is no evidence to confirm this assumption.

Options to manage

- 3.23 There are a wide variety of ways in which to reduce the impacts of disturbance or damage. These can include education programmes (intended to inform people of issues relating to their presence at a site and explaining how to best minimise their impacts) through to statutory measures and legal enforcement. Visitor behaviour can be influenced through planting, path surfacing, vegetation management and other measures which will subtly influence where people go. Fencing, barriers, landscaping and screening represent 'harder' approaches to limit where people go and how visible they are. Many site managers and visitors to coastal sites will already be familiar with many of the techniques and options that can be used.
- 3.24 There are however few studies that show the success of different measures or directly compare different approaches. Identifying 'best practice' is therefore not easy. Ideally studies would present data on visitor behaviour and ecological impacts together, providing clear evidence to support decision-making. Such studies are few and far between, and for many site managers decisions are rarely based on scientific evidence (Pullin & Knight 2001, 2003; Pullin *et al.* 2004; Sutherland *et al.* 2004).
- 3.25 In Table 1 we summarise the main options through which disturbance can be managed. We have grouped the options into five main headings:
- Habitat Management;
 - Planning & Off-site Management Measures;
 - On Site Access Management Measures;
 - Education; and
 - Enforcement.

3.26 After the table we discuss each of these five main types of option in more detail, and provide more background on some of the specific examples mentioned in the summary table.

Table 1 Summary of management options

Management option	Description	Examples and Notes
1 HABITAT MANAGMENT		
1a New habitat creation	Creation of new habitat for the interest feature in areas away from human disturbance. Potential to be carried out in combination with managed realignment schemes and/or disposal of dredgings.	Various examples of work in the US where research has been undertaken to identify the beach habitat requirements of Piping Plover (Maslo, Handel, & Pover 2010). Effectiveness of 'refuges' shown by Madsen, in Denmark (Madsen 1993, 1998).
1b Restoration	Habitat damage, such as loss of material through erosion, can be repaired through for example recharging beach sediment.	At Gairloch in Scotland small-scale beach nourishment has been undertaken to replace sediment lost in part to erosion from trampling damage (Wood 2001).
2 PLANNING & OFF-SITE MANAGEMENT MEASURES		
2a Site development away from MPAs	Much recreational use to sites is local, for example from people living within a short drive or walk of sites. Planning development at a strategic level is a way to reduce the long term future pressures of increased recreation from development. Needs to be taken into account during formulation of Local Development Frameworks.	Relevant core strategies for authorities adjacent to The Thames Basin Heaths SPA, the Dorset Heathlands SPA and the Breckland SPA all have development exclusion zones.
2b Planning conditions on adjacent development (land)	Urban design and planning conditions (such as Section 108 agreements) can ensure that planting, screening, careful routing, provision of access infrastructure (boardwalks, marked paths, steps etc) are incorporated into new developments to influence visitor flows within sites and minimise the potential of people to cause disturbance.	Design for development adjacent to Poole Harbour at the site of the old power station included a ditch to deter access (Hoskin <i>et al.</i> 2007).
2c Planning conditions on adjacent development (buildings)	Consideration of architectural details at the design stage such as layout and massing, arrangement of glazing and balconies and lighting etc can significantly reduce potential impacts related to new buildings close to sensitive sites.	

Table continued...

Management option	Description	Examples and Notes
2d Provide alternative recreational facilities	Provision may need to be combined with other measures such as education and management on the designated site. Likely to need to be carefully designed and targeted to provide a viable alternative. Targeting for dog walkers would need to ensure dog friendliness (Edwards and Knight, 2006) and suitable routes (for example, Liley et al., 2006c, Liley et al., 2006d). For water-based activities, gravel pits or similar may need careful landscaping and particular types of infrastructure.	'SANGS' (suitable alternative natural greenspace) have been promoted around the Thames Basin Heaths and the Dorset Heathlands SPAs. Currently little evidence has been collated to demonstrate effectiveness (Clarke, Sharp, & Liley 2008; Liley, Underhill-Day, & Sharp 2009; Sharp 2010).
2e Provision of designated access points for water sports	Provision of public slipways, trailer & vehicle access to shore etc in predetermined locations where boat access is likely to be away from nature conservation interest.	
2f Attract visitors to less sensitive areas; discourage access to sensitive areas	Provision of attractions/facilities such as toilets, food, improved walking surfaces, hides etc. Manage demand through car-park costs and capacities, restriction of on-road parking by wardening. Establish coast paths where there are gaps to minimise access to beach, realign footpaths where necessary.	Few examples exist where such infrastructure has been reviewed and designed across a wide area to focus visitor pressure away from sensitive areas.

3 ON-SITE ACCESS MANAGEMENT

3a Restrict/prevent access to some areas within the site	Use of landscape barriers (for example, gorse, bramble, ditches etc) and low chestnut paling see-through barriers. Fencing can be used to protect vulnerable vegetation and tern nesting colonies.	Exclosures have been established at Browndown SSSI to protect shingle vegetation (Liley, Underhill-Day, & Gartshore 2006), see Figure 2. Chestnut paling is commonly used on dune sites to protect dune vegetation from trampling. Exclosures to provide safe nesting areas for terns and breeding waders exist at numerous sites such as Holme NNR, Scolt Head NNR, Dawlish Warren, Pagham Harbour LNR and Walberswick NNR.
3b Provide dedicated fenced dog exercise areas	Allowing dogs off leads etc in particular locations that are not sensitive for nature conservation or other reasons may increase their attractiveness to dog walkers.	Dedicated dog exercise facilities exist at Sutton Heath in the Suffolk Sandlings SPA. The enclosure is outside the SPA and draws visitors from a wide area (Cruickshanks, Liley, & Hoskin 2010).

Table continued...

Management option	Description	Examples and Notes
3c Zoning	Designated areas for particular activities. Often zones are set out in a code of conduct and prevention of use for the areas outside the zones is enforced through byelaws.	Dedicated 'zones' for particular activities exist on various estuary sites around the UK.
3d Infrastructure to screen, hide or protect the nature conservation interest	Screens, hides, embankments etc are commonly used to direct visitors along particular routes and screen people from birds or other features vulnerable to disturbance. Such infrastructure can also provide enhanced viewing facilities and opportunities for people to get close to wildlife without causing disturbance. Path design can enhance the extent to which people stray or roam from the path. Boardwalks etc. can protect vulnerable habitats.	Wide range of techniques and infrastructure. Boardwalk, fencing and screening examples are shown in Figure 2. Work in the Pennines demonstrated that path resurfacing resulted in a change in people's behaviour and a resulting reduction in disturbance (Pearce-Higgins & Yalden 1997). Screening has been used in Portsmouth to hide dogs.
3e Management of car-parking	Car-park spaces can be redistributed around a site, parking closed in some areas, parking fees modified (for example, encouraging people not to stay too long) or a permit system be instigated to limit use of car-parks.	Car parks have been temporarily closed as part of CRoW access restrictions on some sites (for example, sites in Breckland with breeding stone curlews) and have been permanently reduced in size or closed at a number of sites such as the New Forest (to considerable public opposition). Evidence from Cannock suggests that results can be unpredictable (Burton & Muir 1974).
3f Path design and management	Surfacing, path clearance and other relatively subtle measures may influence how people move around a site and which routes they select.	
4 EDUCATION, COMMUNICATION TO PUBLIC AND SITE USERS		
4a Signs and interpretation and leaflets	Provision of informative and restrictive signs, and interpretive boards. Directions to alternative less sensitive sites. General information on the conservation interest to highlight nature conservation interest/importance.	Interpretation boards, signs and leaflets are widely used around the UK. Provision of signage and wardening has been shown to result in enhanced breeding success for little terns in Portugal (Medeirosa <i>et al.</i> 2007).

Table continued...

Management option	Description	Examples and Notes
4b Codes of Conduct	Guidance on how to behave to minimise impacts is promoted at a range of sites, through websites, leaflets, interpretation etc. These are sometimes enforced by byelaws and other control measures (see section 5).	On the Humber a generic code of conduct includes different sections for each type of activity and the code is available as a leaflet or a download from the Humber Management Scheme website ¹ . Scottish Natural Heritage have produced comprehensive guidance titled the Marine Wildlife Watching code, covering cetacean boats, otters, seabirds etc ² .
4c Wardening	In addition to an enforcement role (see 4b above) wardens can provide a valuable educational role, showing visitors wildlife etc.	Many sites have wardens who fulfil a range of roles, including interacting with the public and education. Can be both on-site and off-site (for example, school visits).
4d Provision of information off-site to local residents and users.	Local media, newspapers etc can provide means to highlight conservation importance of sites and encourage responsible access. Educational events, provision of items for local TV/other media. Information can be made available in local shops, tourist centres etc. Potential to promote non-designated sites, for example through web / leaflets listing, for example, dog friendly sites.	In Dorset Natural England provide a dog-users website which gives information to dog walkers, it includes codes of conduct and highlights places to walk, indicating which sites requires dogs to be on a lead and when ³ . Many estuaries have management partnerships that host regular forum meetings, estuary festivals and other events that bring local users together and can provide a means of conveying information.
4e Contact with relevant local clubs	Agreed codes of conduct and self-policing can be set up with individual groups and provide a means of ensuring users are aware of how to act responsibly (for example, water-sports club revoking membership for anyone caught speeding (Defra, 2004)).	A range of examples exist, for example the Jersey Canoe Club has a code of conduct for wildlife encounters ⁴ ; In Pembrokeshire a marine code exists in addition to legislation as a voluntary agreement to which all major local wildlife tour boat operators, sub aqua diving organisations, jet ski organisations, sailors and sea kayakers etc. have signed up to ⁵ .
4f Establishment of Voluntary Marine Reserves (VMRs)	By agreement of interested parties.	There are a number of sites around England, such as Purbeck, Looe St. Abbs and Seven Sisters.

Table continued...

Management option	Description	Examples and Notes
4g Off-site education initiatives, such as school visits etc	Proactive education work with local communities, raising awareness and highlighting local issues.	
5 ENFORCEMENT		
5a Dog control orders	Orders to keep dogs on leads, restrict specific access at certain times etc ⁶ .	Difficulties in getting measures agreed, particularly when people have been using an area for a long period. Difficulties in policing. Peer pressure could be effective. Examples include Stanpit Marsh (Christchurch Harbour), the Hayle Estuary (RSPB Reserve) and Chichester Harbour.
5b Covenants regarding keeping of pets in new developments	Covenants prohibiting the keeping of cats and / or dogs for example in flats where a management company could enforce the restriction.	In a review of planning appeal decisions in the Thames Basin Heaths SPA (Hoskin and Tyldesley, 2006), a number of cases rejected the use of covenants as ineffective and / or unenforceable and in ten appeals, such covenants were found to be insufficient to avoid harm to the SPA because they would not deter other recreational visits not related to dog walking.
5c Legal enforcement	Byelaws can be established by a range of bodies including local authorities, the Marine Management Organisation, the MOD, National Trust, Parish Councils etc. Other options include special nature conservation orders or prosecution under SSSI legislation.	Policing of watercraft zoning, speed limits etc, with fines or other penalties for infringement ⁷ . Enforcement facilitated when a system of permits and vessel registrations is in place. Byelaws also often used for activities such as kite surfing (for example, the Hayle Estuary and at Seaforth). Byelaws exist at a range of sites to control bait digging, for example, The NNR part of Teesmouth and Cleveland Coast SPA/EMS.

Table continued...

Management option	Description	Examples and Notes
5d Wardening	Wardens have both educational (see 4c above) and enforcement roles. With respect to the latter, wardens can provide direct contact and intervene when they observe particular activities (such as dogs off the lead on mudflats). The ability of a warden to control disturbing activities is clearly related to whether control measures are in place, and their nature. The more specific and statutory in nature the control, the greater the potential for enforcement by a warden.	Many sites have wardens who fulfil a range of roles, including interacting with the public dealing with disturbance issues. At Teesmouth and Cleveland Coast SPA/EMS, one targeted patrol per week allows NE on-ground presence to be demonstrated, but is very resource intensive.
5e Limiting visitor numbers	Visitor numbers capped, for example through tickets, permits or a similar system.	Commonly used in the past at various nature reserves around the UK such as Minsmere. Widely used in American National Parks.

Notes:

¹ <http://humberems.co.uk/downloads/Codes%20Of%20Conduct%20PDF.pdf>

² www.marinecode.org/documents/Scottish-Marine-Code-web.pdf

³ www.dorsetdogs.org.uk/

⁴ www.jerseycanooclub.co.uk/docs4dl/wildlife_coc.pdf

⁵ www.pembrokeshiremarinecode.org.uk/code%20conduct.htm

⁶ See defra guidance at: www.defra.gov.uk/environment/quality/local/legislation/cnea/documents/dogcontrol-orders.pdf

⁷ Model byelaws provided at: www.mcga.gov.uk/c4mca/cons_mca_guidance_pleasure_boat_model_byelaws_amenda.pdf



Figure 2 Examples of different management: a) Viewing facilities for Penguin colony, Cape Town, South Africa; b) reed screen, Slapton, UK; c) & d) signs and fencing around Least Tern/Piping Plover enclosure, Cape Cod, U.S.A; e) board walk, Pagham Harbour; f) Kite Surfer code of conduct sign, Exe Estuary; g) Enclosure to protect shingle vegetation, Browdown SSSI

Habitat management

- 3.27 For many species, such as terns and breeding waders there are relatively simple modifications to the habitat that can enhance breeding success or attract individuals to nest in particular locations. There have been recent publications in the U.S. looking at Piping Plovers (a beach nesting wader similar to Ringed Plovers) and their nesting requirements, with the work designed to inform how beach recharge and other management measures may be best focused to provide suitable habitat to maximise the breeding population (Maslo 2010; Maslo *et al.* 2010). Such habitat works, if undertaken in areas of low disturbance, have the potential to increase the population of target species and in particular ensure that a proportion of the population is distributed on sites where disturbance is not an issue.
- 3.28 Many coastal sites now have dedicated lagoon areas designed and built to provide safe roost sites and breeding locations. The techniques for the development of such sites are well documented (Rehfishch 1994; Rehfishch *et al.* 1996; for example, Symes & Robertson 2004).
- 3.29 An example of the creation of secure roost sites for waders is the dedicated island built as a roost site at Hartlepool West Harbour (Burton, Evans, & Robinson 1996). Here redevelopment of the site in the early 1990s involved replacing an old pier (that was the main roost site for waders such as purple sandpipers *Calidris maritima*, turnstones *Arenaria interpres* and knots *Calidris canutus*) with a new pier and an island built specially for the birds. Numbers of waders declined in the two years after the development was completed and Burton *et al.* (1996) suggest that an increase in disturbance, particularly from people and boats (a result of increased access and the creation of a marina) as probable causes. The island does however form the main roost site.

Planning & off-site management measures

- 3.30 The creation of alternative sites to divert visitors from sensitive sites has been widely promoted as a means to resolve issues relating to new housing development and impacts from access. It would seem intuitive that by increasing the amount of green infrastructure in an area, and providing sites designed to be welcoming and attractive to particular users, the levels of visitor use on nearby sensitive sites such as SPAs would decrease. In the Thames Basin Heaths and the Dorset Heaths these alternative sites are referred to as SANGs ('Suitable Alternative Natural Greenspace) and have become a key component in a suite of mitigation measures designed to ensure no adverse effect on the integrity of the European Sites as a result of new development (Liley *et al.* 2006; Burley 2007; Thames Basin Heaths Joint Strategic Partnership Board 2009).
- 3.31 Such alternative sites are as yet untested, but guidelines and recommendations for site design are available (Liley, Mallord, & Lobley 2006; Liley *et al.* 2009). There is evidence that the greater the availability of green space sites, the more they are used (Maat & de Vries 2006). Work in Dorset has shown that residents that have a large area of greenspace around where they live did not visit heaths any less; however the number of greenspace sites was significant, i.e. residents with lots of greenspace sites around them did tend to visit heaths slightly less (Clarke *et al.* 2008). The issues are complex because:
- People will visit heaths and other semi-natural sites because such sites offer a particular experience (large sites, wild feel etc) that are potentially hard to replicate (for example, Liley *et al.* 2006).
 - The presence of significant green infrastructure etc. may mean that new housing is occupied by people attracted by the presence of the greenspace – for example dog owners.
 - People may have particular affinity to visit sites they know well – access patterns may take a long time to change.
- 3.32 Alternative sites are therefore most likely to be successful if very carefully designed and tailored to particular areas and types of use. In terms of visitors to the coast, alternative sites are most likely to work for types of access that are not dependent on particular coastal features – for example visitors who are simply drawn to sites because it is the nearest open space to their

home, or because it is a convenient place to walk the dog and let the dog off a lead. The options to create alternative sites that provide alternative dramatic coastal scenery or beautiful beaches are likely to be limited.

- 3.33 There is clearly scope for further research on alternative sites, and some detailed case studies showing visitor use over time would be useful to guide 'best practice'. There is perhaps the most scope with sites designed for dog walking or for particular water sports (such as training areas for kite surfers, wind surfers etc).

On-site access management measures

Creating dedicated zones for activities

- 3.34 Zoning essentially partitions types of access, determining the overall distribution of visitors on land and water, in both time and space. Zoning is positive in that it creates dedicated areas for particular activities. There are numerous examples from around the UK coast of zones for particular water-based activities, such as water-skiing or kite surfing. These zones are often set out in codes of conduct, usually developed with local users and user groups. The codes of conduct are sometimes also linked to byelaws (see paragraph 0), and the implementation of the zones is often driven by safety issues rather than with the aim to minimise disturbance.
- 3.35 Clubs can address a wide range of issues and adapt quickly to change, particularly where members communicate through forums and electronic discussion rooms. Working with local groups or clubs is a good way to resolve a lack of awareness or to highlight conservation issues or coastal byelaws. Clubs can provide a means for getting information across and help implement any zoning if they have been involved from the outset.

Set-back distances and exclosures

- 3.36 In many locations and circumstances people and wildlife are separated through the use of fencing, barriers, exclosures or even through the definition of dedicated approach distances (for example, for boats approach cetaceans). There are numerous examples, some of which are shown in Figure 2. Areas supporting breeding terns and beach nesting waders are fenced at numerous beaches, for example most little tern breeding sites in England are protected from disturbance (and predators) with fencing. The area fenced varies between sites, for example around 10ha of Church Norton Spit (Pagham Harbour) are fenced and access excluded from April – July each year, while at Holme NNR, 5 exclosures, totalling around 2.5ha protect the little tern and nesting ringed plovers. Such approaches are supported by research – for example one study suggests that the hypothetical elimination of all access from a beach in Norfolk would result in an increase of 85% in the number of ringed plovers that site could support (Liley & Sutherland 2007).
- 3.37 Fencing or dedicated viewing facilities (such as the penguin viewing platform shown in Figure 2) work best where there is particular demand to see wildlife such as at tourist hotspots or popular reserves. Comparison of disturbance impacts at a fur seal colony in Uruguay (Cassini, Szteren, & Fernandez-Juricic 2004) before and after fences were erected to keep people back from the seals show that such approaches can work. There was no reduction in the number of visitors (indicating that the fences did not deter visitors), yet the presence of a fence significantly reduced overall fur seal responses to tourists and in particular the authors highlight a reduction in the most intense behavioural responses (threat, attack, leaving the colony) by more than half.
- 3.38 Many authors define a definitive distance beyond which disturbance is assumed to have no effect and this is then used to determine set-back distances or similar (Rodgers & Smith 1995, 1997; Stalmaster & Kaiser 1997; Fernandez-Juricic, Jimenez, & Lucas 2001; Fernandez-Juricic, Vaca, & Schroeder 2004; Fernandez-Juricic *et al.* 2005). It is difficult and probably often inappropriate to set such distances as responses to disturbance vary between species (Blumstein *et al.* 2005) and between individuals of the same species (Beale & Monaghan 2004a). Particular circumstances, such as habitat, flock size, cold weather or variations in food availability will also influence birds'

abilities to respond to disturbance and hence the scale of the impact (Stillman *et al.* 2001; Rees, Bruce, & White 2005; Goss-Custard *et al.* 2006). Birds can also modify their behaviour to compensate for disturbance, for example by feeding for longer time periods (for example, Urfi, Goss-Custard, & Lev. Dit Durell 1996). Birds can become habituated (Nisbet 2000; Kloppers, St Clair, & Hurd 2005; Walker *et al.* 2006; Baudains & Lloyd 2007) to particular disturbance events or types of disturbance, and this habituation can develop over short time periods (for example, Rees *et al.* 2005). The frequency of the disturbance event will determine the extent to which birds can become habituated, and therefore the distance at which they respond.

3.39 Rather than rely on set distances, it is instead necessary to consider the species' ecology, use of an area, habitat quality and other factors that may influence the scale of the disturbance. This information can then be used to identify what kinds of disturbance, at which locations, are likely to have an impact. It is important to understand the human use of the area in detail. The spatial patterns of recreational access (both on the water and on the shore) and other disturbance (commercial shipping, industry, military training etc) are also critical to understand. Disturbance can then be understood in context. It is often necessary to understand the access patterns and recreational use in detail, through for example detailed visitor surveys, in order to determine how frequently particular activities occur, in which locations and under what conditions. Such visitor work is often the missing piece in the jigsaw as few ecologists are interested in such research (but see Clarke *et al.*, 2008b, Liley *et al.*, 2008, Liley *et al.*, 2006b).

3.40 We therefore urge caution in the use of set-back distances and stress that distances applied at one location may not necessarily be applicable at other locations. As an indication of the kind of distances and the variation at which species respond, we summarise a selection of distance examples from the scientific literature below:

- 180m as the 'safe' distance for approach for pedestrians and boats for tern colonies, based on work in Florida (Rodgers & Smith 1995).
- 118m as a recommendation for zoning around Black Skimmer colonies in New Jersey (118m representing the distance within which 95% of flushing events occurred) (Burger *et al.* 2010).
- 70m as a recommended distance to protect roosting cormorants, gulls and oystercatchers from disturbance from kayaks and motorboats off Vancouver Island (Chatwin 2010).
- 200m as the necessary zoning required to protect common tern colonies from disturbance (people on foot) at colonies in Virginia and New Carolina (Erwin 1989).
- 100m as the necessary zoning required to protect least (very similar to little) and royal tern colonies from disturbance (people on foot) at colonies in Virginia and New Carolina (Erwin 1989).
- 100m as the necessary distance to protect nesting common terns from disturbance effects of personal watercraft in New Jersey (Burger 1998).
- 200m as the approximate distance at which curlews roosting on saltmarsh in Holland could be approached before taking flight (Smit & Visser 1993).
- 25-550m as the distance at which different wader species and brent geese were recorded taking flight when approached by someone walking across mudflats at two different sites in Holland (Smit & Visser 1993).
- 260m (range 32-675m) the mean approach distance for black guillemots (foraging on the sea in Canada) in relation to boats (Ronconi & St. Clair 2002).
- 5-178m (median 52m) as the distance at which brent geese responded to a potential disturbance event on the Solent. Data from 20 locations (Liley, Stillman, & Fearnley 2010).
- 10-200m (median 46m) as the distance at which oystercatchers responded to a potential disturbance event on the Solent. Data from 20 locations (Liley *et al.* 2010).
- 75-150 (median 44.5m) as the distance at which redshanks responded to a potential disturbance event on the Solent. Data from 20 locations (Liley *et al.* 2010).
- 25-200m (median 75m) as the distance at which curlews responded to a potential disturbance event on the Solent. Data from 20 locations (Liley *et al.* 2010).

3.41 Another important consideration where exclosures are established to provide disturbance-free zones is the size of the exclosure that is necessary. For a small annual plant exclosures can be small, but in order to provide safe-nesting locations for terns or breeding waders exclosures may need to exceed a hectare. Breeding waders such as ringed plovers *Charadrius hiaticula* will have territories that span the tide line and fore dune areas (Liley 1999; Liley & Sutherland 2007). Nests may occur on the tide line or well up the beach and the chicks will often spend much of their time around the water's edge or the tide line area. Exclosures that encompass this whole beach width are likely to inhibit access for people walking along the beach and therefore such an approach can be difficult. At Holkham NNR individual nests of ringed plovers are fenced off each year, with site wardens finding the nests each year. They use their judgement and knowledge of how the birds use the site in order to determine where to put the fences, which simply consist of a single strand of baler twine between temporary fence posts, each exclosure is accompanied by a sign indicating that nesting birds are present. Little terns *Sterna albifrons* at Holkham tend to nest in the same areas each year, and therefore the fencing is typically erected in approximately the same location each year, however if new suitable habitat (areas of open shingle above the tide line) does form these are fenced too.

Influencing choice of route, access infrastructure and parking

- 3.42 Where people choose to go within sites is influenced by a range of factors, such as site knowledge, the existing path network, ease and availability of parking, signs, habitats, scenery etc. Modification of some of these features can help redistribute visitors. As most visitors will stay on paths (for example, Keirle & Stephens 2004) simply where paths are provided will determine visitor distribution within sites. The design of paths can determine the extent to which people stray from the path (Pearce-Higgins & Yalden 1997). The access management handbook (Taylor *et al.* 2006) sets out various suggestions for path design and route modification and discusses issues such as costs and legal issues.
- 3.43 Closing car-parks can be contentious; for example proposals to close car-parks in the New Forest National Park have been strongly opposed by local dog walkers⁹. Any closures should only be undertaken after careful consultation and survey work to ascertain people's reactions and where access might be deflected to. Preventing parking in lay-bys, on verges and other informal parking locations may be easier to achieve than closing formal car-parks. At Dungeness the judicious positioning of small 'grips' or dykes by the roadside or placing bollards protects rare plants growing near the road (Doody & Randall 2003b). Along the Luce Bay shingle, in Scotland, designated access points for parking have been improved while other possible vehicle access points have been made more difficult to use (Doody & Randall 2003b).

Signs

- 3.44 Signs are an important means of conveying information to visitors. Considerable guidance is available, for example describing design principles, wording etc for signs and interpretation. (Kim, Airey, & Szivas; Ham 1992; Mcleavy 1998; Kuo 2002; Hall, Roberts, & Mitchell 2003; Littlefair 2003; Taylor *et al.* 2006; Bell 2008). The following key points are relevant:
- Signs should be carefully located where they are most likely to be read by the target audience.
 - Information on signs should be unambiguous, clear, accurate and easy to read.
 - Positive messages work better than negative ones. Where negative messages are required it is best if there are reasons explaining why something is not allowed.
 - Symbols and pictures can help convey simple messages.

⁹www.bournemouthcho.co.uk/news/districts/newforest/888601.Dog_owners___fury_over_car_park_closures/

Limiting visitor numbers

- 3.45 Regulating access through limiting visitor numbers to sites is in conflict with the aim of many organisations to promote access and the enjoyment of the countryside. Options for capping visitor numbers, for example through advance reservation, queuing, permits etc are discussed by Newsome *et al.* (2002), who highlight the difficulties in ascertaining what limit to use and how to ensure a system is fair.
- 3.46 One, perhaps slightly unusual example of limiting boat numbers on a site comes from Pagham Harbour, West Sussex. Here the Local Nature Reserve, when established, gave 10 permits to local residents to launch boats in the harbour. A right of navigation exists for the whole harbour, but launching is only possible from a limited number of locations all controlled by the Local Nature Reserve. The permits are not transferable and subject to a series of strict conditions set out in a code of conduct. The permits must be renewed each year and each user must report on the levels and amount of use. Only four permits are currently issued, as other permit holders have either moved or passed away. The issuing of the permits (and the potential to issue new permits) has recently been subject to appropriate assessment as the site is an SPA and therefore the permit system was subject to a review of consent.

Communication to public and site users

- 3.47 Education is widely regarded as crucial to reducing impacts by visitors to natural areas (Newsome *et al.* 2002). Education initiatives, such as interpretation, guided walks, wardening, school visits, community events etc., are widely used and accepted as they do not overtly regulate or control visitors. Such approaches are proactive, rather than reactive, but clearly they are unlikely to solve problems in the short term and depend largely on the audience and style of communication. Good communication and education measures can ensure users understand the importance of the site and why it is managed in a particular way.
- 3.48 Studies have shown that tourists undertaking particular wildlife watching trips are keen to learn more about the environment around them (for example, Lück 2003). Tests of the effectiveness of education and interpretation in reducing visitor impacts are limited (Newsome *et al.* 2002), but studies would seem to indicate that they can be effective if targeted and well designed (Littlefair 2003).
- 3.49 As a result of concerns about human disturbance (in particular dogs off leads) on the Wash and North Norfolk Coast SPA, a communications consultancy has been commissioned to produce a range of material aimed at disseminating information about the impact of human disturbance on wildlife (document doctor 2009); the material has however not been widely adopted. Other examples of education programmes aimed at minimising visitor's impacts include the international Tread Lightly programme and the Leave No Trace programme promoted across the U.S.A.
- 3.50 At some sites, stakeholders have come together to establish voluntary codes of conduct and reserves. For example in 1984, local fishermen, divers and conservationists established St Abbs & Eyemouth Voluntary Marine Reserve, now part of the Berwickshire and North Northumberland Coast EMS. The voluntary reserve aims to balance the needs of the area's marine life with the needs of recreation & traditional creel fishing. Responsible behaviour is promoted through a voluntary code of conduct, the reserve has a dedicated website¹⁰ and produces leaflets, guides and runs a series of events. Volunteer events take place regularly and include beach cleaning/litter collection. Such reserves, with strong links to the local community and a strong approach to communication and education provide good examples of the potential to work closely with local users and promote respect among visitors.

¹⁰ www.marine-reserve.co.uk/volunteers-conservation/enjoy/guides.php

Enforcement

- 3.51 Various statutory mechanisms exist for prohibiting activities or tackling activities that are causing disturbance. These include:
- Habitat Regulations;
 - SSSI legislation;
 - Byelaws;
 - Special Nature Conservation Orders; and
 - Dog Control Orders.

Habitats Regulations

- 3.52 The Conservation of Habitats and Species Regulations 2010, generally referred to as the 'Habitats Regulations' provide protection for European wildlife sites from activities that may adversely affect such sites and the ability to meet their conservation objectives. Where a new activity is being proposed that may cause disturbance to a species that forms the interest feature of a European wildlife site, and that activity requires some form of permission, the authority charged with granting the permission, 'the competent authority,' must firstly consider the activity's potential for harm by taking it through a number of steps set out within the Regulations. Competent authorities include public bodies, local planning authorities and statutory undertakers, for example.
- 3.53 All competent authorities are required by Regulation 9 of the Habitats Regulations to have regard to the requirements of the Habitats Directive in the exercise of their functions, i.e. in any role that they undertake. In consideration of European sites, this charges competent authorities with both assessing the implications of their own action, and also undertaking a proper assessment of the implications of any activity for which they give permission.
- 3.54 Natural England itself is a competent authority under the Habitats Regulations. Natural England issues consents to SSSI landowners or occupiers to enable them to undertake activities that have the potential to damage the SSSI, after full consideration of potential impacts and how harm to the SSSI can be prevented. In issuing consents where the site also holds a European designation, in accordance with Regulation 21 of the Habitats Regulations, Natural England must also consider whether the activity will significantly affect the European site interest features, and if so, must undertake a more detailed assessment, an 'appropriate assessment,' to establish whether the site interest features will be adversely affect and what measures could be put in place to prevent such effects. Natural England regularly restricts activities that may cause disturbance following assessment under Regulation 21, with activities including sporting events such as horse trials, model aircraft flying and wake board competitions.
- 3.55 If the activity requires permission from a competent authority other than Natural England, then that competent authority is similarly required under Regulation 61 to consider whether the permission would be likely to have a significant effect upon a European site's interest features and the ability to meet its conservation objectives. With a likelihood of significant effects, or uncertainty of effect, again a more detailed appropriate assessment would be undertaken by that competent authority. Regulation 61(3) requires the competent authority to consult Natural England on any appropriate assessment, and have regard to the representations made. Any planning application for an activity that has the potential to disturb European site interest features would be considered under regulation 61.
- 3.56 A further requirement of the Habitats Regulations is the review of any existing permission given by a competent authority prior to the date upon which a site became a European site. In accordance with Regulation 63 of the Habitats Regulations, a competent authority must make an appropriate assessment of any existing permission that is not yet complete where it is determined that the activity is likely to have a significant effect upon the European site now in place. The

competent authority must modify, or if necessary revoke any such permission where it cannot be ascertained that adverse effects upon the integrity of the European site are not occurring, or will not occur. As noted previously, a review of existing boating permits was undertaken by West Sussex County Council with regard to potential impacts upon Pagham Harbour SPA and Ramsar site.

SSSI legislation

- 3.57 As noted above, activities that may potentially damage a SSSI should not be carried out without firstly notifying Natural England of the intention to undertake such activities. Section 28 of the Wildlife and Countryside Act, as amended by the Countryside and Rights of Way Act 2000, sets out such requirements for both land owners and occupiers, and also for public bodies wishing to undertake such activities. Natural England issues consents (for owners and occupiers) and assents (for public bodies) once satisfied that appropriate measures are in place to protect the notified features of the SSSI from harm. Festivals with the potential to disturb SSSI interest have been restricted under consents relating to Eridge Park SSSI and also the Wakestock event at Blenheim Park SSSI, with both sites having breeding bird interest in their range of notified features of interest. Geocaching is becoming a popular activity that Natural England is also having to consider under European site and SSSI legislation.
- 3.58 Enforcement against individuals for disturbance under SSSI legislation is difficult due to the level of evidence required to take forward a successful prosecution. Resulting fines can be low. Where damage is caused to a habitat (for example damaging operations by an owner) it is generally easier to gain evidence.
- 3.59 SSSI legislation has been used in relation to disturbance from dogs. A successful prosecution was brought by Natural England against an individual for recklessly causing disturbance to birds by releasing their dogs on a nature reserve. The incident happened on an RSPB Nature Reserve within the Hayle Estuary in January 2008. This was the first time Natural England had used the provisions under section 28P(6A) of the Wildlife & Countryside Act 1981 as substituted by Schedule 9 to the Countryside and Rights of Way Act 2000 and amendments made by the Natural Environment and Rural Communities Act 2006 and was seen as a landmark case. The prosecution was brought against a man whose dogs were witnessed by a member of the public running loose on the reserve and were seen to attack some mute swans. The SSSI is designated for its wintering bird assemblage, the judge accepted the evidence that the swans were part of the wintering assemblage. The man pleaded guilty to the offence (“recklessly disturbing birds”) and was fined £250 and ordered to pay £250 costs.
- 3.60 Natural England agreed to accept the guilty plea in relation to reckless disturbance [to the Feature] in return for dropping the charge of reckless damage [to the swan]. Whilst this resulted in a small fine it did ensure that there was a conviction in a case where ‘recklessness’ may have been difficult to prove.

Byelaws¹¹

- 3.61 A byelaw is a local law that is made by a statutory body, such as a local authority, under an enabling power conferred by an Act of Parliament. It is not just local authorities that can create byelaws, other bodies such as the National Trust, the Marine Management Organisation, the MOD and even parish councils can create byelaws. Byelaws are not normally considered to be a suitable regulatory mechanism in cases where there are express powers in primary legislation. Defra advise that they should be considered only when all other means of control (such as voluntary schemes) have been tried and failed, or are not considered appropriate. The Marine Management Organisation has the ability to make byelaws, including emergency byelaws under regulation 38 of the Habitats Regulations in conjunction with Part 5 of the Marine and Coastal

¹¹ See defra guidance at: www.defra.gov.uk/rural/documents/countryside/byelaw-cr1.pdf

Access Act 2009 if necessary for the protection of European marine sites. The MMO website includes a flowchart setting out options for byelaws¹².

Special Nature Conservation Order (SNCO)

- 3.62 Under Regulation 22 of the Habitats Regulations, Natural England can apply to the Secretary of State for a SNCO to be put in place to restrict activities that might otherwise affect the interest features of a European site. SNCOs are infrequently used, but enable Natural England to regulate activities that may affect a European site where the normal consenting process described above cannot be applied to the associated SSSIs. Natural England may use SNCOs where the activity requiring regulation is being undertaken by a third party and not the SSSI owner occupier, for example. In some limited cases, SAC's below mean low water do not have associated SSSIs, and in the absence of powers to regulate activities under SSSI legislation, Natural England may use an SNCO, for activities such as power boat or jet ski use, for example. Defra will generally only use SNCOs in the marine environment if the new powers under the Marine and Coastal Access Act 2009 to make byelaws are deemed inadequate. The maximum fine for breaching a stop notice issued under an SNCO is £5,000 on summary conviction, or unlimited on conviction on indictment.
- 3.63 A Special Nature Conservation Order (SNCO) was introduced to prevent commercial bait digging within Fareham Creek (Solent European Marine Site). Despite its introduction and efforts by the Police to enforce it, the SNCO is considered to be ineffective as it is difficult to prove that the collection is for commercial purposes rather than personal use. Research is being carried out on the effects of bait digging and to assess the effectiveness of the different management methods by a joint Natural England and Crown Estate project.

Dog Control Orders

- 3.64 The Dog Control Orders (Prescribed Offences and Penalties, etc.) Regulations 2006 and the Dog Control Orders (Procedures) Regulations 2006, implement sections 55 and 56 of the Clean Neighbourhoods and Environment Act 2005. Dog Control Orders replace the previous system of byelaws for the control of dogs, and also the Dogs (Fouling of Land) Act 1996, which has been repealed.
- 3.65 The Dog Control Orders Regulations provide for five offences which may be prescribed in a Dog Control Order: failing to remove dog faeces; not keeping a dog on a lead; not putting, and keeping, a dog on a lead when directed to do so by an authorised officer; permitting a dog to enter land from which dogs are excluded; and taking more than a specified number of dogs onto land. A Dog Control Order can be made in respect of any land which is open to the air and to which the public are entitled or permitted to have access (with or without payment).
- 3.66 Both primary and secondary authorities may make Dog Control Orders, provided that they are satisfied that an order is justified and have followed the necessary procedures. Primary and secondary authorities are defined in section 58 of the Clean Neighbourhoods and Environment Act. Primary authorities in England are: a district council; a county council for an area where there is no district council; a London borough council; the Common Council of the City of London; and the Council of the Isles of Scilly. Parish councils constitute secondary authorities. In addition, the Secretary of State has the power to designate other bodies as secondary authorities. This power enables bodies which have byelaw-making powers in respect of dogs, for example some commons conservators under private legislation, to be designated as secondary authorities, and so be able to make Dog Control Orders rather than byelaws.
- 3.67 It is important for any authority considering a Dog Control Order to be able to show that it is a necessary and proportionate response to problems caused by the activities of dogs and those in charge of them. The authority needs to balance the interests of those in charge of dogs against the interests of those affected by the activities of dogs, bearing in mind the need for people, in

¹² http://marinemanagement.org.uk/protecting/conservation/documents/byelaw_options.pdf

particular children, to have access to dog-free areas and areas where dogs are kept under strict control, and the need for those in charge of dogs to have access to areas where they can exercise their dogs without undue restrictions.

- 3.68 If an authority is considering making a Dog Control Order which would affect open access land it must consult the appropriate access authority (the local highway authority or, the National Park Authority for land within a National Park); the relevant authority (the National Park Authority for land within a National Park; the Forestry Commission for land that has been dedicated as access land and which consists wholly or predominantly of woodland, or Natural England in all other cases) if it is not also the access authority; and the local access forum. There are already comprehensive dog control provisions which may be applied to access land, including if necessary the banning of dogs. An authority should therefore pay particular attention to the views of these bodies in deciding whether any proposed Dog Control Order affecting open access land is necessary.
- 3.69 The Secretary of State can designate types of land which are not to be subject to all or some Dog Control Orders. These are Forestry Commission land in respect of all Dog Control Orders and roads (including highways) in respect of a Dog Control Order excluding dogs from land specified in the order. A 'road' includes not only public rights of way, including footpaths, but also ways to which the public has access by permission of the landowner, rather than by right.
- 3.70 Fixed penalties for offences under Dog Control Orders may be issued by authorised officers. Authorised officers are employees of primary and secondary authorities who are authorised for this purpose and any person authorised (including employees of that person) in writing by a primary or secondary authority in pursuance of arrangements made by that person and the relevant authority.
- 3.71 Experience to date of obtaining Dog Control Orders has shown that it can be difficult for conservation bodies to persuade primary or secondary authorities of the need to make Orders. Opposition from dog walkers can be high. However, by collecting appropriate evidence, it is possible to make a persuasive case for the implementation of Orders. On the Hayle Estuary in Cornwall, the RSPB collected eye-witness reports of all disturbances on the estuary over a 12-month period. This showed that, of the 262 recorded instances of disturbance during the year, 67% were dog-related. The public consultation period resulted in Cornwall Council receiving 109 letters in support of the Order and 18 in opposition. The RSPB sought and won the help of the police to enforce the Order (which excluded dogs from part of the Reserve and SSSI) once implemented via the Fixed Penalty Notice system.
- 3.72 A similar exercise was undertaken at Stanpit Marsh, Christchurch Harbour. Christchurch Harbour Borough Council Countryside Services Wardens supported by members of the Christchurch Harbour Ornithological Group took the lead in gathering evidence of dog-related disturbance incidents. The data revealed that between January and October 2009, dogs were the greatest single cause of disturbance to wildlife. Of a total of 318 recorded events, 58% led to a recorded disturbance to wildlife. Of these, 64 disturbances were caused by walkers with dogs (59) and dogs alone (5). This represents 34% of total disturbance incidents on the Nature Reserve. As at the Hayle Estuary, a majority of people who responded to public consultation on the proposal to implement a Dog Control Order were in favour of it; the Order (which requires that dogs be kept on a lead within the Reserve) was introduced in October 2010.
- 3.73 Initial signs are that the dog control order at Stanpit has been a success in reducing disturbance events. To date three fixed penalty notices for £75 have been issued and anecdotal evidence suggests that a majority of dog-walkers have gone elsewhere, resulting in a decrease in people using the marsh and a marked reduction in the levels of disturbance at this site.

