BTO Research Report No. 657

Review of knowledge regarding the effect of major estuarine developments on bird populations with reference to proposals for an airport in the Thames Estuary

Authors

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Report of work carried out by the British Trust for Ornithology

May 2014

The British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU
Registered Charity No. 216652

British Trust for Ornithology

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ISBN 978-1-908581-43-3

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EXECUTIVE SUMMARY

1. The proposal to build an airport on the Hoo Peninsula / Isle of Grain would cause a significant loss of both freshwater and intertidal coastal wetland habitat, largely within the Thames Estuary and Marshes Special Protection Area (SPA). It would also cause some loss of habitat from within the Medway Estuary and Marshes SPA. These areas are protected under international law for their internationally important bird populations.
2. Coastal wetland habitat loss of this type has been widely demonstrated to have significant impacts on the bird populations that the habitat supports. We can therefore be confident that habitat loss due to airport development would have significant negative impacts on the bird populations that depend on the areas lost. The Thames Estuary and Marshes and Medway Estuary and Marshes SPAs are designated because together they support populations of 140,515 birds, many of which would be affected by the development either directly (through habitat loss within the airport footprint) or indirectly (e.g. through disturbance or habitat change to areas close to the airport). Over 21,000 waterbirds currently use the area proposed for development and therefore would be directly affect by habitat loss within the airport footprint – this represents around 25% of the current total bird population on the two affected SPAs.
3. Should an airport in the Thames Estuary be taken forward, there would need to be:
    - An appropriate assessment (under the 2010 Habitats Directive (92/43/EEC)) to determine any 'likely significant effects' to these SPAs following any proposed mitigation.
    - If 'likely significant effects' following mitigation are identified in the appropriate assessment, article 6(4) of the EC Habitats Directive allows plans or projects which may have an adverse effect on the integrity of a European site or European marine site (such as an SPA) to go ahead on grounds of 'imperative reasons of overriding public interest' (IROPI) when there are no alternative solutions, but only if compensatory measures have been secured.

   Therefore, should an airport development in the Thames Estuary be constructed it is highly likely that mitigation and compensation would be required to provide alternative habitat for displaced birds.
4. Habitats Directive guidance suggests the area of compensatory habitat provided should be at least twice the area lost, meaning that replacing the habitats lost by the construction of the proposed airport (estimated as 1700 hectares) would require a new site or sites of at least 3400 hectares to be created. Finding suitable areas for such large-scale habitat creation will be challenging given the many competing demands for coastal land use in south-east England.
5. Creating compensatory habitat should an airport be built is further complicated by the types of habitat that would be destroyed, especially intertidal habitat. We currently have limited understanding of how best to engineer and successfully retain the exact sorts of habitats the birds require and therefore uncertainty about the density of each bird species that would be supported on newly created habitat. It is therefore realistic to anticipate the need to create new areas of inter-tidal that were larger than those lost to maximise the chance of suitable habitat developing to support the number of birds lost.
6. As well as the physical challenges of compensation there is also significant financial cost to add to the construction costs of the airport. The cost of creating compensatory habitat is likely to be over £70,000 per hectare and may well be considerably more than this, depending on the sites chosen and site-specific considerations.
7. The challenges caused by the development of an airport in the Thames Estuary vary among the bird species present in the area; for example, many of the bird species affected are site-faithful, and therefore colonisation of new habitat provided some distance away would only occur over a period of many years through the recruitment of juvenile birds to the new sites. Adult birds of site-faithful species displaced from the development area would be likely to remain in the

Thames and Medway Estuaries and would suffer increased mortality over several years following development due to the reduced habitat (and therefore food) availability. Compensatory habitat provided at a distance would therefore not provide direct compensation for displaced individuals of these site-faithful species, but may eventually support equivalent population sizes of these species following several years of recruitment to the new site. However, the long-term consequences of this for bird populations are highly uncertain.