Wardening

- 3.74 Wardens can provide an official and visible presence at a site, and people are more likely to behave in a responsible manner.
- 3.75 Wardening on the Dorset Heaths is provided by the Urban Heaths Partnership which runs a mobile team that provide a visible presence on sites. Although not a marine site, the wardening provides a good case-study as the wardens fulfil a role to minimise disturbance and other impacts to the internationally important heaths. The wardens' time is focused on the urban sites which have the most visitor pressure and the wardens are present on the sites at the busiest times. They watch for fires and illegal activities and talk directly to visitors. They also undertake some educational work (such as school visits, monitoring (for example, of access levels) and in the winter help with some land management tasks. The team is a mobile team, working across multiple sites and landowners. The team have clearly recognisable vehicles and clothing and are managed by the County Council, with part funding from developer contributions gathered from developments adjacent to the heaths. In this (non-coastal) example, the key points are:
- The warden team works on different sites and is mobile, allowing staff time to be focused as required in time and space.
 - The team is well known, to the police, site managers and visitors, providing an important link and direct face-face contact.
 - The team is but one element in a series of measures to reduce visitor impacts (including disturbance) across the heaths, and is not therefore seen as a solution on its own.
- 3.76 In such examples it is difficult to clearly show the effectiveness of the wardening as many different sites are covered, the issues are complex and long-term data is lacking. However, there is some evidence that fire incidence (through arson) has decreased in recent years, potentially indicating that the wardening is having a positive effect (Fearnley & Liley 2010).
- 3.77 Few studies have demonstrated the efficacy of wardening in reducing disturbance. One good example of the success of implementing wardening (in combination with other measures) comes from Portugal, where low breeding success of little terns has shown to be associated with human activities (Calado 1996). Detailed nest monitoring (Medeirosa *et al.*, 2007) has evaluated the influence of human disturbance on breeding success and the difference between unprotected and protected sites/seasons. The presence/absence of warning signs and wardening was the most important predictor of nesting success, with birds being up to 34 times more likely to succeed with such protective measures in place. Wardens are employed at a number of sites where for example large tern colonies exist or seals haul-out (for example, Donna Nook). The warden's role is to greet people, talk to visitors and ensure no disturbance takes place. Other duties (depending on the site) may include predator control, monitoring and maintenance of fences etc.
- 3.78 The little tern colony at North Denes, Great Yarmouth is the largest in England. Detailed accounts of the history of the colony are provided by Allard (1990) and also by Brown & Grice (2005). There were no records of little terns nesting in the area until the second world-war. In the early years birds nested on off-shore sand banks and on the main beach area, but breeding success was poor and numbers very low and breeding erratic, perhaps due to disturbance. Around 1985 a substantial colony became established and fifty-five pairs nested in 1986. Rapid action by Yarmouth RSPB members' group, supported by the RSPB regional office and volunteers from Strumpshaw reserve and with support of Yarmouth Borough Council resulted in the colony being roped off. A full-time RSPB warden was quickly appointed and 96 flying young were fledged. Numbers have fluctuated markedly since, and breeding success varies between years. There has been a major vandalism incident (in 2002) when vandals virtually destroyed the site and smashed eggs. Predation and flooding are major causes of nest failure. The colony is now intensively managed by the RSPB with permanent wardening, double fencing, CCTV etc. The wardens' role

are to show people the birds, monitor the success of nests and ensure protection from disturbance.

Implementation of control measures

3.79 There is a spectrum of potential ways in which control measures can be implemented. At one end is a warden dispensing informal advice and seeking to influence the behaviour of individuals whose recreational activities are causing disturbance. At the other end is a warden backed by a statutory instrument such as a bye law or a Dog Control Order enabling them to formally penalise offenders. In between are Voluntary Codes of Conduct, agreed with particular user groups to control and regulate potentially disturbing activities. The advantages and disadvantages of these approaches are discussed below.

Provision of informal advice by warden

3.80 The provision of ad hoc informal advice by wardens is simple and requires very little prior organisation. An example of such an approach is a warden seeking to persuade the owners of errant dogs to keep them under control.

3.81 However, this approach is very resource intensive and difficult to manage. The warden will encounter a range of people, some of whom will be amenable to his/her advice, others less so. Some encounters will be short and productive, others long and potentially counter-productive. The warden has no sanction if the individual(s) will not cease or modify their behaviour, and unless there are advisory notices on the site, it is extremely difficult to reach a large audience.

Voluntary Codes of Conduct/other agreements with user groups

3.82 Codes of Conduct/other agreements with user groups can be very effective in addressing instances where recreational disturbance is primarily caused by one particular user group. An example of such an approach is a Code of Conduct for kite surfers in an estuary. Such a code would typically delineate the area in which kite surfing can take place, and identify any time restrictions related to seasons or tide states. The Code is also likely to specify insurance arrangements and require that kite surfers belong to a recognized body such as the user group.

3.83 The advantage of this approach is that the conservation organisation is dealing with one point of contact related to the recreational use, rather than a series of individuals, each of whom is likely to have a slightly different perspective. The weakness in the approach is that it does not necessarily deal with individuals who choose to remain outside the user group. However, self-policing peer pressure can occur and be effective in addressing the actions of these individuals (see paragraph 3.87).

Statutory instruments

3.84 In some respects, the use of statutory instruments such as bye laws or Dog Control Orders can be appealing to conservation organisations as it can give them the means to deal with recurring instances of recreational disturbance that are not amenable to more informal methods of control. The disadvantage is that sometimes they can be resource intensive, both in terms of their establishment, and subsequent enforcement. Bye laws and Dog Control Orders are invariably made by local authorities or other statutory bodies such as those with responsibility for regulating fisheries or harbours. Such bodies will often require that conservation organisations rigorously establish the need for the implementation of statutory instruments. This can involve the collection of recreational disturbance data over a protracted period (often a year). The process of making a statutory instrument can also be a lengthy political process, with particular interest groups potentially able to unduly influence the process.

Engagement with stakeholders

3.85 Whatever approach is adopted, it is essential that conservation organisations engage fully with interested parties/stakeholders. The aim should always be, wherever practicable, to develop an

approach that can be agreed by all those involved. Successful approaches typically involve parties that are keen to see resolution and to work together to clearly understand and identify different needs. Discussions and subsequent agreement may be bilateral between the conservation organisation and one particular user group, or multilateral involving multiple agencies and parties with a variety of issues to address. The latter approach is often undertaken under the aegis of a management group or forums; these have been established at a number of estuarine MPA's, for example on the Mersey¹³ and Exe Estuaries¹⁴.

Case studies

3.86 In this section we consider some case studies in more detail, grouped by activity type. Rather than a comprehensive review of all types of activity (instead see Saunders *et al.* 2000), we focus on activities highlighted by Coyle & Wiggins (2010), activities that are particularly common or activities that are increasing in popularity. Different approaches are more effective for different activities, and the selection below allows us to explore the characteristics of different activities that mean different approaches to management are appropriate.

Water sports

- 3.87 Water-based recreation has expanded rapidly in the past few decades, with several new sports having developed, such as kite boarding and kite surfing (Whitfield & Roche 2007). There is relatively little work on the disturbance impacts of these new activities (but see Smith 2004), however there are general reviews and studies of disturbance from water based activities (Batten 1977; Kirby *et al.* 2004; Peters & Otis 2006). For activities such as kite surfing the potential for disturbance comes not only from the activity on the water. Users will often set up their equipment and raise their kites on beaches etc. before going on the water, and this can of course mean that impacts of disturbance arise on the shore.
- 3.88 Many of these newer activities are undertaken by individuals who are not part of a dedicated club or group, and can be undertaken by individuals without the requirements for any particular unique infrastructure, insurance or group interaction (such as events, regattas or races). However even with such activities it seems that there are good communication networks between individuals, for example through internet forums and voluntary codes of conduct and self-policing seem to work well, particularly where there is the back-up of legal measures to restrict use should the codes fail. For activities such as kite surfing it seems that the activity is limited to very specific locations, meaning that management also needs to be location specific.
- 3.89 At Brancaster in North Norfolk the National Trust/Brancaster Commons Committee has produced guidelines for kite surfers that highlights the SSSI designation and clearly set out a launch/landing zone and which areas offshore that are 'out of bounds' to kite surfers¹⁵. The launch zone is signposted and clearly marked on the map. Kite surfer forums indicate that so far this has worked well¹⁶. Other example of voluntary codes of conduct include the Exe Estuary¹⁷,
- 3.90 In the Lower Saxony area of the Wadden Sea, dedicated areas for kite surfing have been established, through kite surfing schools. Local authorities apply for permission to the National Park for a kite surf zone and then they each work with one surf school which directs surfers to the permitted locations. Zones are permitted for 2 years initially to allow monitoring. It is hoped that if a kite surf interest group becomes established, the sport is more likely to become self-regulatory in due course.

¹³ www.merseybasin.org.uk/archive/assets/166/original/Mersey_Estuary_Management_Plan_Executive_Summary.pdf

¹⁴ www.exe-estuary.org/index.htm

¹⁵ www.kitesurfhub.org/images/bran-sign.jpg

¹⁶ www.kiteforum.com/viewtopic.php?f=1&t=2337260&start=30

¹⁷ www.exe-kiteboarders.co.uk/code-of-conduct.html

- 3.91 On the Hayle Estuary, the Hayle Harbour Authority permits kite surfing in the area they control provided a Code of Conduct is applied with at all times¹⁸. The code specifies a zone where kite surfing is permitted, If this Code is broken or ignored, permission to kite surf will be withdrawn and any kite surfer may be prosecuted and fined up to £1000. The code itself makes no mention of nature conservation issues, but the zone where kite surfing is permitted is outside the estuary (where the main bird interest is present).
- 3.92 A similar approach is in place at Ainsdale¹⁹, where Sefton Council have established a dedicated kite surfing area and an area where kite surfing is not permitted due to concerns about disturbance to birds. In this particular example kite surfers are issued with permits, which are only issued to those kite surfers who have valid insurance. Surfers with permits must wear special vests and sign that they have read the rules and have seen the maps showing the dedicated kite surfing zones. These zones are seasonal, and the zones, timing and success of the system is reviewed annually.
- 3.93 A case study on canoeing on the North Solent NNR - Beaulieu River (Hampshire) is provided on the Best of Both Worlds website²⁰. At this site, English Nature became concerned about the increase in canoeing and potential impacts to birds (breeding, passage and winter visitors) and damage to river-side and inter-tidal habitats. The increase in use was associated with a particular company running tours. English Nature met with the company and eventually granted consent subject to operational guidelines that included temporary exclusion from 3 areas of creek and saltmarsh; the relocation of 'more noisy activity groups' to different, less sensitive locations and a refocusing upon adults and small family groups using the river. Careful monitoring has also been established.
- 3.94 Voluntary agreements have been shown to be successful for canoeists, with research published by the Environment Agency demonstrating success on four inland rivers in the UK (Environment Agency 2006).
- 3.95 At Loch Leven, in Scotland, local access guidance²¹ provides detail of which activities are permitted on the loch and when they may take place. The guidance highlights the site's international importance for birds and explains why disturbance is an issue. The guidance advises against sailing, windsurfing or similar craft/activities on the loch, as these are considered to be most likely to cause disturbance, to the bird interest. The guidance also advises against any water-borne access at all during the winter, as this is when large numbers of birds are present. During the spring and summer (defined as 1st April – 31st August) the guidance states that canoes, kayaks, rowing boats and other craft are welcome. A map indicates areas that are still sensitive at this time of year, and within these areas users are requested to remain at least 200m from the shore and islands, to avoid paddling towards ducks with young and to stay at least 200m from flocks of moulting birds. Dedicated launch areas are cited, and buoys at these locations provide a marked access route by which users can access the main area of the loch.

Motorboats and personal watercraft

- 3.96 Whitefield & Roche (2007) make the point that origins of much of the conflict surrounding personal watercraft usage are likely to be social in origin, relating to the status of many personal watercraft operators as outsiders in coastal communities, and the divergent recreational goals of personal watercraft users (excitement, speed) and more traditional coastal users such as sailors and fishers (relaxation, tranquillity). Motorboats and personal watercraft are often cited as particular issues and there are a range of studies showing disturbance impacts (Hume 1976; Kahl

¹⁸ www.hayleharbourauthority.com/Public/Hayle%20Kitesurfing%20Code%20of%20Conduct%20amended.pdf

¹⁹ www.westcoastkiteboarding.co.uk/Ainsdale.htm

²⁰ www.bobw.co.uk/Uploads/CMS/Files/298/CS%20Beaulieu%20River%20pdf.pdf

²¹ www.snh.org.uk/pdfs/publications/designatedareas/Local_Access-Guidance.pdf

1991; Mikola *et al.* 1994; Galicia & Baldassarre 1997; Burger 1998, 2003; Burger & Leonard 2000; Bright, Waas, & Innes 2004; Bellefleur, Lee, & Ronconi 2009).

- 3.97 Ronconi and St. Clair (Ronconi & St. Clair 2002) suggest that relatively minor adjustments to boat behaviour might significantly reduce the impact of boat disturbance to foraging seabirds. Working on black guillemots in Canada, the authors identify management recommendations based on the response of the birds to boats. Boat speed and distance from the birds were significant factors in whether the birds took flight or not. The birds tended to feed relatively close to the shore, but this varied with the tide. Taking the mean distance from the shore that birds were recorded feeding across all states of the tide (111m) and the mean boat speed recorded (25 km/h), the authors suggest that were boat traffic to be kept back 600m from the shore, this would reduce the probability of a boat flushing the birds to 10% or less. They recognise that such distances are probably site specific and they did not look at the actual impact of the flushing on the birds (i.e. the 10% level of flushing has no biological meaning), but the results highlight that speed restrictions and limits on where boats go may be effective management measures.
- 3.98 On the Conway in Wales concern relating to motorised craft and disturbance to birds has led to a voluntary restriction area and code of conduct for the river. The project has been documented as a case study on the best of both worlds website²². The water sports exclusion zone and associated code of conduct were developed by the local user group. There was already a 10 knot speed limit (under the jurisdiction of the harbour master), however upstream, in part of the site important for the birds, there is no statutory navigation authority. A voluntary approach in this case was chosen, and apparently works well because there are few launching sites, and every boat launched is photographed by the harbour master's staff and also handed a copy of the birds and boats leaflet.
- 3.99 There is also a harmonised scheme for control of powered craft around the majority of the North Wales coast, meaning that an infringement of the launching conditions may result in a ban from any of the controlled launching points in North Wales. So a craft banned from one launch site will become banned from all controlled launch sites across North Wales.
- 3.100 On the Thames the Port of London Authority provides a code of conduct with clear guidance for Personal Watercraft Users²³, the guidance is summarised on the website and a separate leaflet is also available. The guidance indicates where users can launch, how they should behave to minimise disturbance and a map highlights areas where use is restricted. Local groups and clubs are also listed, and users are encouraged to join one of the local groups. The code of conduct is backed up by byelaws.

Footfall on coastal habitats

- 3.101 Footfall results in wear on vegetation, compaction of the substrate and can increase the rate of erosion.
- 3.102 Visitor infrastructure such as car parking is often, by necessity, set back behind any dune system, and visitors will typically wish to walk to the water's edge and along the beach. Infrastructure such as fencing used to direct people in open beach habitats is difficult due to the large areas involved, the dynamic nature of the ground and the effect of tide. In sand dune and shingle habitats the provision of boardwalks or marked routes is a widely used and effective way of directing visitor flows and preventing widespread trampling. Such infrastructure typically run from the back of the beach to the beach front, providing access to the water's edge. The boardwalk at Pagham Spit (Figure 2) is an example. The boardwalk is easier to walk on than the shingle, and starting right at the car-park it serves to direct people and reduce trampling on a larger area. Other locations with coastal vegetated shingle where boardwalks have been successfully used include Dungeness, Walmer and Chesil (Doody & Randall 2003b).

²² www.bobw.co.uk/Default.aspx?page=Water%20Based%20Case%20Studies49519

²³ www.pla.co.uk/display_fixedpage.cfm/id/2324

- 3.103 At sites such as Studland or Orfordness marked paths provide a clear route that the majority of visitors follow through areas sensitive to trampling. While such approaches certainly reduce widespread damage, on heavily visited sites they are not adequate. For example work at Dawlish Warren would indicate that trampling levels are currently having an impact on the habitats present, despite the marked routes, boardwalks etc (Lake 2010).
- 3.104 Wood (2001) describes management measures at Gairloch in Scotland. The beach here is a popular sandy beach. The dune complex is relatively stable, however there is a localised tendency for erosion to occur at the northern end of the beach and deposition to occur at the more sheltered southern end of the beach. Visitor pressure is concentrated at the northern end and the coincidence of natural and human forces resulted in a need for remedial action. Originally access was channelled along particular routes, access was restricted and attempts were made to allow vegetation cover to re-establish. Following a substantial erosion event sediment transfer was then carried out. Small scale beach nourishment was undertaken, moving beach sediment from the southern end to the northern end. The nourishment was considered relatively inexpensive.

Bait digging and similar activities

- 3.105 Bait digging is particularly highlighted by Coyle & Wiggins (2010) as an issue across a number of sites. We group a range of different activities such as hand digging for bait, crab tiling and shellfishing by hand. These all typically involve people out on intertidal habitats, often in areas important for birds. The activities can result in the depletion of prey for birds and also can cause disturbance; there are a variety of studies addressing these impacts (Jackson & James 1979; Townshend & O'Connor 1993; Dyrinda & Lewis 1994; Farrell 1998; Fowler 2002; Smith & Murray 2005; Morrison 2006).
- 3.106 A detailed review of impacts and options for management is provided by Fowler (1999). Bait digging is one area where enforcement has proved particularly difficult. In the future regulation will be vested to IFCAs.
- 3.107 Voluntary codes of conduct are often used to manage bait digging. For example Cruickshanks *et al.* (2010) describe the use of a bait digging Code of Conduct given out when people apply for licences to dig for bait on the Humber in North East Lincolnshire. The code of conduct states that recreational anglers may gather bait but digging is restricted in certain areas. Around Cleethorpes, a licence is required from the Tourist Information Centre to dig bait in the designated areas. On the north side of the Humber, there are no bylaws restricting bait digging at Spurn with around six to eight groups undertaking commercial trench digging which, due to the lucrative nature of the activity, is very difficult to police. In this case it seems that bye-laws and policing may be necessary.
- 3.108 The existing, current legal framework for bait digging is discussed by Fowler (1999). There is generally a public right to collect seafish (including crabs and molluscs, but not worms) from the shore. This public right may be severed under a Several Order, which confers the right of fishery to one body for the purpose of developing the fishery, or regulated under various fisheries byelaws (all species of sea fish, including molluscs and peeler crabs, are made subject to fisheries legislation). In practice, resources will limit the extent to which the targeted exploitation of additional 'sea fish' (for example, shore crab *Carcinus maenus*) may be brought under control. Marine bait worms are not seafish, but certain rules still apply to their collection. Collection for personal use is permitted, but collection for commercial sale is illegal unless approved by the landowner or (extremely rarely) under certain other, exceptional, circumstances where private rights apply.
- 3.109 Poole Harbour Steering Group has published a leaflet on bait digging²⁴ yet concern still remains about the impacts of bait digging on Poole Harbour SPA/Ramsar. The Borough of Poole is

²⁴ www.phc.co.uk/downloads/environment/env_bait_diggers1.pdf

working to introduce a local bye-law to regulate the activity in one area of the harbour (Holes Bay). Natural England has concerns about this activity taking place in this location as it has been highlighted as one of the most important feeding and roosting sites for birds in Poole Harbour.

Dogs

- 3.110 The issues relating to dogs are principally disturbance and impacts of nutrient enrichment through fouling. Dog walking is one of the most commonly given reasons for people to visit sites, for example dog walking was the main activity identified in a visitor survey covering SPA sites on the Solent during the winter (Fearnley *et al.* 2010) and there are a number of studies highlighting the disturbance impacts of dogs (Pienkowski 1984; Bull 1998; Lord *et al.* 2001; Taylor *et al.* 2005; Randler 2006; Banks & Bryant 2007).
- 3.111 A range of management options are available, including dog control orders, which are discussed above (see paragraph 0).
- 3.112 At some sites dedicated dog facilities have been provided. At Saltfleetby-Threddlethorpe Dunes NNR a small fenced area is provided in the corner of the car-park for dogs, with the idea that owners will let their dogs into the area when they first arrive and dog fouling will be 'contained' within this area. Owners are still encouraged to 'pick-up' after their dog, and a dedicated dog bin is provided. There is no evidence as to how successful the approach has been in containing the impacts of dog fouling.
- 3.113 At Sutton Heath (part of the Sandlings SPA) in Suffolk, a large fenced compound is provided for dogs. The idea was to provide a dedicated area where dogs could be off the lead. The area is around 2ha, is largely grass and contains a few small shrubs. It is next to the main car-park, and while the compound itself is actually outside the SPA, the surrounding heath is all part of the European Site. Informal discussion and observation of dog walkers using the area (*pers. obs.*) indicates that the compound is used, and that it draws people from a wide area who visit because they have unruly dogs or dogs that need to be exercised in a safe, fenced environment where they can be let off the lead. Some people let their dogs off within the compound and then put the dogs on a lead before going for a walk on the heath. This would seem to suggest that the compound is partly successful, but may actually result in an increase in dog walking (albeit on leads) on the heath.
- 3.114 Dedicated trails with agility areas for dogs have been successfully promoted at some sites, particularly by the Forestry Commission. Design guidance and discussion of a trail built in March 2008 at Coatham Community Woodland, near Yarm, Teesside are given in Jenkinson (Jenkinson 2009). The trails include jumps, tunnels, slalom posts etc for the dogs, providing a facility where dog owners and their pets can exercise together. We are not aware of any such trails at coastal sites.
- 3.115 Work in Hampshire has explored the motivations and 'psychology' of dog walkers in order to better understand how issues can be resolved (Edwards & Knight 2006). The study found that the preferences and needs of dogs influences where the owners choose to walk with favourite sites being those where the dogs were to be perceived to gain the most enjoyment - where they are permitted to run off lead, where they can socialise with other dogs and where there is little danger of road traffic. Dog walkers also chose sites where their dog could socialise with other dogs, and dog walkers tended to see themselves as members of a group. The study recommends that landowners and site managers are positive towards dog walkers and promote desired dog walking behaviour within the dog walking community. Dog walkers have different needs to walkers without dogs and the requirements of their pet influence where people go and how they behave (Jenkinson & McCloy 2008). Clearly providing safe and welcoming areas where owners and their dogs can socialise would seem to be effective.

Initiatives across multiple sites

- 3.116 The scale of management approaches and intervention is relevant. On some sites management will need to be very specific, for example it may be necessary to simply focus on a particular location such as a roost site. At other sites a much more strategic approach is necessary, and there are opportunities where access provision is considered at a large spatial scale.
- 3.117 Sites such as the Wadden Sea span 3 countries (Netherlands, Germany and Denmark). A trilateral agreement sets out joint management agreement and describes shared principles across the three countries. In all three countries 'core zones' are defined where there is no public access – for example in the Dutch part about 7% is a 'special protection zone' where no public access is allowed (Koffijberg *et al.* 2003). This encompasses a number of seal haul out sites and important concentrations of breeding birds. The scale of the site and the management means there is enough space to provide areas for recreation and core refuges for the birds.
- 3.118 The Kent Coastal Forum established a working group involving organisations such as Local and Harbour Authorities, the then English Nature, Kent Police, the Personal Watercraft Partnership and local Personal Watercraft clubs. This partnership looked to tackle personal watercraft problems across the whole county, and brought together a wide range of interests in order to improve understanding of the aims of each organisation and the challenges they face. A code of conduct was published that covered the whole of Kent²⁵, and promoted particular locations for the use of personal watercraft. The ability to promote a wide range of sites is the advantage of a project operating at this kind of scale.

Monitoring and research

- 3.119 It can be seen that the issues are complex and there is, in general, a lack of information on the relative success of different measures. It is often difficult to understand whether disturbance is having an impact on the conservation interest of a site due for example to the difficulties in assessing whether behavioural responses (such as birds taking flight) are really an issue or simply a feature of large sites where mobile species can redistribute according to the tide and availability of food. It is even harder to then understand what effect a particular measure may have on visitor behaviour and the knock-on consequences in terms of reduced disturbance. Ideally social research and ecological data need to be combined to inform management and it is usually necessary for research to be tailored to individual sites.
- 3.120 There have been a wide range of studies of disturbance impacts and there are also now a range of visitor studies and surveys of access patterns on coastal sites. Few studies directly link visitor and disturbance data, or assess management measures. Given the complexities involved in the management of sites and disturbance issues we recommend that monitoring of any management measure is implemented and that ideally management measures are informed by research. At the time of writing there are projects in place at a range of sites, such as the Solent, the Thames and the Exe Estuary. We highlight below a checklist of key questions which may help plan research on a site. The questions are all relevant to management and the answers would help underpin management measures at a site.

²⁵ www.deal.gov.uk/Uploads/Site328/Files/pwc-guide.pdf

Ecological Questions

Visitor Questions

Questions Relating to both Ecology and Visitors

- | | | |
|---|--|---|
| 1) What evidence is there for ecological impacts from recreation? | 1) Have the levels of use of recreational use increased? | 1) Which activities are instigated in the problem? |
| 2) Is there evidence of declines of one or more species? | 2) Have types of access or patterns of use changed? | 2) What levels of the particular activities result in the impact occurring? |
| 3) Are these declines site specific or widespread? | 3) What underpins where people go and how they behave? | 3) Are there particular circumstances when the impact occurs (i.e. particular tides, weather conditions, times of year etc.)? |
| 4) How severe are the declines? | 4) How do people get information on where to go and how to behave? | |
| 5) Do the declines relate to a designated impact feature? | 5) What management measures might visitors find acceptable or even improve access? | |
| 6) Is the condition of the site affected? | 6) Do users belong to any particular affiliation/club/group? | |
| 7) Which specific locations within the site are impacted? | 7) What proportion of visitors to the site cause the problem(s)? | |
| 8) Are there any other factors involved in the decline? | 8) Where do visitors come from—are they local or widely dispersed? | |

Recommendations: Choice of management measures implemented at different sites

- 3.121 A wide range of approaches are available to resolve disturbance issues and damage, and different approaches are used at different sites. This is inevitable. The scale of any impacts will be site specific, depending on the prey abundance, habitat type and quality, the geography of sites, levels of recreational use, types of access, how access is distributed etc. A wide range of management organisations and approaches to management exist, with some sites being managed solely for their nature conservation interest while other sites will have multiple management objectives. The choice of management options need to be tailored to sites and based on a detailed understanding of the scale of the impact, the visitor use and the characteristics of the site. There is a need for more research and careful monitoring of any management measures.

3.122 Successful management would ensure that people have access to the countryside and are able to enjoy their chosen activities with the least restriction. There are widespread benefits of access to the countryside, for example in terms of health (English Nature 2002; Morris 2003; Bird 2004; Pretty *et al.* 2005), well-being and sense of place (English Nature 2002; Thompson 2005; Ward Thompson, Travlou, & Roe 2006; Maller *et al.* 2006). Ideally access management should ensure visitors' experiences are positive and they maximise their enjoyment without there being any negative impacts. In general, approaches to managing disturbance are therefore best where access is not restricted and visitors feel welcomed.

Benefits of a range of measures

3.123 In most of the examples discussed in this section a suite of measures are usually in place. For example wardens are often present on sites managed by nature conservation bodies, where dedicated viewing facilities, screening, exclosures and interpretation are also in place. The ability of a warden to control disturbing activities is clearly related to the powers of enforcement that are in place, and their nature. These may be thought of as a spectrum from no specific control, through voluntary codes of conduct to statutory controls such as byelaws and Dog Control Orders.

3.124 It is therefore difficult to isolate particular measures and assess their relative success, in most of the examples set out in this section it is the combined approach of various different measures that probably underpins the success of any management. In particular, clear communication with users, ensuring that they understand potential impacts and why they are being asked to behave in a particular way are fundamental. In Table 2 we review the measures listed earlier in this section and indicate circumstances when each measure is relevant. We also make the following general points:

- In general access levels to the UK countryside are increasing, and coastal sites tend to draw high numbers of people. Impacts from recreation are therefore likely to increase over time.
- Disturbance – i.e. to birds and other animals – is complicated as behavioural responses (such as flying away) may not necessarily equate to impacts to the population. Detailed research or assessment may be necessary to determine whether disturbance is a cause for concern at sites; the impacts are likely to be site specific.
- Damage to habitats, through trampling, dog fouling etc. will largely relate to the volume of people visiting a site. Management options that reduce numbers of people in sensitive locations should therefore be effective. Fore-dunes are particularly sensitive to trampling impacts.
- It may be difficult to single out particular user groups or activities without detailed research. Particularly in the case of disturbance impacts, impacts may occur as a result of multiple activities happening simultaneously, for example water-based and shore-based activities.
- Many management solutions listed in this report involve positive measures, such as creating alternative sites, enhancing access in other locations or improving interpretation and information. Such measures are likely to be well received by users and therefore potentially more effective.
- Alternative sites are an appealing and intuitive way of redirecting visitor pressure, however there is little evidence to support their effectiveness and it may be difficult to find alternatives given the attractiveness and particular features of many MPAs.
- Impacts from dogs (both disturbance and fouling) are a widespread issue. Provision of dedicated fenced areas, areas where dog walkers are welcomed and areas where the dog can be off the lead seems to draw dog walkers. By contrast there are examples where the implementation of a dog control order has resulted in the number of dog walkers using a site markedly decreasing. Alternative sites may therefore be effective for this particular user group, if combined with other measures.
- Measures relating to infrastructure, such as car-parking, beach access, visitor centres, toilets etc. would ideally be planned to focus visitor use in particular (non-sensitive) areas. Such

infrastructure is best planned from the start and difficult to alter retrospectively. Opportunities such as planning applications or new plans should look widely at visitor flows and implications.

- There are examples where direct contact with user groups has resulted in positive dialogue and establishment of agreed codes of conduct. Clear messages about the impact and how it can be avoided are therefore necessary. Direct contact with user groups and codes of conduct appear to be widely used with water-based activities such as kite surfing, kayaking. Even activities such as the use of personal watercraft (where individuals appear to not have any affiliation or group membership) may well have internet forums and other means of sharing information and where to go.
- Enforcement measures may antagonise users, but the threat of prosecution or prevention of access is a strong incentive.

Table 2 Summary of management options and when to implement

Management option		Evidence for effectiveness		Cost	When to Implement
		Peer reviewed studies	Anecdotal / grey literature		
1 HABITAT MANAGEMENT					
1a	New habitat creation	Some		Very expensive, but could be funded through developer contributions.	Large projects, for example as mitigation. Easier to create breeding/roost sites for birds than to create particular vegetation communities.
1b	Restoration		Some	Depends on scale. Potentially relatively inexpensive.	Best suited for situations where erosion or other damage has occurred.
2 PLANNING & OFF-SITE MANAGEMENT MEASURES					
2a	Site development away from MPAs		Some	Potentially relatively low cost, difficult to estimate.	A strategic and long-term response where problem identified in advance.
2b	Planning conditions on adjacent development (land)			Normally low cost, particularly in context of overall costs of development.	Where specific new development likely to have particular impacts.
2c	Planning conditions on adjacent development (buildings)			Normally low cost, particularly in context of overall costs of development; best addressed at design stage.	Where specific new development likely to have particular impacts.

Table continued...

Management option		Evidence for effectiveness		Cost	When to Implement
		Peer reviewed studies	Anecdotal / grey literature		
2d	Provide alternative recreational facilities		V. limited	Expensive, but could be funded through developer contributions.	A long term and strategic solution. Likely to be successful only where activities are not dependent on specific features at coastal sites
2e	Provision of designated access points for water sports			Costs vary according to extent of required measures.	Likely to be effective if there are opportunities for new access in areas where disturbance can be limited, and where the access points do not result in increased disturbance.
2f	Attract visitors to less sensitive areas; discourage access to sensitive areas			Costs of additional facilities dependent on scale. Relatively low cost to implement changes to car-parking arrangements; liaison, consultation and wardening likely to be the most expensive element.	Dependent on opportunities at and around each site. Ideally implemented at design stage of new infrastructure (car-parking, toilets, cafes etc) to ensure visitor pressure focussed in best areas

3 ON-SITE ACCESS MANAGEMENT

3a	Restrict/prevent access to some areas within the site	Some	Good	Costs vary according to extent of required measures.	Exclosures best suited to specific areas important for particular species/groups: for example, rare plants, breeding birds (tern colonies/waders), roost sites etc. Often erected for limited time period on annual basis.
3b	Provide dedicated fenced dog exercise areas		V. limited	Costs vary according to extent of required measures.	Where dog walkers a particular issue and suitable areas exist to provide dedicated areas

Table continued...

Management option		Evidence for effectiveness		Cost	When to Implement
		Peer reviewed studies	Anecdotal / grey literature		
3c	Zoning	Some	Some	Low cost, but may be officer time intensive to establish and enforce.	Best done as part of a strategic review of access – for example a recreation strategy or revision of management plan – where sensitive and non-sensitive areas can be identified and options assessed.
3d	Infrastructure to screen, hide or protect the nature conservation interest			Costs vary according to extent of required measures, although usually relatively low.	Where disturbance to birds is an issue at a particular location. Perhaps best suited to situations where people loitering or trying to view wildlife is causing disturbance
3e	Management of car-parking		Some	Varies according to detail. Ditches, dragon's teeth etc relatively cheap; new car-parks etc more expensive.	Where opportunities exist to manipulate parking in a positive fashion, for example enhancing parking in one area and limiting (rather than closing) car parking in other locations. May create public opposition.
3f	Path design and management	Good	Good	Relatively low cost.	Where visitor pressure is spread over a wide area; where erosion etc is apparent and path braiding occurs. Where new desire lines occur. Where there are opportunities to focus and direct visitors.
4 EDUCATION AND COMMUNICATION TO PUBLIC AND SITE USERS					
4a	Signs, interpretation and leaflets		Limited	Low cost	Where impact appears to occur because of lack of understanding of users. Probably particularly effective where recreational use is unrelated to wildlife (for example, jogging, dog walking etc).

Table continued...

Management option		Evidence for effectiveness		Cost	When to Implement
		Peer reviewed studies	Anecdotal / grey literature		
4b	Codes of Conduct	Limited	Limited	Low cost	Where clear guidance on how to behave is likely to resolve impacts. Visitor studies may highlight where confusion exists. Best targeted at individual groups and types of use.
4c	Wardening	Some		Expensive; voluntary wardening has potential to reduce costs.	Where face-to-face contact will work well to convey message. Most useful on sites with high levels of access and where management may be contentious.
4d	Provision of information off-site to local residents and other users.		Some	Costs dependent on extent and coverage. Very cheap if done using internet.	Where opportunities exist to promote other areas and where users are perhaps not appreciating the problems. Good promotion in media can help engender local support.
4e	Contact with relevant local clubs		Some	Low cost.	Where particular activities are causing impacts and where the users creating the impacts are likely to be associated with particular groups.
4f	Establishment of Voluntary Marine Reserves (VMRs)			Low cost, but may be officer time-intensive to establish.	Where range of local users, potential to enhance links with the local community.
4g	Off-site education initiatives, such as school visits etc			Requires staff time and can be labour intensive. For NGOs provides an opportunity to gather membership, donations and interact with younger generations.	Where schools and local communities are adjacent to sites. Perhaps most likely to be successful where local children or family groups are having an impact.

Table continued...

Management option	Evidence for effectiveness		Cost	When to Implement
	Peer reviewed studies	Anecdotal / grey literature		
5 ENFORCEMENT				
5a	Dog control orders		Costs are primarily related to liaison, consultation and wardening/enforcement.	Where dogs are a particular issue and DCO can be applied. Ideally applied as a last resort and in tandem with other measures such as provision of alternative sites.
5b	Covenants regarding keeping of pets in new developments	Little or no evidence	Low cost.	Where new development occurs adjacent to sites and there are options (such as a housing warden) to check and enforce.
5c	Legal enforcement		Costs are primarily related to liaison, consultation and wardening/enforcement.	Legal enforcement such as prosecution best used as a last resort as may alienate users. Prosecution can be brought on designated sites (SSSIs) where good evidence that damage/disturbance has occurred. On Natura 2000 sites, existing consents subject to review through Review of Consents; new plans/projects which may result in impacts subject to appropriate assessment and review. SNCO can be established by Natural England in specific circumstances where an activity is causing damage or disturbance. Byelaws and Dog Control Orders are also applicable at local level.
5d	Wardening	Some	Expensive; voluntary wardening has potential to reduce costs.	Where wardens have power to enforce byelaws etc and can collect evidence to support prosecution etc then likely to be very effective. Best used where repeated problems that 'policing' is necessary or where short-term face-to-face contact is likely to ensure problems are resolved.

Table continued...

Management option		Evidence for effectiveness		Cost	When to Implement
		Peer reviewed studies	Anecdotal / grey literature		
5e	Limiting visitor numbers	Some	Some	Depends on means of implementation. Likely to involve staff time and infrastructure, although costs can be met through charging (for example, for permits)	Where there are options to implement permit systems and physically control access through gateways etc. Likely to be difficult where multiple entry points and high proportion of visitors enter on foot. Best suited to islands etc. where visitors have to book boat or similar in advance.

4 Potential strategies for the mitigation and reduction of the bycatch of cetaceans and seabirds in fisheries in UK Marine Protected Areas (MPAs)

Overview of issue

- 4.1 Bycatch is usually defined as ‘the incidental take of undesirable size or age classes of the target species (for example, juveniles or large females), or to the incidental take of other non-target species – (Lewison *et al.* 2004). Individuals caught as bycatch can be unharmed, released with injuries, or killed (Lewison *et al.* 2004). However, it has recently been suggested that bycatch should be defined as ‘catch that is either unused or unmanaged’ (Davies *et al.* 2009). While it can sometimes be difficult to identify exactly what constitutes non-target species, due to changes in the economic value of specific organisms, and particularly fish species, over time, in terms of cetaceans and seabirds in UK waters bycatch simply refers to any individuals which are caught, and almost always killed, in fishing gear of any description. This is because there is no commercial value of any kind for either cetaceans or seabirds in the UK.
- 4.2 Around the world, bycatch is recognised as one of the most important conservation issues for many seabird and cetacean species, and fisheries bycatch has been implicated in the decline of many populations, including the North Atlantic harbour porpoises, the vaquita (a porpoise), the Mediterranean striped dolphins, and the wandering albatross and white-chinned petrel of the Southern Ocean (Lewison *et al.* 2004). The levels of bycatch in some fisheries of specific species is substantial. For example, it has been estimated that long-line fisheries in the central North Pacific may kill as many as 10 000 black-footed albatross per year. This equates to 5% of the total population size and is such that it is likely to lead to substantial declines in the population size over the short to medium term (Lewison & Crowder 2003).
- 4.3 However, in many cases, it is very difficult to obtain the information required to fully assess the impact of bycatch on cetacean and seabird populations. This is because bycaught animals are often discarded at sea and the bycatch incidents not reported. Therefore, it is likely that the extent of the impact of bycatch on many cetacean and seabird species is under-estimated.
- 4.4 The extent of bycatch of seabirds and cetaceans in many parts of the world has led to the development of a variety of measures which can be implemented to reduce the number of bycaught individuals. These range from the complete closure of fisheries with unsustainable levels of bycatch threatened species to suggested modification of fisheries practices or gear (see below). However, which bycatch mitigation and reduction methods actually work for an individual fishery will depend on a number of factors. These include the species which are being caught, the fishing gear type, the spatial and temporal extent of the bycatch, the effect on the economic viability of the fishery and the ability of local, regional or global governmental organisations to implement and enforce any mitigation measures.
- 4.5 Within the northeast Atlantic, the main bycatch issues for seabirds involve long-line fisheries operating in deep waters to the west and south of Ireland which are estimated to kill more than 50,000 individuals per year belonging to six species, of which the majority are great shearwaters (Birdlife International 2009), while northern fulmars may also be taken in large numbers throughout the northern northeast Atlantic (Dunn & Steel 2001), and the bycatch of between 90,000 and 200,000 per year of diving seabirds, such as divers, grebes, sea ducks, diving ducks, auks and cormorants in trawl, drift-net and gill net fisheries (Zydalis *et al.* 2009). For cetaceans

the main bycatch issues involve the capture of pelagic species, such as common dolphin in pelagic trawl fisheries, and the capture of neritic species, such as harbour porpoises, in gillnet and set net fisheries (Northridge & Thomas 2003).

- 4.6 MPAs in UK waters are set up to protect and conserve hotspots for diversity or key areas for individual species. Therefore, it is of primary importance to reduce bycatch of cetaceans and seabirds in such areas as they have already been identified as being important for the conservation and protection of these species. This report will detail a range of possible mitigation and bycatch reduction methods which could be applied to fisheries in UK waters in MPAs in order to reduce cetacean and seabird bycatch, and make recommendations of which are most appropriate given the main bycatch issues experienced in these waters.

Options to manage

- 4.7 There are a wide variety of potential options for managing the bycatch of seabirds and cetaceans in fisheries. These can be divided into five basic categories. While the grouping of potential mitigation measures into these categories is somewhat subjective and non-exclusive, they are useful as they represent separate angles from which to approach this issue, each of which may be applicable to different fisheries, circumstances and bycatch issues, and require different information in order to implement them. These categories are:
- Temporally-based measures;
 - Spatially-based measures;
 - Technically-based measures;
 - Socially-based measures; and
 - Fisheries management-based measures.
- 4.8 Temporally-based management measures are based on the concept that the risk or rate of bycatch may not be equally distributed in time. That is, for some reason, bycatch in a specific fishery may be substantially higher at some times than others. This may be driven by temporal differences in the behaviour of the target species, temporal differences in the behaviour of the bycatch species, or temporal differences in the risk of the bycaught species becoming entangled in fishing gear. For example, surface-feeding seabirds are primarily visual foragers, and rely on being able to see potential prey items in order to target them. As a result, bycatch in long-line fisheries is likely to be substantially higher when the lines are set during daylight hours (for example, Birdlife International 2009), when the birds can see the baited hooks as they enter the water, than at night, when they cannot. Similarly, the bycatch of diving seabirds in gill nets, such as auks, may be highest at dusk and dawn (for example, Melvin & Parrish 1999) when they are least likely to be able to see the nets within the water column. Similar factors may also operate at other temporal scales. For example, bycatch may be greater at some phases of the moon than others or at different seasons of the year (for example, Melvin and Parrish 1999). If such temporal patterns in bycatch can be identified, this means that time-based management measures can be implemented to reduce bycatch. Thus, fishing activities could be limited or banned at specific times of day, phases of the moon or times of year to reduce bycatch. For example, the setting of long-lines during daylight hours could be eliminated, or fisheries closed at times of year when bycatch is particularly high. Alternatively, specific technically-based mitigation measures (see below) could be implemented at times when bycatch is particularly high. This has the advantage that such mitigation measures which may be costly to implement in terms of time, effort, capital investment in fishing gear, or reduced catch would only be required at times when they would have the greatest impact in bycatch reduction. However, identifying temporal patterns in bycatch may prove difficult, and may take a substantial amount of time to achieve. Thus implementing temporally-based management measures can prove difficult, especially if they must be implemented in the short term. In addition, temporally-based mitigation approaches may be more difficult to monitor and police than approaches which remain constant over time. However, the

use of vessel monitoring schemes (VMS) would greatly enhance the ability to enforce and police any temporally-based mitigation approaches.

- 4.9 Spatially-based management measures are based on the concept that the risk or rate of bycatch may not be equally distributed in space. That is, for some reason, bycatch in a specific fishery may be substantially higher at some locations than others. These spatial differences may result from a number of different factors. For example, the spatial distribution of a given fishing activity may only overlap with the distribution of a given bycatch species at specific locations or in specific habitats, meaning that bycatch only occurs in such areas. Similarly, the environmental characteristics of specific locations may increase the risk of bycatch for certain species. For example, cetacean bycatch in gill nets and fixed net fisheries may be particularly high in areas where there is a lot of noise, due to strong currents, which make it more difficult for animals to detect fishing gear present in the water. If such spatial patterns in bycatch can be identified, this means that spatially-based mitigation measures can be implemented. Thus, fishing activities could be limited or banned in specific locations where bycatch is known to be high. Alternatively, specific technically-based mitigation measures (see below) could be implemented in locations where bycatch is particularly high. This has the advantage that such mitigation measures, which may be costly to implement in terms of time, effort, capital investment in fishing gear, or reduced catch, would only be required at locations when they would have the greatest impact in bycatch reduction. However, identifying spatial patterns in bycatch may prove difficult, and may take a substantial amount of time to achieve. Thus implementing spatially-based management measures can prove difficult, especially if they must be implemented in the short term. In addition, spatially-based mitigation approaches may be more difficult to monitor and police than approaches which apply the same rules throughout a fishery or region. However, the use of vessel monitoring schemes (VMS) would greatly enhance the ability to enforce and police any spatially-based mitigation approaches.
- 4.10 Technically-based management measures are based on the concept that changes in the fishing gear and the way that it is set can help reduce the levels of bycatch. These measures can be divided into two types. Those that require a modification of the way in which the gear are deployed and those which require a modification of the gear itself. For example, in long line fisheries, it is generally accepted that bycatch of seabirds primarily occurs when the baited hooks are being deployed from the vessel and are close enough to the surface for surface feeding seabirds to pick up the bait and so become caught on the hooks (for example, Birdlife International 2009). This bycatch can be reduced by changing the way that the gear is deployed including using a setting shoot to deploy the hooks under water and using streamers to prevent the birds getting close enough to the vessel to pick up the bait before it sinks (for example, Birdlife International 2009). However, bycatch can also be reduced by changing the gear itself. For example, by using thawed rather than frozen bait or by using weighted lines, both of which help the gear sink faster to a depth below which seabirds can take it.
- 4.11 In general, technical measures which can be used to reduce the bycatch of seabirds are unlikely to work for cetaceans and vice versa. This is due to the differences in the processes which lead to entanglement. For example, the deployment of passive acoustic reflectors, nets made from high density materials and the use of pingers as active acoustic alerting systems can be used to reduce bycatch of cetaceans, such as the harbour porpoise, in gill nets, but are likely to have little impact on the bycatch of diving seabirds in the same nets. This is because while cetaceans are primarily acoustic foragers, diving seabirds are primarily visual foragers, and these technical mitigation measures are aimed at acoustic foragers. In addition, technical mitigation measures often need to be tailored to specific fisheries and fishing techniques due to differences in the modes of fishing between them. However, while technically-based mitigation measures are generally aimed at allowing fishing effort to continue while reducing the level of bycatch of specific species, there is often a worry that they may be costly to implement in terms of time, effort, capital investment in fishing gear, or reduced catch. Therefore, it is important that technically-based mitigation procedures are not imposed indiscriminately. Instead it is important to ensure that they do, indeed, reduce bycatch to acceptable levels, that they are suited to the

fisheries where they are to be deployed and that they do not have unforeseen costs when used in a commercial context.

- 4.12 Socially-based management measures are based on the concept that bycatch can be reduced by altering the social context of the fishery in some way. These can be divided into two types. Those which seek to educate fishermen about this issue in the hope that this will lead to them taking steps to reduce bycatch, and those which seek to reduce fishing effort in some way. Examples of the former include sharing information between vessels as to what species of cetaceans are currently in a given area, and providing information to fishermen about the biology, ecology and distribution of cetaceans in their fishing areas. Examples of the latter include the removal of abandoned or lost fishing gear which may continue to entangle marine organisms for long periods of time (so called ghost fishing), and buying up fishing quotas or licences.
- 4.13 Fisheries management-based mitigation measures are based on the concept of controlling the levels of fishing effort in order to control the levels of bycatch. These measures can include reducing the length of gill nets, reducing the number of nets per vessels, reducing the length of the fishing season or even closing a fishery completely in order to stop bycatch altogether. In addition, the introduction of vessel monitoring schemes (VMS) to fisheries can be an important component of bycatch reduction strategies as it can provide information on where and when bycatch is occurring, providing bycatch reporting is also implemented, and can also form the basis for implementing temporally and/or spatially based mitigation measures which require a good knowledge of where fishing vessels are present for enforcement and policing purposes. Similarly, making the reporting of bycatch a requirement of fisheries can also provide the type of information required to implement other mitigation strategies. However, fisheries management based mitigation measures are often difficult to introduce as they usually involve changes in local, regional, national or international governmental policies to allow them to be implemented.

Table 3 Summary of management options available to reduce bycatch of seabirds and cetaceans in UK fisheries

Management option	Description	What type of fishery can it be applied to?	What species of bycatch can it reduce?	Examples of its application	Reference(s)
SPATIALLY-BASED MITIGATION MEASURES					
1	Combine fishing effort to identify times with high bycatch where fishing could be limited/closed.	All types	Cetaceans and seabird species	Identify specific locations and/or habitats where the levels of bycatch are particularly high and restrict fishing effort in these locations/habitats.	Kaschner 2003
2	Application of technical mitigation measures to areas of high bycatch.	All types	Cetaceans and seabirds	Require that technical mitigation measures are used in specific locations/habitats where bycatch is known to be particularly high for specific fishing gear.	Kaschner 2003
3	Close fisheries in areas with high levels of bycatch.	All types	Cetaceans and seabirds	Ban fishing in locations/habitats where individual fisheries have particularly high levels of bycatch.	Kaschner 2003
TEMPORALLY-BASED MITIGATION MEASURES					
4	Restrict the time of day when fishing can take place.	Gillnets; Longline fisheries	Seabirds	Limit fishing at dawn and dusk when visual predators, such as auks, are most likely to not detect nets and become entangled.	Klaer & Polacheck 1998; Melvin, Parrish, & Conquest 1999
5	Restrict the days on which fishing can take place.	Longline fisheries	Seabirds	Limit fishing at new moon when visual predators, such as auks, are least likely to detect nets and become entangled.	Klaer and Polacheck 1998

Table continued...

Management option	Description	What type of fishery can it be applied to?	What species of bycatch can it reduce?	Examples of its application	Reference(s)
6	Combine fishing effort to identify times with high bycatch where fishing could be limited/closed.	All fisheries	Cetaceans and seabirds	Identify specific times of day/month/year when the levels of bycatch are particularly high and restrict fishing effort in these locations/habitats.	Read 2000; Kaschner 2003
7	Application of technical mitigation measures to times of high bycatch.	All fisheries	Cetaceans and seabirds	Require that technical mitigation measures are used at specific times of day/month/year where bycatch is known to be particularly high for specific fishing gear.	Kaschner 2003

TECHNICALLY-BASED MITIGATION

8	Modify gear to make it more detectable by bycatch species.	Gillnets	Cetaceans and seabirds	Use high density nets, increased knot size or passive reflectors which increase the strength of echoes from nets, making them more visible to cetacean echolocation.	Melvin <i>et al.</i> 1999; Kaschner 2003
9	Use of devices to deter seabirds from taking bait while lines are being set.	Longline fisheries	Seabirds	The application of bird scaring lines and bird curtains, side shooting.	Lokkeborg 2000; Gilman, Boggs, & Brothers 2003; Gilman, Brothers, & Kobayashi 2007

Table continued...

Management option	Description	What type of fishery can it be applied to?	What species of bycatch can it reduce?	Examples of its application	Reference(s)
10	Limit the availability of baited hooks to surface foraging seabirds.	Longline fisheries	Seabirds	Use devices to set hooks underwater, use weighted lines, use thawed rather than frozen bait.	Lokkeborg 2000; Ryan & Watkins 2002; Peterson 2007; Gilman <i>et al.</i> 2007
11	The use of active acoustics devices.	Gillnets; Trawl fisheries	Cetaceans	The use of 'pingers' to alert cetaceans to the presence of fishing gear; the use of acoustic deterrent devices to prevent cetaceans coming too close to nets.	Barlow & Cameron 2003; Cox <i>et al.</i> 2007; Atlantic Trawl Gear Take Reduction Team 2008
12	Make bait less attractive to bycatch species.	Longline fisheries	Seabirds	The use of blue-died bait to make it less visible/palatable to seabirds.	Gilman <i>et al.</i> 2003; Gilman 2004
13	The use of alternative designs for fishing hooks.	Longline fisheries	Seabirds	The use of circle hooks to prevent seabirds ingesting hooks.	Peterson 2007
14	The use of special devices in fishing gear to prevent non-target species being entangled in nets.	Trawl fisheries; Purse seine fisheries	Cetaceans	Exclusion devices in trawl nets, medina panels in purse seine nets.	Lewison <i>et al.</i> 2004; Atlantic Trawl Gear Take Reduction Team 2008
15	Change properties of fishing nets to reduce the chance of entanglement.	Gillnets	Cetaceans	Increase mesh size.	Read 2000

Table continued...

Management option	Description	What type of fishery can it be applied to?	What species of bycatch can it reduce?	Examples of its application	Reference(s)
16	Change behaviour of fishing gear while underwater to reduce risk of entanglement.	Gillnets	Cetaceans	Tie down to reduce the height of the net.	Read 2000
SOCIALLY-BASED MITIGATION MEASURES					
17	Increased communication between fishing vessels.	Trawl fisheries	Cetaceans	Sharing information on what marine mammals are present within an area at any given time.	Atlantic Trawl Gear Take Reduction Team 2008
18	Education of fishermen about the ecology of non-target species.	Trawl fisheries	Cetaceans	Increase awareness amongst fishermen of marine mammal identification and distribution.	Atlantic Trawl Gear Take Reduction Team 2008
19	Removal of unattended, abandoned or lost fishing gear.	Gillnets	Cetaceans	Clearing of 'ghost' nets to prevent them continuing to entangle marine organisms.	Kaschner 2003
20	Provide financial incentives to reduce fishing effort.	All types	All types	Buy out of fishing licences/quotas/boats to reduce fishing effort.	Read 2000
FISHERIES- MANAGEMENT BASED MITIGATION MEASURES					
20	Control opening times of fisheries to minimise the risk of bycatch.	Gillnets	Seabirds – Auks	Time the opening of fisheries to coincide with the highest availability of target species so reducing total fishing effort.	Melvin <i>et al.</i> 1999

Table continued...

Management option	Description	What type of fishery can it be applied to?	What species of bycatch can it reduce?	Examples of its application	Reference(s)
21	Change behaviour of fishing vessels to limit the risk of bycatch.	Trawl fisheries; Longline fisheries	Cetaceans	Reduced number of turns of vessel while trawl net is set as cetaceans are most likely to become trapped in trawl nets when they make a sudden turn; Avoid discard of offal when fishing as this attracts foraging seabirds.	Cherel, Weimerskirch, & Duhamel 1996; Atlantic Trawl Gear Take Reduction Team 2008
22	Reduce total fishing effort.	Gillnets	Cetaceans	Restriction on net length, limited entry to fishery, cap number of nets per vessel; Close fishery; Reduce the amount of time fishing gear is in the water.	Read 2000; Kaschner 2003; Atlantic Trawl Gear Take Reduction Team 2008
23	Monitoring of fishing vessels.	All fisheries	Cetaceans and seabirds	Fisheries observer schemes to ensure that fishermen conform to bycatch mitigation measures.	Read 2000
24	Vessel Monitoring Systems (VMS).	All fisheries	Cetaceans and seabirds	The use of VMS to monitor the time of day which long-lines are deployed in fisheries where the extent of bycatch varies with time of day.	Birdlife 2009
25	Requirement to record and report all instances of bycatch.	All fisheries	Cetaceans and seabirds	Contracting and paying fishermen to produce a log of all bycatch incidents.	Birdlife 2009

Examples of management

Evidence used to underpin management decisions

- 4.14 It is important that any management decisions aimed at reducing bycatch is evidence-based to ensure that it is effective. In terms of bycatch in UK waters, there have been three main types of fisheries where bycatch mitigation measures have been specifically investigated. These are:
- Long-line fisheries in the Atlantic to the west of the UK where there is a bycatch of seabirds.
 - Trawl fisheries to the south and west of the UK where there is a high level of bycatch of common dolphin and other cetacean species.
 - Gillnet fisheries in shelf waters, and particularly the North Sea, where there has been a high level of bycatch of cetaceans, such as the harbour porpoises, and potentially a high level of bycatch of diving seabirds, such as auks.
- 4.15 Therefore, in order to investigate potential mitigation measures to reduce these specific instances of bycatch, a case study was conducted for each of these types of fishery and bycatch. These case studies were based on fishery types rather than specific studies as multiple mitigation approaches are often required to reduce bycatch in a specific fishery and few individual studies cover more than one or two possible mitigation approaches.

Case Study 1: Reduction of bycatch of seabirds in long-line fisheries

- 4.16 In long-line fisheries in the northern northeast Atlantic, which almost exclusively take northern fulmars, the use of pair streamer lines, underwater setting tubes and the use of weighted lines reduce levels of bycatch substantially, with streamer lines being the most effective, and are unlikely to affect the productivity of the fishery (Dunn & Steel 2001). The use of streamers alone has been found to reduce bycatch in these fisheries by 98-100% (Lokkeborg 2000). In addition, the use of streamers has generally been found to be acceptable to fishermen and also applicable to mechanised line-setting, which can limit the application of some other approaches in such fisheries (Lokkeborg 2000). Finally, as streamers reduce the amount of bait lost to foraging seabirds, their use can increase catches and efficiency, providing an incentive for fishermen to adopt their use (Lokkeborg 2000). Similarly, the use of underwater setting tubes has been found to reduce bycatch in this fishery by between 72% and 92%, depending on the length of the tube used (Lokkeborg 2000).
- 4.17 These mitigation measures have also been applied to other fisheries around the world to prevent bycatch of other species. For example, underwater setting tubes have been found to reduce the bycatch of North Pacific albatrosses in the Hawaii pelagic longline tuna fishery by 95%, while also resulting in an increase in fishing efficiency by between 14.7% and 29.6% in areas where albatrosses are abundant (Gilman *et al.* 2003). As a result, the costs of implementing the use of underwater setting tubes can be recouped after a maximum of two fishing trips (Gilman *et al.* 2003).
- 4.18 Similarly, the use of paired-streamers has been found to reduce the bycatch of seabirds (primarily northern fulmars, albatross and gull species) by between 88% and 100% in Alaskan demersal long line fisheries (Melvin & Parrish 1999). The use of underwater setting tubes was also found to reduce bycatch in this fishery, although to a lesser extent, with a reduction of 37% to 76% depending on the target fish species (Melvin & Parrish 1999). The use of weighted lines had a similar level of reduction in seabird bycatch (Melvin & Parrish 1999).
- 4.19 In addition, there is evidence that the number of bycaught birds may be related to the number of birds present around the boat (Dunn and Steel 2001). As these birds may be attracted by offal discharges from the vessels, avoiding discharging offal during line setting may also help to reduce bycatch, although this has not been fully investigated.

- 4.20 However, while the application of streamers has been found to be widely successful in reducing bycatch, they are not always acceptable to fishermen. For example, in the Gran Sol long line fishery to the west of Ireland, fishermen are not keen on using streamers as they report that they may become tangled in the fishing line as it is being deployed (Birdlife 2009). However, in this fishery, which primarily takes great shearwaters, when lines are set at night bycatch is greatly reduced in comparison to setting during the day. In addition, when setting at night, the bycatch can be virtually eliminated if the deck lights, which might otherwise attract birds and allow them to see the baited hooks, are switched off (Birdlife 2009). The risk of bycatch has been found to be time of day dependent in other fisheries as well. However, the times of day of peak bycatch may differ substantially in different fisheries. For example, in the Alaskan demersal long line fisheries, the bycatch of northern fulmars is 10 times higher at night and sunrise in comparison to daytime and sunset (Melvin & Parrish 1999). Therefore, the implementation of 'time of day' mitigation measures are likely to be specific both to the seabird species being bycaught and the fishery where it is conducted.
- 4.21 In addition, in some fisheries, it may not be possible to implement such mitigation strategies. For example, in the northern North Atlantic, it is effectively daylight 24 hours a day in summer months, meaning that lines cannot be set at night (Lokkeborg 2000).
- 4.22 These studies suggest that bycatch of seabirds in long-line fisheries can be greatly reduced using relatively simple technically-based mitigation measures, which can be applied at low costs and can increase fishing efficiency, and these could be introduced as a requirement for entry into any such fishery. In particular, the use of streamers and underwater setting devices has been found to almost completely eliminate bycatch in fisheries where they have been tested. In those fisheries where these measures are not acceptable to fishermen, limiting the time of day when lines are set, and eliminating factors which may attract seabirds to the boats when the lines are being set, such as switching off deck lights, can also prove very effective. However, ensuring that these regulations are followed may prove difficult. For example, the setting at night and the switching off of deck lights is already a requirement in the Gran Sol fishery, but these regulations do not seem to be followed (Birdlife 2009).

Case Study 2: Reduction of bycatch of cetaceans trawl fisheries

- 4.23 Trawl fisheries in the UK primarily take cetaceans rather than seabirds. In particular, there is a high level of bycatch of common dolphin in waters to the south and west of the UK (Northridge & Thomas 2003; Stephenson, Wells, & King 2008). The primary avenue of investigation has been the use of acoustic deterrents to prevent cetaceans coming close to the fishing gear, and the use of devices designed to exclude cetaceans from the cod end and allow them to escape from the trawl nets.
- 4.24 In general, acoustic devices have been found to be ineffective (Stephenson *et al.* 2008). However, exclusion grids have been found to be successful in fisheries where this has been tried (for example, Stephenson *et al.* 2008) and seem to offer the best solution to the bycatch of cetaceans in trawl fisheries.
- 4.25 The use of such exclusion grids has been applied to a number of fisheries around the world. For example, in trawl fisheries off the northwest coast of Africa, the use of excluder grids which deflects pelagic megafauna into an escape tunnel along the bottom of the trawl can reduce the bycatch mortality of marine megafauna by 40-100% (Zeeberg, Corten, & de Graaf 2006). Similarly, in the Pilbara Trawl Fishery in western Australia, the bycatch of dolphin can be reduced by between about 50 and 66% by the use of a selection grid which prevents dolphins entering the cod end and instead deflects them to an escape opening in the bottom of the net (Stephenson *et al.* 2008). Therefore, the use of exclusion grids which guide cetaceans towards escape routes appears to offer a suitable approach for providing substantial reductions in the bycatch of cetaceans in trawl fisheries.

Case Study 3: Reduction of bycatch of seabirds and cetaceans in gill net fisheries

- 4.26 Gill net fisheries potentially offer the most difficult fishery to reduce bycatch as unlike long line fisheries which primarily take seabirds, and trawl fisheries which primarily take cetaceans, gill net fisheries may take substantial numbers of both seabirds and cetaceans.
- 4.27 In terms of reducing seabird bycatch, little work has been done on this in European waters or indeed in other parts of the world. In the UK, there are some small-scale examples such as the Filey Bay Fisheries Byelaw enacted by the Environment Agency in 2010, which restricts the use of “T and J” nets during June to reduce bycatch of razorbill and guillemots.
- 4.28 Research in the eastern Pacific has suggested that seabird bycatch in drift gill nets can be reduced by up to 75% without a reduction in target fishing efficiency through a number of relatively simple measures (Melvin & Parrish 1999). These include modifying the nets to make them more visible, restricting the setting of nets at dawn and dusk and only allowing fishing at times when the target species was present in high abundance (as this reduced the amount of time the nets had to be present in the water with a concomitant reduction in bycatch as a result). How transferable these results are to UK gill net fisheries is currently unknown. In addition, encouraging the use of alternative fishing methods, such as fish traps, in locations with high levels of bird bycatch in gill nets may prove a useful approach in some circumstances (Birdlife 2009).
- 4.29 Much more research has been conducted into the reduction of bycatch of cetaceans in gill nets. This has primarily focussed on enhancing the detectability of gill nets by cetaceans. Of these, the use of acoustic pingers to alert cetaceans to the presence of gill nets has been most widely researched (Read 2000) and applied to reduce cetacean bycatch, and is currently the favoured approach in most parts of the world, including Europe (Kaschner 2003). For example, the use of pingers has been found to reduce the bycatch of harbour porpoises by 77% to 90% in bottom set gill net fisheries in a range of locations, including the North Sea, the Bay of Fundy, the Gulf of Maine and the Olympic Peninsula in the Pacific northwest (Kraus *et al.* 1997; Trippel *et al.* 1999; Gearin *et al.* 2000; Barlow & Cameron 2003). Similarly, the use of pingers has been found to reduce the bycatch of common dolphin by 12 fold, and other cetacean species by four fold in pelagic drift net fisheries for swordfish in California (Barlow and Cameron 2003). In the same fishery, the use of pingers during commercial fishing appears to have completely eliminated bycatch of beaked whales (Carretta, Barlow, & Enriquez 2008). Therefore, pingers appear to provide a method of bycatch reduction in gill net fisheries which applies to a wide variety of species. The fact that the application of pingers may also reduce the bycatch of diving seabirds in the gill net fisheries (Melvin & Parrish 1999), enhances option as a mitigation measure. However, the use of pingers needs to be monitored to ensure that the devices remain functional throughout their lifetime.

Implementing bycatch reduction strategies

- 4.30 While it may be relatively easy to identify effective methods for reducing the bycatch of cetaceans and seabirds in fisheries, successfully implementing any bycatch reduction strategy requires a concerted effort. In particular, simply making the use of mitigation measures a requirement of a fishery is not enough to ensure that it is actually implemented and that vessels comply with them. For example, despite the fact that there is a requirement for deck lights not to be used in the Gran Sol fishery (which virtually eliminates seabird bycatch in this instance), there is evidence that few vessels comply with this requirement (Birdlife 2009). Similarly, even when fitted to gill nets, pingers may malfunction if not regularly inspected meaning that they will not function to reduce bycatch (Cox *et al.* 2007). The successful implementation of bycatch mitigation measures generally require three characteristics. These are:
- Collaboration with fishermen, to educate them about the problem, to provide sufficient training to ensure that they successfully deploy and maintain any technically-based mitigation measures, and to allow feedback to occur between fishermen, managers, policy makers and scientists.

- Monitoring of the levels of bycatch to ensure that the mitigation measures are being applied and that they remain effective.
- Ensuring that there is compliance through the use of incentives and enforcement measures (Cox *et al.* 2007). In particular, the involvement of the fishermen themselves as early as possible in the implementation process is an essential feature of a successful bycatch reduction programme.

4.31 In terms of monitoring the levels of bycatch, in general it is recognised that more accurate, and higher, bycatch numbers are recorded when trained and independent observers are used rather than relying on self-recording and reporting by fishermen (Stephenson *et al.* 2008). In addition, it is important that monitoring does not just involve the levels of bycatch, but also the functionality of any technically-based mitigations measures, such as the use of streamers in long-line fisheries, or the use of pingers in gill net fisheries. For example, bycatch reduction using pingers appears to be more successful when the functionality of the pingers is monitored as well as the levels of bycatch (Cox *et al.* 2007). As a result, the successful implementation of bycatch reduction programmes has generally been more successful in smaller fisheries, where it is easier to provide adequate monitoring, enforcement and, indeed, education and training, than in larger fisheries (Cox *et al.* 2007). As a result, working with small groups of fishermen who operate in specific areas with high levels of bycatch within larger fisheries, may prove a more effective approach for implementing bycatch reduction programmes than blanket coverage of an entire fishery, especially in the context of reducing bycatch within marine protected areas.

Recommendations

- 4.32 In order to implement any bycatch reduction plan, it is first essential that the full extent of the problem is understood. In addition, it is essential that any proposed bycatch mitigation procedures are supported by the available evidence, and that they are assessed to understand the feasibility, implementation costs, policing monitoring costs and economic impacts.
- 4.33 In terms of the bycatch of cetaceans and seabirds in UK waters, three basic strategies are suggested, each of which applies to an individual fishery type where bycatch has the highest potential to occur, and which have previously been demonstrated to be effective. These are:
- For long-line fisheries, the aim should be to reduce the risk of sea birds being attracted to vessels when setting lines and being caught on baited hooks. In order to prevent sea birds being attracted to vessels during line setting, the discharge of offal should be avoided, lines should be set at times of the day when bycatch will be lowest and deck lights should not be used when setting at night. In order to prevent birds being caught on baited hooks, bird streamers should be used, the lines should be set under water and/or weighted lines should be used to ensure that the baited hooks sink below the foraging depth of sea birds as quickly as possible.
 - For trawl fisheries, the use of exclusion devices should be required in areas and fisheries where high levels of cetacean bycatch are recorded.
 - For gill net fisheries, acoustic alerts or pingers should be required to reduce the bycatch of cetaceans and seabirds. In addition, area and time-based management strategies should be considered to limit the risk of diving seabirds being caught in fishing nets. Furthermore, in areas and at times where bycatch is particularly high, consideration should be given to whether fisheries could use alternative gear, such as fish traps, in which bycatch is not as high.
- 4.34 In all cases, it is likely that these strategies would require the introduction of specific rules by management authorities, rather than voluntary participation. However, it is essential that the fishermen are involved in the process as early as possible and are provided with sufficient information and training to ensure that they understand the need for bycatch mitigation procedures and how to use and maintain any additional equipment required. In addition, it is likely that constant monitoring by independent observers would be required to ensure that the

mitigation measures are implemented correctly and effectively. For example, it may be necessary to regularly inspect acoustic pingers fitted to gill nets to ensure that they remain functional. Similarly, long line vessels may need to be monitored to ensure that they use bird streamers, and that offal is not discharged while setting lines.

- 4.35 However, these measures are primarily aimed at reducing bycatch across entire fisheries, and may be difficult to implement solely within the boundaries of MPAs, particularly smaller ones. In these cases, spatial and/or temporal closures of fisheries using specific gear may prove more efficient in terms of implementation, enforcement and monitoring. For example, banning the use of gill nets entirely or at certain times of day, such as dawn and dusk, close to important colonies of diving seabirds, such as auks, during the breeding season in an MPA may prove easier to implement and monitor than requiring all vessels fishing within that area to use acoustic alerts on their nets. Therefore, when the size of MPAs make implementing and monitoring the technically-based mitigation measures outlined above impractical, spatio-temporal mitigation measures, such as closures of fisheries to particular fishing gear, should be considered as a viable alternative. However, this may need to be combined with vessel monitoring systems (VMS) in order to monitor and police compliance.

Table 4 Summary of management recommendations and when to implement

Management option	Approach		Relative Cost to implement		Evidence for effectiveness		Reference (s)	When to implement	Notes	
	Voluntary participation	Legal enforcement	Low	High	Peer reviewed studies	Anecdotal / grey literature				
LONG LINE FISHERIES										
Avoid discharge of offal while setting lines		✓	✓			Unspecified	Seabirds: Dunn and Steel 2001	At all times	Unlikely to affect catches	
Set lines at at times of day when bycatch is lowest		✓	✓			Unspecified	High	Seabirds: Birdlife 2009; Melvin and Parrish 1999	At all times	
Avoid use of deck lights when setting lines at night		✓	✓				High	Seabirds: Birdlife 2009	At all times	Where this has been tested, this can almost completely eliminate seabird bycatch at almost no cost.
Use of bird streamers		✓	✓			High	High	Seabirds: Dunn and Steel 2001; Melvin and Parrish 1999; Lokkeborg 2000	At all times	Can prove unpopular with fishermen as they can become tangled in the line as it is being set.
Use of underwater setting tubes		✓	✓			Medium to High	Medium to High	Seabirds: Gilman <i>et al.</i> 2003; Lokkeborg 2000; Melvin and Parrish 1999	At all times	
Use of weighted lines		✓	✓			Medium to High		Seabirds: Melvin and Parrish 1999	At all times	

Table continued...

Management option	Approach		Relative Cost to implement		Evidence for effectiveness		Reference (s)	When to implement	Notes
	Voluntary participation	Legal enforcement	Low	High	Peer reviewed studies	Anecdotal / grey literature			
TRAWL FISHERIES									
Use of exclusion devices to prevent cetaceans entering the cod end and escape routes to allow them to exit the nets.		✓		✓	Medium to High	Unspecified	Cetaceans: Northridge and Thomas 2003; Stephenson 2008; Zeeberg 2006	At times of year and locations where bycatch of cetaceans is known to be high.	This technology is still being developed and this may limit its implementation.
GILL NET FISHERIES									
Use of pingers (acoustic alerting devices)		✓		✓	Low to High (depending on study and species)	Low to High (depending on study and species)	Cetaceans: Kaschner, Report To Ascobans; Read 2000; Kraus <i>et al.</i> 1997; Trippel <i>et al.</i> 1999; Gearin <i>et al.</i> 2000; Barlow and Cameron 2003; Carretta <i>et al.</i> 2008; Seabirds: Melvin and Parrish 1999	At all times	This mitigation measure requires that the pingers are functional at all times, meaning that they require regular testing. In addition, a large number may be needed for nets resulting in a high cost.
Limit the setting of nets at dawn and dusk		✓	✓		High		Seabirds: Melvin and Parrish 1999	At times of year or in areas where bycatch is known to be high.	

Table continued...

Management option	Approach		Relative Cost to implement		Evidence for effectiveness		Reference (s)	When to implement	Notes
	Voluntary participation	Legal enforcement	Low	High	Peer reviewed studies	Anecdotal / grey literature			
Limit times of year when nets can be set.		✓	✓		High		Seabirds: Melvin and Parrish 1999	At times of year or in areas where bycatch is known to be high.	Requires a detailed knowledge of when bycatch is highest within a specific area.
Limit areas where nets can be set.		✓	✓		High		Seabirds: Melvin and Parrish 1999	At times of year where bycatch is known to be high in a specific area.	Requires a detailed knowledge of where bycatch is highest.
Use of alternative fishing gear with lower levels of bycatch		✓		✓		Unspecified	Seabirds: Birdlife 2009	At times of year where bycatch is known to be high in a specific area.	There may be considerable resistance to changing from existing fishing methods.
Implimentation of Vessel Monitoring Scheme		✓	✓			Unspecified	Seabirds: Birdlife 2009	VMS shouldbe implimented alongside any spatial or temporal mitigation measures to aid in enforcement and policing.	There may be considerable resistance implimenting VMS from fishermen who do not wish to have their activities monitored.

NOTE:

For evidence of effectiveness, four categories were used:

High: Evidence that bycatch could be reduced by more than 75%;

Medium: Evidence suggests that bycatch could be reduced by between 25% and 50%;

Low: Evidence that bycatch could be reduced by between 1% and 25%; and

Unspecified: Evidence that bycatch was reduced but by an unspecified amount

5 Non-natives and ballast water

Overview of issue

- 5.1 There is growing concern over the impacts of non-native species in the marine environment. If an introduced species becomes established it has the potential to displace native species, change community structure and alter processes such as nutrient cycling and sedimentation (*Molnar et al.* 2008). Economic and health impacts often associated with invasions include depletion of fisheries, fouling which requires removal, blocking of systems such as intake pipes and transmission of diseases. The problem has existed on a global scale for millennia but it has only gained focal attention in the last few decades (McNeely 2001; Gollasch 2002). Here we present the background and policy context to the issue, some of the problems caused by non-native species, the options for management and the gaps that exist between science and policy. To exemplify best practice we present a limited number of case studies demonstrating successful eradication of non-native species. We also review prevention measures as the preferred management option with examples at the national and local level that involve ballast water management plans and systems, awareness raising, long term project commitment and ongoing monitoring.
- 5.2 A general definition of a non-native species is any species of plant or animal that exists and survives outside of its historical or natural range as a result of human activity (Street 2010). A variety of terms are used to describe non-native species such as 'alien', 'exotic' or 'non-indigenous' species and the exact definitions differ slightly between organisations. In the UK the Joint Nature Conservation Committee (JNCC) defines a non-native species as: 'any species or race [of animal or plant] that does not occur naturally in an area'. Specifically an invasive non-native species (INNS) is regarded as one which has the ability to spread rapidly and become dominant in an area or ecosystem, and which causes unwanted ecological (for example, loss of biodiversity) or societal effects (for example, effects on human health). The CBD defines INNS as: 'A [non-native] species whose introduction and/or spread threatens biological diversity'. For the purposes of this assessment we will use the term 'Invasive non-native species (INNS)' as we are making recommendations for management within protected sites.

Policy context

- 5.3 The UK Government is obliged to take action to control INNS under several international agreements. These include the UN Convention on Biological Diversity (CBD) and the Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention, 1979). The Wildlife and Countryside Act 1981, which applies to the waters around Great Britain, states that it is an offence to release (or allow to escape) into the wild any kind of non-native animal, except under licence. The GB Invasive Non-Native Species Framework Strategy was launched by Defra, the Scottish Government and the Welsh Assembly Government in May 2008 (Defra 2008a). The strategy was developed in the context of the European Strategy on Invasive Alien Species developed in 2003 under the Bern Convention (Genovesi & Shine 2004). The UK strategy is based on a preventative approach following the CBD three stage hierarchy:
1. Prevention of entry of invasive non-native species.
 2. Early eradication: actions should be undertaken to prevent the establishment and spread of alien species.
 3. Control and containment to mitigate the effects once a species has become established.

Preventing the arrival of new potentially invasive species is prioritised in the hierarchy and is widely accepted as being the most cost effective and desirable approach over eradication or

control in the long term. The UK strategy aims to minimise the risks posed and reduce the negative impacts caused by INNS in Great Britain. However, the GB Strategy acknowledges that with the increasingly global extent of trade, introduction pathways are broadening and a completely watertight system is not achievable. Therefore the UK's approach is through a 'robust risk assessment with effective horizon scanning to enable the effective targeting of resources to address the most serious risks'. The GB Non-native Species Secretariat (GBNNS) co-ordinates the GB response to INNS and is currently building a database for research (and management) of non-native species²⁶.

- 5.4 It is important to recognise that to date, no marine INNS has ever been successfully eradicated in UK waters (Barton & Heard 2004). The spread of non-native species presents a widespread issue across UK EMS and the nature of the issue combined with the lack of precise worked examples of management means that a relatively low level of confidence is given to estimating the true risk of an invasion. The recent European Marine Site Risk Review (Coyle & Wiggins 2010) identified non-natives as a medium risk level with the level of harm potential uncertain and limited management in place. The fact that INNS affect such a significant number of EMS means that they require additional research into the specific measures available. This section aims to provide a better understanding of the issue and management options as exemplified by existing plans and proven techniques around the UK EMS and further afield.

Characteristics of INNS and their management

- 5.5 The process by which INNS establish themselves can be divided into four phases: 1) Arrival- Dispersal of individuals to a new recipient region. 2) Establishment- The non-native population persists by means of local reproduction and recruitment, may also involve local spread. 3) Integration- The new invader and the recipient region species respond to each other ecologically and evolutionarily (for example, competition, new host, hybridisation). However, if the invader colonises a new habitat then integration may not necessarily occur. 4) Spread- The invader increases its geographical distribution within the recipient region.
- 5.6 In terms of arrival there are two main mechanisms for INNS: natural expansion where physical or biological barriers are no longer present and anthropogenic origin which includes deliberate or accidental releases or via human mediated transport (for example, hull fouling, ballast water, accidental transfer via fishing and aquaculture). Ballast water transfer has historically and still continues to be the most significant vector for the transfer of INNS (Molnar *et al.* 2008). A review of prevention measures or 'pre-border' controls using ballast water treatment options and current legislation is given here along with examples of enforced legislation at the site level whereby procedures and standards of ballast treatment are set for entry into a particular port or harbour.
- 5.7 There is increasing evidence of the transfer of non-native species from recreational craft through hull fouling particularly since the TBT ban (Griffith *et al.* 2009; Acosta & Forrest 2009). Whilst this may present a significant route for INNS arrival, there is a limit to the effectiveness of measures for managing transfer via recreational craft as they are not subject to the same legislation as commercial vessels as directed by the International Maritime Organisation (IMO). Therefore it is becoming increasingly important to raise awareness amongst local communities and hence encourage better practice with regards boat cleaning and reporting. Furthermore eradication or control programmes often rely on public support, for example in allowing access to land. Where the public are well-informed of the issues surrounding INNS and the problems they cause, they are more supportive of eradication and control programmes (Bremner & Park 2007).
- 5.8 It is widely known that non-native species can threaten ecosystem functions, public health and economic activities such as tourism, fishing or aquaculture. In terms of preventing or minimising the arrival of invasive species in the marine environment, only commercial activities (shipping, fishing and aquaculture) can be specifically targeted for prevention through national legislation and in some cases, site based or regional management programmes. The non-legislative

²⁶ <https://secure.fera.defra.gov.uk/nonnativespecies/home/index.cfm>

approach can also be effective through partnership working which pulls upon local action groups, co-ordinated control by landowners and monitoring by conservation bodies (Defra 2008b).

- 5.9 The eradication of INNS or 'post-border control' is a more targeted issue and is therefore expected to be implemented through the conservation of the designated interest feature for each site but only where success is likely with the available funds. The examples provided here relate to the management measures that can be specifically applied by relevant/competent authorities or management schemes to either detect and monitor invasive species or to control and/or eradicate established INNS. We also describe higher level legislative arrangements for prevention measures which require government and industry level commitment.

Options to manage

- 5.10 In view of the difficulties associated with eradication or long-term control, neither of which may be effective and both of which are expensive, prevention is recognised as the most appropriate and cheapest policy intervention in stemming the rise of marine INNS and their consequences. Here we provide an overview of the options to manage invasive non-native species with a detailed review of ballast water management techniques followed by brief introductions to the prevention through controls on aquaculture and biofouling, control of existing non-native species, eradication of species and awareness raising programmes. The overview of options is followed by a summary table of examples of management and outcomes.

Ballast water management

- 5.11 Shipping transports over 80% of the world's commodities. Up to ten billion tonnes of shipping ballast water is estimated to be carried around the world each year (Rigby, Hallegraef, & Sutton 1999), although some authors suggest lower levels (Endresen *et al.* 2004). Ships' ballast water and the associated sediments have been implicated in the world-wide transport and introduction of non-native marine organisms (Carlton & Geller 1993, Molnar *et al.* 2008). Internationally there are some 10,000 species estimated to be in transit around the world in ballast water (Bax *et al.* 2003), and once established, non-indigenous aquatic organisms may cause serious ecological, economic and public health problems (Carlton & Geller 1993; Ruiz *et al.* 2000).
- 5.12 The problem arises from water taken from shallow waters in ports and used to balance cargo ships across the oceans and then released into new harbours and ports. The water that is transported often contains many different species including pathogens, algae and plankton. If these species possess the necessary generalist traits and can survive the conditions within the ballast tanks then they may colonise new areas often displacing the native species.
- 5.13 Ballast water management is a complex issue raising the challenge of merging international regulations, ship's specific configurations along with ecological conservation (Endresen *et al.* 2004). The issue has been recognised in European and UK government policy (Defra 2002, 2008a; Genovesi & Shine 2004), but effective solutions are a long way off (Bax *et al.* 2003; Genovesi 2005; Williams & Grosholz 2008).
- 5.14 Options for managing the impacts include heating the water in ballast tanks (Rigby *et al.* 1999); deoxygenation of ballast water (Tamburri, Wasson, & Matsuda 2002); flushing of tanks (Eames *et al.* 2008); ozone treatment (Wright *et al.* 2010) and UV treatment (Kazumi 2007). However, concerns have been expressed regarding residual environmental polluting components, health and safety problems related to storage of chemicals and compatibility with cargo carried on board as well as direct and indirect handling of chemicals by crew members.
- 5.15 In response to the threats posed by invasive marine species, the United Nations Conference held in Rio de Janeiro in 1992, in its Agenda 21 called on the International Maritime Organization (IMO) and other international bodies to take action to address the transfer of harmful organisms by ships. The IMO Convention for the Control and Management of Ship's Ballast Water and Sediments was adopted in February 2004 (IMO 2004). Main measures required by the

Convention are: provision of ballast water treatment to meet ballast water performance standards after 2014/2016 for existing ships or from 2009 for new ships; provision of sediment reception facilities where cleaning or repair of ballast water tanks takes place; a commitment to carry out research on the development of treatment technologies and the impacts on non-indigenous species; and enforcement through survey, certification and inspection.

- 5.16 The Convention provides two ballast water discharge performance standards for the industry – the first providing a standard for ballast water exchange and the second based on ballast water treatment. These are set out below:
- D1 Standard - Ballast Water Exchange (at least 95% volumetric exchange) or if using the pump through method - pumping through three times the volume of each tank.
 - D2 Standard - Ballast Water Treatment systems approved by the Administration which treat ballast water to an efficacy of:
 - less than 10 viable organisms per m³ >50 micrometres in minimum dimension; and
 - less than 10 viable organisms per millilitre < 50 micrometres in minimum dimension and >10 micrometers in minimum dimension.
- 5.17 The GEF/UNDP/IMO Global Ballast Water Management Programme (GloBallast) is assisting developing countries to; reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water, implement the IMO ballast water Guidelines and prepare for the new IMO ballast water Convention²⁷.
- 5.18 The Convention will enter into force 12 months after ratification by 30 States, representing 35% of world merchant shipping tonnage. As of 2010 the Convention had not been sufficiently ratified to enter into force. However considerable effort is being made by administrators, industry stakeholders, legislating bodies and research laboratories to develop and test ballast water treatment technologies (Veldhuis *et al.* 2010a). One such initiative is the Ballast Water Opportunity programme, a European Regional Development Fund programme of the seven countries bordering the North Sea²⁸.
- 5.19 Around the world the level of organisation and scale at which it occurs varies dramatically. Despite the extensive and comprehensive approach to a number of conservation and environmental protection issues, currently there is no EU wide ballast water management system in place (David & Gollasch 2008). In advance of IMO Convention entry into force a number of locations (waterway regions, geographic regions and countries) have developed their own extensive systems. Indeed these systems span not only the pre-border control measures (ballast water management and monitoring) but they also incorporate education, industry communication and also invasion planning alongside continued control and eradication projects (post border measures).