8. There is no precedent for the creation of compensatory habitat at a distance from the area affected by development (for example in Essex or elsewhere in East Anglia as suggested by Foster and partners) and there is considerable uncertainty as to whether providing compensatory habitat at a distance from the Thames and Medway Estuaries would be effective in supporting displaced bird populations, or whether it would be legally viable. The creation of new habitats at a distance from the Thames Estuary and Marshes and Medway Estuary and Marshes SPAs either through managed realignment, topographic modification, or the creation of freshwater wetlands, is likely to be less effective than providing such habitats locally, although it could still be partially effective for several species guilds.
9. The provision of replacement habitat within or adjacent to the Thames and Medway Estuaries is likely to be the most effective option to compensate for the effects of the development on bird populations, although it should be noted that it may be challenging to find suitable sites for this, especially given there are already existing commitments to recreate intertidal habitat in the area to compensate for that lost through coastal squeeze.
10. *Limitations of the study*: This study has been limited to reviewing the likely impact on birds of habitat loss due to the footprint of the airport development, and not any impacts caused by wider infrastructure requirements, such as surface access or housing, on the ability to provide local replacement habitats. The study has not reviewed any wider non-habitat related issues, such as disturbance to birds in areas surrounding the proposed airport. Such impacts are likely to be smaller than the direct habitat loss caused by the airport development, but it will be important to take them into account in an Environmental Impact Assessment should the airport proposal be taken forward.

1. INTRODUCTION

1.1 Background

There has been considerable debate over many years about the need for increased airport capacity in the South East of England and this has led to a number of proposals for a new London Airport in the greater Thames Estuary. The focus of this work is on the recent proposal for a Thames Hub Airport (Foster and Partners), but many of the general issues raised here will also be applicable to other recent proposals including the Goodwin Sands Airport (Beckett Rankine), London Britannia Airport (Gensler), London Jubilee International Airport (Trestad), and Cliffe Airport (John Olsen) although the precise impact of each of these proposals on the internationally important bird populations would vary.

The Thames Estuary is the fifth most important for waterbirds in the UK (Austin *et al*. 2014) and this and adjoining sites such as the Medway Estuary and Swale Estuary are covered by a number of national and international designations which mean that the bird populations are legally protected, and any residual adverse impacts of a development (after mitigation) would have to be compensated for. To date most of the environmental work relating to proposed airports in the greater Thames Estuary has focused on the bird strike risk rather than the effect on the bird populations that depend on the area.

This work aims to address this gap by producing a review of the science behind the prediction of the impacts on bird populations of such developments and empirical evidence from a number of case studies around the world where the impacts of developments have been monitored.

It will also review the mitigation or compensation approaches that have been used and their feasibility and effectiveness to enable likely implementation issues and costs to be broadly understood.

1.2 Project Objectives

The work aims to cover the following areas:

1. Assessment of the importance of the Thames Estuary and Marshes Special Protection Area (SPA), the Medway Estuary and Marshes SPA and relevant adjoining sites for bird populations from published sources;
2. Assessment of the key species and potential numbers that may be impacted by the proposed Thames Hub (note this can only be very approximate as detailed designs are not yet produced);
3. A review of the ability of bird populations to respond to the loss of habitat associated with large scale developments, using examples taken from around the world;
4. A high-level review of potential habitat creation mitigation / compensation measures available and associated issues, and the approximate costs per unit area or bird of such mitigation measures.

Points 3 and 4 will be the core of this work as they will help to inform the debate about what is achievable and what does not work. This part of the project will be produced in the form of a scientific paper that will be submitted to a scientific journal as we believe that a published paper will be helpful in informing the debate.

2. IMPORTANCE OF THE THAMES ESTUARY AND ADJOINING SITES FOR BIRDS

2.1 Importance of the Greater Thames Estuary

The Greater Thames Estuary is a highly important area for birds, and is covered by a number of national and international designations, including six SPAs (Figure 1). It is also a wetland of international importance under the Ramsar Convention. Within Europe there have been extensive long-term historical losses of coastal wetland habitats, such as mudflats, saltmarshes and coastal grazing marsh, due to land reclamation and drainage, flood defences and coastal infrastructure development. More recently, sea-level rise as a result of climate change has also led to loss of these habitats. This means that capacity for remaining habitat to maintain the biodiversity, in particular the internationally important populations of migratory birds that rely on these coastal wetland habitats, is increasingly under pressure. Due to the importance of these sites for migratory birds, a very large proportion of the remaining coastal wetlands around Europe are now protected under international legislation, through the Natura 2000 network which, under the EC Directive on the Conservation of Wild Birds (Directive 2009/147/EC - the codified version of Council Directive 79/409/EEC as amended – the 'Birds Directive'; http://jncc.defra.gov.uk/page-162), includes the designation of Special Protection Areas for birds. The UK is particularly important for migratory waterbird species, with its large areas of coastline, critical position on the migratory flyways of many species, and relatively mild winter climate.

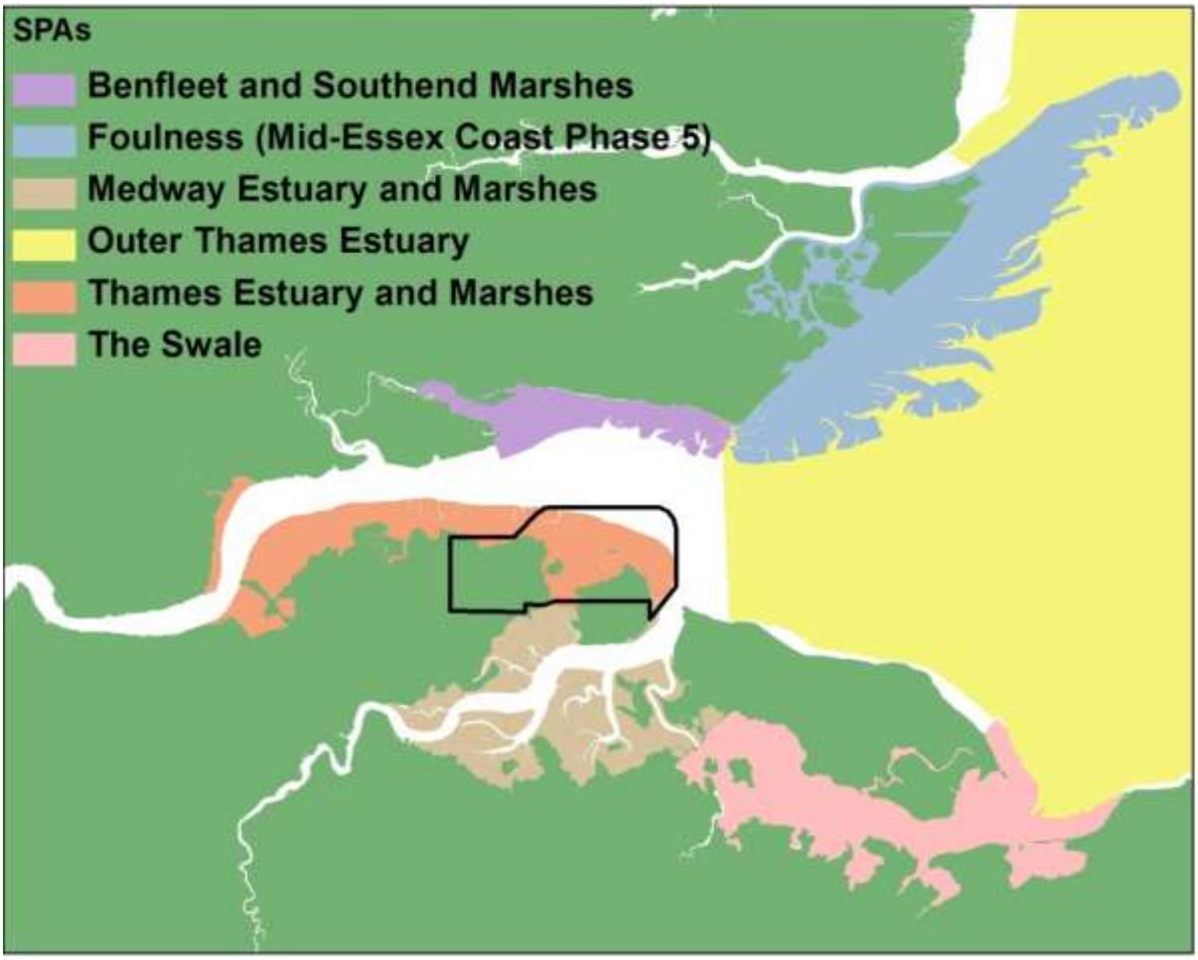

Figure 1. The Greater Thames Estuary, showing the locations of six local Special Protection Areas (SPAs) where birds are protected under EC legislation. The approximate location of a potential airport on the Isle of Grain is outlined in black.