Ballast water treatment methods

- 5.20 Here we provide an overview of the existing and emerging ballast water management measures and their effectiveness. Details of the following measures are provided:
- Exchanging ballast water at sea.
 - Ballastless ships.
 - Mechanical treatment methods such as filtration and separation.
 - Physical treatment methods such as sterilisation by ozone, ultra-violet light, electric currents and heat treatment.

²⁷ <http://globallast.imo.org/>

²⁸ www.NorthSeaBallast.eu

- Chemical treatment methods such adding biocides to ballast water to kill organisms.
- Onshore treatment stations.
- Various combinations of the above.

Exchanging ballast water at sea

- 5.21 These can include simple concepts such as pumping water in and out of ballast tanks at speed to more complex solutions that aim to flush out residual sediment. Despite the fact that even pumps result in a considerable mortality of organisms, on average 90%, the abundance of remaining organisms is still well above the IMO D2-Standard for residual numbers (Veldhuis *et al.* 2010b). It would require the overall efficacy to be equal that of the filling and emptying the ballast water tank three times in a row. This takes considerable time and many ships will pass through different biogeographical regions within this time span.
- 5.22 The IMO guidelines recommend exchanging ballast water at sea, replacing it with 'clean' open ocean water. Any marine species taken on at the source port are less likely to survive in the open ocean, where environmental conditions are different from coastal and port waters. Re-ballasting at sea is currently the best available measure to reduce the risk of transfer of aquatic organisms, however it is subject to limitations in order to maintain the safety of the ship, its crew and cargo. Even when it is fully implemented it is less than 100% effective in removing organisms from ballast water. There is evidence that re-ballasting at sea may contribute to the wider dispersal of invasive species from oceanic to shallow areas down-stream of re-ballasting areas due to ocean currents and wind and wave dispersion.
- 5.23 Three methods are considered as appropriate to carry out exchange of ballast water at sea: (a) empty/refill, (b) continuous flow-through of ballast water and (c) dilution method (continuous flushing) (Gollasch 2002). The efficiency of water exchange will vary between ships and will largely depend on the ballast tank design, safety requirements, sea conditions, volume of water pumped and the pumping system design. The movement of ballast water in the tanks affects the stability of the ship due to a change in forces acting upon the hull. Therefore ballast water operations can have a strong effect on the stability and manoeuvrability of the vessel and must not compromise safety.
- 5.24 When considering the introduction of a water exchange system it is important to note that most organisms tend to concentrate near the bottom of the ballast tank where the sediment has settled or on the tank walls. Indeed there is evidence that phytoplankton and zooplankton from the source port can remain in the bottom layer of the tank after exchange (Taylor & Bruce 2000).
- 5.25 Studies have proven that three times volumetric exchange of ballast water results in approximately 95% removal of viable algal cells and approximately 60% removal of zooplankton organisms (Gollasch 2002). However, a 90-100% reduction of source port taxa was achieved following the flow through method (Taylor & Bruce 2000). A review of the effectiveness of ballast exchange measures is provided in Gollasch (2002).

Ballastless ships

- 5.26 The most comprehensive solution to the problem would be to have ballastless ships such as the Variable Buoyancy Ship concept²⁹. Removing the need for ballast removes the risk of carrying INNS in ballast water. However, there are several issues with ballastless ships including the issue of sediment in the tanks which will have to be periodically cleaned. It would also require a complete redesign of ships, port facilities and associated industries. This type of innovation would be expensive and would take considerable time before it would be globally implemented (Veldhuis *et al.* 2010a).

²⁹ www.tos.nl/nl/nieuws/2010/4/ballast-free_ship_design_saves_on_fuel.2485.htm

Onshore treatment stations

5.27 There have been several studies looking into the feasibility of onshore ballast treatment (Brown & Caldwell; Donner 2010; Pereira, Botter, & Brinati 2010). Currently there are three treatment units for ballast water around the world, responsible for separating oil from ballast water: Valdez in Alaska, Sullom Voe and Scapa Flow in Scotland (Pereira *et al.* 2010). Treating ballast water at onshore treatment stations for INNS is an attractive option particularly for small harbours with only a limited amount of short sea traffic. The reception facility would need to have an effective method of treatment and recycling of the water for it to be returned to the harbour or departing ships. Onshore solutions require that vessels are capable of linking in to the system and would therefore require substantial investment and development of facilities. The idea of onshore ballast treatment does not take into account that ships will de-ballast before entering the shallow waters of ports to pass barriers such as sills. A disused barge or tanker could be used to receive ballast water at the same time as cargo is exchanged such that time is not lost in port (Gollasch 2002) or to meet vessels outside the shallow water areas. Indeed it has been shown that it is possible to collect, store and treat ballast water on land without compromising the port operation (Pereira *et al.* 2010).

Filtration and physical separation

5.28 Filtration is an environmentally sound technique for the control of ballast water organisms that works by capturing organisms and particles as water passes through a porous screen, filtration medium or stacks of special grooved disks (Lloyd's Register 2010). Filtration is relatively expensive, costing an estimated \$0.06–0.19 per ton of ballast water (including capital cost) (Perakis & Yang 2003). Whilst lacking any negative environmental side effects, smaller organisms are more difficult to remove by mechanical filtration. Testing of mechanical techniques indicate varying efficiency (up to 99% removal of larger zooplankton and up to 94% removal of phytoplankton and smaller zooplankton, Gollasch 2002). Filtration methods do not remove smaller microorganisms, bacteria, viruses and dinoflagellate cysts from ballast water and secondary treatment is required to inactivate microorganisms.

5.29 The process of physical separation is based on the addition of flocculating detergents to enhance sedimentation rates of particles by increasing their size and therefore their weight. On discharge care must be taken to prevent disturbance of the sediment layer. Over time the accumulation of sediments will require a more frequent cleaning of ballast water tanks. The accumulation of sediment may become a disadvantage as more sediment means less cargo hold.

Heat treatment

5.30 The use of heat for treating organisms in ballast water is potentially cost effective. One proposed method uses waste heat from the ships engine cooling system and exhaust to treat ballast water, which significantly reduces costs (Perkovic *et al.* 2001).

UV radiation

5.31 Three wavelength bands are of interest for the control of organisms; gamma ray, microwave and ultra-violet (Gregg *et al.* 2009). A triple effect synergistic ballast water treatment system SeaLifeCare using Microwaves, UV and Ozone technology has been found to effectively and economically kill pathogenic microorganisms in air, water, liquids, sediments and sludge (Taube 2010). However, only preliminary testing has been undertaken and the high capital and operational costs required by gamma ray and microwave technology may be prohibitive (Gregg *et al.* 2009).

Chemical treatment methods

5.32 A variety of chemical disinfectants and biocidal agents are commercially available for ballast water treatment that have been used successfully for many years in land-based treatment facilities. The use of chemical treatment for ballast water is more complicated than in land based systems as the precise requirements of each tank will be different and the treated ballast water

will need to be discharged which has associated environmental issues. The long-term accumulating effects of chemicals are largely unknown and there may be associated health and safety risks to crew members and compatibility with cargo. The most common way to apply chemical treatment is during ballast water uptake although in cases where ballast water in cargo holds has been treated, the tanks would need to be cleaned to a high standard before cargo could be loaded thus increasing the cost of the operation. Overall the costs are thought to be comparable with other options (Rigby & Taylor 2001). Suggested methods of chemical control include ozone, hydrogen peroxide, chlorination, electrolytically generated metal ions, de-oxygenation, pH and salinity adjustment as well as the use of organic biocides.

- 5.33 There are around 25 systems based on chemical, physio-chemical and physical mechanisms in various stages of the administrative evaluation process, as of July 2009 eight systems had been given IMO final approval³⁰ (Veldhuis *et al.* 2010a). These include the use of chemicals- two of which are based on a chlorine related active substance (Ecochlor and BalPure) and one using an organic acid H₂O₂ mixture (PERACLEAN Ocean). In a recent study comparing treatments PERACLEAN Ocean was the most effective biocide against bacteria causing >90% mortality at 20mg/l (La Carbona *et al.* 2010).
- 5.34 Biological control is another option for in-tank treatment for specific INNS. This has been shown to work well on the phytoplankton *Phaeocystis globosa* and its bloom controlling virus in the North Sea (Brussaard, Kuipers, & Veldhuis 2005; Veldhuis *et al.* 2006).

Summary

- 5.35 With respect to ballast water management methods, in-tank treatments have the main advantage of not being immediately linked to an active treatment during intake or discharge of ballast water but can switch on at any convenient moment during a voyage. Further, since there are no major changes in the water volume or flow, the stability of the ship will also not be affected. However ballast water exchange at sea is currently a widely used method and is recommended in the IMO convention D-2 standard.
- 5.36 All ballast water management techniques currently require significant further research effort and in some cases investment into port facilities and integration into recognised legislative structures (for example, full ratification and adherence to the IMO Convention). One of the problems encountered in the effort to stop ballast water invasions is that despite the IMO approvals and the Globallast (Global Ballast Water Management Programme) initiative³¹ there are currently no internationally agreed and approved performance standards or evaluation system for the formal acceptance of any new techniques that are developed. In addition, many groups are working in isolation from each other, and there are no formal mechanisms in place to ensure effective lines of communication between the shipping community, governments and ship designers, builders and owners (Bax *et al.* 2001). This has led to a level of confusion and lack of confidence among the technology developers as well as ship owners.

Prevention through controls on aquaculture and biofouling

- 5.37 Global aquaculture production more than doubled during the decade prior to 2001 and provides one third of seafood consumed worldwide (Naylor, Williams, & Strong 2001). The opportunities for profits from commercial harvesting of non-native species are high resulting in very few of the widespread cultured species being native to their farmed sites. Given the nature of the aquatic system and dispersal mechanisms, chances of escape and establishment can be high. The impacts from species transferred via the aquaculture industry are likely to be more acute as the species have been selected and bred to thrive in their farmed environment. The impacts include ecological and environmental effects on native species and habitats, genetic impacts from mixing of farmed and wild stocks and the transfer of pathogens and parasites to native species (ICES

³⁰ www.intertanko.com/templates/intertanko/issue.aspx?id=43797

³¹ <http://globallast.imo.org/>

2005). Current options to manage established INNS in the context of aquaculture as a pathway for introduction are the same as those described more generally below (control and eradication). Given the growth and globalisation of the industry, there are legislative controls and recommendations in place which promote good practice and reduce the chances of non-native establishment (ICES, 2005). The measures focus on effective procedures for risk assessment, auditing of stock movements, monitoring and good husbandry and aquaculture practices including control and prevention of biofouling and rapid co-ordinated action where an invasion is identified.

- 5.38 Biofouling affects all commercial and recreational users of the marine environment and presents a significant pathway for the introduction of non-native species. Species which are transported via the hulls of ships can become established under the correct conditions at their destination port and impact negatively upon the local environment. Control of introductions via this route will differ between commercial and recreational vessels with the latter being unenforceable and the former being supported by International Maritime Organisation (IMO) guidelines³². Whilst global commercial shipping and petroleum exploration presents a pathway for foreign introductions, recreational user numbers are higher and more often encountered in Marine Protected Areas whilst commercial fishing boats range relatively long distances and are a relatively common occurrence in MPAs. Recreational craft will most likely operate shorter journeys but they have the potential to move INNS introduced via another route between adjacent ports (over land and in the water) therefore it is important that owners act responsibly with respect to biofouling and keep vessels and equipment clean. Fortunately the economic and performance impact of hull fouling means that recreational users benefit from removing fouled material in dry docks and using anti-fouling systems. Likewise, managers of marinas and ports need to ensure that their equipment is cleaned routinely and consideration should be given to the disposal of the removed material.

Control of existing non-native populations

- 5.39 Where successful establishment of an INNS has occurred and there are significant implications for the ecology of the site, local economy or amenity then the control of the species may be optimal, particularly if eradication is unrealistic (see criteria below). In all cases of intervention a clear end point must be defined for the management to commence with the knowledge that further spread can be avoided. The chances of controlling the spread of a species will be improved if the species is highly conspicuous, large, with high habitat specificity, short dispersal range rather than small and cryptic with a long planktonic larval stage (Piola *et al.* 2009). Furthermore the characteristics of the site will dictate the chances of containment such that an accessible site with clear, shallow and calm waters will provide better chances than locations with complex substrates, rough conditions and poor visibility (Forrest, Taylor, & Sinner 2006). Indeed understanding the natural barriers (oceanographic, environmental or habitat constraints to dispersal) to the spread of the species will greatly improve the chances of containment (Forrest, Gardner, & Taylor 2009).

Eradication of species

- 5.40 Due to the nature of the marine environment, successful eradication of INNS is rarely accomplished and indeed has never been fully achieved in European waters (Williams & Grosholz 2008). Therefore attempts at eradication often revert to control programmes (see above) and should only be considered when the chances of success are high.
- 5.41 Methods employed in eradication include physical removal by hand in cases of small scale invasions, removal with machinery (including mowing, suction, spraying), treatment with chemicals, heat treatment, encapsulation and smothering methods, dessication (dry docking) and freshwater treatment (see Piola *et al.* (2009) for a summary).

³² www.imo.org/OurWork/Environment/Anti-foulingSystems/Documents/FOULING2003.pdf

Awareness raising programmes

- 5.42 There is increasing evidence that awareness raising, monitoring and efficient public reporting systems can be effective and should be publicised where possible. In cases where there is an economic or amenity impact of INNS it may be easier to gain support from the local community. With community interest and awareness it is easier to implement management measures which impact upon recreational users it also improves lines of communication for access to sites from private landowners. It is also possible to gather data and with a co-ordinated reporting system then managers and authorities can act sooner if a species is detected.
- 5.43 With all these methods there are cost implications and a requirement for long term commitment, particularly in the case of a widespread invasion. There are also considerations to be given to the potential physical and ecological damage to the site and indirectly to other species.

Table 5 Summary table of examples of management approaches

Management option	Mechanism	Cost	Examples	Notes
1 PREVENTION				
1a International ballast water legislation	Ballast control measures - IMO Convention standards (IMO 2004).	N/A	Not yet in force but see below. A summary of emerging and existing water treatment methods and their safety and efficacy is provided in Bowmer & Linders (2010); Veldhuis <i>et al.</i> (2010); Lloyd's Register (2010).	
	More stringent operational procedures than the IMO convention, for example, National Ballast Water Management Strategy or a site plan due to the nature conservation value and physical features of the site.	N/A	Voluntary regional ballast water management framework in the North Sea (OSPAR and HELCOM regions) ^{1,2} in advance of IMO convention enforcement. Orkney Islands 'Special Ballast Management Arrangements'. Discharge is only permitted through the ballast water reception and treatment facilities that are provided at the Flotta Oil terminal ³ . Great Lakes Seaway Ballast Water Working Group (BWWG) ⁴ . Caspian Sea appraisal of ballast water management options indicate land-based reception and treatment facilities would be optimal (Hilliard & Kazansky 2006).	
1b Anti fouling treatments	A variety of non-TBT methods to prevent hull fouling are in use in commercial and recreational vessels.	N/A	Copper based, tin free, non stick, natural (for example, enzymes and hydrophilic surfaces), electrical current, prickly surfaces. See IMO guidelines and research for more detail ⁵ .	

Table continued...

Management option	Mechanism	Cost	Examples	Notes
	Code of practice for biofouling removal and antifouling treatment.		The Australia and New Zealand Environment and Conservation Council promote a Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance ⁶ .	
1c Aquaculture controls	Code of practice, licensing and inspection.	N/A	<p>ICES Code of Practice on the Introductions and Transfers of Marine Organisms (2005) sets out recommended procedures and practices to diminish the risks of detrimental effects from the intentional introduction and transfer of marine (including brackish water) organisms.</p> <p>In Northern Ireland the Loughs Agencies are the responsible authorities to implement the EC Regulation on the use of alien and locally absent species in aquaculture and the Aquatic Animal Health Regulations. These regulations control the movement of shellfish into and within Northern Ireland and are subject to inspection by Fisheries Inspectors⁷.</p> <p>In Ireland a voluntary code of practice has been established via the Invasive Species Ireland project⁸. Recommendations include: Establishment of an effective risk assessment protocol, 'inspect-remove-dispose-report' approach, audit of all activities to monitor species movements, biofouling control on equipment, prevention of fouling on vessels and moorings, de-fouling prior to journeys, removal of unused equipment and stock, use of triploid <i>C. gigas</i> (for example, Strangford Lough) and to be aware of developments via the Invasive Species Ireland Project.</p>	

Table continued...

Management option	Mechanism	Cost	Examples	Notes
1d Species planning	Put in place clear species action plans for current and potential INNS.	N/A	Chinese Mitten Crab- Species Action Plan for Ireland (Kelly & Maguire 2009) details a programme of traps, trawling, physical and electric barriers to prevent spread.	Limited success of planned methods.
		A\$10.96 million per year for all species plans	National Control Plan for <i>Undaria pinnatifida</i> through the Australian National Introduced Marine Pests Coordination Group (NIMPCG). The plan has three components: prevention, emergency response and ongoing monitoring and control.	
1e In water cleaning		N/A	Mainly used on small recreational vessels by hand or in some cases on larger vessels using diver operated equipment where a high risk has been identified (Hopkins & Forrest 2008). Technology developed to capture material during cleaning (Woods <i>et al.</i> 2007).	Re-infection risk
1f Monitoring/ research	Baseline surveys and monitoring.	N/A	The Australian Centre for Research on Introduced Marine Pests (CRIMP) developed standard IAS survey protocols in 1996. These have been widely tested with 34 Australian ports surveyed since 1996. The protocols were revised and republished in 2001 (Hewitt & Martin 2001).	
		N/A	The Trilateral Monitoring and Assessment Program (TMAP) to monitor the extent of Pacific Oyster populations and develop research (Nehring 2006).	Regional monitoring and research can underpin successful control elsewhere and for other species in the future.

Table continued...

Management option	Mechanism	Cost	Examples	Notes
1g Community engagement	Ongoing monitoring undertaken by the local community to provide data, act as an early warning system and also to raise awareness of the issues and prevention methods for recreational vessels.	N/A	Community engagement and monitoring projects in the UK co-ordinated by the Marine Aliens II Consortium ⁹ . Australia: Detection Kits for community-based monitoring of introduced marine pests (Sutton & Hewitt, 2004).	
1h Assessment of vector and pathway risks	Foreign and national shipping movements.	N/A	Australian Ballast Water Decision Support System (BWDSS) for assessing the risk within each tank based on vessel origin thus enabling ships to manage their ballast water en-route. Described in Tamelander <i>et al.</i> (2010). <i>Mytilopsis adamsi</i> invasion in Darwin (Northern Territory, Australia) where a vessel tracking database was established specifically to identify at risk vessels for hull cleaning treatment (Bax <i>et al.</i> 2002). Tracking high risk recreational vessels for cleaning as part of the <i>Didemnum vexillum</i> eradication in New Zealand (Sinner & Coutts 2003).	
2 CONTROL/ ERADICATION				
2a Integrated Pest Management approach	Combined physical removal with herbicide treatment.	\$1.17M (1999–00) and \$718K (2000–01)	<i>Spartina alterniflora</i> (control only). In Washington state and federal funds were used for eradication programs; (including \$200K mowing machine; \$60K two airboats) (Murphy, Taylor, & Phillips 2007a). The programme involves treatment with Imazapyr.	Non target species and habitats effects.

Table continued...

Management option	Mechanism	Cost	Examples	Notes
			San Francisco California Coastal Conservancy's Invasive Spartina Project ¹⁰ .	Ongoing project, expensive with long-term commitment, research, monitoring and stakeholder engagement (Murphy, Taylor, & Phillips 2007b)(Murphy <i>et al.</i> 2007a)(Murphy <i>et al.</i> 2007a)(Murphy <i>et al.</i> 2007a)(Murphy <i>et al.</i> 2007a)(Murphy <i>et al.</i> 2007a).
2a Physical	Encapsulation with impermeable PVC wrapping.	<NZ\$200K	<i>Didemnum vexillum</i> eradication on wharf piles (Pannell & Coutts 2007; Coutts & Forrest 2007).	Reduced non target species and habitats effects.
		N/A	<i>Undaria pinnatifida</i> eradication on wharf piles through sterilisation using bromine compounds within PVC sleeves (Stuart 2002).	Reduced non target species and habitats effects.
	Jute matting	N/A	Successfully used for eradication of <i>Caulerpa taxifolia</i> on small areas of seabed (Glasby, Creese, & Gibson 2005).	Cheaper and more environmentally friendly than PVC.
			Jute matting combined with absorbed copper sulphate for treatment of <i>Caulerpa taxifolia</i> in the Mediterranean (Uchimura <i>et al.</i> 2000).	
	Smothering with dredge spoil.	N/A	Trapping and creation of anoxic conditions for the starfish <i>Asterias forbesi</i> (Loosanoff 1961).	Non target species and habitats effects.
	Hull cleaning methods in response to species detection.	N/A	Risks can be managed through the installation of barriers such as filters and containment tanks, to prevent defouled material re-entering the marine environment (Hopkins & Forrest 2008). Alternatively hull cleaning can take place in a dry dock through desiccation (Piola <i>et al.</i> 2009).	

Table continued...

Management option	Mechanism	Cost	Examples	Notes
	Removal	N/A	South Australia Pacific Oyster removal ¹¹ . A four year project removing wild oysters in the Ceduna and Coffin Bay area involving local fisheries stakeholders (finished in 2010).	Successful due to industry support and appropriate legislation.
		Saving A\$90K per year	Targeted approach to remove localised wild populations of Pacific Oysters in New South Wales Estuaries ¹² .	Used diverse stakeholder and community workforce.
			Oosterschelde, Wadden Sea: Pacific oysters have been locally removed efficiently even in dense reefs, however, the effort required to do so was considerable (20 days per ha) (Wijsman <i>et al.</i> 2006).	
		>US\$7.7M (6 year)	<i>Caulerpa taxifolia</i> . Southern California control and monitoring– examples from (Carlton 2001; Williams & Grosholz 2008).	Non target species and habitats effects.
		N/A	<i>Spartina alterniflora</i> (control only) Tasmania (Kriwoken & Hedge 2000).	Non target species and habitats effects.
		N/A	In 1951 a population of more than 60 adult Japanese oyster drills (<i>Thais clavigera</i>) were removed by hand from Ladysmith Harbour, Canada (Carlton 2001).	Small scale, early response.
		US\$4680	<i>Ascophyllum nodosum</i> successful eradication San Francisco Bay, California (Miller <i>et al.</i> 2004).	Small scale, early response.
		N/A	<i>Littorina littorea</i> removal at the non-established phase of invasion. California, USA- results to be published (Chang <i>et al.</i> 2011). San Francisco Estuary Partnership project ¹³ .	

Table continued...

Management option	Mechanism	Cost	Examples	Notes
	Suction dredging	€54-300K per year	<i>Crepidula fornicata</i> – Large scale (~30,000t/yr) industrial collection by suction dredge in northern France (CREOCEAN 2006).	Non target species and habitats effects.
		N/A	Collection of <i>C. fornicata</i> by fisherman and harbour authority vessels in the Fal Estuary as a means of control (Fitzgerald 2007).	
	Harrowing	N/A	<i>C. fornicata</i> destruction by chain harrowing to break up groups (“chains”) of individuals to reduce breeding success and increase predation but this may actually increase breeding success (Fitzgerald 2007).	Non target species and habitats effects.
	Heat treatment	NZ\$2,923,500	Successful heat treatment to 70°C on a sunken trawler to kill the invasive seaweed <i>Undaria pinnatifida</i> in the Chatham Islands, New Zealand (Wotton <i>et al.</i> 2004). Impractical in large water bodies and can be damaging to non-target species.	Expensive and restricted to enclosed water bodies.
2b Chemical	Herbicide control (unsuccessful eradication).	N/A	<i>Spartina anglica</i> – Northern Ireland (Hammond & Cooper 2004).	Ongoing control.
	Chlorine and Copper Sulphate eradication.	A\$2.2 million	Treatment within a marina of invasive freshwater mussel <i>Mytilopsis adamsi</i> (Ferguson 2000; Bax <i>et al.</i> 2002).	Successful eradication in enclosed marinas.
	Acetic acid (4%) with encapsulation.	N/A	Complete mortality of the Stalked Sea Squirt (<i>Styela clava</i>) from pontoons and marina structures (Coutts & Forrest 2005).	For use on small scale infestations.
	Treatment with salt (NaCl).	Expensive	Application of salt to small isolated coastal water bodies to control <i>Caulerpa taxifolia</i> in New South Wales (Hilliard 1999; Glasby <i>et al.</i> 2005).	Small scale, early response, expensive technique.

Table continued...

Management option	Mechanism	Cost	Examples	Notes
	Treatment with lime.	N/A	Lime is known to corrode calcium carbonate therefore acting as a suitable control substance when targeting crustacean, for example, <i>Asterias amurens</i> (McEnulty <i>et al.</i> 2001).	
2c Biological	Removal of the most susceptible native host.	Several US\$K	Removal of the most highly susceptible host of an invasive sabellid polychaete (<i>Terebrasabella heterouncinata</i>) (Culver & Kuris 2000).	Successful eradication.
	Use of semiochemicals.		This management option is currently in development.	Research detailed in (Kjerfve 2010).
2d Genetic	Breeding methods to reduce fertility in introduced farmed species.	N/A	Planned UK protocol: Cultivation of triploid Pacific oysters to significantly reduce larval dispersal from aquaculture areas ¹⁴ . Risk based approach to diploid/triploid cultivation combined with monitoring of reproductive state of farmed stock and temperature monitoring to predict breeding status.	Untested

Notes:

¹ www.northseaballast.eu

² www.intertanko.com/upload/Tim/HELCOM%20Draft%20Recommendation%20on%20Invasive%20Species.pdf

³ www.orkneyharbours.com/ballast_water_management.asp

⁴ www.d9publicaffairs.com/posted/443/2009_Great_Lakes_Seaway_Ballast_Water_Working_Group_Report_Final.475699.pdf

⁵ www.imo.org/OurWork/Environment/Anti-foulingSystems/Documents/FOULING2003.pdf

⁶ www.environment.gov.au/coasts/pollution/antifouling/code/pubs/code.pdf

⁷ www.doeni.gov.uk/niea/3_invasive_alien_species.pdf

⁸ www.invasivespeciesireland.com/wp-content/uploads/2010/07/Aquaculture_CoP.pdf

⁹ www.marlin.ac.uk/marine_alien/

¹⁰ www.spartina.org/index.htm

¹¹ www.pir.sa.gov.au/pirsa/media_list/biosecurity/aquatics/sa_success_controlling_wild_oysters

¹² www.coastalconference.com/2010/papers2010/Jillian%20Keating%20ful%20paper.pdf

¹³ www.sfestuary.org/projects/detail.php?projectID=19

¹⁴ www.fish.wa.gov.au/docs/pub/IMPMarine/IMPMarinePage08a.php?0506

Case studies

5.44 Here we provide further details on a selection of case studies under each broad management area of strategic prevention measures, ballast water management, control and eradication.

Strategic approach

Australian National System for the prevention and management of marine pest incursions

5.45 The National System is a suite of measures aimed at preventing marine pests from arriving in Australian waters or spreading to new areas, providing a coordinated emergency response should a new pest arrive in Australian waters and controlling and managing existing marine pests where eradication is not feasible³³.

5.46 The National System has three major aspects:

- Prevention – systems to reduce the risk of introduction and spread of marine pests, including management arrangements for ballast water and biofouling.
- Emergency management – a national response mechanism to control or eradicate pests that do arrive.
- Ongoing management and control – management of existing marine pests where eradication is not feasible.

5.47 There are also four supporting components:

- Monitoring – ongoing national program to provide early detection of new pests.
- Communication – industry and community awareness and education, for example, Detection Kits for community-based monitoring of introduced marine pests (Sutton & Hewitt, 2004).
- Research and development – targeted research to assist with development of policy and management measures.
- Evaluation and review – evaluating the effectiveness of the National System.

5.48 The measures and arrangements under the National System are being implemented by the National Introduced Marine Pests Coordination Group (NIMPCG) which consists of representatives of each of the governments, industry and environmental partners of the National System. The group is chaired by the Department of Agriculture, Fisheries and Forestry and the implementation is overseen by the National System Implementation Group comprising higher level representation from each jurisdiction. As an indication of cost A\$10.96 million is spent per year for all species plans executed within NIMPCG.

Ballast water management

Great Lakes, North America

5.49 The introduction of the Zebra Mussel to the Great Lakes followed by the subsequent eradication and then spread of the invasive round goby has caused large economical and environmental problems in the area. As a result the Great Lakes Seaway Ballast Water Working Group (BWWG) was set up³⁴. A coordinated bi-national, multi-agency comprised of representatives from the United States Coast Guard, the U.S Saint Lawrence Seaway Development Corporation, Transport Canada Marine Safety and the Canadian St Lawrence Seaway Management

³³ www.marinepests.gov.au/national_system

³⁴ www.d9publicaffairs.com/posted/443/2009_Great_Lakes_Seaway_Ballast_Water_Working_Group_Report_Final.475699.pdf

Corporation. Its mandate is to develop, enhance and coordinate binational enforcement and compliance efforts to reduce the introduction of aquatic invasive species via ballast water. This has resulted in some of the most stringent ballast water management requirements in the world. Comprising of:

- Ballast Water Exchange;
- Saltwater Flushing of no ballast on board “NOBOB” tanks;
- Rigorous Vessel Inspection Protocol; and
- Civil Penalties for non-Compliance.

- 5.50 Since 2006 Canadian and U.S. regulations include saltwater flushing, detailed documentation requirements, increased inspections and civil penalties which can be enforced through letters of retention or warning, notices of violation or fines up to \$36,625. The growing evidence in support of salt water flushing and ensuring that ballast tanks maintain salinity levels of 30 ppt, means that all international ships entering the seaway must comply. It is also required that all ocean-going ships to exchange their ballast tanks at sea. This has resulted in no unmanaged ballast water entering the Great Lakes from ocean-going ships. Furthermore every ship that enters the Great Lakes has to travel through the St. Lawrence River, through a series of locks in New York. From 1st January 2012, no ocean-going ship can travel through New York waters without having a ballast water treatment technology that approaches zero discharge of invasive species.
- 5.51 In 2009 a summary of Great Lakes Seaway Ballast Water Management report was compiled by the BWWG. A total of 5450 ballast tanks, onboard 295 vessels, were sampled and had a 97.9% compliance rate. Vessels that failed to properly manage their ballast tanks were required to either retain the ballast water and residuals on board, treat the ballast water in an environmentally sound and approved manner, or return to sea to conduct a ballast water exchange. No ballast water with salinity less than 30ppt was discharged in the Great Lakes Seaway System from ocean-going vessels.
- 5.52 There have been no new species invasions since 2006 and this represents the longest period of “non-establishment” since at least 1959. Increased efforts have been made to identify location and type of INNS in various Great Lakes ports and whether routes can be identified as “high risk” or “low risk” as a dispersal vector. Increased efforts have also been made by Lake operators to identify procedures and technologies that will have an immediate impact on mitigating the spread.

Australia

- 5.53 Collaborative effort supported by the Australian Government, state and territory governments, marine industries, researchers and conservation groups enables the implementation of the National System for the Prevention and Management of Marine Pest Incursions³⁵. Under Australian legislation tanks identified as carrying high-risk ballast water require treatment and/or management by a method acceptable to the Australian Quarantine and Inspection Service. The acceptable methods are described in Tamelander *et al.* (2010) and listed below:
- exchange of ballast water at sea through sequential exchange, flow-through or dilution;
 - non-discharge of high risk ballast tanks;
 - tank-to-tank transfer; or
 - comparable treatment options as developed.

³⁵ www.marinepests.gov.au/national_system

Control

California Coastal Conservancy's Invasive *Spartina* Project

- 5.54 The California State Coastal Conservancy (Conservancy) established the Invasive *Spartina* Project (ISP) in 2000³⁶. The overall goal of the project is to develop a regionally coordinated project to address the rapid spread of four introduced and highly invasive *Spartina* (cordgrass) species in the San Francisco Estuary. The Conservancy has a broad mandate to protect the coastal resources of California. The ISP is comprised of a number of components including outreach, research, permitting, mapping, monitoring, and the allocation of funds for efforts to eliminate populations of non-indigenous *Spartina*.
- 5.55 Funding for the Invasive *Spartina* Project comes from the CALFED Bay-Delta Program, United States Fish and Wildlife Service Coastal Program, National Fish and Wildlife Foundation, and the California State Coastal Conservancy.
- 5.56 The 2007 ISP monitoring efforts have shown that the invasive *Spartina* in the San Francisco Estuary is decreasing in response to control efforts. The dominant invaders, *S. alterniflora* hybrids, which represent 99% of the coverage of invasive *Spartina* species around the Estuary, have been reduced to less than one acre at the majority of sub-areas treated. The herbicide Imazapyr has been shown to be highly effective in controlling *Spartina*. Herbicide efforts are expected to take several years to accomplish elimination of target populations through a structured programme of ongoing management. The decreases in invasive *Spartina* cover documented in the 2007 inventory and efficacy monitoring efforts demonstrate that the coordinated control of non-native *Spartina* is proceeding to achieve the goals of the California Coastal Conservancy's Invasive *Spartina* Project.

Pacific Oyster fishery New South Wales

- 5.57 The issue of the Pacific Oyster is complex and challenging with strong opinions from fisheries stakeholders and growing fear over the impacts of this species on designated sites (see Ruesink *et al.* 2005 for an overview). The Pacific oyster *Crassostrea gigas* is native to Japan and south east Asia and was first introduced for aquaculture to Tasmania, Victoria and South Australia in the 1950s and 1960s. Today this species is the most extensively cultivated shellfish species worldwide but has come to establish wild populations, outcompeting native species and causing widespread habitat change.
- 5.58 Populations of the pest were interfering with the highly sought after Sydney Rock Oyster (*Saccostrea glomerata*) cultivation in New South Wales so an innovative project was launched to eradicate the species and at the same time improve the sustainability of the south coast oyster industry and provided additional linked opportunities for the local Aboriginal community (Keating *et al.* 2010). The work to control wild populations is underpinned by the legal framework. Specifically the Fisheries Management Act (1994) lists Pacific Oysters as a Class 2 Noxious Species in NSW, requiring oyster farmers to undertake control work on their leases, except in some estuaries where triploid cultivation is permitted under issued approval.
- 5.59 Prior to 2000 Pacific Oysters generally only posed periodic and largely manageable problems for the South Coast Oyster Industry but in 2008 a large rainfall event led to increased numbers of Pacific Oysters in the area. Increased effort to remove the species was occurring by growers from stock and leases areas but large areas of public land were harbouring significant populations with the potential to cause large economic damage. A rapid and targeted approach was launched with co-operative management intervention to prevent widespread economic and environmental problems. Local growers partnered with government agencies including Southern Rivers Catchment Management Authority (CMA), Industry and Investment NSW (both the Aquaculture Unit and local officers) and Marine Park Authority, and volunteers from the Nature Coast Marine Group to determine a control strategy.

³⁶ www.spartina.org/

- 5.60 Prior to control work commencing, detailed project planning was undertaken which included planning with the tide, season (most effective prior to spawning) and project longevity (several years commitment needed). Surveys were undertaken to assess the extent of the problem and to identify hotspots. Extensive training was given to the workers in identification and method. A site based approach was taken with different methods for different estuaries. The community and partner engagement 'Smash-up Days' involved small teams led by growers allocated to a stretch of foreshore and feral oysters were scored and physically removed with hammers and/or metal poles. In the Clyde and Wagonga Estuaries, teams of divers used snorkelling and/or SCUBA to target priority areas on the bed of the estuaries and in some locations derelict oyster rearing equipment was removed as it is known to harbour breeding populations.
- 5.61 Overall more than 37,000 Pacific Oysters have been removed from the three systems. Although control efforts are still ongoing, between 2007/8 and 2008/9 the number of Pacifics removed fell from over 18,000 to 9,780. It is estimated that the project has saved farmers A\$90K per year in reduction of manual removal of Pacifics. A detailed project review of the three year programme is currently being undertaken. If report findings reveal that Pacifics have reached a manageable threshold, it is anticipated that intensive control work could be replaced by an annual monitoring and maintenance program.

Eradication

Treatment within a marina of invasive freshwater mussel *Mytilopsis adamsi*

- 5.62 The Black Striped Mussel was detected in a marina in Darwin in March 1999 and later identified in two further marinas. Following confirmation of the identity of the bivalve and recognition of its potential as a serious marine pest, a high level management committee was established in the Northern Territory (NT) led by the NT Department of Primary Industry and Fisheries (DPIF). The committee included relevant Ministers and senior officials from the NT Government. The three infected sites were quarantined and a dive survey of all surrounding buoys, wharves, marinas, oil rigs, barge landings and nearby Darwin Harbour shorelines was undertaken to establish the extent of the species' spread.
- 5.63 The response management committee involved over 300 staff and was responsible for the on-ground containment and treatment actions. The main actions included the tracking and treatment of vessels that had left infected sites, the treatment of three sites and almost three hundred vessels in the Darwin area and the initiation of a public awareness program.
- 5.64 Commonwealth agencies led by Agriculture Fisheries and Forestry - Australia (AFFA) established a national working group to coordinate national action to prevent the spread of the mussel to other States. A local scientific sub-committee comprising representatives from CSIRO CRIMP, NT Museum and Art Gallery, DPIF and the Northern Territory University developed national protocols to detect and treat the Black Striped Mussel at the Darwin sites and on vectors considered to be at risk.
- 5.65 The treatment involved the complete isolation of the marinas and addition of chlorine (calcium and sodium hypochlorite) and copper sulphate to the marina waters. Both treatments killed mussels but the copper sulphate was most effective. By April 1999, 100% of the exotic Black Striped Mussels were deemed successfully eradicated and all three marinas were reopened for normal use. Procedures were established for continued monitoring to detect possible new infestations with no further infestations detected to date (Ferguson 2000; Bax *et al.* 2002). The overall cost of the operation was A\$2.2 million (Williams & Grosholz 2008).

Caulerpa taxifolia eradication in Southern California

- 5.66 *Caulerpa taxifolia* is a highly invasive species that was initially spread through the aquarium trade. The species was detected in a native eel grass bed in southern California in 2000 and due to the launch of an immediate programme the species was fully eradicated by 2006 at a cost of around US\$7.7 million (Williams & Grosholz 2008). This species has a high profile given its

extensive distribution throughout the Mediterranean where it is deemed too extensive to attempt eradication (Meinesz *et al.* 2001). The eradication process was helped along by the fact that the species had been added to the US Noxious Weed list in 1999 but also by the establishment of the ad hoc management team SCCAT (Southern California *Caulerpa* Action Team). SCCAT was formed by local and regional managers who implemented the sourcing of funds, a public education programme and organised the permissions for operations including chemical application despite resistance from marine conservation bodies over the use of toxic chemicals in the marine environment.

- 5.67 The successful eradication was achieved by covering colonies (1-500m² in size) of the alga with PVC tarpaulin and applying bleach in liquid and solid tablet form (Anderson 2005). Despite the successful eradication and the National *Caulerpa* Management Plan, there are barriers to the long term exclusion. The aquarium trade has blocked a genus-wide ban on *Caulerpa* which would be needed to prevent future invasions due to the fact that the *C. taxifolia* is difficult to separate from other similar species (Williams & Grosholz 2008).

Recommendations

Prevention

- 5.68 The key to successful prevention is down to an effective National Programme which is linked in to the European and Global alert systems (for example, the European Network on Alien Invasive Species - NOBANIS). Participation in the NOBANIS programme would represent the UK's inclusion into a fully structured and supported alert system that would enable rapid response in the event of an invasion. Currently there is insufficient cohesion at the UK level which is mirrored by similar problems across Europe. The approaches adopted by Australia and New Zealand make it easy to access information, understand the regulations, operate ballast water management appropriately, design and launch a control/eradication programme, raise the alarm and engage the community to support any measures.
- 5.69 The first line of defence in pre-border control will be entry into force of the IMO Convention. Further steps beyond the requirements of the convention will be dictated by the UK government but also on a site by site basis where the designated interest feature may be at risk (as identified by a comprehensive early warning system). More stringent ballast management procedures are a viable option to limiting the arrival of future INNS but will need the appropriate legislation and shipping industry agreement.

Control and eradication

- 5.70 Very few successful large scale eradications have occurred globally. Those which have been successful have required long term funding commitment to maintain management programmes, carry out monitoring and gain stakeholder support. There are examples of successful small scale eradication events which are underpinned by early detection, a high level of awareness of potential risk species, effective reporting systems and co-ordinated monitoring. The key to successful eradication is down to the characteristics of the invasion (small and restricted, for example, the Black striped Mussel eradication), the availability of resources (human and financial with long term commitment, for example, Californian Invasive *Spartina* Programme) and early action taken as summarised below:
- Early identification and detection of the INNS through high level of industry and community awareness and co-ordinated monitoring.
 - Expert knowledge about the biology and ecology of the INNS.
 - Sufficient resources to fund a programme to its full conclusion.
 - The existence of effective control procedures for the target pest organism.
 - Monitoring and review during and after the response is launched.
 - Implementation of protocols to prevent reinvasion.

- 5.71 Should full eradication be deemed possible then it is highly important to ensure the removal of either all individuals or to commit to the reduction of the population to below a level that could sustain a viable population (Coutts & Forrest 2007). Where partial or site based eradication is deemed appropriate then the goal of the programme needs to be made clear and every effort put in place to minimise the risk of re-invasion. Furthermore all chemical and physical eradication measures have varying degrees of associated effects on non target species (McEnnulty *et al.* 2001) and/or habitats and would be subject to Appropriate Assessment procedures with respect to English European Marine Sites. A case by case approach to eradication should be adopted with a full appraisal of the options and risks.