While an airport development on the Isle of Grain would only cause direct habitat loss on parts of the Thames Estuary and Marshes SPA, and possibly some parts of the Medway Estuary and Marshes SPA, there are also potential impacts (for example due to disturbance from air traffic) on bird populations on the other local SPA sites shown in Figure 1. However, for the purposes of this high-level review of potential mitigation and compensation measures, we focus on the impacts of habitat loss, and therefore focus on key issues for those species listed in the SPA designations for the Thames Estuary and Marshes SPA and the Medway Estuary and Marshes SPA (Table 1).

Table 1. Population sizes of each species protected under the designations* for the Thames Estuary and Marshes SPA and the Medway Estuary and Marshes SPA. Figures are usually given as the number of individual birds of each species that the SPA supports, except for species protected during the breeding season where figures are the number of breeding pairs – these are denoted by a letter P after the number. The season during which the species occurs in important numbers is denoted in brackets after the population size figure (B = breeding season, P = on passage (during migration in spring or autumn), W = winter). Some species are not listed individually (with population sizes) on the SPA designation, but are named as part of the species assemblage present on site during either the winter or the breeding season. Such species are denoted with BA = part of the breeding assemblage or WA = part of the wintering assemblage.

Species	**Thames Estuary and Marshes**	**Medway Estuary and Marshes**
Bewick's swan *Cygnus columbianus*		16 (W)
Dark-bellied brent goose *Branta bernicla bernicla*		3,205 (W)
Common shelduck *Tadorna tadorna*		4,465 (W)
Eurasian wigeon *Anas penelope*		4,346 (W)
Eurasian teal *Anas crecca*		1,824 (W)
Mallard *Anas platyrhynchos*		BA, WA
Northern pintail *Anas acuta*		697 (W)
Northern shoveler *Anas clypeata*		76 (W)
Common pochard *Aythya ferina*		BA, WA
Red-throated diver *Gavia stellata*		BA, WA
Great cormorant *Phalacrocorax carbo*		BA, WA
Great crested grebe *Podiceps cristatus*		67 (W)
Hen harrier *Circus cyaneus*	7 (W)	BA
Pied avocet *Recurvirostra avosetta*	283 (W)	28 P (B), 314 (W)
Eurasian oystercatcher *Haematopus ostralegus*		3,672 (W)
Grey plover *Pluvialis squatarola*	2,593 (W)	3,406 (W)
Northern lapwing *Vanellus vanellus*		BA, WA
Common ringed plover *Charadrius hiaticula*	1,324 (P)	768 (W)
Eurasian curlew *Numenius arquata*		1,900 (W)
Black-tailed godwit *Limosa limosa islandica*	1,699 (W)	957 (W)
Ruddy turnstone *Arenaria interpres*		561 (W)
Red knot *Calidris canutus*	4,848 (W)	541 (W)
Dunlin *Calidris alpina alpina*	29,646 (W)	25,936 (W)
Common greenshank *Tringa nebularia*		10 (W)
Common redshank *Tringa totanus*	3,251 (W)	3,690 (W)
Little tern *Sternula albifrons*		28 P (B)
Common tern *Sterna hirundo*		77 P (B)
Short-eared owl *Asio flammeus*		BA
Common kingfisher *Alcedo atthis*		BA
Merlin *Falco columbarius*		BA
Winter assemblage size	75,019	65,496

* Note that the figures given here are for the species and population sizes listed on the Natura 2000 data form, which is the information sent to the EU as part of the SPA designation process. Additional figures for the species occurring in important numbers on these SPAs are available from the SPA Review (Stroud *et al*. 2001); these do not always match the figures in the Natura 2000 form as the

assessment was carried out at a different time. Were an airport development to be taken forward it may be necessary to also consider, as part of the EIA process, any additional species listed as occurring in important numbers on these sites in the SPA review. For these sites, this would add greater white-fronted goose *Anser albifrons*, common shelduck, gadwall *Anas strepera*, northern pintail, northern shoveler, little grebe *Tachybaptus ruficollis*, northern lapwing and whimbrel *Numenius phaeopus* to the list of species named as part of the wintering assemblage on the Thames Estuary and Marshes SPA, and little grebe and whimbrel to the species named as part of the wintering assemblage on the Medway Estuary and Marshes SPA. It would also make it necessary to consider both passage and wintering populations of common ringed plover on both sites.