6 Dredging

Overview of issue

- 6.1 Dredging is the process of removing material from the sea bed to create greater depths of water or to extract minerals from the sea bed. For the purposes of this analysis, the descriptions of dredging will be confined to those activities associated with navigation, ports and harbours. It is also important to bear in mind that no two ports or estuaries are the same, and consequently any attempt to quantify 'best practice' runs the risk of comparing apples with pears and applying techniques that are applicable to one place but are quite inappropriate to the location in question. This section therefore sets out to provide assistance in establishing best practice by making sure that the practitioner understands what they are dealing with and how range and variation can influence decision-making.
- 6.2 Best practice must also recognise that ports and harbours have a legitimate role and a legal obligation to provide safe navigation to declared depths. Consequently it must also involve the way in which ports and Natural England interact. Best practice therefore comprises:
- How, when and why should ports and Natural England engage to ensure environmentally and economically sustainable outcomes are secured? It is incumbent upon the port to engage in sufficient time to resolve issues and is equally important that Natural England engages in good time rather than at the last minute.
 - Identification of the issues that are genuinely relevant, rather than simply going through the list and requiring in-depth analysis of an issue that can be readily dismissed. In this respect the crucial issue is to establish a clear audit trail of why particular issues were included or discounted.
 - Use of techniques that are appropriate to the location concerned.
 - Consideration of the scale of the dredging and its relative significance; i.e. what may be a small dredge in one location may be proportionately much more significant in another.
 - Recognition that some options are either impractical or economically unsustainable.
 - Recognition that dredging through some habitats is not acceptable because of their rarity or fragility (or both).

Why is dredging undertaken?

- 6.3 Shipping requires sufficient water depths to allow it to pass safely from its point of departure to its final destination. Insufficient depth means that a ship will not reach its intended destination and consequently this limits the size of ships that can access particular ports (including ports for leisure vessels otherwise referred to as 'marinas').
- 6.4 The majority of ports were designed to accommodate sailing vessels and are located in sheltered locations, primarily in estuaries in the UK and northern Europe. Early mariners would have sought a point where they could get their vessels as close to the shore as possible. Many older ports are therefore located on the natural navigation channel and consequently they have been sited in naturally suitable locations. Early ports were often a long way up river systems because the vessels they accommodated were small with a shallow draught that allowed them to navigate deep inland.
- 6.5 In the UK, most of these original inland locations such as Norwich, Blythburgh or York have long ceased to be important ports because ships have increased in size and cannot navigate the river system concerned. In northern Europe some of these inland ports have continued to develop far beyond their natural limits, but the rivers concerned are big and consequently shipping continued to use them until it was possible to significantly deepen the access channels. This is why ports

such as Antwerp and Hamburg remain amongst the biggest in Europe and are competitive with coastal ports such as Rotterdam or Zeebrugge. Comparable situations no longer exist in the UK, although the great locked docks in the East End of London remained active until the 1980s and the Mersey Ship Canal does allow access for bigger vessels as far as Manchester.

- 6.6 From the onset, providing access to the shore has presented mariners with a challenge. Shorelines tend to slope seaward in a natural geometry that is governed by wave and tidal action, together with associated movement of sediments. This has meant that since pre-Roman times structures have been built to allow ships to berth. Such structures doubtless involved extensions onto the river or sea shore in the first instance with a vertical quay line adjacent to deep water. Today, jetties such as the oil terminal at Immingham do much the same thing only at a far bigger scale.
- 6.7 Until relatively recently the physical process of maintaining access would have limited the size of ships that could be accommodated. If ships were too big they could not berth alongside the shore and the process of supplying them, loading and unloading would have been long and slow, involving hundreds of men. If a quay silted up, then it would normally have been abandoned and replaced with a newer one with access to deep water, unless silt could be removed at low tide.
- 6.8 Industrialisation brought change and the possibility of improving efficiency. Ships propelled by steam had to be bigger, and of course steam meant that the process of maintaining deep water could be greatly improved. At this point, dredging became a realistic way of maintaining berths and navigation channels: if the port was too small for new ships it had two choices - provide deeper water or lose trade. Clearly some ceased to compete and this is why there are numerous small inland ports that were once major centres of marine trade. Examples include Boston, Rye and Sandwich.

Definitions of dredging

- 6.9 Cutting new access channels and deepening the water adjacent to quays and wharfs introduces the concept of '**capital dredging**'. This is the first stage in maintaining or improving a port's competitiveness. If the water depth is too shallow only smaller vessels can reach the port, whereas deeper water will allow bigger vessels to access the port. Depth, however, is only part of the solution because bigger vessels require more manoeuvring room, and consequently channel deepening is usually accompanied by widening.
- 6.10 In theory, channel deepening might be perceived as a simple process, but it has considerable implications for the geometry of the coastline or estuary concerned and this in turn leads to changes in sedimentation patterns. Consequently, deepening is normally followed by sediment accumulation and in-filling. The rate of in-filling is entirely dependent upon sediment availability and so the need to re-deepen cut channels and berths will vary. On many estuaries on the east coast of England the rate of infill will be comparatively fast, whilst in low sediment environments such as some estuaries in south west England the rate of accumulation may be much slower. Re-deepening to the original depth is usually referred to as '**maintenance dredging**'.
- 6.11 Dredging is expensive and therefore during periods of port inactivity re-deepening may not occur very frequently. This will depend upon the depth of original deepening and the degree to which natural in-filling can be accommodated without affecting port efficiency. Consequently, there will be places where intervals between dredges are extremely long. Longer durations between re-deepening can have a major bearing on the levels of contamination encountered in some sediments.

- 6.12 The definitions of capital and maintenance dredging are set according to different parameters by Defra and latterly the Marine Management Organisation:
- Capital dredging involves either the initial process of deepening channels and berths or the process of re-deepening previously cut channels and berths if they have not been maintained to their original depth in the preceding ten years (DEFRA 2007).
 - Maintenance dredging involves re-deepening as far as, but not beyond the depth achieved by the original deepening, provided a period of no more than ten years has elapsed since the previous deepening.

Where does dredging occur?

- 6.13 There are numerous situations where dredging may be necessary, but in essence they can be broken down into the following:
- **Navigation channels** (fairways): the main access routes between the port or marina and the open sea. Channels are frequently maintained to allow access to the biggest ships on only part of the tide because the cost of maintaining deep water throughout the tidal cycle is too great. This means that some ports can only take ships of great draught for part of each month and consequently careful scheduling arrivals and departures is extremely important. Where ports deal with complete cargoes this process can be managed by adjusting steaming speeds and holding vessels offshore until suitable depths are available. However, car ferries and container ships require more constant access and consequently ports that deal with the bigger ships serving these trades will generally maintain constant or near-constant access.
 - **Berthing pockets**: the void adjacent to a quay side. Berth pockets are often deeper than the main navigation channel because most modern ships are not designed to rest on the sea bed at low tide. The berth pockets must therefore be deep enough to accommodate the ship on all tides.
 - **Locked berthing basins**: traditionally these will have been accommodated within a locked system, but modern ports are rapidly moving away from such structures because the width and depth of the locks governs the size of the ships that can be accommodated. Many locks were built at a time when ships were considerably narrower and had a shallower draught. Ship owners may not sign new contracts unless bigger ships can be accommodated. This is part of the reason behind the major changes in the ports industry in the UK since the early 1990s as riverside berths have been sought. Locked berths do still occur, however, such as at Bristol, Hull, Immingham and Liverpool. Locked berths will gradually fill with sediment that enters in suspension as ships enter, after which it falls to the bottom. Again, the rate of infill depends upon volumes of sediment in suspension - which can be extremely high in the case of ports such as Hull and Bristol.
 - **Marina basins**: mostly in shallower water than for major ports, but varying in depth according to the boats concerned. These are generally not locked but do create bodies of water with similar low energy characteristics that lead to relatively rapid sedimentation.

Who undertakes dredging?

- 6.14 Dredging has undergone many changes since it was first employed to maintain deep water. Originally, a port or group of closely approximated ports would have owned and operated their own dredger. In these cases maintained depths were often much greater than was absolutely necessary: the equipment was permanently available and there was less certainty about the depth available. Traditional bucket ladder dredgers are the immediate mental image many people have of a dredger. However, modern dredging is a much more refined process: the equipment used is much more powerful and fast; and it can be used with far greater precision.
- 6.15 Greater efficiency means that dredgers can operate for much shorter periods to achieve what was once done by a permanent team working to maintain the port. Consequently, very few ports

have their own dredger permanently available. There are exceptions such as Poole Harbour Commissioners who have a small dredger but also bring in bigger ones when necessary.

- 6.16 Dredging is therefore undertaken in one of two basic arrangements. Where a port owns its own dredger there may be an ongoing process of small incremental dredges away from the deepest water where bigger equipment is needed. These small dredgers allow rapid adjustment to small areas but are not suitable for the big volumes of sediment involved in major shipping channels. Where big volumes are involved, dredges take place at particular times of year, usually defined by the periods of greatest sedimentation such as in the aftermath of stormy conditions. These dredges are usually referred to as 'campaigns' and will last for several days or weeks.
- 6.17 There are a small number of big dredging contractors that are capable of undertaking major dredging campaigns. Most are based in The Netherlands and Germany. These contractors will be brought in on a one-off contract to deliver new capacity i.e. a capital dredge such as past deepening at Harwich or Southampton. Alternatively, where a port requires regular maintenance, a contractor will be appointed for a set period, after which the contract will be re-tendered. Dredging is one of the biggest ongoing costs for most ports and consequently they will try to keep dredging to an absolute minimum.
- 6.18 Mobilisation of dredgers is expensive and therefore ports often need to fit in with contractors' other commitments. This is an important consideration when it is necessary for a port to renew consent for dredging or dredge disposal. It often means that options for changing dredging methods may require new contracts or possibly different contractors, depending on the nature of changes required in dredging methods and frequency.
- 6.19 Responsibility for dredging varies according to the legal arrangements within individual ports. Some consent dredging by others (for example, marinas), some commission dredging and a few may have their own dredgers (for example, Poole Harbour Commissioners). Dredging itself is not specifically consented - the process of disposal is subjected to controls, and in some places outside the jurisdiction of ports consent may be granted after evaluation of navigational implications. Consent under Relevant licenses (see paragraphs 6.36 - 6.41) will be given to the applicant; which will either be a port or a marina. It is not normally the responsibility of the dredging contractor to seek the consents, but companies appointed to maintain military ports manage the consents process on behalf of the MOD. Dredging companies must abide by the conditions set.

Types of dredger and their uses

- 6.20 The nature of the sea bed, depths required and the profile of the area to be dredged will have an important bearing on the type of dredger employed. This means that it is important to understand the different applications of dredging equipment and what it may be capable of. Thus, for the conservation adviser it is also important to understand the characteristics of different types of dredger. Key issues such as noise, dredged plumes and the nature of sediment deposited at dump grounds are all relevant. There are many variants on the theme of dredging, but the following are the main ones that will be encountered in day to day port activity. They have been listed alphabetically as each will be used under particular circumstances rather than making any judgements about the appropriateness of any particular technique:

Backhoe dredger

- 6.21 In essence, the backhoe dredger is simply a version of the ubiquitous Hmac seen on building sites. It comprises a bucket attached to a hydraulic arm on a barge and either delivers material to a series of independent barges, or retains material within its own hopper. This type of dredger is most regularly used where sediments are relatively coherent and there is a need to retain coherence for economic or environmental reasons (for example, reducing the dredged plume). It is not suitable for weakly consolidated materials that rapidly disaggregate when disturbed (for example, maintenance dredging).

- 6.22 Material removed by backhoe dredgers will remain more consolidated than it would if removed by a trailer hopper, suction dredger or cutter hopper suction dredger and consequently it is less suitable for disposal at locations where rapid dispersal is needed to maintain bed depths. If destined for high dispersal sites, the solid blocks have to be broken up in the hopper. Disposal sites therefore have to be carefully chosen because the material involved may remain in situ for a long while. If the dredger has its own hopper then it will have to operate on a cyclical basis filling the hopper before sailing to the disposal ground to deposit the dredged material. Use of auxillary barges means that the dredger can work around the clock.

Bucket ladder dredger

- 6.23 This is the traditional dredger that comprises a series of 'buckets' arranged as a continuous loop within a rigid frame. Material raised by the buckets is transferred to a series of barges whilst the dredger itself remains in position, anchored in such a way that the bucket chain rotates across the sea bed to cut the required channel.
- 6.24 Bucket ladder dredgers are capable of dealing with most types of sediment and some soft rocks but require a great deal of space in which to place their anchors. They are comparatively noisy and this makes them inappropriate for areas where there are high levels of residential properties. These constraints mean that they are impractical for use in confined spaces and in busy waterways. Bucket ladder dredgers have largely been replaced by backhoe dredgers and various suction dredgers and are rarely if ever deployed in UK waters.

Cutter suction dredger

- 6.25 Where the sea bed is consolidated, the drag head may be modified to accommodate a set of rotating teeth that are used to break up the sediment before it is sucked into the hopper. Depending on the nature of the sea bed, the cutter head will vary and the dredger may be anchored as it cuts across an arc to loosen material so that it can be sucked to the hopper. Some poorly consolidated rocks such as mudstones may be suitable for removal by cutter suction dredgers but harder rocks require more aggressive methods such as blasting.
- 6.26 Cutter suction dredgers can be equipped with their own hopper or they may feed a series of barges that relay material to a disposal site or reclamation site. If they retain their own hopper then they will only operate until the hopper is full, after which they will depart for the disposal ground. In these cases the dredger will only be active for several short periods in any 24-hour cycle. In some cases they may feed a fixed pipeline to dispose of cut material ashore. Occasionally a cutter head may be used to loosen material before a suction dredger passes over the cut area to remove the material. One example of this was channel deepening in Southampton Water in 1996, when the cut coincided with exceptionally high tides and led to deposition of large quantities of sediment on the foreshore (see paragraph 6.157).
- 6.27 Material arising from a cutter suction dredger will usually comprise a mixture of slurry and larger lumps of material that will only degrade over time. This means that this type of material is likely to fall to the sea bed and form a raised mound at the disposal site.

Grab dredger

- 6.28 The grab is a relatively inefficient means of removing material from the sea bed and is consequently used in specialised circumstances such as localised areas that are difficult to access using other techniques. Grabs will cope with unconsolidated sediments such as sands and silts, together with some consolidated sediments and pre-loosened material.

Plough dredging

- 6.29 This is a form of agitation dredging in which a steel bar is drawn across the sea bed to mobilise surface sediments. It is an extremely inefficient means of dredging and can only be used to

scrape away surface layers. This technique is usually used after more intensive dredging campaigns as a bed leveller to remove any unwanted undulations. It will create a plume and some of the mobilised material will enter the water column but the majority of material will remain in the vicinity of the sea bed.

Trailer suction hopper dredger

- 6.30 This is best likened to a giant Hoover that sucks up relatively unconsolidated material from the sea bed and is most suitable for removal of fine sediments, sands and gravels. During the suction process, some sediment will be disturbed to create a plume of suspended sediment close to the sea bed, but except in shallow water or where sediment loads in the water column are naturally very low, this plume is unlikely to be visible from the surface.
- 6.31 Sediment is delivered into the ship's own hoppers as a slurry that is predominantly water. Thus, the hopper will rapidly fill with fluid. Efficient use of the ship means that the water content needs to be discharged so that the hopper contains a more consolidated mixture of sediment and water. This discharge or 'over-spilling' often involves loss of some muds, silts and finer sands that form a plume within the water column.
- 6.32 Once the hopper is full, the dredger must cease work and head for the disposal ground. This means that in any 24-hour cycle the dredger will only be working for part of the time. It also means that a high proportion of the cost of dredging arises from the time it takes to travel to and from the disposal ground. In some cases the disposal ground may be tens of kilometres away and consequently for every hour of active dredging the time spent travelling to the disposal grounds may be considerably greater. This is why the dredger will try to maximise use of the hoppers by over-spilling to remove excess water.
- 6.33 The material excavated by a trailer hopper suction dredger is predominantly light, and consequently it will be delivered at the dump site as a mobilisable slurry that will form a fine plume within the water column. This means that a lot of the sediment released will not reach the sea bed but will sit within the water column and be dispersed over considerable distances.

Water injection dredger

- 6.34 The water injection dredger involves delivery of water into the sea bed under low pressure so that mud forms a fluidised layer close to the sea bed. This mud travels as a gravity plume until it is dispersed by local currents. As the gravity plume remains close to the sea bed it is generally not visible from the surface in the muddy estuaries where it has been used.
- 6.35 Water injection dredging can only be used in certain very specialised circumstances and it carries risks to ports because the mobilised sediment may end up in places where it is not wanted. This means that whilst it is a comparatively cheap (and therefore attractive) technique, it is not particularly widely used. It is used extensively by the Port of London Authority and occasionally at some localised places such as Haslar Marina in Portsmouth Harbour and in Salcombe Harbour.

Who consents dredging?

Port authorities – own legislation

- 6.36 It is important to bear in mind that the act of dredging has generally been consented when the port was established. This is because each port was first created under its own Act of Parliament which set out the legal provisions for its jurisdiction and responsibilities. Part of the responsibilities conferred on the port include a requirement to maintain safe navigation and consequently it could be argued that ports with such legislation not only have a right to dredge but are actually required to do so in order to provide safe navigation within their jurisdiction.

6.37 Port Authorities often retain jurisdiction over a much wider area than their own infrastructure and therefore they will often be the licensing authority for other ports who wish to deepen or maintain their access channels. This means that as part of the consents process, Natural England should normally be consulted by the Port Authority (often the Harbour Master) where it is responsible for granting consent to dredge. In practice almost all ports of any significance are within or adjacent to designated sites (Special Areas of Conservation or Special Protection Areas) and so are required to consult Natural England. Outside designated sites there is no absolute onus on authorities to consult Natural England.

Marine Management Organisation

- 6.38 Although there is no specific legislation under which dredging is consented, disposal of dredged material requires consent if undertaken at sea. If the dredge is to take place outside the jurisdiction of the navigation authority it may also require a license to ensure that it is not interfering with lawful navigation rights. (But be aware that this may change under secondary legislation following the Marine and Coastal Access Act, 2009).
- 6.39 The legislation governing these two aspects of regulation by the Marine Management Organisation are:
- Section 34 of the Coast Protection Act (1949) governs activities that may be detrimental to navigation and consequently is relevant to dredging because the act of dredging has implications for navigation. (see Marine Management Organisation website³⁷).
 - Part II of the Food & Environmental Protection Act (1985) establishes controls over the deposit of materials on the sea bed "that are submerged at mean high water springs" (see Marine Management Organisation website). This includes the deposition of dredged materials at a licensed disposal ground. In this respect, it is important to bear in mind that the disposal ground must be designated and it will have been defined in order to achieve high dispersal. Where major dredges are undertaken and will generate material that is not expected to disperse, a new disposal site may be established strictly for this purpose: it will only be established following rigorous evaluation for biological and navigation implications.
 - Consents are only granted by the Marine Management Organisation once all key issues have been evaluated, including sediment quality. Analysis of sediment quality is undertaken by CEFAS (Centre for Environment, Fisheries & Aquaculture Science) who are also responsible for providing advice to decision-makers on the implications of individual levels of contamination. Consequently, this is an area of specialised advice that at the moment need not impose heavily upon Natural England. It is, however, worth noting that parts of the ports industry are keen to make the analysis more competitive and to remove CEFAS as the sole contractor. Were this to happen, the statutory nature conservation organisations would need to develop an overseeing role to ensure current rigour is maintained.
- 6.40 FEPA and CPA legislation remained in force until 5 April 2011 after which FEPA licences and CPA consents were replaced by a marine licence. The majority of the licensing provisions of FEPA and CPA were transferred into the Marine Licensing arrangements but the legislation also takes account of activities such as water injection and plough dredging that were hitherto not subjected to the licensing regime. Consent for water injection and plough dredging became a requirement from April 2012 onwards.
- 6.41 It is also important to bear in mind that assessment of maintenance dredging to meet the requirements of the Water Framework Directive will be conducted by the Environment Agency. There is a guide for ports on how to assess the implications³⁸. The basic stages are described in paragraphs 6.168 – 6.172.

³⁷ <http://marinemanagement.org.uk/works/licensing/cpa.htm>

³⁸ www.environment-agency.gov.uk/business/sectors/116352.aspx

Sediment quality – chemical analysis

- 6.42 There are no sediment quality standards set for UK waters. The UK takes a risk-based approach that involves an element of expert judgement. This differs from the commonly quoted 'Dutch Reference Standards' and the more rigorous 'Canadian Reference Standards' (DeIValis *et al.*, 2004). Specific advice on contaminants is provided in the outputs of the UK Marine SACs project³⁹. Consent for disposal is dependent upon the sediment involved undergoing assessment by CEFAS and satisfying their risk assessment.

Dredge disposal sites

- 6.43 Dredged materials cannot simply be dumped at sea. Each port has access to one or more disposal sites according to their needs. Many of these have been longstanding locations. New disposal sites are licensed relatively infrequently and only after detailed characterisation. Particular attention is paid to the likely impact on local and more distant marine assemblages and of course on fisheries interests.
- 6.44 Individual sites are clearly defined and conform to specific characteristics, most notably for the dynamics of the tidal conditions and their tendency to high dispersion. This makes sense because the greatest risk to navigation is the establishment of a disposal site that gradually shallows and becomes a risk to shipping. Furthermore, if the site becomes too shallow, then it cannot service the dredgers that require sufficient water depth in order to dispose of their contents.
- 6.45 Registered disposal sites are regularly monitored by CEFAS and a substantial part of the fee paid for the dredge disposal licence under FEPA is linked to the costs of monitoring.
- 6.46 Offshore disposal sites are often favoured in order to minimise sediment returning the dredged channels concerned. In some large estuaries, such as the Humber, and Western Schelde, disposal sites are relatively close to the navigation channels and this can then simply involve sediment cycling rather than complete removal. These examples reflect a fine balance between the costs of dredging and the costs of permanent disposal.

Understanding the impacts of dredging

- 6.47 There are many different ways of looking at dredging and its potential nature conservation implications. Marine biologists will focus on contaminants, sediment plumes and smothering; fish biologists may worry about sediment loads, impacts on biological oxygen demand and underwater noise; whilst geomorphologists will highlight changes to the way the coast works. This analysis focuses primarily upon the geomorphological implications because these have been the highest matter of concern in England in the past 20 years.
- 6.48 Geomorphological impacts on coastal wildlife can be profound, and yet the solutions that are offered may be perceived as incompatible with other aspects of wildlife or fisheries management. If one starts with the relationship with coastal morphology and sediment type, it is possible to place dredging into context and this will help to establish the degree of biological impacts. So, for example, most direct biological risk will arise in clear-water environments, whilst the lowest risks will present where the system is naturally turbid and prone to episodic high energy manipulation of the near-shore environment.

³⁹ www.ukmarinesac.org.uk/activities/water-quality/wq4_3.htm

Geographical variation

6.49 The English coastline is one of the most varied in Europe. This reflects the remarkable suite of rocks involved and the extent of the geological sequence that is exposed on the coast. Consequently, the first issue to consider is where the proposed dredging will occur and how this relates to coastal geology. Table 6 and accompanying Figure 3, provides a rough indication of the range and variation in sediment regimes.

Table 6 Descriptions of sediment regimes in proposed dredging sediment zones

Section	Description	Notes
1	Tweed to Flamborough. Predominantly rocky or sandy with limited mud and some exposed rock.	Inner reaches of the Blyth, Tyne, Tees and Wear are muddy.
2	Holderness to Swale. Soft sediment coastline with a mixture of mud and sand. Estuaries generally muddy with relatively high sediment loads and cohesive sediments.	Considerable variation in sediment loads depending on available sediments from eroding coasts.
3	Shellness to Durlston Head. Mixed rocky and sandy coastlines with muddy estuaries and shingle deposits. Relatively low levels of suspended sediment except where exposures of clay are unprotected.	Sediment supplies within the Greater Solent are very limited and are probably insufficient to keep pace with sea level rise. Supplies are augmented by saltmarsh erosion.
4	Durlston Head to Porlock. Predominantly rocky coastline with sandy bays. Low levels of muddy sediments. Rias with limited exposed sediment on the foreshore (for example, Fal/Helford).	Very limited muddy habitat. Saltmarshes are also relatively scarce. Estuaries are dominated by sandy habitats.
5	Porlock and Severn Estuary. Relatively low sediment inputs but high sediment loads within the Severn Estuary as a result of extreme tidal propagation. Fine sands and muddy sediments.	Sediments highly mobile. Dredge disposal within the estuary and hence unlikely to be a matter of concern.
6	Dee and Mersey Estuaries. Predominantly muddy, with sand in Liverpool Bay.	Main dredging issues relate to sandy deposits in the approaches to the Mersey, and to the Port of Mostyn (Wales).
7	Liverpool to Solway Coast. Predominantly sandy with limited mud in upper estuarine reaches.	
8	Severn to the Dee. A mixture of rocky and sandy with relatively little fine or cohesive sediments.	

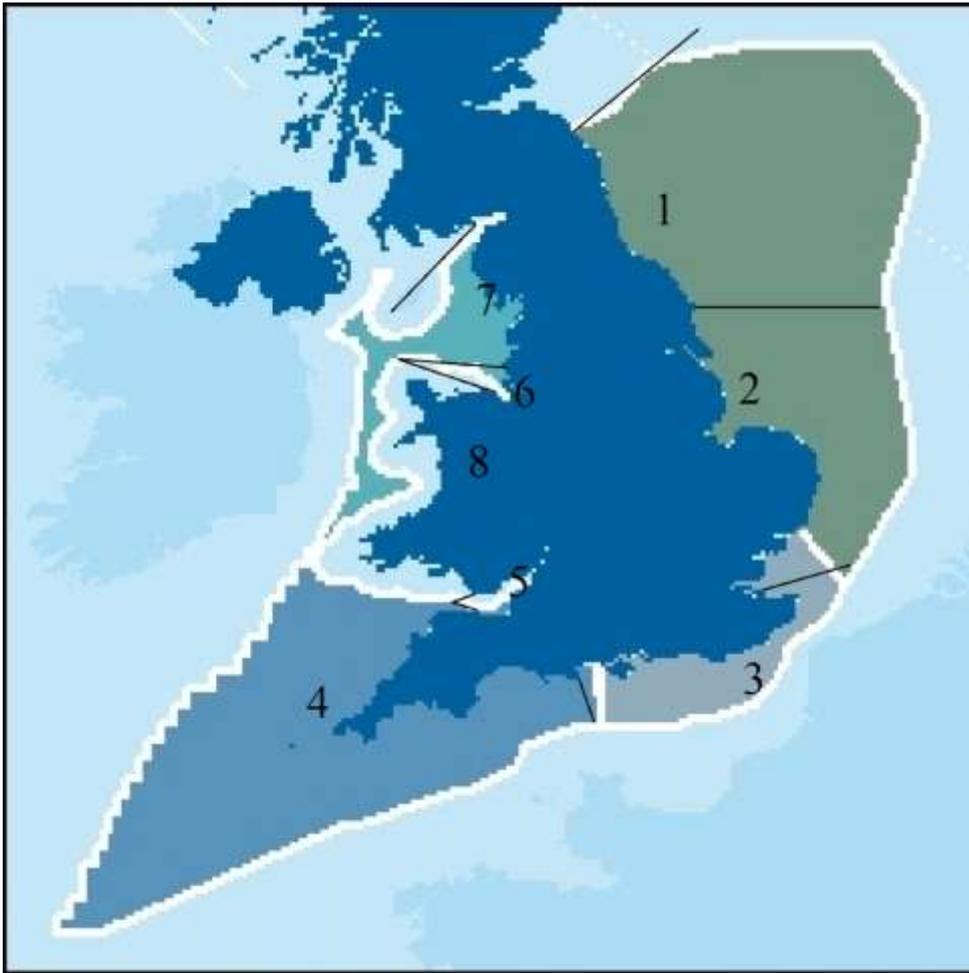


Figure 3 Sediment zones relating to Marine Protected Areas

Dredging and physical processes

- 6.50 In order to understand the impact of dredging on physical processes it is necessary to be aware of the way the coast has evolved over the past 10,000 years - the Holocene evolution of coastal form. This is especially relevant in estuaries, where rapid sea level rise until around 4,500 before present (Whitehouse *et al.* 2009) has profoundly influenced coastal evolution.
- 6.51 Sea level rise since the peak of the last ice age some 18,000 years ago has been in the order of 100 metres or more. This has led to the development of the shallow seas around our coast, and has also been responsible for the evolution of coastal geometry that increases tidal propagation in estuaries and leads to some exceptional tidal ranges such as those of the Severn, Mersey and Solway. Once sea levels stabilised, the coast has tried to establish a new dynamic equilibrium. In estuaries, where the effects of navigation dredging are most significant, there has been an ongoing process of sediment accumulation.
- 6.52 Sediment supplies to estuaries derive from a variety of sources and these vary according to adjacent geology. In the immediate aftermath of the glaciation, plasticity in the landscape would have meant that large quantities of mobilisable sediment were carried by rivers to the coast where it was deposited. This source has long-since declined to negligible levels. For example, in the Humber Estuary, which is arguably the muddiest in the UK, less than 5% of the sediment in the water column derives from fluvial sources. The rest comes from various marine sources, including coastal erosion and erosion of the adjacent wave-cut platform.

- 6.53 Most UK estuaries actually derive from drowned river valleys but they have evolved in different ways that depend upon the nature and sources of sediments (see Dyer 2002, for classification). This process of evolution is critical to our understanding of estuarine responses to dredging. The Coastal Geomorphology Partnership (1999) provided initial analysis used to develop favourable condition tables for Estuary SACs. This analysis uses the O'Brien rule (O'Brien, 1931, 1969) in which it is postulated that there is a direct relationship between the cross-sectional area of the mouth of an estuary and the tidal prism upstream.
- 6.54 Estuaries have a tendency to fill up with sediment provided the duration of the flood tide is shorter than that of the ebb tide (in other words, flood dominance), and provided there is sufficient sediment to provide infill. This infilling will continue until the point is reached where ebb tide currents are faster than those on the flood tide and are sufficient to erode sediment deposited during the flood tide and the high tide stand. Once erosion commences, sediment is exported and the estuary widens and deepens to achieve equilibrium geometry. Of course, this geometry can never be achieved because the monthly spring-neap cycle and the 18.6 year lunar nodal cycle lead to constant changes in tidal propagation. Consequently, provided sediment supplies are maintained there will be constant oscillation around the equilibrium value with periods of accretion and erosion.
- 6.55 Capital dredging takes the estuary away from its equilibrium form. This creates conditions that generally favour sub-tidal sedimentation, which drive the need for maintenance dredging. It is therefore necessary to think about the processes involved and to put them into context when evaluating the impact of capital dredges. Questions that need to be asked include:
- How big is the estuary? Bigger estuaries require more of a change to initiate discernible effects than small ones do. This is because the change is proportional to the volumes of the existing void and to the existing tidal prism.
 - How big is the dredge in relation to the size of the estuary? A capital dredge of 50,000 cubic metres in a very large estuary such as the Humber, Thames, Severn or Mersey is likely to have very little, if any discernible effect on its geometry and hence on its morphological evolution. Conversely, the same sized dredge in a small estuary such as the Hamble, Medina or Lymington River may have a profound effect on the morphology of that estuary. But, it is important to bear in mind that where there are big estuaries there are also big ports and these ports will seek to serve the biggest ships, so some capital dredges can be very big (for example, Harwich Haven capital dredge, London Gateway capital dredge and Southampton Water capital dredge).
 - What are the likely implications for tidal propagation? Big changes to the depth and width of the thalweg (the main channel) can influence the way the tide propagates in an estuary. In some cases (for example, Harwich capital dredge) there will be an increase in both the high tide and low tide levels; in others, increased high tides will be accompanied by decreased low tides (for example, the Ems Estuary in Germany, and the Seine Estuary in France); and in some, such as the proposed deepening in Southampton Water, there will be a mixture of changes with both elevated and decreased low tide levels. These changes will influence the extent and duration of inter-tidal exposure and hence the overall extent of inter-tidal habitat (can be gains or losses). They may also influence the distribution of sediments depending upon the ways in which flood and ebb tides sort fine sediments. Changes in saline incursion changes will also affect flocculation and the point in the estuary where fine sediment deposition is accentuated by these processes.
 - Will channel deepening affect sediment mobilisation on the flood tide? In some European estuaries channel deepening has led to considerable increases in tidal range inland. Such increases in tidal propagation mean that flood tides travel at higher speeds and this in turn may lead to sediment deposited on the ebb tide being re-suspended and carried further upstream; a process which is referred to as 'tidal pumping' and which is now causing severe water quality problems on the Ems Estuary (Germany). If such effects are predicted, there is a need to think about the likely implications for suspended sediment levels upstream and the potential for development of fluid mud.

- What will happen to sediment deposited in dredged channels when it is removed by maintenance dredging? In most cases, dredged sediment is removed from the estuary and deposited offshore. This in effect creates a deficit on the accounts of the sediment budget for the estuary, and if the budget is shifted too far away from sediment import it will affect inter-tidal sedimentation.
- What are the implications for the sediment budget of the estuary? (for implications see paragraphs 6.102-6.107). The sediment budget is a concept based around the various components of sediment supply within an estuary. It will comprise: volumes accreting and volumes eroding. Dredging and removal offshore will therefore add to the sediment erosion part of the balance sheet. Historic estuarine evolution has depended upon sediment supplies feeding foreshore evolution. These supplies are now governed by reduced fluvial supplies and reduced marine supplies as a result of exhaustion of post-glacial supplies, abrasion, leakage into deep water offshore sinks and reductions in new supplies from coastal erosion. Lack of sediment arriving on the foreshore will reduce the ability of mudflats and saltmarshes to keep pace with sea level rise by accreting. Moreover, reduced sediment load in the water column may shift the balance between foreshore accretion and foreshore erosion and this in turn will lead to loss of sloppy sediments favoured by benthic in-fauna and ultimately to exposure of more consolidated sediments that are not suitable for benthic organisms and thus it will influence usage by migratory waterfowl.

6.56 Ports on the open coast will also accumulate sediment. Some sediment may end up in navigable channels but the removal of this from the navigable areas is of much lower significance than in estuaries because the volumes involved are relatively small and generally do not affect sedimentary processes elsewhere. However, where the port lies in the path of long-shore drift and therefore intercepts sediment that would travel to a more distant location there can be a problem because this can lead to down-drift sediment starvation. Good examples of this sort of sediment interruption include the harbour arm at Rye, which has led to the development of the extensive shingle structure to the west of the River Rother. Other examples include the harbour training wall at Southwold, and the new Great Yarmouth Outer Harbour. At the latter port, part of the mitigation agreement required the applicant to ensure that a sediment by-pass scheme was established to make sure that down-drift beaches were not denuded of sand.

Sediment plumes

- 6.57 There are several ways in which sediment plumes may arise; disturbance of the sea bed by the drag head, over-spilling as the dredger de-waters, and as a result of sediment deposited at the disposal ground. The plumes arising from the drag head are relatively insignificant and are pretty well unavoidable. Plumes arising from over-spilling and disposal can be much more significant and therefore deserve particular attention.
- 6.58 Historically, over-spilling simply involved allowing water to cascade over the edges of the hopper but it subsequently evolved to return excess water via chutes into the water column. There have been further changes designed to deliver associated sediment into deeper water and latterly to remove air bubbles that contribute to sediment remaining in suspension for longer periods. Even so, the only way of avoiding over-spill plumes is not to over-spill and this has severe cost implications because the dredger will be transporting large quantities of water rather than sediment to disposal grounds.
- 6.59 Sediment plumes at disposal sites are unavoidable and if there are important marine nature conservation resources close to disposal sites then it may be necessary to consider alternative disposal sites. The disposal sites located close to the first tranche of marine protected areas (i.e. near-shore marine SACs) have already been evaluated and addressed. Consequently, these sites should not evoke further concern. There may therefore be a need to undertake further review in the light of additions to the marine protected areas series.
- 6.60 The critical issues at disposal sites include the nature of the sea bed and its proximity to the marine protected area, and the degree to which material disposed of at the site disperses into the

relevant marine protected area. This will depend upon the density of the material deposited, the depth of water in which the sediment is deposited, the influences of local currents and tidal influences. Each disposal site will have specific characteristics but it is worth bearing in mind that sites defined for disposal of maintenance dredging are normally highly dispersive and need to be in order to avoid a build-up of dredged sediment causing a navigation hazard for the dredger or other shipping.

- 6.61 The remainder of this section therefore refers to dredging plumes associated with navigation dredging in estuaries.
- 6.62 The location of the plume, the amount of sediment released and its density, the speed of tidal currents and background levels of sediment within the water column will all influence the rates of dispersal and decay within sediment plumes. Consequently it is not possible to provide helpful indications of the temporal parameters of dredged plumes.
- 6.63 In tidal situations, sediment plumes do not remain static; they will be drawn further afield by tidal action, currents and wave action, all of which lead to rapid reductions in sediment concentrations. In estuaries, where such plumes may be regarded as particularly significant it is important to bear in mind that the plume will not travel outwards like ripples in a pond, but will form a cigar shape that will eventually disperse (Figure 4).

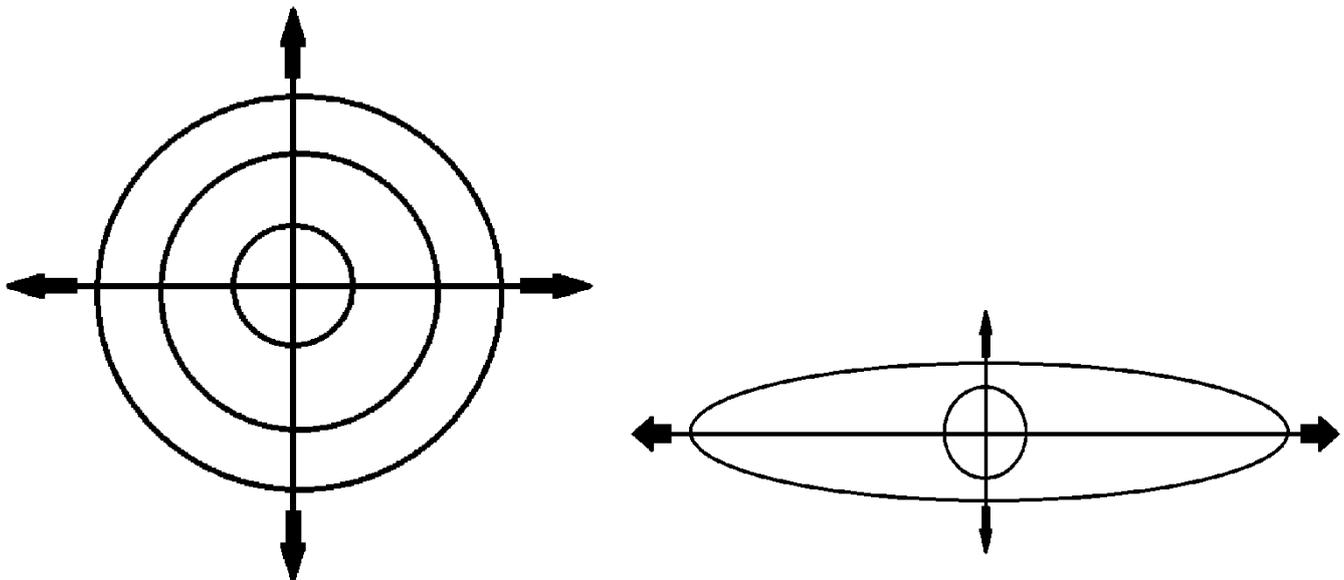


Figure 4 Differences in sediment plumes, with and without tidal influences. Left - no tidal or wind influences leading to outward passage similar to ripples on a pond. Right - the plume is drawn into a cigar shape by tidal influences within an estuary

- 6.64 When evaluating sediment plumes and the relative merits of over-spilling, there are several important considerations to bear in mind:
- Is the estuary or marine area naturally turbid? The levels of natural variation in turbidity will provide a useful indication of the likely significance of dredging plumes. For example, a naturally turbid east coast estuary will experience huge variation in suspended sediment levels according to weather conditions. A big storm can readily elevate suspended sediment levels by several orders of magnitude. In this respect, estuaries which have limited suspended sediment may give more reason for anxiety because the lack of natural turbidity will influence the organisms present (those that dwell in turbid estuaries must be adapted to periods of high suspended sediment because this is a frequent naturally occurring event).

- If the estuary is naturally turbid, will elevating background sediment levels have a beneficial impact on sediment deposition on foreshores? In essence, this is a contribution to positive management that is analogous to some sediment feeding techniques discussed later on.
- The size of the estuary in relation to the likely size of the dredging plume? Dispersal means that the most intense sediment load is relatively close to the dredger and consequently in bigger estuaries the effects will be proportionately smaller.
- How long will the dredger be over-spilling? In any 24-hour period it is likely that the dredger will only be active for a relatively limited period, depending upon the distance it has to travel to the disposal ground. In many cases, for every hour dredging it is likely that there will be three hours lost to disposal, thus suggesting that the creation of a dredged plume will occur twice on any one tide and that it will be largely dispersed by the time dredging resumes. This cyclical process may be referred to as a dredge cycle.
- In tidal waters, the impacts of dredged plumes are likely to be time limited (Ospar Commission 2004) and consequently are short-lived biological impacts particularly significant?
- The time of year when dredging is expected to take place? There may be more reason for concern about dredging during summer months when storms are less frequent and background sediment loads in the water column are that much lower and water temperatures are higher.