2.2 Importance of the proposed airport site

Bird numbers on the airport site itself can be assessed using data from the Wetland Bird Survey (WeBS). WeBS is the scheme which monitors non-breeding waterbirds in the UK. The principal aims of WeBS are to identify population sizes, determine trends in numbers and distribution and to identify important sites for waterbirds (Austin *et al*. 2014). The data from the scheme have been used to inform SPA and Ramsar site designations and allow statutory agencies to assess the status of bird populations in SPAs and SSSIs (Cook *et al*. 2013), and the scheme is therefore widely recognised as a reliable reference source for bird population information. WeBS data are collected by many different volunteers counting bird numbers on small sub-sections of the estuary known as count sectors. We can therefore use the data from the count sectors that overlap the likely airport site to assess the numbers of birds that might be affected by habitat loss if an airport development were to go ahead (Figure 2).

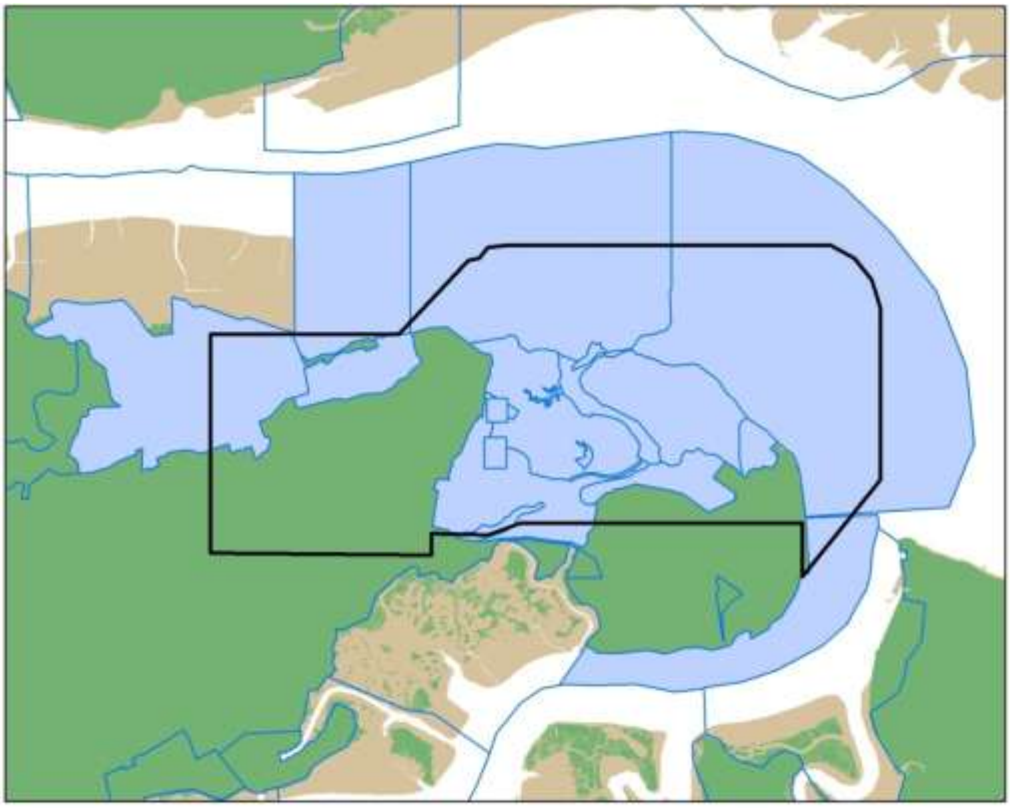

Figure 2. The Isle of Grain, showing the possible location of an airport development (black outline) with WeBS count sectors (blue outlines). Count sectors that overlap the likely location of an airport development, and have been used for the purposes of this assessment, are shaded in blue.