Loss of habitat

- 6.65 The most immediate impression of dredging, especially capital dredging, is that it will lead to the loss of sea bed habitat. This is correct, and the levels of loss can be calculated from the overall footprint of the dredge. It is possible in some situations that there will be some natural recovery, especially in rocky environments where the dredge essentially deepens the geometry but is not expected to lead to increased sedimentation. Such situations are rare, but include places such as the Severn Estuary where high sediment loads are dictated by the spring-neap tidal cycle (see Kirby & Parker, 1983).
- 6.66 In most places, any recovery of benthic populations will be short-lived as the need to maintain the channel will lead to removal of newly accumulated sediment and the animals within it. Thus, dredged channels can mostly be regarded to involve a change from stable assemblages to transitory assemblages. The absolute level of loss will depend upon the degree to which a channel or berthing pocket is already maintained, and so the actual loss will usually involve any change in the lateral dimensions of the dredged footprint.
- 6.67 Changes to tidal geometry and sediment loads generate much more complicated questions and can lead to very complex investigations to ensure that there will not be detrimental impacts on coastal habitats. This is because foreshore evolution is closely linked to sediment loads within the water column and wave energy that causes re-mobilisation. For example, it has been shown that foreshore evolution within the Severn Estuary can be extremely sensitive to changes to sediment loads.
- 6.68 The relationship between water column sediment loads and foreshore deposition is also illustrated by the stratigraphy of recent sediment deposition in Southampton Water where the impacts of past dredges can be discerned from sediment layers (Peter Whitehead, ABPmer, *pers. comm.*). The last major dredge in Southampton Water was undertaken in such a manner that suspended sediment levels were greatly elevated and resulted in deposition of a thick layer of whitish sediment.
- 6.69 Shortfalls in sediment can reduce foreshore sedimentation and this affects the relationship between foreshore accretion that compensates for sediment mobilised by wave action. Both capital and maintenance dredging have important implications for sediment availability and the following issues need to be given detailed consideration:

- How will channel deepening affect sedimentation levels and the need to dredge to maintain the declared depth? In most cases, channel deepening creates a void that promotes sedimentation in part of the estuary. Most sedimentation is likely to be in dredged areas and consequently it is important to determine the projected increases in sediment that will have to be removed by maintenance dredging.
- If there is a projected increase in maintenance dredging, where is this sediment coming from and what sort of sediment is it (fine silts and clays or sand)? Coarser material will generally arrive as bedload (i.e. driven along the sea bed in a tumbling fashion rather than in suspension), whilst finer sediments will fall from suspension. It is important to bear in mind that volumes of sediment arriving in suspension from the open sea will only increase at a level consistent with any projected increase in the tidal prism. Therefore, the source of any increased sedimentation is likely to be either an increase in sediment lost from the water column on each tide, or sediment sourced from somewhere else.
- If levels of sediment available to foreshore evolution are reduced by increased sub-tidal deposition then there will be two possible outcomes. Firstly, there may be insufficient sediment available to allow vertical accretion of saltmarshes and mudflats so that they keep pace with sea level rise. In many estuaries, sediment sources have already been compromised by erosion control on the open coast, and so as sea level rise accelerates, sediment shortfalls will lead to drowning of saltmarshes; a process that may be exacerbated by dredging. Secondly, reduced sediment loads in the water column mean that the balance between foreshore accretion and erosion caused by wind-driven waves will adjust such that erosion plays a more significant role. This relationship has not been fully investigated in relation to dredging but is now better understood in relation to reduced sediment loads associated with tidal energy barrages.
- If there is an increasing demand for maintenance dredging then the sediment budget for the estuary needs to be carefully evaluated. Apparent shortfalls cannot be resolved simply by assuming that increased demand for sediment will be met by increased levels of marine-derived sediment.

Smothering

- 6.70 Smothering of benthic and sessile organisms is a potential issue where sediment levels are significantly elevated, either during over-spilling to increase dredger efficiency, or as a result of dredge disposal. The degree to which this will be an issue depends upon a variety of factors, including the nature of the sea bed and the associated organisms, and the types of material involved.
- 6.71 Within muddy estuaries smothering from dredging plumes is unlikely to be a significant issue apart from very exceptional circumstances such as the unusual event in Southampton Water associated with channel deepening in 1996-1997. This is because natural levels of turbidity are extremely variable and will be elevated to very high levels during storms when fine sediments are mobilised from the sea bed in shallow water (where this is within the influences of storm wave depths). Estuaries that exhibit these characteristics support plant and animal assemblages that are adapted to these stressful conditions and consequently localised changes in sediment load are unlikely to have a significant influence on the overall condition of these assemblages.
- 6.72 The issue becomes much more significant as natural sediment loads in the water column diminish, and consequently smothering should be recognised as a matter of concern in estuaries such as the Fal and Helford or Salcombe-Kingsbridge Estuary where there is high water clarity and little sediment is available for mobilisation during winter storms. It may also be important in places such as some estuaries in the Solent such as the Medina.

Contaminated sediments

- 6.73 There are six principal sources of contaminants entering sediments:
- Those derived from rocks eroded by tributaries to the river(s) that form estuaries. These mainly occur in northern and western regions, especially Cornwall where the levels of naturally occurring metals such as copper, arsenic and tin are high. Levels of heavy metals in sediments in some estuaries have also been elevated by eroded mining spoil.
 - Contaminants arising from industrial discharges until tighter restrictions were imposed in the 1970s (for details see UK marine SAC website⁴⁰). These contaminants are often hidden beneath subsequent deposits of clean sediment.
 - Contaminants such as oil and metals (formerly including lead) in storm water overflows containing road run-off.
 - Incidental losses from anti-fouling paint (TBT) on larger vessels, and from poor working practices in boatyards and marinas leading to scrapings being washed back into the marine environment.
 - Oil spills, leading to high levels of poly-aromatic hydrocarbons (PAHs) in some sediments (for example, a contaminated layer caused by the Sivand oil spill in 1983 can still be detected in sediments in the Humber).
 - Inputs of poly-aromatic compounds (PACs) arising from the burning of wood and fossil fuels (coal and oil) from airborne sources entering the water system.
- 6.74 This means that assessment of the implications of re-suspension of contaminated sediments can be extremely complicated. However, there are some useful points to bear in mind.
- 6.75 Capital dredging is the most likely occasion when high levels of contaminants will be encountered. Where major navigation channels are regularly maintained the sediment can be expected to be relatively clean unless there are complicating factors such as high levels of re-mobilisation from contaminated foreshores. This is a form of contamination is most likely to happen in some of the industrial estuaries in north-east England. Frequent dredging in estuaries such as the Humber, Southampton Water and the Stour-Orwell can be reasonably assumed to be clean, although all sediments are tested and assessed by CEFAS before consent is granted.
- 6.76 Problems can occur in some marinas where dredging is infrequent and there may have been historic incidents of poor waterside hygiene leading to material scraped from boats re-entering the marine environment. This problem should have abated because Tributyl-Tin is no longer used in anti-foulants on leisure craft. It is worth bearing in mind, however, that elevated levels of TBT can often be attributed to a single flake of paint and in this respect a misleading reading may be inferred.
- 6.77 Contaminated sediments are an important consideration for marine management. This is why the Food and Environmental Protection Act (1985) regulates disposal of such sediment at sea. However, disposal licences are not granted unless they have been sampled and assessed by CEFAS. Consequently, this is an issue where critical assessment can be deferred to the most competent body (i.e. CEFAS). If the link between CEFAS assessment and consent by the Marine Management Organisation (MMO) is severed at some stage, then there will be more grounds for careful scrutiny and assessment of the implications of elevated levels of contaminants.
- 6.78 The UK does not use tightly defined parameters for judging the acceptability of particular sediments for disposal at sea. EIAs will frequently refer to Dutch reference levels and more rarely to Canadian thresholds, which are considerably tighter. The UK system uses alert thresholds and involves expert interpretation of the data before a decision is made. Natural England and CCW use Canadian guidelines to inform their assessments of the impacts of contaminants in SACs and SPAs. Where it is judged that contaminant levels are unacceptable, dredged sediment has to be

⁴⁰ www.ukmarinesac.org.uk/activities/water-quality/wq1_2.htm

placed in specialist contaminated sediment dumps. This is relatively rarely required, although there have been a number of cases where highly contaminated sediments have been buried at sea as a cheaper alternative. This has recently happened at the Port of Tyne and in Falmouth. In both cases attempts were made to minimise re-distribution of contaminants by use of a backhoe dredger and by burying contaminated sediments under clean sediments.

Water quality

6.79 Elevated suspended sediment can be an issue during the dredging process and when sediments are deposited at offshore disposal grounds. This can have a variety of implications for water quality and for organisms within the marine environment:

- Higher suspended sediment loads can lead to interference with the gills and membranes of marine animals.
- If the sediment contains organic matter, this may remain in the water column. This is a greater risk in muddy environments as sand retains less organic matter. Elevated levels of organic matter will increase potential for microbial action and this in turn has the potential to create a greater demand on available oxygen (Biological Oxygen Demand), leading to reduced levels of dissolved oxygen within the water column.
- Release of nutrients into the water column that enhance phytoplankton growth and in turn lead to greater BOD and reduced levels of dissolved oxygen. This is most likely to be an issue in normally clear water environments, as muddy estuaries tend to undergo periodic sediment re-suspension during periods of increased wave activity.
- Release of toxic contaminants into the water column through desorption from sediment triggered by physical disturbance.

6.80 Water quality problems are most likely to emerge in summer months when water temperatures are higher and biological activity is more pronounced. But, issues may emerge at other times of year coincident with the passage of migratory fish or their larvae returning to the sea. The potential scale of the issue will be highly dependent upon the size of the dredge, its duration and the relative size of the water body concerned. It is also more likely to be an issue in waters that are rarely turbid because those with high levels of turbidity are unlikely to experience significantly higher levels of sediment loading, organic matter and nutrients than are already mobilised.

6.81 The timing of dredging is sometimes used to regulate the levels of suspended sediment created by overspilling and dredged plumes. This may reduce impacts on sensitive organisms such as fish larvae, but there are also geomorphological disadvantages. If sediment loads are higher during periods of quiescence (usually during the summer) then there is more chance of sediment being deposited and remaining on the foreshore. During the winter there is more chance of bigger waves and sediment re-suspension.

Noise

6.82 This is an issue that has received relatively little attention. The most comprehensive review available is Thomsen *et al.* (2009) whose work is predominantly related to the impact of aggregate dredging. This analysis can reasonably be translated into the coastal environment and the impacts of both maintenance and capital dredging because largely similar techniques and equipment are employed (note, bucket ladder dredgers and backhoes are not generally used in aggregate extraction).

6.83 The noise emitted into the water environment by dredgers depends upon a variety of factors including the technique employed and the nature of the sea bed. In general, noise levels are higher where more effort is required to extract the sea bed. This means that the greatest noise levels will arise where capital dredging is cutting through highly consolidated sediments such as mudstones. Higher noise levels will arise where blasting is necessary.

- 6.84 Responses of marine organisms to underwater noise are not fully understood, but there are records of fish exhibiting avoidance strategies, and it is known that low frequency noise emitted by dredgers lies within the wavelengths audible to many cetaceans and seals. The most significant marine mammals in the context of inshore navigation dredging are likely to be seals and harbour porpoise. Fish with swim bladders are more likely to be affected by underwater noise where pressure waves will affect the swim bladder.
- 6.85 Thomsen *et al.* (2009) suggest that the envelope of possible influence from dredging noise could be several kilometres away from the source, and so there are grounds for making an assessment of the possible implications for vertebrates. Much less is known about invertebrates, although decapod crustaceans are known to be able to detect substrate vibrations.
- 6.86 There have been reports of concern about noise emitted by maintenance dredgers affecting shorebirds but this concern should be discounted for the following reasons:
- Almost all of the noise emitted is relatively continuous and consequently birds can be expected to rapidly become habituated, if indeed they are affected at all. (Note, monitoring of bird disturbance by pile-driving for South Humber Bank Power Station demonstrated that shorebirds rapidly habituated to pile-driving nearby).
 - Dredgers usually operate some distance offshore and consequently any significant noise envelope will be some distance away from the shore.
 - There may be a perception that dredging normally involves bucket ladder dredgers, which might be expected to be noisy. However, this sort of dredger is not normally used for maintenance dredging in the UK.

Disposal sites

- 6.87 Disposal of dredged materials at sea is very tightly controlled in the UK. FEPA licenses clearly identify the location of the disposal site and the volumes that are permitted to be deposited by specific vessels. These licenses are also time-limited, and consequently there is scope for review of any issues arising. Disposal sites usually lie in long-established locations or are established after detailed scrutiny and liaison with local interests.
- 6.88 The choice of disposal sites will depend upon the nature of the material to be deposited, and many are selected because the local environment is highly dispersive. This is important because it is not desirable to create uncharted shallow water that would be a hazard to shipping. Grounds for disposal of capital material, which is likely to be more consolidated and less readily mobilised will be in deep water away from major shipping routes. As these are likely to gradually gain elevation, a permitted volume will normally be set for the site. Where major capital dredges are planned, the volumes involved can be immense and in these cases it may be necessary to use a new site specifically allocated for capital material. New disposal sites are rarely consented and this follows extensive assessment and local consultation.
- 6.89 There are several designs that allow dredgers to dispose of dredged material. Those that use offshore disposal grounds are likely to be equipped with doors in the bottom of the hull that allow the material to fall from the hopper. Some, however are designed so that the whole vessel splits in two to allow the hopper to empty. Disposal usually occurs whilst the vessel is moving, so disposal occurs over a broad area within the dump site. This aids dispersal as much of the finest material will be mobilised away from the site before it reaches the sea bed.
- 6.90 Some dredged material is disposed of on land in special disposal sites such as the Cliffe Lagoons, Rushenden disposal site and Barksore Marshes (closed). This material is usually delivered as a slurry and pumped ashore. It offers several advantages in that it reduces pressure on offshore disposal and is now seen as a possible source of recycled aggregates. However, careful consideration needs to be given to impacts on sediment budgets within estuaries (see dredging and physical processes).



© Roger Morris/Bright Angel Coastal Consultants

Figure 5 Rushenden dredge disposal site, 1993. This is the point where sediment arrives in barges and is pumped ashore



© Roger Morris/Bright Angel Coastal Consultants

Figure 6 Rushenden disposal site, 1993. This shows settled material, which includes a high proportion of aggregate that is now being mined to yield commercial aggregate supplies

Commercial issues

- 6.91 Dredging is an inevitable companion of port activity, and consequently it must be expected that there will be some interaction with Marine Protected Areas (MPA) if port facilities (including approach channels) lie within or adjacent to an MPA. Achieving best practice clearly requires both parties (the port and Natural England) to be familiar with and cognisant of the biological issues. However, establishing best practice also benefits greatly from the conservation staff involved understanding the constraints that the port is working to.

Timing

- 6.92 Dredging is one of the most expensive elements of port outlay, and consequently they will try to avoid dredging unless it is absolutely necessary. As it is expensive, and of fundamental importance to port operations, it is very important to bear in mind the timescales that are critical to maintaining port operations.
- 6.93 Capital dredging to deepen existing navigation channels will be dependent upon the completion of the consents process and consequently this should be considered in the context of engaging for major projects. Best practice for this is provided by several projects: Harwich Haven channel deepening (1998) (paragraphs 6.135 to 6.140) and Immingham Outer Harbour (Morris & Gibson, 2007) are particularly useful in this context.
- 6.94 Maintenance dredging where channels have been substantially deepened already is a separate matter. In many cases it is possible to have a broad picture of annual dredging requirements and when dredging is most likely to be necessary. For example, high sediment mobilisation during winter months may mean that more dredging is required in late winter and early spring than in mid-summer. Unseasonal stormy weather may lead to the need for additional dredging and catastrophic events such as the floods in the River Derwent at Workington in 2009 may lead to the need for a rapid response. Consequently there is scope for advance planning of dredging licenses and putting in place the necessary measures to simplify the consents process. This is the underlying principle behind the Maintenance Dredging Protocol (paragraphs 6.163-6.167).
- 6.95 If a port has not signed up to the Maintenance Dredging Protocol and lies within or adjacent to an Natura 2000 site or Ramsar Site, then they will need to leave sufficient time for preparation of supporting environmental information (EIA) to accompany their application for consent under FEPA and the Coast Protection Act (where applicable). If, on the other hand, the port has committed to the maintenance dredging protocol, then they should have prepared a 'baseline document' and should be in a position to seek consent in accordance with the provisions of the agreed baseline.
- 6.96 Occasionally, ports inform the MMO and Natural England at short notice that their disposal licence needs to be renewed. This often means that the MMO and Natural England are required to act under the threat of negative publicity about closing the port. It is incumbent on the industry to recognise that whilst emergencies do occur, this is not an acceptable method of ensuring consent. There are, however, occasional exceptional situations such as the aftermath of the Floods at Workington in 2009, for which Natural England's contribution to the provision of an emergency consent was recognised.
- 6.97 Maintenance dredging consents can take several months to secure, however, and delays often arise because the MMO has to wait for responses from statutory consultees. Fast turn-around of responses and early engagement with the MMO and the port are therefore an essential component of good practice.

Navigation responsibility

- 6.98 Ports are navigation authorities that are required by statute to provide a particular level of access and to declare the safe navigable depth. Each port is authorised by its own piece of legislation.

Formerly this was a specific Act of Parliament, but today it is achieved through a Harbour Revision Order (HRO) under the Harbours Act (1964). Determination of HROs passed from the Department for Transport to the Marine Management Organisation 2010.

- 6.99 It is consequently important to bear in mind that ports have a primary responsibility to ensure that shipping can safely reach berths. However, this does not absolve them of their wider responsibilities. As bodies with specific powers, they are competent authorities and are required to follow the provisions of relevant environmental legislation such as the Conservation of Habitats & Species Regulations, 2010 (also the Natural Environment & Rural Communities Act 2006 and Marine & Coastal Access Act, 2009). It is consequently unacceptable for ports to emphasise that they have more responsibility towards navigation than to the environment, but it is correct to say that their primary function is to facilitate navigation and to recognise that this function may at times be incompatible with nature conservation objectives (or to that matter any other policy priority).

Mobilisation and deployment costs

- 6.100 As ports do not own their dredging capacity, it is important to bear in mind that routine dredging has to be scheduled to fit in with the deployment of a particular vessel. Normally, a port will have a designated contractor, appointed through European tender processes, and consequently there is little flexibility within existing contracts. Consequently, any substantial changes to the types of dredging and timing needs to be considered as a process rather than an abrupt change in regime. This is an important reason for making sure that ports maintain dialogue with Natural England. It is also a significant underpinning factor that makes the Maintenance Dredging Protocol a sensible approach to managing the ongoing process of maintenance of declared depths.
- 6.101 The size of modern dredgers is also increasing, and there is a limited supply of small dredgers that are capable of visiting smaller ports and distributing relatively small volumes of sediment. It is an issue that may become more important with time, as small dredgers can be very important in reducing the impact of sediment loss from estuaries by placing sediment in suitable places for foreshore feeding.

Principles underpinning good nature conservation outcomes: sediment management

Inter-tidal sedimentation

- 6.102 Sediment is the building block of all saltmarshes and mudflats. If there is insufficient sediment then the balance between accretion and erosion will change. This problem is highlighted because most sediment that feeds estuaries in England comes from marine sources (from cliff and wave-cut platform erosion). In many places, cliff erosion has been significantly attenuated by defences and consequently sediment supplies to some estuary systems have been disrupted. This is particularly noteworthy in the Greater Solent where defences now prevent erosion in many places and where adjoining sources such as the cliffs between Bournemouth and Hurst Castle have been highly constrained. It is also an issue in Kent, Essex and Suffolk to varying degrees.
- 6.103 Sediment is needed for two reasons:
- There is a constant cycling of sediment with periods of erosion and periods of accretion. Erosion is most prevalent during periodic storms, whilst accretion tends to happen during periods of quiescence. Accretion and de-watering is also assisted by binding by diatom growth, with primarily occurs during the summer.
 - Relative sea level rise (the combined effects of eustatic and isostatic adjustments) means that saltmarshes and mudflats need to accrete in order to maintain their position within the tidal frame.

- 6.104 This is especially important in estuaries where the majority of SPAs and Ramsar Sites are designated for overwintering migratory waterfowl. Importantly, most of the major port activity and dredging demand lies in muddy estuaries that are very important for migratory waterfowl, and/or are important for various halophytic communities [habitat 1310 *Salicornia* and other annuals colonising mud and sand; habitat 1330 Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*); habitat 1420 Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)]. Many of these estuaries are also designated for the suite of inter-tidal muddy and sandy communities under Habitat 1130 Estuaries.
- 6.105 Consequently, much of the focus of the past 20 years around coastal nature conservation management has concentrated on retaining sediment within systems that need a sediment supply to maintain their form.

Sediment budgets

- 6.106 The use of sediment budgets to evaluate the impact of dredging on estuaries was introduced in the 1990s. The concept is based on the idea that estuaries will naturally progress towards an equilibrium form in which erosive and building processes are roughly balanced. This balance is not static as there are several cycles that change tide levels; most notably the 14 day spring-neap cycle, and the 18.6 year Lunar Nodal Cycle. Consequently the 'equilibrium' is dynamic and fluctuates around a generalised point. This means that erosion and accretion are both part of the process, provided dynamic equilibrium or 'Regime' has been reached.
- 6.107 We have already established that channel deepening alters tidal symmetry and this in turn means that there is a greater potential for sub-tidal sediment deposition, which also means that the estuary is seeking to re-attain its 'Regime form'. Part of the equation is whether there is enough sediment available to feed saltmarshes and mudflats and thus to allow them to adjust to the effects of sea level rise.
- 6.108 A further part of the process is the degree to which eroded sediment is carried offshore and deposited in a locality where it cannot be re-mobilised. Sediment export in higher energy situations is part of the process of 'coastal squeeze' and represents the relationship between incoming wave energy and sediment deposition. If the balance changes such that there is less sediment available for deposition on foreshores there is a greater tendency towards erosion rather than accretion, and consequently loss of sediment can be highly significant to foreshore evolution. The sensitivity of the relationship between sediment availability and wave energy was recently highlighted by studies into the proposed Severn Estuary Tidal Barrage (H. R. Wallingford Ltd. 2010).
- 6.109 There are several components to a sediment budget:

Imports

Fluvial sources (usually small)
Cliff erosion
Sub-tidal erosion
Foreshore lowering (mudflats)
Saltmarsh erosion

Exports

Sub-tidal deposition
Inter-tidal deposition
Export as bedload
Deposition on mudflats
Deposition on saltmarshes
Export as dredged sediment

- 6.110 A useful example of a sediment budget for Southampton Water can be found in the online estuaries guide⁴¹ which is reproduced below (Table 7). This illustrates how inter-tidal sediment erosion is closely aligned to the volumes dredged each year and it may be inferred that dredging is responsible for the net export of eroded sediment from Southampton Water.

⁴¹ www.estuary-guide.net

Table 7 Sediment budget for Southampton Water, reproduced from online estuaries guide (see footnote above)

Sources of Sediment x103 m ³ /year			Sinks and Removal of Sediment x103 m ³ /year		
Intertidal erosion	Southampton Water	53	Intertidal siltation	Southampton Water	-
	Test	23		Test	-
	Itchen	-		Itchen	2
	Hamble	3		Hamble	-
Subtidal erosion	Southampton Water	35	Subtidal siltation	Southampton Water	-
	Test	13		Test	-
	Itchen	2		Itchen	-
	Hamble	-		Hamble	-
Cliff	Southampton Water	5	Dredging	Southampton Water	285
Rivers	Test	10		Test	170
	Itchen	6		Itchen	7
	Hamble	1		Hamble	13
Saltmarsh		6	Saltmarsh		-
Marine Import		321			
Total		480	Total		480

6.111 When capital dredging is modelled it is usually possible to estimate any changes in likely sedimentation and this will have a bearing on the balance within the sediment budget. If dredging requirements are increased then it is likely that the sediment budget will be pushed into deficit (if it is not already in such a situation).

Offsetting measures – sediment husbandry

6.112 The implications of loss of sediment or reductions in sediment supply are that inter-tidal habitats will tend to erode, or they will fail to keep pace with sea level rise.

6.113 In many places such as the Blyth Estuary (French & Burningham 2003), sediment supply is currently sufficient to maintain vertical accretion in saltmarshes despite foreshore lowering on mudflats. It must be borne in mind that sediment mobilised by foreshore erosion will contribute to this process.

6.114 There are, however, many other localities where shortfalls in sediment supply are potentially responsible for disintegration of saltmarsh structure. This is illustrated most comprehensively in the Lympington River where saltmarshes are fragmenting and eroding rapidly. The absolute reasons for decline in Lympington are complex, but reference back to the estuarine form in the 1856 OS map shows how this estuary was then depicted as extensive saltmarshes and close to its 'Regime' form. Subsequent morphological changes been made include excavation of a marina basin and construction of a ferry terminal with associated dredged channel (Morris, in prep.).

6.115 These factors mean that various techniques have been evolved to provide an alternative supply of sediment to saltmarshes and mudflats. These include:

- **Sacrificial deposits on mudflats** (Figure 7a). This involves placement of muddy dredged sediment onto a mudflat with the intention of allowing it to erode and disperse onto adjacent mudflats. Volumes used are small (50-100 m³) and the impact is designed to be small but incremental. The biggest problem with this approach is that equipment suitable for this sort of work is very scarce.
- **Sub-tidal placement on the near-shore seabed** (Figure 7b). This involves placement of sediment from the dredge hopper by opening the hopper doors in shallow water. Controlling factors include water depth and the size of the dredger, which must be small.
- **Rainbowing sediment into the intertidal zone** (Figure 7c). This is a technique that has been trialled in several ways, either placing sediment directly onto mudflats and saltmarshes (Horsey Island), or by placing sediment into the water column above mudflats at high tide (Stour Estuary).

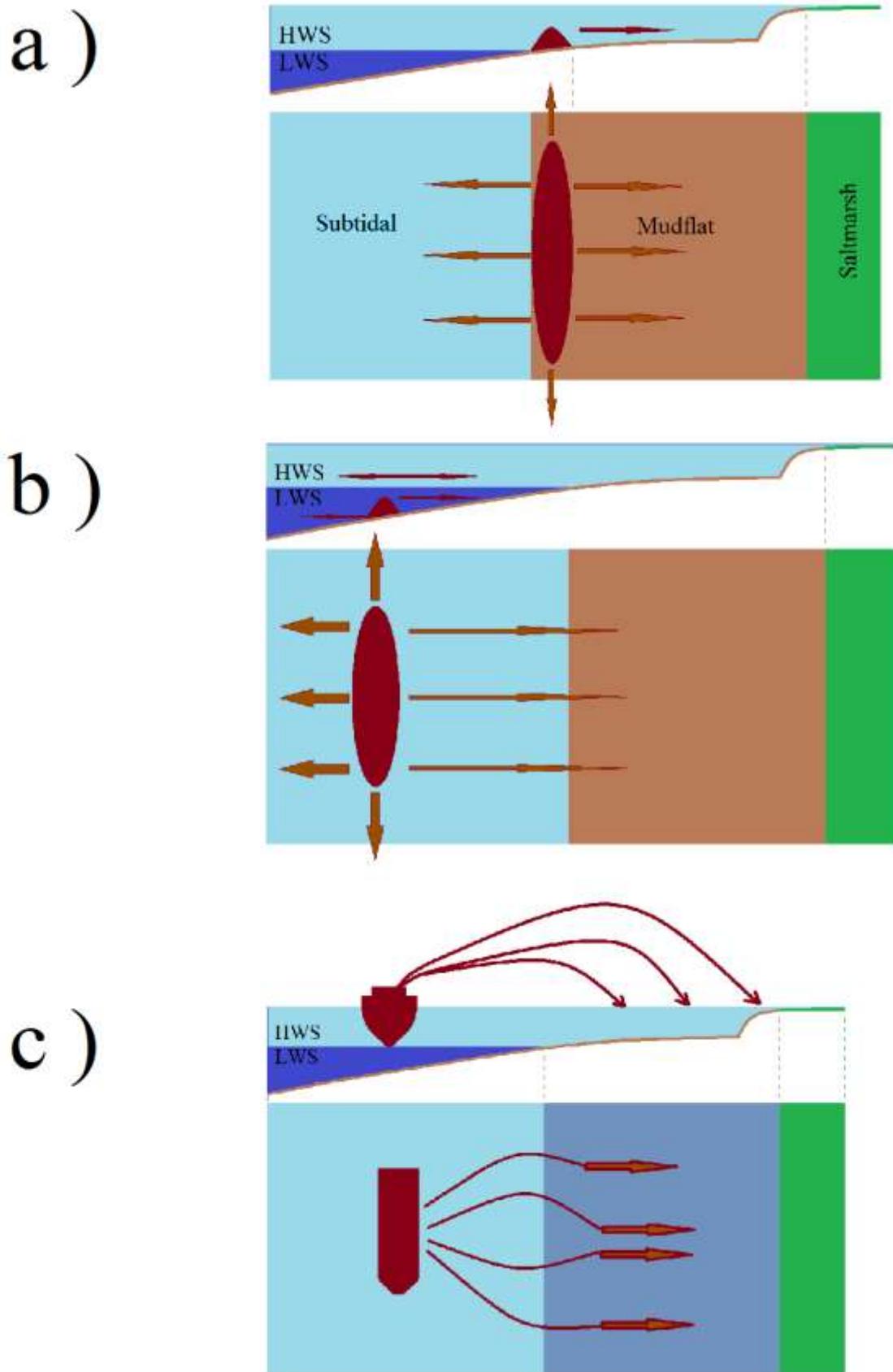


Figure 7 Techniques to augment sediment supplies to saltmarshes and mudflats. a) inter-tidal placement; b) sub-tidal placement; and c) rainbowing

- 6.116 Many of these techniques have been pioneered by Harwich Haven Authority who have developed much of modern 'best practice'. There are now some 12 years of data arising from techniques employed by Harwich Haven Authority and some of this learning can be usefully extrapolated for deployed elsewhere.

Offsetting measures – habitat replacement

- 6.117 When substantial changes are made to the geometry of estuaries by deepening approach channels and the main channel to the port, it is very likely that tidal propagation will be changed. In the UK this has generally resulted in comparatively small changes but in estuaries such as the Elbe and Ems the changes have been profound, involving tens of centimetres or more in far-upstream sections (for example, Herrling & Niemeyer 2006).
- 6.118 In the UK modified tidal propagation has been predicted by modelling in both the Stour-Orwell Estuary and in Southampton Water and the Solent. In the Stour-Orwell it was predicted that low tide levels would rise by 18 mm. Extrapolated around the estuary, it was estimated that the loss of inter-tidal habitat would amount to 4 ha (Morris & Gibson 2007) and was compensated by the creation of a 16.5 ha managed realignment at Trimley. This figure is arrived at by multiplying the width of inter-tidal change and the total length of the foreshore. By comparison, modelling for the current channel deepening of the approach channel to Southampton Water has highlighted reductions of exposure in Southampton Water (muddy) and increases in exposure within the Solent (sandy).

Beneficial use of dredged sediment

- 6.119 The licensing authority is required to consider practical alternative disposal options before consenting disposal at sea. This includes possible beneficial uses of dredged materials. There are several ways in which dredged sediment may be used beneficially in the marine environment, or more particularly in the coastal interface between sea and land. This depends upon the nature of the material to be dredged.
- 6.120 Sandy substrates often lend themselves to beach recharge. This approach is used at Poole Harbour where sand has been used to improve the pleasure beach at Bournemouth. A similar approach has also been used in the mouth of Chichester Harbour where dredged sand has been used to recharge the beaches on Hayling Island. Both of these examples involve sand transported over relatively short distances and used to maintain sediment transport within the sediment cell. In the case of the Chichester Harbour dredge some of the sand is expected to travel westwards towards Portsmouth Harbour and some can be expected to re-circulate into the tidal delta around Chichester Harbour.
- 6.121 Some material won during capital dredging projects can be used for construction of associated port capacity. This approach has been used in several places such as at London Gateway. It is important to differentiate here between capital dredging and maintenance dredging.
- 6.122 Capital dredging largely removes non-mobilisable sediments and consequently will not directly impact on overall sediment budgets apart from the mobilisable sediment within the direct footprint of the dredge. Maintenance dredging, on the other hand, is intended to remove mobilised sediments that play an important part in overall sediment budgets for coastal locations. Loss of these sediments can be significant, and consequently it is not appropriate for sand dredged in this manner to be regarded as a commercial resource.
- 6.123 The best test of this argument is to consider whether aggregate winning would be permitted in the nearshore environment occupied by most dredged channels. This is unlikely because assessment of offshore aggregate resources includes consideration of impact on the near-shore geometry and its implications for wave propagation. Extreme examples of inappropriate removal of near-shore sediments include the case of Hallsands in Devon, a village that was swept away

by a major storm because its protective shingle bank had been exploited for port construction in Plymouth in the late 19th Century (see Melia 2002).

Overspilling

6.124 Overspilling is a natural function of dredging operations and can be a useful way of re-introducing fine fractions back into the water column. It involves returning excess water (with some fine suspended sediment) from the hopper back into the water column and is done to improve the volumes of sediment actually transported on each run to the disposal site. The silts and clays that are released are potentially important to foreshore evolution and consequently their presence in the water column. In general, overspilling is not used specifically for conservation management but is an option that could be utilised where it was felt that there is a need to reintroduce sediment into the water column. Discussions concerning proposed channel deepening in Southampton Water have included the possibility that overspilling might be used to elevate sediment loads in the water column, but this has encountered separate problems with possible impacts on migratory fish.

Tidal cycle

6.125 When considering ways of tackling maintenance dredging and making best use of sediment plumes for foreshore feeding it is worth bearing in mind that suspended sediment stands more chance of being deposited on foreshores when released on rising tides. Conversely, if there is concern about the impact of dredged plumes affecting fish or submerged benthic organisms, dredging on the ebb tide will often be assisted by the tide drawing sediment offshore and mixing it in the open sea. In both cases, however, it should be borne in mind that restricting dredging activity to particular tides will increase costs substantially and may therefore be impractical other than as a general principle to try to get the dredging cycle better aligned with flood or ebb tides. It is worth bearing in mind that spring and neap tides reach different parts of the foreshore and possibly the greatest benefit of elevating sediment loads will be gained on the biggest tides when upper inter-tidal is inundated. This provides sediment that will allow saltmarshes to gain elevation.

Disposal sites – policy implications

- 6.126 At the moment, offshore disposal grounds are located according to the relative pressures of economic disposal distance, highly dispersive situations and the desire to prevent sediment return to its point of origin. This means that over time near-shore sediment depletion may be a pressing issue. For example, the sediment budget for Southampton Water clearly shows how a very substantial part of the sediment disposed at offshore grounds originates from eroding saltmarshes and mudflats. A similar situation almost certainly occurs in the Lymington River (analysis in Morris *in prep*). It may therefore be necessary to re-evaluate dredge disposal to try to keep more dredged sediment in the near-shore environment so that sediment depletion is arrested.
- 6.127 Even though marine disposal in offshore locations has the potential to be an increasingly important problem, disposal to land-fill is more important because this sediment is permanently lost to coastal processes. Pump-ashore facilities are still used by the Port of London Authority at Cliffe Pools and at Rainham Marshes and there is also a land-side disposal site at Rushenden on the Isle of Sheppey that is currently being mined for recyclable aggregates.
- 6.128 Sea level rise will exacerbate these problems because there is a need for adequate supplies of marine sediment to allow foreshores to gain height in the face of lateral erosion (Figure 8). Consequently, the possible importance of marine disposed sediment may gain higher prominence.

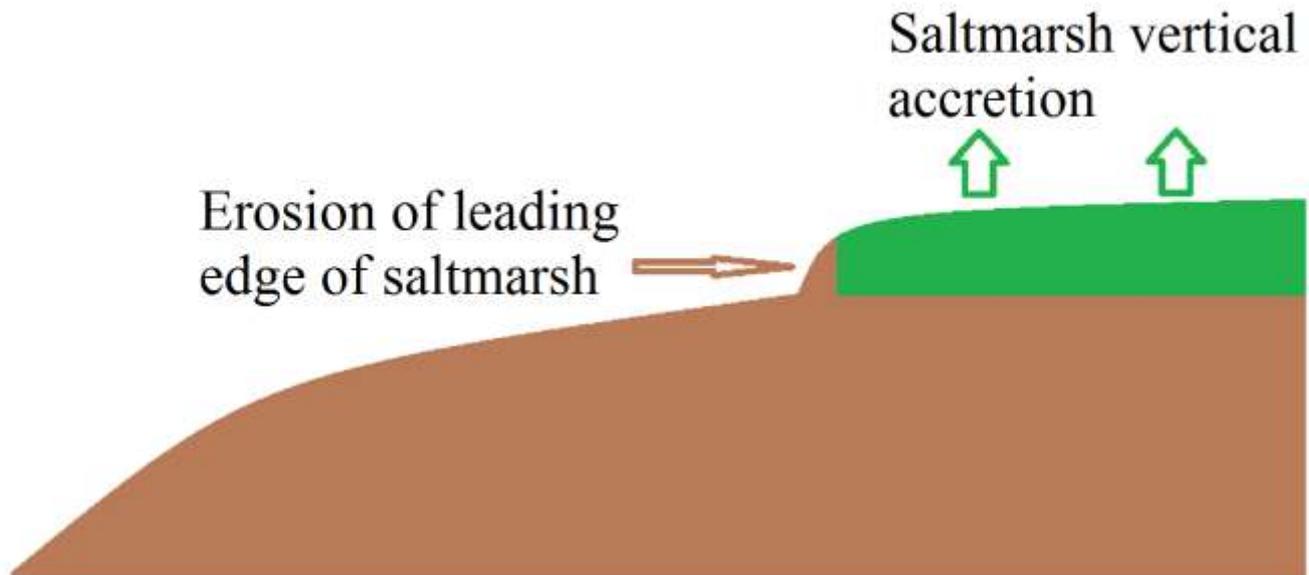


Figure 8 Erosion of the lateral edge of a saltmarsh may also be accompanied by vertical accretion with some of the sediment released by erosion feeding the process of accretion

Case studies

6.129 The following cases have been selected to illustrate the basic principles of evaluating offsetting the effects of dredging. They illustrate how each case is very different, both in the nature and scale of the dredge, as well as in the nature of the sediment and how it can be used. The descriptions have been highly abridged and therefore absolute detail has been lost. Critical learning points are highlighted to illustrate the package of relevant knowledge that may be applied to new cases.

Chichester harbour (beneficial use of dredged materials)

6.130 The navigation channel at the mouth of Chichester Harbour intermittently requires dredging with volumes of around 50,000 m³ of sand arising. This has the potential to deplete sand feeding the spit at East Head, which has been a matter of concern for many years. Part of the solution in the past has been to place the dredged sand on the beach of the adjacent Hayling Island. This foreshore recharge has served three purposes:

- It has been used to improve the leisure beach and its role as a primary flood defence.
- It has kept sand in the overall drift system from Chichester Harbour to Portsmouth Harbour.
- It has taken place in the vicinity of a drift divide, in which some sediment is re-circulated within the mouth of Chichester Harbour and this has allowed some sediment to be naturally circulated back into the mouth of the Harbour.



(based on Google Earth image)

Figure 9 Conceptualised illustration of sediment movement in the mouth of Chichester Harbour

6.131 This example is important for the following reasons:

- Maintenance dredged material is mainly kept within the sediment transport system and as such this minimises overall levels of disruption.
- The choice of placement can be adjusted so that concerns about geomorphological impacts can be addressed to a degree.
- It illustrates how the statutory requirement to maintain navigational access may only be resolved by making best use of the dredged material on adjacent beaches.

Ems Estuary channel deepening (severely elevated tidal propagation)

6.132 The Ems Estuary in north-west Germany has been deepened on several occasions to improve depths to the Meyer Werft shipyard at Papenburg. Progressive deepening has been accompanied by increased tidal propagation (higher high tides and reduced low tides) as far as the weir at Hebrum. This has been accompanied by increased sediment load within the water column referred to as 'Tidal Pumping'. 'Tidal pumping' is a process that is also recognised in the Elbe Estuary as a consequence of channel deepening as far as the port of Hamburg, and elevated tides are also seen in the Western Schelde (Belgium). The implications of deepening in the Ems have been severe:

- Increased sediment load within the water column leads to significant oxygen sags in summer months.
- Fish populations have crashed.
- Numbers of benthic organisms have been significantly reduced.
- Water tables in adjacent sandy and peaty soils have dropped and caused subsidence to buildings (Note, similar situations have occurred on the Seine Estuary).
- Volumes of dredging necessary to maintain the channel have increased substantially and are now a significant economic drain on the local authorities' budgets.

- 6.133 The processes that cause 'tidal pumping' are also seen in other circumstances, exemplified by the spring-neap sediment cycle in the Severn Estuary (Kirby & Parker, 1993). The crucial issue is that the flood tide enters at a sufficiently fast rate to re-mobilise sediment that has been deposited on the flood stand and over the ebb tide. This sediment is combined with newly arrived sediment from marine sources and gradually the overall sediment load increases and fluid mud develops in upstream sections. Various solutions have been proposed, involving physical changes to the mouth (a sill and also constriction of the mouth). Soft engineering solutions that have been suggested include re-connecting tributaries of the estuary, removal of the upstream weir and the creation of sedimentation basins (essentially a form of managed realignment).
- 6.134 This case is important because:
- It demonstrates how under certain circumstances channel deepening in an estuary that lacks adequate accommodation space leads to elevated sediment loads.
 - It highlights severe environmental risks from increased tidal propagation under very specific circumstances.
 - It is closely linked to providing access to ports at far-inland locations (this is not a major issue in the UK but may arise as pressure to accommodate bigger ships at smaller inland ports increases).
 - The associated environmental problems are very difficult to resolve and may be economically unrealistic. This may have a bearing on whether offsetting measures can be devised that are both environmentally and economically sustainable.

Harwich Haven capital dredge (1998/1999) (compensation and mitigation)

- 6.135 This is one of the most important cases involving channel deepening because it highlighted the potential for channel deepening to lead to changes in tidal propagation. It was also important because the package of offsetting measures was finally judged to be a combination of mitigation and compensation. This has an important bearing on how present and future channel deepening in estuaries may influence decisions relating to inter-tidal nature conservation.
- 6.136 Modelling predictions indicated that reduced tidal range (18mm) would lead to the immediate loss of 4ha of muddy inter-tidal (i.e. no longer exposed). This figure was arrived at by extrapolating the increase in low tide levels combined with the slope of the inter-tidal and the overall length of the foreshore within the designated site (SPA & Ramsar). In addition, it was predicted that interception of fine sediment in the dredged channel would lead to increased foreshore erosion, adding a further 2.5 ha per year of losses.
- 6.137 The offsetting package therefore comprised: 4ha to offset the initial loss, together with 12.5 ha to offset the risk that an accompanying package of foreshore sediment feeding would take time to take effect. This was judged by the then Department for Environment, Transport & the Regions (DETR) to involve compensation because the offsetting involved realignment of sea wall to create new habitat outside the designated site.
- 6.138 The sediment feeding programme, which involved 600,000 wet tonnes of maintenance dredged sediments was judged to be mitigation. It has involved a mixture of sediment placement within the Stour Estuary close to and on the foreshore, and placement at the mouth of the Stour/Orwell. Arrangements for sediment feeding have been adjusted in consultation with the Regulators Group that was established to oversee the programme of mitigation. This group technically only comprises statutory bodies but is also attended by the NGOs; it is judged to be one of the factors behind the success of the overall package.
- 6.139 Subsequently, this sediment feeding package has been adjusted to take account of new developments (Felixstowe Trinity IIIb, Felixstowe South) and in response to monitoring results. Monitoring suggests that this approach has been successful in countering loss of sediment from foreshores and may even have improved sedimentation over some foreshores. However, the

numbers of some migratory waterfowl in the Stour-Orwell appear to have dropped (high tide counts). Numbers of species preferring muddy coasts (for example, dunlin) have dropped, whilst numbers of species that prefer more sandy substrates have risen (for example, bar-tailed godwit). The reasons for these changes are as yet unresolved.

6.140 This case is important because:

- It establishes the relationship between channel deepening and possible loss of inter-tidal habitat (note other cases involve different changes - see Ems Estuary).
- It creates a link between dredging and loss of sediment that compounds foreshore erosion.
- It established a testing ground for sediment feeding that has demonstrably led to stabilisation of negative impacts of maintenance dredging.
- It established the principle of convening a Regulators Group with additional representation by NGOs that has created a positive working environment in which changes to the programme of measures can be discussed and agreed in response to monitoring outputs.
- It establishes good practice and emphasises that ports can behave in an environmentally responsible manner.

Humber Estuary: Sunk Dredged Channel (incidental beneficial use)

6.141 The Humber Estuary is a very unusual system. It is the most heavily sediment-laden estuary in the UK and its waters are often distinctly muddy. This is the type of environment where heavy sedimentation might be expected; and this is certainly the case where realignments to flood defences have been undertaken. However, inter-tidal habitats are poorly represented by saltmarsh and this suggests that the estuary has insufficient accommodation space to disperse wave and tidal energy (see Morris *et al.* 2004).

6.142 The main dredging in the Humber occurs within the locked ports of Grimsby & Immingham and Hull, and within the main navigation channel: the Sunk Dredged Channel. Dredging demand varies greatly from year to year (from 5.4m wet tonnes in 1993 to 17.1m wet tonnes in 1996 (ABP, 2008). All dredged sediment is returned to the estuary at a variety of localities, several of which are in the outer estuary. The dredging regime in the Sunk Dredged Channel is of particular interest because dredging demand varies hugely (Figure 10) and apparently cyclically.

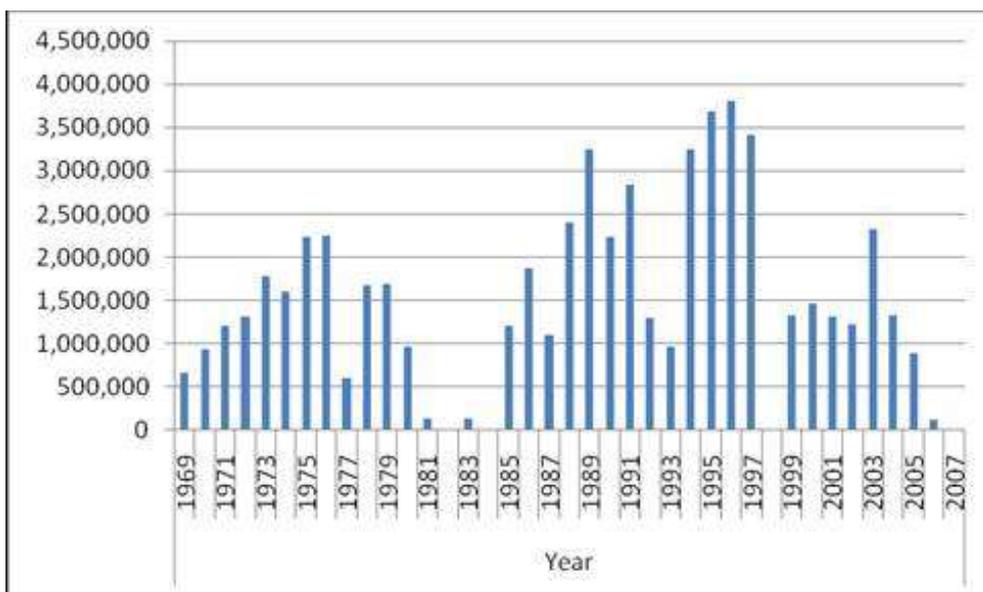


Figure 10 Maintenance dredging (cubic metres) from the Sunk Dredged Channel, Humber Estuary [after ABP (2008)]

- 6.143 The mechanism that controls this rise and fall in dredging demand is believed to be associated with rainfall (Pontee *et al.*, 2004). This variability is important because it shows the dynamism in sediment mobilisation and deposition that makes it difficult to fully evaluate individual dredges in a wider context. Long runs of data help to put the system into perspective and consequently it is important to evaluate maintenance dredging in this broader context.
- 6.144 The practice of returning sediment to the system is best illustrated by the Humber Estuary but this must be put into context. The estuary is naturally muddy; it carries huge volumes of sediment on each tide and consequently the additional loads imposed on the system are relatively small and will not be discernible far from the disposal site. Such scenarios are relatively rare and are mainly confined to a few muddy estuaries on the east coast. Elsewhere, sediment loads in the water column are much lower and dramatic increases in sediment load may not be quite so appropriate.
- 6.145 This case is important because:
- It highlights a mechanism for fluctuating levels of sediment mobilisation;
 - It exemplifies the practice of sediment husbandry and retention within the system;
 - It is a situation where economic expediency and geomorphological pressures coincide to deliver a sustainable solution; and
 - It demonstrates the close relationship between sediment loading and accommodation space (even though there is adequate sediment there is virtually no saltmarsh in the estuary).

Port of Rotterdam (landside disposal of contaminated sediment)

- 6.146 The Port of Rotterdam lies at the mouth of the River Rhine, which passes through major industrial centres in Germany. This means that the port is effectively the sink for contaminants carried downstream from industrial sources. Consequently, contaminant loads in dredged sediments can be at levels that are unacceptable for disposal at sea. The solution at Rotterdam has been the construction of a sedimentation basin 'The Slufter' near the entrance to the port. Contaminated sediments are transferred to this site where they are allowed to de-water. Treated water is returned to the sea, whilst contaminated sediments are stored. Some sand is treated and used commercially.
- 6.147 This case is important because:
- It provides a possible model for managing highly contaminated dredged sediments.
 - It illustrates how the costs of remediation of contamination may be borne by a third party (i.e. the port rather than the original source of contaminants).

- 6.148 The Rotterdam model is not one that will necessarily be needed in the UK but there are parallels such as the use of disused docks to provide a sealed environment in which contaminated sediment can be isolated.

Port of Tyne (trial burying of contaminated sediment)

- 6.149 The port of Tyne needed to dispose of 60,000m³ of heavily contaminated sediment (TBT/DBT & heavy metals). Costs precluded terrestrial landfill disposal and an offshore solution was sought. The agreed approach (with CEFAS) was for the dredged sediment to be capped with a combination of silt and then sand in accordance with techniques developed by the US Army Corps of Engineers (Palermo *et al.* 1998).
- 6.150 The contaminated sediment was raised using a backhoe dredger. This is an important consideration because this technique allows a high proportion of consolidated material to remain as lumps: the larger the better because this minimises the surface area/volume ratio over which material may be eroded and liquidised. Placement at the disposal site was by a split-hopper barge (in other words, the hopper splits in two at the designated point and the dredged material

falls to the sea bed, predominantly as large lumps). Subsequently a cap of clean silt and then clean sand were placed over the contaminated material. The objective of capping was to ensure that there should be at least a 60cm cap over that part of the disposal site with more than 20cm of contaminated dredged material.

- 6.151 Monitoring (Wilson & Flemming, 2009) indicates that the cap has met its design objectives with substantial areas of cap in excess of 1 metre depth. Levels of contaminants within the disposal site are within acceptable limits with (below Action Level 1).
- 6.152 There are a number of important points to bear in mind from this trial:
- The disposal site is in an area where water depths on the charts are between 43 and 46 metres, which should be below storm wave depth. However, monitoring so far may not have included a period of extreme conditions.
 - Monitoring has indicated that there has been some sediment movement but levels of change have been judged acceptable.
 - The technique is described within the USACE guidance (Palermo *et al.* 1998) as compliant with the London Convention, but the Marine Conservation Society is challenging this interpretation.
 - There will have been an inevitable mobilisation of a proportion of the contaminated material because dredging and disposal are both agitation processes that disarticulate cohesive sediment.
- 6.153 These various points mean that it would be unwise to regard offshore disposal and capping as a readily acceptable approach. It is one that will require assessment on a case-by-case basis and should only be undertaken under very tightly defined parameters. Depending upon longer-term evolution of the cap it may be necessary to consider replenishment of the cap with a coarser material to make sure that the integrity of the mound is maintained.

Seaforth Container Terminal, Port of Liverpool (sediment feeding)

- 6.154 The approach channel to the Port of Liverpool and other ports within the Mersey Estuary crosses the natural line of sediment transport within Liverpool Bay. Progressive construction of training walls designed to reduce the need for dredging has substantially altered both the tidal regime and the wave climate on the Sefton coast (Palermo *et al.* 1998). These changes have led to considerable modifications in the morphology of this coastline with areas of accelerated accretion and erosion. The proposed Seaforth Terminal and related approach channel deepening highlighted concerns about interruption of sediment pathways across Liverpool Bay and into the Mersey Estuary. These comprised:
- Modelling highlighted the potential for a small but significant increase in erosion on the Sefton Coast at Blundell Sands.
 - It was possible that fine sediment deposited within the berthing pockets at Seaforth would otherwise have travelled into the Mersey Estuary where it would have potentially contributed to foreshore accretion.
 - Concerns had been raised that additional sediment that might otherwise reach the Sefton Coast would be intercepted by the deepened channel.
- 6.155 A broad package of mitigation was therefore agreed to offset environmental impacts of the container terminal development (ABPmer 2006). This comprised:
- Re-distribution of sediment from the Seaforth berthing pockets so that fine sediment was returned to the Mersey Estuary where it would distribute into natural sinks within the estuary.
 - Placement of 375,000 m³ of maintenance dredged sediment placed onto the northern side of the dredged channel using two techniques.

- Bottom placement of between 100 - 150,000 m³ in the gap between the training walls off Formby Point.
- Possible use of rainbowing of pipes to place sediment north of the training walls at a variety of locations, thus allowing sediment levels to be replenished and monitored.
- Monitoring and adjusting the volumes taking account of foreshore evolution and any concerns about back pressure on the training walls.

6.156 This case is important because:

- It illustrates the use of a variety of techniques to secure sustainable sediment management.
- It recognises the potential for the sediment feeding ultimately to deliver positive benefits rather than simply maintaining the status-quo.

Southampton Water capital dredge (1996/1997) (sediment mobilisation by spring tides)

6.157 Deepening of the approach channel the port of Southampton from 10.2m to 12.6m⁴². It was not predicted to impose a significant morphological impact on Southampton Water, although it is also important to stress that this case preceded the Harwich Haven Capital Dredge in which issues surrounding changes to propagation were first highlighted. This case is mainly of interest because of the techniques used in the dredge and the impact this had on sedimentation within Southampton Water.

6.158 As this was a capital dredge, the material to be removed was consolidated. This called for the use of both cutting and suction equipment. The chosen approach was to pre-cut the bed and then to use a trailer suction dredger to remove the cut material. This coincided with a major spring tide which mobilised the finer fractions of the cut material and led to deposition of substantial amounts of fine pale sediment on the foreshores, in places exceeding ten centimetres. This was not the intended outcome and is not a technique that is proposed for the forthcoming deepening of Southampton Water.

6.159 Sedimentation in Southampton Water is very closely linked to the spring-neap cycle, with foreshore sedimentation mainly concentrated around spring tides. The mechanism involved relates to the speed of incoming tides which are sufficient to mobilise fine sediment lying in the navigation channel. Hence coincidence between the dredging pre-cut and spring tides led to substantial deposition on the foreshore.

6.160 This case is important because:

- It illustrates how high sediment loads within the water column are associated with foreshore deposition.
- It shows how under certain circumstances high sediment loads within the water column are associated with changes to tidal propagation arising from channel deepening.
- It provides a parallel case to sediment mobilisation in the Severn Estuary on spring tides. Unlike the Severn, neap tides do not appear to be associated with the development of a fluid mud layer, but the risk of such a development is increased by further channel deepening.
- The sedimentation processes can be used as a helpful analogue to describe how water column sediment feeding can be used to improve foreshore sedimentation.

⁴² www.estuary-guide.net

Wallasea Island managed realignment (beneficial use of maintenance dredged material)

6.161 This managed realignment site to offset the loss of Lappel Bank (Port of Sheerness) and Fagbury Flats (Port of Felixstowe) included the need to create 32 ha of saltmarsh. The topography of the site was too low to naturally support saltmarsh and consequently there was a need to find an alternative source of sediment to create suitable habitat. This was secured by creating three independent bunds and pumping 550,000 m³ of maintenance dredged sediment from Harwich Haven (Dixon *et al.* 2008) in to the void. Once settled and consolidated these bunds lay in the approximate tidal elevation suitable for saltmarsh development. Each lay at a slightly different level and consequently this was expected to influence the nature of saltmarsh colonisation.

6.162 This case is important because it:

- Demonstrates how maintenance dredged sediment can be used positively to create new inter tidal habitat.
- Exemplifies co-operative working between ports and nature conservation bodies.
- Establishes the principles for design of realignment sites elsewhere in southern and eastern England.
- Provides a template for inter-tidal habitat restoration to secure better conservation status within marine protected areas.



© Roger Morris/Bright Angel Coastal Consultants

Figure 11 Newly developing *Salicornia* saltmarsh at Wallasea Island, 2008. Note that the main growth is as a band closest to the new sea wall



© Roger Morris/Bright Angel Coastal Consultants

Figure 12 Saltmarsh cover at Wallasea Island spring 2009. Local topographic variation is clear from the patchy nature of the distribution of plants

Regulatory controls

Maintenance dredging protocol

6.163 Maintenance dredging requires individual consents that last for between one and three years and consequently in some estuaries there can be a steady stream of consent applications, all of which need to be assessed in accordance with the Habitats Regulations. This is because any works that requires consent is deemed as a plan or project and therefore Article 6(3) of the Habitats Directive applies. The ports industry has not accepted this interpretation, and the European Dredging Association is still contesting this interpretation. European Commission guidance on the application of the Birds and Habitats Directives in relation to port management advises that where possible such on-going operations should be addressed through the management plan for Natura 2000 sites (European Commission 2011). In the UK, Defra has recognised the problem of multiple and ongoing consents and developed the 'Maintenance Dredging Protocol' in a joint initiative with the ports industry and English Nature. It was finally adopted after Natural England signed off the concept in 2007.

6.164 The main rationale for the Maintenance Dredging Protocol is as follows:

- In theory, where maintenance dredging affects Natura 2000 sites (or SSSI) applications should be accompanied by an Environmental Statement. This creates a permanent administrative loop that is both costly to supply and also costs the statutory bodies a great deal in time and effort. Each leads to costs and delays that cannot be regarded as 'better regulation' and therefore a streamlined approach was felt to be needed.
- In bigger estuaries, several ports may be involved, together with a variety of other operators. This means that there can be a constant flow of consent applications which are a severe drain on the Regulator's and Statutory Nature Conservation Organisation's resources.
- Putting individual dredges into context is extremely difficult because the sediment management issues invariably involve long-term incremental change that is difficult to detect at the scale of individual dredges. Moreover, small dredges for marinas could be excessively disadvantaged if judged in combination with large dredges for a major port.
- From a conservation management perspective, it is the cumulative effects of dredging that are critical to avoiding negative geomorphological issues. Consequently the most practical way of assessing the impact of dredging is to look at historic levels of dredging and placing them into context of the overall sediment budget for the estuary concerned.
- There is a need to meet the requirements of both the Habitats Directive and the EIA Directive, but to do so in a manner that is proportional and practical; otherwise regulatory processes could be undermined.

6.165 The Protocol has therefore been developed on the following lines:

- It was designed strictly to deal with problems in Natura 2000 sites and was not intended for other SSSI and preceded Marine Conservation Zones.
- In most (but not all) cases where maintenance dredging occurs regularly there will already be a substantial body of information available on volumes and impacts. This is especially true where ports have recently sought consent to deepen or widen navigation channels and have commissioned modelling and associated EIA. In these cases there should be sufficient information to prepare a baseline document that sets out the sum of knowledge.
- There is a need for ports within a particular estuary to reach accord and to agree a lead port to commission the preparation of a baseline document. Costs can then be dispersed according to the relative levels of dredging undertaken by individual ports and marinas.
- The model for the baseline document will depend upon the size of the ports, the level of dredging and the significance of dredging as an issue in relation to the Natura 2000 interest. Three trials were tested: Humber, Medina and Fal-Helford.
- Preparation of the Baseline Document requires the active input of Natural England. Their contribution is the drafting of the description of the nature conservation interest and also in defining the likely impacts of dredging. The document effectively includes an 'Appropriate Assessment' in which the likely significant effects are assessed and any mitigation measures (for the impacts of maintenance dredging).
- Once a Baseline Document has been prepared it is submitted to Defra for 'sign off', at which point Natural England is required to confirm that it concurs with the findings.
- Once a Baseline Document has been agreed, the consents process becomes streamlined with the Competent Authority (Marine Management Organisation) consulting the Statutory Nature Conservation Organisation which should be able to issue a standard letter confirming that the proposed maintenance dredge conforms to the description in the Baseline Document.
- If one of the participating ports seeks consent for new dredged pockets or channel deepening, responsibility for updating the Baseline Document falls to that Authority. Any offsetting measures associated with capital projects need to be embedded within the baseline document.
- The main point where questions may arise is in peculiar circumstances where a particular maintenance dredge is projected to significantly exceed the limits of deviation set within the

Baseline Document. These limits will normally be the uppermost level of dredging that have occurred in a particular locality over the preceding ten years.

- 6.166 All ports within or adjacent to Natura 2000 sites were invited to participate in the development of baseline documents. Uptake has been patchy and some have probably not recognised the benefits this approach brings. If they choose not to prepare a baseline document then they must expect to submit full documentation when seeking consent for future maintenance dredging projects. A prioritised list of ports was prepared in 2007 and it was anticipated that the programme would be complete by 2011. A total of six baseline documents have been developed and 10 are under development; however momentum has been lost. The Port of London's Dredging Liaison Group is particularly noteworthy.
- 6.167 There are, however, potential pitfalls to the use of the Maintenance Dredging Protocol:
- The approach is dependent upon all ports within a particular estuary of geomorphologically coherent water body committing to the development of a baseline document.
 - There is a need for a lead authority and for participating ports to contribute to the preparation and revision of the document. Ports that do not sign up to the Protocol and its objectives must continue to submit a full EIA with applications for maintenance dredging.
 - There is a need to maintain corporate memory on the use of this approach. New staff in ports, the MMO and in Natural England may not be familiar with the Protocol. There is a risk of a breakdown of communication.
 - Preparation of the nature conservation analysis embedded within the Baseline Document demands technical competency within the relevant Natural England staff. Understanding of the driving principles is patchy and weakened by rapid staff turnover.
 - The rationale for the Protocol may be lost over time as administrative over-load reduces and problems that were faced before the Protocol are forgotten.
 - Revision of baseline documents may not be factored into the process: there is a need to revise the document and its conclusions in response to ongoing Natura 2000 monitoring.

Water Framework Directive

- 6.168 In order to ensure compliance with the Water Framework Directive, the Environment Agency has issued on-line guidance to help applicants for dredging and disposal licences. This is a four-stage process, which includes screening of maintenance operations that were not carried out in the period 2006-2008.
- 6.169 Screening is only applicable to projects that were initiated or ongoing in the period 2006-2008 when the WFD condition assessments were being made. Maintenance activities or those activities that significantly deviate from levels in 2006-2008 require further assessment and pass on to the scoping stage.
- 6.170 Scoping is designed to help regulators and operators evaluate the potential for a non-temporary effect on water status at water body level. It helps the applicant identify those WFD parameters that might be affected and the level to which assessment is required.
- 6.171 Assessment only considers whether the activity will have a significant non-temporary impact at a water body level. In this respect, it differs from assessment under the Maintenance Dredging Protocol because the WFD addresses a wider set of parameters.
- 6.172 Identification & evaluation of measures that can be implemented to reduce effects or lead to environmental improvement.

Good practice matrix

Table 8 Principles of good practice to be employed in considering the management of dredging activities

MEASURE	BY WHOM?	NOTES
Early consultation with statutory agencies	Port/Port's consultants	Where major capital dredges are proposed it is advisable to include the NGOs in discussions. This approach means that key nature conservation interests are fully up to speed and are able to assist in development of offsetting measures.
Timely submission of consent applications	Port	Last-minute applications where the need for renewal is known can only cause problems for SNCBs and this generates mistrust.
Timely responses to Competent Authorities (MMO)	Natural England	Delays cost the port money, increase tensions and cause reputational damage.
Sediment feeding	Port (dredging contractor)	Requires use of appropriate equipment. May be improved by use of small incremental placement by local contractor with small barges. If suitable equipment is not available, may be worth several ports combining resources to commission suitable equipment to service their communal needs.
Over-spilling	Port (dredging contractor)	Under certain circumstances increased over-spilling may be used on the flood tide to place sediment onto foreshores.
Compensatory measures	Port	In certain circumstances, where the loss of inter-tidal to changed tidal propagation is predicted, it may be necessary to create new habitat. This is established as a compensatory measure. Experience has shown that agreement on compensatory measures prior to submission of the application to deepen navigation channels is a fundamental part of the process.
Timing of dredging	Port	Where elevated sediment loads within the water column are likely to impact on migratory fish, it may be necessary to time major dredges to avoid critical times of fish passage (either adults upstream or juveniles travelling to sea).
Beneficial use	Port	Various models exist. These include use of sand to feed nearby pleasure beaches, and delivery of muddy sediments to improve managed realignment sites.

7 References

- ABPmer. (2006) *Mersey Docks & Harbour Company, Seaforth River Terminal and channel deepening: mitigation and monitoring methodology*.
- Acosta, H. & Forrest, B.M. (2009) The spread of marine non-indigenous species via recreational boating: A conceptual model for risk assessment based on fault tree analysis. *Ecological Modelling*, **220**, 1586-1598.
- Addressi, L. (1994) Human disturbance and long-term changes on a rocky intertidal community. *Ecological Applications*, **4**, 786-797.
- Allard, P.R. (1990) *The birds of Great Yarmouth*. Norfolk and Norwich Naturalists' Society, Norwich.
- Andersen, U.V. (1995) Resistance of Danish coastal vegetation types to human trampling. *Biological Conservation*, **71**, 223-230.
- Anderson, L.W.J. (2005) California's Reaction to *Caulerpa taxifolia*: A Model for Invasive Species Rapid Response*. *Biological Invasions*, **7**, 1003-1016.
- Arndt, E., Aydin, N. & Aydin, G. (2005) Tourism impairs tiger beetle (Cicindellidae) populations – a case study in a Mediterranean beach habitat. *Journal of Insect Conservation*, **9**, 201-206.
- Arroyo, B. & Razin, M. (2006) Effect of human activities on bearded vulture behaviour and breeding success in the French pyrenees. *Biological Conservation*, **128**, 276-284.
- Atlantic Trawl Gear Take Reduction Team. (2008) *Draft Atlantic Trawl Reduction Strategy*.
- Bally, R. & Griffiths, C.L. (2008) Effects of human trampling on an exposed rocky shore. *International Journal of Environmental Studies*, **34**, 115 - 125.
- Banks, P.B. & Bryant, J.V. (2007) Four-legged friend of foe? Dog-walking displaces native birds from natural areas. *Biology Letters*, **3**, 611-613.
- Barca-Bravo, S., Servia, M.J., Cobo, F. & Gonzalez, M.A. (2008) The effect of human use of sandy beaches on developmental stability of *Talitrus saltator* (Montagu, 1808) (Crustacea, Amphipoda). A study on fluctuating asymmetry. *Marine Ecology*, **29**, 91-98.
- Barlow, J. & Cameron, G.A. (2003) Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science*, **19**, 265-283.
- Barton, E. & Heard, J. (2004) *Marine Life Topic Note. Alien, Non-native and Invasive Marine species*. Marine Biological Association of the United Kingdom, Plymouth.
- Batten, L. (1977) Sailing on reservoirs and its effects on water birds. *Biological Conservation*, **11**, 49-58.
- Baudains, T.P. & Lloyd, P. (2007) Habituation and habitat changes can moderate the impacts of human disturbance on shorebird breeding performance. *Animal Conservation*, **10**, 400-407.
- Bax, N., Carlton, J.T., Mathews-Amos, A., Haedrich, R.L., Howarth, F.G., Purcell, J.E., Rieser, A. & Gray, A. (2001) The Control of Biological Invasions in the World's Oceans. *Conservation Biology*, **15**, 1234-1246.
- Bax, N., Hayes, K., Marshall, A., Parry, D. & Thresher, R. (2002) Man-made marinas as sheltered islands for alien marine organisms: Establishment and eradication of an alien invasive marine species. *Proceedings of the International Conference on Eradication of Island Invasives*. pp. 26-39.
- Bax, N., Williamson, A., Agüero, M., Gonzalez, E. & Geeves, W. (2003) Marine invasive alien species: a threat to global biodiversity. *Marine Policy*, **27**, 313-323.
- Beale, C.M. & Monaghan, P. (2004) Behavioural responses to human disturbance: a matter of choice? *Anim. Behav.*, **68**, 1065-1069.

- Beale, C.M. & Monaghan, P. (2005) Modeling the Effects of Limiting the Number of Visitors on Failure Rates of Seabird Nests. *Conservation Biology*, **19**, 2015-2019.
- Beauchamp, K. & Gowing, M. (2003a) A quantitative assessment of human trampling effects on a rocky intertidal community. *Marine Environmental Research*, **7**, 279-293.
- Beauchamp, K. & Gowing, M. (2003b) A quantitative assessment of human trampling effects on a rocky intertidal community. *Marine Environmental Research*, **7**, 279-293.
- Bell, S. (2008) *Design for Outdoor Recreation*. Taylor & Francis.
- Bellefleur, D., Lee, P. & Ronconi, R.A. (2009) The impact of recreational boat traffic on Marbled Murrelets (*Brachyramphus marmoratus*). *Journal of Environmental Management*, **90**, 531-538.
- Bird, D.M. (2004) *Natural fit, can green space and biodiversity increase levels of physical activity*. RSPB, Sandy, Bedfordshire.
- Birdlife International. (2009) *European Community Plan of Action (ECPOA) for reducing incidental catch of seabirds in fisheries*. Cambridge, UK.
- Blumstein, D.T., Anthony, L.L., Harcourt, R. & Ross, G. (2003) Testing a key assumption of wildlife buffer zones: is flight initiation distance a species-specific trait? *Biol. Conserv.*, **110**, 97-100.
- Blumstein, D.T., Fernandez-Juricic, E., Zollner, P.A. & Garity, S.C. (2005) Inter-specific variation in avian responses to human disturbance. *Journal of Applied Ecology*.
- Bolduc, F. & Guillemette, M. (2003) Human disturbance and nesting success of Common Eiders: interaction between visitors and gulls. *BIOLOGICAL CONSERVATION*, **110**, 77-83.
- Bonte, D. & Hoffman, M. (2005) Are coastal dune management actions for biodiversity restoration and conservation underpinned by internationally published scientific research? *International conference on nature restoration practices in European coastal habitats*. (eds J. Herrier, J. Mees, A. Salman, J. Syes, H. Van Nieuwenhuysse & I. Dobbelaere), pp. 165-178. VLIZ, Koksijde, Belgium.
- Bonte, D. & Maes, D. Trampling affects the distribution of specialised coastal dune arthropods. *Basic and Applied Ecology*.
- Boorman, L.A. & Fuller, R.M. (1977) Studies on the impact of paths on dune vegetation at Winterton, Norfolk, England. *Biological Conservation*, **12**, 141-148.
- Boorman, L. (2003) *Saltmarsh Review. An overview of coastal saltmarshes, their dynamic and sensitivity characteristics for conservation and management*. JNCC.
- Bowmer, T. & Linders, J. (2010) A Summary of Findings from the First 25 Ballast Water Treatment Systems Evaluated by GESAMP. *Proceedings of the IMO-WMU Research and Development Forum*. Malmo, Sweden.
- Brambilla, M., Rubolini, D. & Guidali, F. (2004) Rock climbing and Raven *Corvus corax* occurrence depress breeding success of cliff-nesting Peregrines *Falco peregrinus*. *Ardeola*, **51**, 425-430.
- Bremner, A. & Park, K. (2007) Public attitudes to the management of invasive nonnative species in Scotland. *Biological Conservation*, **139**, 306-314.
- Bright, A., Waas, J.R. & Innes, J. (2004) Correlations between human-made structures, boat-pass frequency and the number of New Zealand dabchicks (*Poliiocephalus rufopectus*) on the Rotorua Lakes, New Zealand. *N. Z. J. Ecol.*, **28**, 137-142.
- Brown & Caldwell. (2007) Port of Milwaukee Onshore Ballast Water Treatment Feasibility Study Report.
- Brown, A.C. & Grice, P. (2005) *Birds in England*. T.A.D. Poyser, London.
- Brussaard, C., Kuipers, B. & Veldhuis, M. (2005) A mesocosms study of *Phaeocystis globosa* population dynamics. I. Regulatory role of viruses in bloom control. *Harmful Algae*, **4**, 859-874.
- Bull, S.E. (1998) *The impact of dogs on National Trust properties*. Estates Dept., National Trust, Cirencester.

- Burger, J. (1998) Effects of motorboats and personal watercraft on flight behavior over a colony of Common Terns. *Condor*, **100**, 528-534.
- Burger, J. (2003) Personal watercraft and boats: Coastal conflicts with common terns. *Lake Reserv. Manag.*, **19**, 26-34.
- Burger, J., Gochfeld, M., Jenkins, C.D. & Lesser, F. (2010) Effect of Approaching Boats on Nesting Black Skimmers: Using Response Distances to Establish Protective Buffer Zones. *Journal of Wildlife Management*, **74**, 102-108.
- Burger, J. & Leonard, J. (2000) Conflict resolution in coastal waters: the case of personal watercraft. *Marine Policy*, **24**, 61-67.
- Burley, P. (2007) *Report to the panel for the draft south east plan examination in public on the Thames Basin Heaths Special Protection Area and Natural England's Draft Delivery Plan*. Inspectorate, Planning.
- Burton, N.H.K., Evans, P.R. & Robinson, M.A. (1996) Effects on shorebird numbers of disturbance, the loss of a roost site and its replacement by an artificial island at Hartlepool, Cleveland. *Biological Conservation*, **77**, 193-201.
- Burton, R.C.J. & Muir, K. (1974) *The recreational carrying capacity of the countryside, a research report presenting the methodology & results of ecological and psychological surveys of Cannock Chase, Staffordshire*. Keele University.
- Cairns, D.K., Dibblee, R.L. & Daoust, P.Y. (1998) Displacement of a large Double-crested Cormorant, *Phalacrocorax auritus*, colony following human disturbance. *Canadian Field-Naturalist*, **112**, 520-522.
- Calado, M. (1996) Little Tern status and conservation at Ria Formosa Natural Park, Algarve, Portugal. *Colonial Waterbirds.*, **19**, 78-80.
- Carlton, J.T. (2001) *Introduced species in U.S. coastal waters: environmental impacts and management priorities*. Arlington, Virginia.
- Carlton, J.T. & Geller, J.B. (1993) Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms. *Science*, **261**, 78-82.
- Carretta, J.V., Barlow, J. & Enriquez, L. (2008) Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. *Marine Mammal Science*, ???-???
- Cassini, M.H. (2001) Behavioural responses of South American fur seals to approach by tourists — a brief report. *Applied Animal Behaviour Science*, **71**, 341-346.
- Cassini, M.H., Szteren, D. & Fernandez-Juricic, E. (2004) Fence effects on the behavioural responses of South American fur seals to tourist approaches. *J. Ethol.*, **22**, 127-133.
- Casu, D., Ceccherelli, G., Curini-Galletti, M. & Castelli, A. (2006) Short-term effects of experimental trampling on polychaetes of a rocky intertidal substratum (Asinara Island MPA, NW Mediterranean). *Scientia Marin*, **70**, 179-186.
- Chandrasekara, W.U. & Frid, C.L.J. (1996) Effects of human trampling on tidalflat infauna. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**, 299-311.
- Chang, A., Blakeslee, A., Miller, A. & Ruiz, G. (2011) Establishment Failure in Biological Invasions: A Case History of *Littorina littorea* in California, USA. *PLoS One*, **6**, e16035.
- Chatwin, T. (2010) Set-back distances to protect nesting and roosting seabirds off Vancouver Island from boat disturbance.
- Cherel, Y., Weimerskirch, H. & Duhamel, G. (1996) Interactions between longline vessels and seabirds in Kerguelen waters and a method to reduce seabird mortality. *Biological Conservation*, **75**, 63-70.
- Christensen, S. & Johnsen, I. (2001) The lichen rich coastal heath vegetation on the isle of Anholt, Denmark - conservation and management. *Journal of Coastal Conservation*, **7**, 13-22.
- Clarke, R., Sharp, J. & Liley, D. (2008) *Access patterns in south-east Dorset. The Dorset household survey: consequences for future housing and greenspace provision*. Footprint Ecology.

- Coastal Geomorphology Partnership. (1999) *Estuarine morphology and the Habitats Regulations*. Department of Marine Sciences and Coastal Management, University of Newcastle, Report for English Nature.
- Coombes, E.G. (2007) The effects of climate change on coastal recreation and biodiversity.
- Coutts, A. & Forrest, B.M. (2005) *Evaluation of eradication tools for the clubbed tunicate Styela clava*.
- Coutts, A.D. & Forrest, B.M. (2007) Development and application of tools for incursion response: Lessons learned from the management of the fouling pest *Didemnum vexillum*. *Journal of Experimental Marine Biology and Ecology*, **342**, 154-162.
- Covey, R. & Laffoley, D. (2002) *Maritime State of Nature Report for England: getting onto an even keel*. English Nature, Peterborough.
- Cox, T.M., Lewison, R.L., Žydelis, R., Crowder, L.B., Safina, C. & Read, A.J. (2007) Comparing Effectiveness of Experimental and Implemented Bycatch Reduction Measures: the Ideal and the Real. *Conservation Biology*, **21**, 1155-1164.
- Coyle, M. & Wiggins, S. (2010) *European Marine Site Risk Review*. Natural England.
- Creed, J.C. & Amado Filho, G.M. (1999) Disturbance and recovery of the macroflora of a seagrass (*Halodule wrightii* Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. *Journal of Experimental Marine Biology and Ecology*, **235**, 285-306.
- CREOCEAN. (2006) *Projet D'Extraction Et De Transformation De La Crepidule en Rade De Brest*.
- Cruickshanks, K., Liley, D., Fearnley, H., Stillman, R., Harvell, P., Hoskin, R. & Underhill-Day, J. (2010) *Desk based study on recreational disturbance to birds on the Humber Estuary*. Footprint Ecology / Humber Management Scheme.
- Cruickshanks, K., Liley, D. & Hoskin, R. (2010) *Suffolk Sandlings Visitor Survey Report*. Footprint Ecology/Suffolk Wildlife Trust.
- Culver, C.S. & Kuris, A.M. (2000) The Apparent Eradication of a Locally Established Introduced Marine Pest. *Biological Invasions*, **2**, 245-253.
- Curr, R., Koh, A., Edwards, E., Williams, A. & Davies, P. (2000) Assessing anthropogenic impact on Mediterranean sand dunes from aerial digital photography. *Journal of Coastal Conservation*, **6**, 15-22.
- David, M. & Gollasch, S. (2008) EU shipping in the dawn of managing the ballast water issue. *Marine Pollution Bulletin*, **56**, 1966-1972.
- Davies, R., Cripps, S., Nickson, A. & Porter, G. (2009) Defining and estimating global marine fisheries bycatch. *Marine Policy*, **33**, 661-672.
- Davison, D.M. & Hughes, D.J. (1998) *Zostera Biotopes: an overview of dynamics and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science (UK Marine SACs Project).
- DEFRA. (2007) *Maintenance Dredging and the Habitats Regulations 1994: A Conservation Assessment Protocol for England*. Department for Environment, Food and Rural Affairs, Bristol.
- Defra. (2002) *Safeguarding our seas*.
- Defra. (2008a) *The Invasive Non-Native Species Framework Strategy for Great Britain*. Department for the Environment, Food and Rural Affairs.
- Defra. (2008b) *The Invasive Non-Native Species Framework Strategy for Great Britain*. Department for the Environment, Food and Rural Affairs.
- Delaney, D.K., Grubb, T.G., Beier, P., Pater, L.L. & Reiser, M.H. (1999) Effects of helicopter noise on spotted owls. *Journal of Wildlife Management*, **63**, 60-76.
- DelValls, T.A., Andres, A., Belzunce, M.J., Buceta, J.L., Casado-Martinez, M.C., Castro, R., Riba, I., Viguri, J.R., & Blasco, J., 2004. Chemical and ecotoxicological guidelines for managing disposal of dredged material. *Trends in Analytical Chemistry*, **23**: 819-828.

- Denis, T. (2003) Effects of human for traffic on the standing stock, reproduction and size structure of populations of the intertidal rockweed *Silvetia compressa* (O. Fucales).
- Dixon, M., Morris, R.K.A., Scott, C.R., Birchenough, A. & Colclough, S. (2008) Managed realignment: experiences at Wallasea Island. *Maritime Engineering*, **161**, 61-71.
- Donner, P. (2010) Ballast Water Treatment Ashore Brings More Benefits. *Proceedings of the IMO-WMU Research and Development Forum*. Malmö, Sweden.
- Doody, P. & Randall, R. (2003a) *Guidance for the management of coastal vegetated shingle*. Peterborough, UK.
- Doody, P. & Randall, R. (2003b) *Guidance for the management of coastal vegetated shingle*. Peterborough, UK.
- Drewitt, A. (1999) *Disturbance effects of aircraft on birds*. English Nature, Peterborough.
- Dunn, E. & Steel, C. (2001) *The impact of longline fishing on seabirds in the north-east Atlantic: recommendations for reducing mortality*. RSPB.
- Dyer, K.R. (2002) Future Coast Estuary Assessment. *Futurecoast*. Halcrow Ltd.
- Dyrynda, P. & Lewis, K. (1994) *Sedimentary shores in Poole Harbour - Bait harvesting and other human impacts*. Swansea University.
- Eames, I., Landeryou, M., Greig, A. & Snellings, J. (2008) Continuous flushing of contaminants from ballast water tanks. *Marine Pollution Bulletin*, **56**, 250-260.
- Eason, P.K., Sherman, P.T., Rankin, O. & Coleman, B. (2009) Factors Affecting Flight Initiation Distance in American Robins %J *Journal of Wildlife Management*. , **70**, 1796-1800.
- Edwards, V. & Knight, S. (2006) *Understanding the psychology of walkers with dogs: new approaches to better management*. University of Portsmouth, Portsmouth.
- Endresen, Ø., Lee Behrens, H., Brynstad, S., Bjørn Andersen, A. & Skjong, R. (2004) Challenges in global ballast water management. *Marine Pollution Bulletin*, **48**, 615-623.
- English Nature. (2002) *Revealing the value of nature*. English Nature, Peterborough.
- Environment Agency. (2006) *A better place to play, putting pilot voluntary canoe access agreements in place*. Environment Agency, Bristol.
- Erwin, R.M. (1989) Responses to Human Intruders by Birds Nesting in Colonies: Experimental Results and Management Guidelines. *Colonial Waterbirds*, **12**, 104-108.
- European Commission, 2011. The implementation of the Birds and Habitats Directives in estuaries and coastal zones: with particular attention to port development and dredging. 45pp.
- Farrell, P. (1998) Environmental impacts of baitdigging. *Environmental Research for Estuary Management: the Chichester Harbour Approach*. (A de Potiers, Ed.).
- Fearnley, H., Clarke, R.T. & Liley, D. (2010) *The Solent Disturbance and Mitigation Project. Phase II. On-site visitor survey results from the Solent Region*. Footprint Ecology/Solent Forum.
- Fearnley, H. & Liley, D. (2010) *Analysis and presentation of IPF monitoring and projects to inform the heathland DPD*. Footprint Ecology/Dorset County Council.
- Ferguson, R. (2000) *The Effectiveness of Australia's Response to the Black Striped Mussel Incursion in Darwin, Australia*. Darwin.
- Fernandez-Juricic, E., Jimenez, M.D. & Lucas, E. (2001) Alert distance as an alternative measure of bird tolerance to human disturbance: implications for park design. *Environmental Conservation*, **3**, 263 - 269.
- Fernandez-Juricic, E., Jimenez, M.D. & Lucas, E. (2002) Factors affecting intra- and inter-specific variations in the difference between alert distances and flight distances for birds in forested habitats. *Can. J. Zool.-Rev. Can. Zool.*, **80**, 1212-1220.

- Fernandez-Juricic, E., Vaca, R. & Schroeder, N. (2004) Spatial and temporal responses of forest birds to human approaches in a protected area and implications for two management strategies. *Biol. Conserv.*, **117**, 407-416.
- Fernandez-Juricic, E., Venier, M.P., Renison, D. & Blumstein, D.T. (2005) Sensitivity of wildlife to spatial patterns of recreationist behavior: A critical assessment of minimum approaching distances and buffer areas for grassland birds. *Biol. Conserv.*, **125**, 225-235.
- Fitzgerald, A. (2007) *Slipper Limpet Utilisation and Management Final Report*. Port of Truro Authority.
- Fitzpatrick, S. & Bouchez, B. (1998) Effects of recreational disturbance on the foraging behaviour of waders on a rocky beach. *Bird Study*, **45**, 157-171.
- Fletcher, H. & Frid, C.L.J. (1996) Impact and management of visitor pressure on rocky intertidal algal communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**, 287-297.
- Forrest, B.M., Gardner, J.P.A. & Taylor, M.D. (2009) Internal borders for managing invasive marine species. *Journal of Applied Ecology*, **46**, 46-54.
- Forrest, B.M., Taylor, M. & Sinner, J. (2006) Setting priorities for the management of marine pests using a risk-based decision support framework. *Ecological Studies*, **146**, 299-405.
- Fowler, S.L. (1999) *Guidelines for managing the collection of bait and other shoreline animals within UK marine sites*. Prepared for the UK Marine SACs Project by The Nature Conservation Bureau.
- Fowler, S.L. (2002) *Investigation into the extent of bait collection and its impacts on features of conservation interest for biard and intertidal species and habitats within the Solent and Poole Bay Natural Area*.
- Francour, P., Ganteaume, A. & Poulain, M. (1999) Effects of boat anchoring in *Posidonia oceanica* seagrass beds in the Port-Cros National Park (north-western Mediterranean Sea). *Aquatic Conservation: Marine and Freshwater Ecosystems*, **9**, 391-400.
- French, J.R. & Burningham, H. (2003) Tidal marsh sedimentation versus sea-level rise: a southeast England estuarine perspective. Sheraton Sand Key, Clearwater, Florida.
- Galicia, E. & Baldassarre, G.A. (1997) Effects of motorized tourboats on the behavior of nonbreeding American flamingos in Yucatan, Mexico. *Conservation Biology*, **11**, 1159-1165.
- Gearin, P.J., Goshu, M.E., Laake, J.L., Cooke, L., DeLong, R.L. & Hughes, K.M. (2000) Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise, *Phocoena phocoena*, in the state of Washington. *Journal of Cetacean Research and Management*, **2**, 1-10.
- Genovesi, P. & Shine, C. (2004) *European Strategy on Invasive Alien Species*. Convention on the Conservation of European Wildlife and Habitats (Bern Convention), Council of Europe Publishing.
- Genovesi, P. (2005) Eradications of invasive alien species in Europe: a review. *Biological Invasions*, **7**, 127-133.
- Gill, J.A. (1996) Habitat choice in wintering pink-footed geese: quantifying the constraints determining winter site use. *Journal of Applied Ecology*, **33**, 884-892.
- Gill, J.A., Norris, K. & Sutherland, W.J. (2001) Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation*, **97**, 265 - 268.
- Gilman, E. (2004) *Assessment of Strategies to Reduce Seabird Bycatch Employed by Hawaii Pelagic Longline Tuna Vessels and of Observer Program Data Collection Protocols*. Blue Ocean Institute.
- Gilman, E., Boggs, C. & Brothers, N. (2003) Performance assessment of an underwater setting chute to mitigate seabird bycatch in the Hawaii pelagic longline tuna fishery. *Ocean & Coastal Management*, **46**, 985-1010.
- Gilman, E., Brothers, N. & Kobayashi, D.R. (2007) Comparison of three seabird bycatch avoidance methods in Hawaii-based pelagic longline fisheries. *Fisheries Science*, **73**, 208-210.
- Glasby, T.M., Creese, R.G. & Gibson, P.T. (2005) Experimental use of salt to control the invasive marine alga *Caulerpa taxifolia* in New South Wales, Australia. *Biological Conservation*, **122**, 573-580.

- Gollasch, S. (2002) *Report to aid decision making on Ballast Water in OSPAR BDC*. North Seas Directorate, the Netherlands.
- Goss-Custard, J., Triplet, P., Sueur, F. & West, A.D. (2006) Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation*, **127**, 88-97.
- Gough, M.W. & Marrs, R.H. (1990) A comparison of soil fertility between semi-natural and agricultural plant communities: Implications for the creations of species-rich grassland on abandoned agricultural land. *Biological Conservation*, **51**, 83-96.
- Gregg, M., Rigby, G. & Hallegraeff, G. (2009) Review of two decades of progress in the development of management options for reducing or eradicating phytoplankton, zooplankton and bacteria in ship's ballast water. *Aquatic Invasions*, **4**, 521-565.
- Griffith, K., Mowat, S., Holt, R., Ramsay, K., Bishop, J.D., Lambert, G. & Jenkins, S. (2009) First records in Great Britain of the invasive colonial ascidian *Didemnum vexillum* Kott, 2002. *Aquatic Invasions*, **4**, 581-590.
- Grunewald, R. (2006) Assessment of Damages from Recreational Activities on Coastal Dunes of the Southern Baltic Sea. *Journal of Coastal Research*, **22**, 1145-1157.
- H. R. Wallingford Ltd. (2010) *Severn Tidal Power - Sea Topic Paper: Hydraulics and Geomorphology Annex 15 Geo 11: Morphological evolution of the intertidal*. Department of Energy and Climate Change.
- Hall, D.R., Roberts, L. & Mitchell, M. (2003) *New directions in rural tourism*. Ashgate Publishing, Ltd.
- Ham, S.H. (1992) *Environmental interpretation: a practical guide for people with big ideas and small budgets*. Fulcrum Publishing.
- Hammond, M. & Cooper, A. (2004) *Spartina anglica* eradication and inter-tidal recovery in Northern Ireland estuaries. *Proceedings of the International Conference on Eradication of Island Invasives*.
- Hastings, K., Hesp, P. & Kendrick, G.A. (1995) Seagrass loss associated with boat moorings at Rottneest Island, Western Australia. *Ocean & Coastal Management*, **26**, 225-246.
- Herrling, G. & Niemeyer, H.D. (2006) Long-term spatial development of habitats in the Ems-Dollard Estuary. *Harbasins*, 26.
- Hewitt, C. & Martin, R. (2001) *Revised protocols for baseline port surveys for introduced marine species: survey design, sampling protocols and specimen handling*, Centre for Research on Introduced Marine Pests - CSIRO Marine Research, Hobart, Australia.
- Hewitt, D.E. (1973) *Human pressures on soils in coastal areas*.
- Hilliard, R. (1999) *Best Practice for the management of introduced marine pests: a review*. The Global Invasive Species Programme, Cape Town, South Africa.
- Hilliard, R. & Kazansky, O. (2006) *Assessment of Shipping Traffic and Ballast Water Movements to and from Caspian Sea, and preliminary appraisal of possible Ballast Water Management Options*. IMO.
- Hopkins, G.A. & Forrest, B.M. (2008) Management options for vessel hull fouling: an overview of risks posed by in-water cleaning. *ICES Journal of Marine Science: Journal du Conseil*, **65**, 811 -815.
- Hoskin, R., Liley, D., Underhill-Day, J. & Tyldesley, D. (2007) *Lower Hamworthy Former Power Station Site Development Project, Habitats Regulations Assessment*. Footprint Ecology / David Tyldesley Associates / Poole Borough Council.
- Hubert, B. & Huppopp, O. (1993) The influence of excitement on heart rate and oxygen consumption of Kittiwakes (*Rissa tridactyla*). *International Congress on Applied Ethology*. (eds M. Nichelmann, H.K. Wierenga & S. Braun), pp. 540-544. Berlin.
- Hume, R.A. (1976) Reactions of goldeneyes to boating. *British Birds*, **69**, 178-179.
- IMO. (2004) *International Convention for the Control and Management of Ships' Ballast Water and Sediments*. International Maritime Organisation (IMO), Online.

- Irvine, K. (2005) Influence of Trampling Intensity versus Hydration State on Loss of Biomass from the Intertidal Rockweed, *Fucus gardneri*. *Coastal Management*, **33**, 471-481.
- Jackson, M.J. & James, R. (1979) The Influence of Bait Digging on Cockle, *Cerastoderma edule*, Populations in North Norfolk. *The Journal of Applied Ecology*, **16**, 671-679.
- Jenkinson, S. (2009) *Active Woods Design Guidance: Dog and Human Activity Trail*. Forestry Commission/Kennel Club.
- Jenkinson, S. & McCloy, A. (2008) *Walkers with dogs around Winchester*. Hampshire County Council.
- Kahl, R. (1991) Boating Disturbance of Canvasbacks during Migration at Lake Poygan, Wisconsin. *Wildlife Society Bulletin*, **19**, 242-248.
- 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.
- Kaschner, K. (2003) Review of small cetacean bycatch in the ASCOBANS area and adjacent waters - current status and suggested future actions. *4th Meeting of the Parties (MOP 4)*.
- Kazumi, J. (2007) *Ballast Water Treatment Technologies and Their Application for Vessels Entering the Great Lakes via the St. Lawrence Seaway*. Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Phase 2 Transportation Research Board and Division on Earth and Life Studies.
- Keating, J., Maidment, D., MacCallum, M., Christensen, R., Mason, V., Davies, H., Carter, G. & Proctor, M. (2010) *Smash it up! Partnership project to control Pacific pests*. Southern Rivers Catchment Management Authority, New South Wales, Australia.
- Keirle, I. & Stephens, M. (2004) Do walkers stay on footpaths? An observational study of Cwm Idwal in the Snowdonia National Park.
- Kelly, J. & Maguire, C. (2009) *Chinese Mitten Crab (Eriocheir sinensis) Invasive Species Action Plan*.
- Keough, M.J. & Quinn, G.P. (1998) Effects of Periodic Disturbances from Trampling on Rocky Intertidal Algal Beds. *Ecological Applications*, **8**, 141-161.
- Kerbiriou, C., Le Viol, I., Robert, A., Porcher, A., Gourmelon, F. & Julliard, R. (2009) Tourism in protected areas can threaten wild populations: from individual response to population viability of the chough *Pyrrhocorax pyrrhocorax*. *Journal of Applied Ecology*, **46**, 657-665.
- Kim, A.K., Airey, D. & Szivas, E. The Multiple Assessment of Interpretation Effectiveness: Promoting Visitors' Environmental Attitudes and Behavior. *Journal of Travel Research*.
- Kirby, J., Davidson, N., Giles, N., Owen, M. & Spray, C. (2004) *Waterbirds and Wetland Recreation Handbook*. Wildfowl and Wetlands Trust, Slimbridge, Gloucestershire.
- Kirby, P. (2004) *Cambridgeshire cycleway - surveys of selected stretches 2004*. Buglife -The Invertebrate Conservation Trust.
- Kjerfve, B. (2010) IMO-WMU Global R&D Forum on Emerging Ballast Water Management Systems. *Proceedings of the IMO-WMU Research and Development Forum*. Malmo, Sweden.
- Klaer, N. & Polacheck, T. (1998) The Influence of Environmental Factors and Mitigation Measures on By-Catch Rates of Seabirds by Japanese Longline Fishing Vessels in the Australian Region. *EMU*, **98**, 305-316.
- Kloppers, E.L., St Clair, C.C. & Hurd, T.E. (2005) Predator-resembling aversive conditioning for managing habituated wildlife. *Ecol. Soc.*, **10**, U273-U290.

- Koffijberg, K., Blew, J., K. Eskildsen, K., Günther, B., Koks, K., Laursen, L., Rasmussen, P., Potel, P. & Südbeck. (2003) *High Tide Roosts in the Wadden Sea. A Review of Bird Distribution, Protection Regimes and Potential Sources of Anthropogenic Disturbance*. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.
- Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E. & Williamson, J. (1997) Acoustic alarms reduce porpoise mortality. *Nature*, **388**, 525.
- Kriwoken, L.K. & Hedge, P. (2000) Exotic species and estuaries: managing *Spartina anglica* in Tasmania, Australia. *Ocean & Coastal Management*, **43**, 573-584.
- Kuo, I. (2002) The effectiveness of environmental interpretation at resource-Sensitive tourism destinations. *International Journal of Tourism Research*, **4**, 87-101.
- La Carbona, S., Viitasalo-Frösen, S., Masson, D., Sassi, J., Pineau, S., Lehtiniemi, M. & Corroler, D. (2010) Efficacy and environmental acceptability of two ballast water treatment chemicals and an alkylamine based-biocide. *Science of The Total Environment*, **409**, 247-255.
- Laegdsgaard, P. (2006) Ecology, disturbance and restoration of coastal saltmarsh in Australia: a review. *Wetlands Ecology and Management*, **14**, 379-399.
- Lake, S. (2010) *Assessment of recreational impacts on Dawlish Warren Special Area of Conservaton*. Footprint Ecology/Teignbridge District Council.
- Lewis, T. & Mathews, E.A. (2000) *Effects of human visitors on the behaviour of harbor seals Phoca vitulina richardsi at McBride Glacier Fjord, Glacier Bay National Parl*. Glacier Bay National Park, Gustavus, Alaska.
- Lewison, R.L. & Crowder, L.B. (2003) ESTIMATING FISHERY BYCATCH AND EFFECTS ON A VULNERABLE SEABIRD POPULATION. *Ecological Applications*, **13**, 743-753.
- 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.
- Liddle, M.J. & Grieg-Smith, P. (1975) A Survey of Tracks and Paths in a Sand Dune Ecosystem. II. Vegetation. *The Journal of Applied Ecology*, **12**, 909-930.
- Liddle, M. & Greig-Smith, P. (1975) A survey of tracks and paths in a sand dune ecosystem. I. Soils. *Journal of Applied Ecology*, **12**, 893-908.
- Lidgard, D. (1996) *The Effects of Human Disturbance on the Maternal Behaviour & Performance of Grey Seals at Donna Nook, Lincolnshire, UK*. British Ecological Society.
- Liley, D. & Cruickshanks, K. (2010) *Exe Visitor Survey, 2010*. Reignbridge District Council/Footprint Ecology.
- Liley, D., Mallord, J. & Loblely, M. (2006) *The "quality" of green space: features that attract people to open spaces in the Thames Basin Heaths area*. English Nature, Peterborough.
- Liley, D. (1999) Predicting the consequences of human disturbance, predation and sea-level rise for Ringed Plover population size.
- Liley, D. & Clarke, R.T. (2003) The impact of urban development and human disturbance on the numbers of nightjar *Caprimulgus europaeus* on heathlands in Dorset, England. *Biological Conservation*, **114**, 219 - 230.
- Liley, D., Clarke, R.T., Underhill-Day, J. & Tyldesley, D.T. (2006) *Evidence to support the Appropriate Assessment of development plans and projects in south-east Dorset*. Footprint Ecology / Dorset County Council.
- Liley, D., Lake, S., Underhill-Day, J., Sharp, J., White, J., Hoskin, R., Cruickshanks, K. & Fearnley, H. (2010) *Welsh Seasonal Habitat Vulnerability Review*. Footprint Ecology / CCW.
- Liley, D., Stillman, R.A. & Fearnley, H. (2010) *The Solent Disturbance and Mitigation Project Phase II. Results of bird disturbance fieldwork, 2009/10*. Footprint Ecology / Solent Forum.

- Liley, D., Underhill-Day, J. & Gartshore, N. (2006) *Browndown visitor survey and recommendations for access management within the SSSI*. Footprint Ecology / Hampshire County Council, Wareham, Dorset.
- Liley, D., Underhill-Day, J. & Sharp, J. (2009) *Green Space Quality: Guidelines for SANGS surrounding the Thames Basin Heaths SPA*. Footprint Ecology / Natural England.
- Liley, D. & Sutherland, W.J. (2007) Predicting the population consequences of human disturbance for Ringed Plovers *Charadrius hiaticula*: a game theory approach. *Ibis*, **149**, 82-94.
- Littlefair, C.J. (2003) The effectiveness of interpretation in reducing the impacts of visitors in national parks.
- Lloyd's Register. (2010) *Ballast water treatment technology. Current status*. London.
- Loflin, R.K. (1995) The effects of docks on seagrass beds in the Charlotte Harbor estuary. *Florida Scientist*, **58**, 198-205.
- Lokkeborg, S. (2000) *Review and evaluation of three mitigation measures - bird-scaring line, underwater setting and line shooter - to reduce seabird bycatch in the Norwegian longline fishery*.
- Loosanoff, V. (1961) Biology and methods of controlling the starfish *Asterias forbesi*. *U. S. Bur. Commer. Fish., Fishery Leaflet*, **520**, 1-11.
- Lord, A., Waas, J.R., Innes, J. & Whittingham, M.J. (2001) Effects of human approaches to nests of northern New Zealand dotterels. *Biol. Conserv.*, **98**, 233-240.
- Lück, M. (2003) Education on marine mammal tours as agent for conservation--but do tourists want to be educated? *Ocean & Coastal Management*, **46**, 943-956.
- Maat, K. & de Vries, P. (2006) The influence of the residential environment on green-space travel: testing the compensation hypothesis. *Environment and Planning A*, **38**, 2111 - 2127.
- Madsen, J. (1993) Experimental wildlife reserves in Denmark: a summary of results. *Wader Study Group Bulletin*, **68**, 23-28.
- Madsen, J. (1998) Experimental refuges for migratory waterfowl in Danish wetlands. I. Baseline assessment of the disturbance effects of recreational activities. *Journal of Applied Ecology*, **35**, 386-397.
- Maller, C., Townsend, M., Pryor, A., Brown, P. & St Leger, L. (2006) Healthy nature healthy people: 'contact with nature' as an upstream health promotion intervention for populations. *Health Promotion International*, **21**, 45 -54.
- Mallord, J.W., Dolman, P.M., Brown, A.F. & Sutherland, W.J. (2007) Linking recreational disturbance to population size in a ground-nesting passerine. *Journal of Applied Ecology*, **44**, 185-195.
- Maslo, B. (2010) Evidence-based recommendations for Atlantic Coast piping plover (*Charadrius melodus*) conservation and habitat restoration.
- Maslo, B., Handel, S.N. & Pover, T. (2010) Restoring Beaches for Atlantic Coast Piping Plovers (*Charadrius melodus*): A Classification and Regression Tree Analysis of Nest-Site Selection. *Restoration Ecology*, no-no.
- McEnnulty, F., Bax, N., Schaffelke, B. & Campbell, M. (2001) *A review of rapid response options for the control of ABWMAC listed introduced marine pest species and related taxa in Australian waters*. CSIRO Marine Research, Hobart, Australia.
- Mcleavy, A. (1998) An evaluation of the effectiveness of interpretation as a visitor management tool at Lathkill Dale.
- McNeely, J.A. (2001) *The Great Reshuffling: Human Dimensions of Invasive Alien Species*. The World Conservation Union IUCN Biodiversity Policy Coordination Division, Gland, Switzerland and Cambridge, UK.
- Medeirosa, R., Ramosa, J.A., Paivaa, V.H., Almeidac, A., Pedroa, P. & Antunes, S. (2007) Signage reduces the impact of human disturbance on little tern nesting success in Portugal. *Biological Conservation*, **135**, 99-106.

- Meehan, A.J. & West, R.J. (2000) Recovery times for a damaged *Posidonia australis* bed in south eastern Australia. *Aquatic Botany*, **67**, 161-167.
- Meinesz, A., Belsher, T., Thibaut, T., Antolic, B., Mustapha, K.B., Boudouresque, C., Chiaverini, D., Cinelli, F., Cottalorda, J., Djellouli, A., El Abed, A., Orestano, C., Grau, A.M., Ivesa, L., Jaklin, A., Langar, H., Massuti-Pascual, E., Peirano, A., Tunesi, L., de Vaugelas, J., Zavodnik, N. & Zuljevic, A. (2001) The Introduced Green Alga *Caulerpa Taxifolia* Continues to Spread in the Mediterranean. *Biological Invasions*, **3**, 201-210.
- Melia, S. (2002) *Hallsands: a village betrayed*. Forest publishing, Liverton, Devon.
- Melvin, E.F. & Parrish, J.K. (1999) Seabird Bycatch, Trends, Roadblocks, and Solutions. University of Alaska, Blaine, Washington.
- 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.
- Mikola, J., Miettinen, M., Lehikoinen, E. & Lehtilae, K. (1994) The effects of disturbance caused by boating on survival and behaviour of velvet scoter *Melanitta fusca* ducklings. *Biological Conservation*, **67**, 119-124.
- Milazzo, M., Chemello, R., Badalamenti, F. & Riggio, S. (2002) Short-term effect of human trampling on the upper infralittoral macroalgae of Ustica Island MPA (western Mediterranean, Italy). *Journal of the Marine Biological Association of the UK*, **82**, 745-748.
- Milazzo, M., Badalamenti, F., Ceccherelli, G. & Chemello, R. (2004) Boat anchoring on *Posidonia oceanica* beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. *Journal of Experimental Marine Biology and Ecology*, **299**, 51-62.
- Miller, A., Chang, A., Cosention-Manning, N. & Ruiz, G. (2004) A new record and eradication of the north Atlantic alga *Ascophyllum nodosum* (Phaeophyceae) from San Francisco Bay, California, USA. *Journal of Phycology*, **40**, 1028-1031.
- Moffett, M., McLachlan, A., Winter, P. & De Ruyck, A. (1998) Impact of trampling on sandy beach macrofauna. *Journal of Coastal Conservation*, **4**, 87-90.
- Molnar, J.L., Gamboa, R.L., Revenga, C. & Spalding, M.D. (2008) Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and the Environment*, **6**, 485-492.
- Morris, N. (2003) *Health, well-being and open space literature review*. Edinburgh College of Art and Heriot-Watt University, Edinburgh.
- Morris, R.K.A., Reach, I.S., Duffy, M.J., Collins, T.S. & Leafe, R.N. (2004) On the loss of saltmarshes in south-east England and the relationship with *Nereis diversicolor*. *Journal of Applied Ecology*, **41**, 787-791.
- Morris, R.K. & Gibson, C. (2007) Port development and nature conservation--Experiences in England between 1994 and 2005. *Ocean & Coastal Management*, **50**, 443-462.
- Morrison, S.J. (2006) *Holes Bay Survey, effects of bait digging on feeding behaviour of wildfowl and waders, winter 2005/06*.
- Murison, G. (2002) *The impact of human disturbance on the breeding success of nightjar *Caprimulgus europaeus* on heathlands in south Dorset, England*. English Nature, Peterborough.
- Murison, G. (2007) The impact of human disturbance, urbanisation and habitat type on a Dartford warbler *Sylvia undata* population.
- Murphy, K., Taylor, R. & Phillips, C. (2007a) *Progress of the 2006 *Spartina* eradication program*. Washington State Department of Agriculture, Olympia, Washington, USA.
- Murphy, K., Taylor, R. & Phillips, C. (2007b) *Progress of the 2006 *Spartina* eradication program*. Washington State Department of Agriculture, Olympia, Washington, USA.
- Naylor, R.L., Williams, S.L. & Strong, D.R. (2001) Aquaculture--A Gateway for Exotic Species. *Science*, **294**, 1655 -1656.

- Nehring, S. (2006) NOBANIS – Invasive Alien Species Fact Sheet *Crassostrea gigas*.
- Newsome, D., Milewski, A., Phillips, N. & Annear, R. (2002) Effects of Horse Riding on National Parks and Other Natural Ecosystems in Australia: Implications for Management. *Journal of Ecotourism*, **1**, 52-74.
- Newsome, D., Moore, S.A. & Dowling, R.K. (2002) *Natural Area Tourism: Ecology, Impacts and Management*. Channel View Publications, Clevedon.
- Nimon, A.J., Schroter, R.C. & Oxenham, R.K.C. (1996) Artificial eggs: Measuring heart rate and effects of disturbance in nesting penguins. *Physiology & Behavior*, **60**, 1019-1022.
- Nisbet, I. (2000) Disturbance, habituation, and management of waterbird colonies - Commentary. *waterbirds*, **23**, 312-332.
- Northridge, S. & Thomas, L. (2003) *Monitoring levels required in European Fisheries to assess cetacean bycatch, with particular reference to UK fisheries*. Sea Mammal Research Unit, St. Andrews University.
- Ospar Commission. (2004) *Environmental Impacts to marine species and habitats of dredging for navigational purposes*.
- Palermo, M.R., Clausner, J.E., Rollings, M.P., Williams, G.L., Myers, T.E., Fredetta, T.J. & Randall, R.E. (1998) *Guidance for subaqueous dredged material capping*. US Army corps of engineers.
- Pannell, A. & Coutts, A. (2007) *Treatment methods used to manage *Didemnum vexillum* in New Zealand*. New Zealand Marine Farming Association.
- Pearce-Higgins, J.W. & Yalden, D.W. (1997) The effect of resurfacing the Pennine Way on recreational use of blanket bog in the Peak District national park, England. *Biological Conservation*, **82**, 337 - 343.
- Perakis, A. & Yang, Z. (2003) Options for Nonindigenous Species Control and Their Economic Impact on the Great Lakes and St. Lawrence Seaway: A Survey. *Marine Technology*, **40**, 34-41.
- Pereira, N., Botter, R. & Brinati, H. (2010) A Study of Ballast Water Treatment Applied on Iron Ore Ports in Brazil Using Discrete Simulation. *Proceedings of the IMO-WMU Research and Development Forum*. Malmo, Sweden.
- Perkovic, V., Thomson, K.R., Mitchell, P.J., Gibson, R.N., Atkinson, N., Field, P.L. & Becker, G.J. (2001) Treatment of renovascular disease with percutaneous stent insertion: Long-term outcomes. *Australasian Radiology*, **45**, 438-443.
- Peters, K.A. & Otis, D.L. (2006) Wading Bird Response to Recreational Boat Traffic: Does Flushing Translate into Avoidance? (Jacobson, Ed.). *Wildlife Society Bulletin*, **34**, 1383-1391.
- Peterson, S.L. (2007) Mitigation. *Ecosystem Approach To Longline Fisheries In The Benguela: An Assessment Of Impacts On Seabirds, Sea Turtles And Sharks*. pp. 68-79.
- Pienkowski, M.W. (1984) Behaviour of young Ringed Plovers *Charadrius hiaticula* and its relationship to growth and survival to reproductive age. *Ibis*, **126**, 133 - 155.
- Pinn, E. & Rodgers, M. (2005) The influence of visitors on intertidal biodiversity. *Journal of the Marine Biological Association*, **85**, 263-268.
- Piola, R., Denny, C., Forrest, B.M. & Taylor, M. (2009) Marine Biosecurity: management options and response tools. *Invasive Species Management*. Techniques in Ecology and Conservation Series. Oxford University Press.
- Pretty, J., Griffin, M., Peacock, J., Hine, R., Selens, M. & South, N. (2005) A countryside for health and well-being: the physical and mental health benefits of green exercise. *Countryside Recreation*, **13**, 2-7.
- Pullin, A.S. & Knight, T.M. (2001) Effectiveness in conservation practice : Pointers from medicine and public health. *Conservation biology*, **15**, 50-54.
- Pullin, A.S. & Knight, T.M. (2003) Support for decision making in conservation practice: an evidence-based approach. *Journal for Nature Conservation*, **11**, 83-90.

- Pullin, A.S., Knight, T.M., Stone, D.A. & Charman, K. (2004) Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation*, **119**, 245-252.
- Randler, C. (2006) Disturbances by dog barking increase vigilance in coots *Fulica atra*. *European Journal of Wildlife Research*, **52**, 265-270.
- Rasheed, M.A. (1999) Recovery of experimentally created gaps within a tropical *Zostera capricorni* (Aschers.) seagrass meadow, Queensland Australia. *Journal of Experimental Marine Biology and Ecology*, **235**, 183-200.
- Read, A.J. (2000) *Potential mitigation measures for reducing the by-catches of small cetaceans in ASCOBANS waters*. Duke University, Beaufort, USA.
- Rees, E.C., Bruce, J.H. & White, G.T. (2005) Factors affecting the behavioural responses of whooper swans (*Cygnus c. cygnus*) to various human activities. *Biol. Conserv.*, **121**, 369-382.
- Rehfishch, M.M. (1994) Man-made lagoons and how their attractiveness to waders might be increased by manipulating the biomass of an insect benthos. *Journal of Applied Ecology*, **31**, 383-401.
- Rehfishch, M.M., Clark, N.A., Langston, R.H.W. & Greenwood, J.J.D. (1996) A Guide to the Provision of Refuges for Waders: An Analysis of 30 Years of Ringing Data from the Wash, England. *Journal of Applied Ecology*, **33**, 673-687.
- Reijnen, R., Foppen, R. & Meeuwssen, H. (1996) The effects of traffic on the density of breeding birds of Dutch agricultural grasslands. *Biological Conservation*, **75**, 255-260.
- Reijnen, R., Foppen, R. & Veenbaas, G. (1997) Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation*, **6**, 567-581.
- Remage-Healey, L. & Romero, L.M. (2000) Daily and seasonal variation in response to stress in captive starlings (*Sturnus vulgaris*): glucose. *Gen Comp Endocrinol*, **119**, 60-8.
- Riddington, R. (1996) The impact of disturbance on the behaviour and energy budgets of Brent Geese. *Bird Study*, **43**, 269 - 279.
- Rigby, G., Hallegraeff, G. & Sutton, C. (1999) Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. *Marine Ecology Progress Series*, **191**, 289-293.
- Rigby, G. & Taylor, A. (2001) Ballast water management and treatment. *Trans ImarE*, **113**, 79-99.
- Ritchie, W. (2001) Coastal dunes: resultant dynamic position as a conservational managerial objective.
- Robinson, J.A. & Pollitt, M.S. (2002) Sources and extent of human disturbance to waterbirds in the UK: an analysis of Wetland Bird Survey data, 1995/96 to 1998/99: Less than 32% of counters record disturbance at their site, with differences in causes between coastal and inland sites. *Bird Study*, **49**, 205.
- Rodgers, J.A. & Smith, H.T. (1995) Set-Back Distances to Protect Nesting Bird Colonies From Human Disturbance In Florida. *Conservation Biology*, **9**, 89-99.
- Rodgers, J.A. & Smith, H.T. (1997) Buffer zone distances to protect foraging and leafing waterbirds from human disturbance in Florida. *Wildlife Society Bulletin*, **25**, 139-145.
- Ronconi, R.A. & St. Clair, C.C. (2002) Management options to reduce boat disturbance on foraging black guillemots (*Cepphus grylle*) in the Bay of Fundy. *Biological Conservation*, **108**, 265-271.
- Ruhlen, T.D., Abbott, S., Stenzel, L.E. & Page, G.W. (2003) Evidence that human disturbance reduces Snowy Plover chick survival. *J. Field Ornithol.*, **74**, 300-304.
- Ruiz, G.M., Rawlings, T.K., Dobbs, F.C., Drake, L.A., Mullady, T., Huq, A. & Colwell, R.R. (2000) Global spread of microorganisms by ships. *Nature*, **408**, 49-50.
- Ryan, P.G. & Watkins, B.P. (2002) Reducing incidental mortality of seabirds with an underwater longline setting funnel. *Biological Conservation*, **104**, 127-131.

- Saunders, C., Selwyn, J., Richardson, S., May, V. & Heeps, C. (2000) *A review of the effects of recreational interactions within UK European marine sites*. UK CEED & Bournemouth University.
- Schiel, D. & Taylor, D. (1999) Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *Journal of Experimental Marine Biology and Ecology*, **235**, 213-235.
- Sharp, J. (2010) *Evaluating the public use and effectiveness of Sunnyside Farm*. Footprint Ecology.
- Shaw, P., Lankey, K. & Hollingham, S. (1995) Impacts of trampling and dog fouling on vegetation and soil conditions on Headley Heath. *The London Naturalist*, **74**, 77-82.
- Sinner, J. & Coutts, A. (2003) *Benefit-cost analysis of management options for *Didemnum vexillum* in Shakespeare Bay*. Port Marlborough New Zealand Limited.
- Skeate, E. & Perrow, M. (2008) An undercurrent of change for Norfolk's seals. *British Wildlife*, **19**, 305-314.
- Slatter, R.J. (1978) Ecological effects of trampling on sand dune vegetation. *J. of Biological Education*, **12**, 89-96.
- Smit, C.J. & Visser, G.J.M. (1993) Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area. *Wader Study Group Bulletin*, **68**, 6-19.
- Smith, J.R. & Murray, S.N. (2005) The effects of experimental bait collection and trampling on a *Mytilus californianus* mussel bed in southern California. *Marine Biology*, **147**, 699-706.
- Smith, R. (2004) The Effect of Kite Surfing on Wader Roosts at West Kirby, Dee Estuary. *Dee Estuary Conservation Group*.
- Sneddon, P. & Randall, R.E. (1993) *Coastal vegetation shingle structures of Great Britain: Main Report*. Joint Nature Conservation Committee, Peterborough.
- Spokes, K.E. (1997) An investigation into the effects of trampling on shingle vegetation.
- Stalmaster, M.V. & Kaiser, J.L. (1997) Flushing responses of wintering bald eagles to military activity. *Journal Of Wildlife Management*, **61**, 1307-1313.
- Stephenson, R.C., Wells, S.C. & King, J.A. (2008) *Evaluation Of Exclusion Grids To Reduce The Bycatch Of Dolphins, Turtles, Sharks And Rays In The Pilbara Trawl Fishery*. Department of Fisheries, the government of western Australia.
- Stevens, M.A. & Boness, D.J. (2003) Influences of habitat features and human disturbance on use of breeding sites by a declining population of southern fur seals (*Arctocephalus australis*). *J. Zool.*, **260**, 145-152.
- Stillman, R.A., Goss-Custard, J.D., West, A.D., Durell, S., McGroarty, 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. *J. Appl. Ecol.*, **38**, 857-868.
- Stillman, R.A., West, A.D., Caldow, R.W.G. & Durell, S.E.A.L.V.D. (2007) Predicting the effect of disturbance on coastal birds. *Ibis*, **149**, 73-81.
- Street, L. (2010) *Invasive Non-Native Species*. The Scottish Parliament.
- Stuart, M. (2002) *Incursion response tools for undesirable exotic marine organisms*.
- Sutherland, W.J., Pullin, A.S., Dolman, P.M. & Knight, T.M. (2004) The need for evidence-based conservation. *Trends Ecol. Evol.*, **19**, 305-308.
- Sutton, C.A. & Hewitt, C.L. (2004) *Detection Kits for community-based monitoring of introduced marine pests*.
- Symes, N. & Robertson, P. (2004) *A practical guide to the management of saline lagoons*. RSPB, Sandy.
- Tamburri, M.N., Wasson, K. & Matsuda, M. (2002) Ballast water deoxygenation can prevent aquatic introductions while reducing ship corrosion. *Biological Conservation*, **103**, 331-341.

- Tamelander, J., Riddering, L., Haag, F. & Matheickal, J. (2010) *Guidelines for Development of a National Ballast Water Management Strategy*. GEF-UNDP-IMO GloBallast, London, UK and IUCN, Gland, Switzerland.
- Taube, A. (2010) Microwaves + Ultraviolet + Ozone Ballast Water Treatment. *Proceedings of the IMO-WMU Research and Development Forum*. Malmo, Sweden.
- Taylor, K., Anderson, P., Liley, D. & Underhill-Day, J.C. (2006) *Promoting Positive Access Management to Sites of Nature Conservation Value: A Guide to Good Practice*. English Nature / Countryside Agency, Peterborough and Cheltenham.
- Taylor, K., Anderson, P., Taylor, R.P., Longden, K. & Fisher, P. (2005) *Dogs, access and nature conservation*. English Nature, Peterborough.
- Taylor, M. & Bruce, E. (2000) *Mid ocean ballast water exchange: shipboard trials of methods for verifying efficiency*. Cawthron Institute, Halifax, New Zealand.
- Tempel, D.J. & Gutierrez, R.J. (2003) Fecal corticosterone levels in California spotted owls exposed to low-intensity chainsaw sound. *Wildl. Soc. Bull.*, **31**, 698-702.
- Thames Basin Heaths Joint Strategic Partnership Board. (2009) *Thames Basin Heaths Special Protection Area Delivery Framework*.
- Thiel, D., Jenni-Eiermann, S., Palme, R. & Jenni, L. (2011) Winter tourism increases stress hormone levels in the Capercaillie Tetrao urogallus. *Ibis*, **153**, 122-133.
- Thompson, G. (2005) A child's place: why environment matters to children. *ECOS*, **26**, 9-13.
- TNS Research International Travel & Tourism. (2010) Monitor of Engagement with the Natural Environment: The national survey on people and the natural environment - Annual Report from the 2009-10 survey.
- Townshend, D. & O'Connor, D. (1993) Some effects of disturbance to waterfowl from bait digging and wildfowling at Lindisfarne National Nature Reserve, north-east England. *Wader Study Group Bulletin*, **68**, 47-52.
- Trippel, E.A., Strong, M.B., Terhune, J.M. & Conway, J.D. (1999) Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 113-123.
- Uchimura, M., Rival, A., Nato, A., Sandeaux, R., Sandeaux, J. & Baccou, J. (2000) Potential use of Cu²⁺, K⁺ and Na⁺ for the destruction of *Caulerpa taxifolia*: differential effects on photosynthetic parameters. *Journal of Applied Phycology*, **12**, 15-23.
- Ugolini, A., Ungherese, G., Somigli, S., Galanti, G., Baroni, D., Borghini, F., Cipriani, N., Nebbiai, M., Passaponti, M. & Focardi, S. (2008) The amphipod *Talitrus saltator* as a bioindicator of human trampling on sandy beaches. *Marine Environmental Research*, **65**, 349-357.
- Urfi, A.J., Goss-Custard, J.D. & Lev. 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 Applied Ecology*, **33**, 873-883.
- Van de Werfhorst, L. & Pearse, J. (2007) Trampling in the rocky intertidal of central California: A follow-up study. *Bulletin of Marine Science*, **81**, 245-254.
- Veldhuis, M., Fuhr, F., Boon, J. & ten Hallers-Tjabbers, C. (2006) Treatment of ballast water; how to test a system with a modular concept? *Environmental Technology*, **27**, 909-921.
- Veldhuis, M., ten Hallers, C., Brutel de la Riviere, E., Fuhr, F., Finke, J., Steerhouwer, P., van de Star, I. & van Sloote, C. (2010a) Ballast Water Treatment Systems: "Old" and "New" Ones. *Proceedings of the IMO-WMU Research and Development Forum*. A WMU Publication in collaboration with the GEF-UNDP-IMO GloBallast Partnerships programme and the Global Industry Alliance, Malmo, Sweden.

- Veldhuis, M., ten Hallers, C., Brutel de la Riviere, E., Fuhr, F., Finke, J., Steerhouwer, P., van de Star, I. & van Sloote, C. (2010b) Ballast Water Treatment Systems: "Old" and "New" Ones. *Proceedings of the IMO-WMU Research and Development Forum*. A WMU Publication in collaboration with the GEF-UNDP-IMO GloBallast Partnerships programme and the Global Industry Alliance, Malmo, Sweden.
- Verhulst, S., Oosterbeek, K. & Ens, B.J. (2001) Experimental evidence for effects of human disturbance on foraging and parental care in oystercatchers. *Biol. Conserv.*, **101**, 375-380.
- Vermaat, J.E., Agawin, N.S.R., Duarte, C.M., Fortes, M.D., Marb, N. & Uri, J.S. (1995) Meadow maintenance, growth and productivity of a mixed Philippine seagrass bed. *Marine Ecology Progress Series*, **124**, 215-225.
- Walker, B.G., Dee Boersma, P. & Wingfield, J.C. (2006) Habituation of Adult Magellanic Penguins to Human Visitation as Expressed through Behavior and Corticosterone Secretion. *Conservation Biology*, **20**, 146-154.
- Walker, D., Lukatelich, R., Bastyan, G. & McComb, A. (1989) Effect of boat moorings on seagrass beds near Perth, Western Australia. *Aquatic Botany*, **36**, 69-77.
- Ward Thompson, C., Travlou, P. & Roe, J. (2006) *Free-range teenagers: the role of wild adventure space in young people's lives*. Natural England, Peterborough.
- Weimerskirch, H., Shaffer, S.A., Mabile, G., Martin, J., Boutard, O. & Rouanet, J.L. (2002) Heart rate and energy expenditure of incubating wandering albatrosses: basal levels, natural variation, and the effects of human disturbance. *J Exp Biol*, **205**, 475-83.
- West, A.D., Goss-Custard, J.D., Stillman, R.A., Caldow, R.W.G., Durell, S. & McGroarty, S. (2002) Predicting the impacts of disturbance on shorebird mortality using a behaviour-based model. *Biol. Conserv.*, **106**, 319-328.
- Westcott, S.M. & Stringell, T.B. (2003) *Field observations on the disturbance of grey seals in North Wales, 2003*.
- Whitehouse, R., Balson, P., Beech, N., Brampton, A., Blott, S., Burningham, H., Cooper, N., French, J.R., Guthrie, G., Hanson, S., Nicholls, R., Pearson, S., Pye, K., Rossington, K., Sutherland, J. & Walkden, M. (2009) *Characterisation and prediction of large-scale, long-term change of coastal geomorphological behaviours: Final science report*. Environment Agency, Bristol.
- Whitfield, R. & Roche, R. (2007) UK Personal Watercraft Management: A user perspective. *Marine Policy*, **31**, 564-572.
- Wijsman, J., van Stralen, M., Dubbeldam, M., Geene, R., de Kluijver, M., van Zanten, E. & Smaal, A. (2006) *Wegvisproef Japanse oesters in de Oosterschelde, tussentijdse rapportage*.
- Williams, S. & Grosholz, E. (2008) The Invasive Species Challenge in Estuarine and Coastal Environments: Marrying Management and Science. *Estuaries and Coasts*, **31**, 3-20.
- Wood, A.M. (2001) Coastal erosion and tourism in Scotland: A review of protection measures to combat coastal erosion related to tourism activities and facilities. *Coastal Dune Management: Shared Experience of European Conservation Practice*. Liverpool University Press, Liverpool.
- Woods, C., Floerl, O., Fitridge, I., Johnston, O., Robinson, K., Rupp, D. & Davey, N. (2007) *Evaluation of the seasonal efficacy of hull cleaning methods*.
- Wotton, D., O'Brien, C., Stuart, M. & Fergus, D. (2004) Eradication success down under: heat treatment of a sunken trawler to kill the invasive seaweed *Undaria pinnatifida*. *Marine Pollution Bulletin*, **49**, 844-849.
- Wright, D.A., Gensemer, R.W., Mitchelmore, C.L., Stubblefield, W.A., van Genderen, E., Dawson, R., Orano-Dawson, C.E., Berr, J.S., Mueller, R.A. & Cooper, W.J. (2010) Shipboard trials of an ozone-based ballast water treatment system. *Marine Pollution Bulletin*, **60**, 1571-1583.
- Wright, M., Goodman, P. & Cameron, T. (2010) Exploring behavioural responses of shorebirds to impulsive noise. *Wildfowl*, **60**, 150-167.

- Yasue, M. & Dearden, P. (2006) The potential impact of tourism development on habitat availability and productivity of Malaysian plovers *Charadrius peronii*. *Journal of Applied Ecology*, **43**, 978-989.
- Zeeberg, J., Corten, A. & de Graaf, E. (2006) Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa. *Fisheries Research*, **78**, 186-195.
- Zydelis, R., Bellebaum, J., Österblom, H., Vetemaa, M., Schirmeister, B., Stipnice, A., Dagys, M., van Eerden, M. & Garthe, S. (2009) Bycatch in gillnet fisheries - An overlooked threat to waterbird populations. *Biological Conservation*, **142**, 1269-1281.