Table 2. The numbers of waterbirds of each species supported in the potential airport development area (blue shaded count sectors in Figure 2) and therefore potentially affected by habitat loss should a development go ahead. Numbers are presented as the most recent five-year peak mean from WeBS. We also show the percentage of the current population of each species on the combined Thames Estuary and Marshes and Medway Estuary and Marshes SPAs that occurs within the potential airport site. Only those species that are listed under the Thames Estuary and Marshes or Medway Estuary and Marshes SPA designations are shown, though other species also occur.

Species	Numbers in sectors that overlap potential airport (WeBS 5 year peak mean)	Percentage of current Thames and Medway SPA populations on the potential airport site
Bewick's swan	7	70
Dark-bellied brent goose	973	33
Common shelduck	587	13
Eurasian wigeon	290	4
Eurasian teal	4245	85
Mallard	1239	80
Northern pintail	28	3
Northern shoveler	74	9
Common pochard	137	7
Red-throated diver	4	67
Great cormorant	115	28
Great crested grebe	17	8
Hen harrier	No current data	No current data
Pied avocet	24	1
Eurasian oystercatcher	4302	35
Grey plover	767	14
Northern lapwing	1000	7
Common ringed plover	289	34
Eurasian curlew	1969	53
Black-tailed godwit	4486	50
Ruddy turnstone	188	27
Red knot	5770	18
Dunlin	4090	12
Common greenshank	53	43
Common redshank	1035	26
Little tern	5	18
Common tern	41	15
Short-eared owl	No current data	No current data
Common kingfisher	1	14
Merlin	No current data	No current data
All species combined (including non-SPA species)	21,681	25

2.3 Bird species guilds

Within this review, for simplicity and for the purposes of drawing general conclusions bird species have been divided into five guilds with similar traits including feeding habitat and method, habitat dependence, site dependence, site fidelity and lifespan. The guilds are as follows:

- Primarily intertidal invertebrate feeders (except bivalve specialists)
- Primarily intertidal bivalve specialists
- Piscivores
- Generalist wetland species
- Birds of prey

Generalist wetland species are those that use both freshwater and estuarine habitats; some of these species may have specific habitat requirements, and therefore they are not true generalists, but they will all use both freshwater and estuarine habitats. It is important to note that many species may fall into more than one of the categories. In these cases, species have been assigned to their primary guild (Table 3). However such species may benefit from measures that are beneficial for other guilds with which their niche overlaps. For example, black-tailed godwits (a generalist wetland species) tend to feed on bivalves when using intertidal habitat, so they would be likely to benefit from any measures that are beneficial to intertidal bivalve specialists. Other waders, including whimbrel and Eurasian curlew, which have been assigned to the generalist wetland species guild, tend to feed on intertidal invertebrates when using estuarine habitats, so are likely to benefit from any measures that are beneficial to intertidal invertebrate feeders. Within some guilds it is possible to further subdivide the constituent species into families, for example wildfowl *Anatidae* (ducks, geese and swans) and waders *Charadriiformes*.

Table 3. Species guilds, and traits of species within each guild. Only species that are named on the designation for the Thames Estuary and Marshes or Medway Estuary and Marshes SPA designations are included.

Species	Population Status[1]	Habitat Dependence[3]	Site Dependence[4]	Site Fidelity[5]	Typical Lifespan (years)[6]	Migration Distance[7]	Migration Direction[7]
Primarily intertidal mudflat invertebrate feeders (except bivalve specialists)							
Common shelduck	Declining	High	High	Low	10	Short	E
Grey plover	Declining	High	High	High	9	Long	NE
Common ringed plover	Declining	High	Low	High	5	Long	Passage: NE (some NW) Wintering: UK & NE
Ruddy turnstone	Declining[2]	High	Low	High	9	Long	NW
Dunlin	Declining	High	High	High	5	Long	Passage: NW Wintering: NE
Common greenshank	Increasing[2]	High	Low	High[4]	No data	Long	NE
Common redshank	Declining	High	Low	High	4	Long / Short	NW (some NE)
Primarily intertidal mudflat bivalve specialists							
Eurasian oystercatcher	Stable	High	High	High	12	Short	NE
Red knot	Declining	High	High	Low	7	Long	NW
Piscivores							
Great cormorant	Declining	Low	Low	High	11	Short	UK (some E)
Red-throated diver	No data	High	Low	No data	9	Short	NE (NW)
Great crested grebe	Declining	Low	Low	High	No data	Short	UK (some E)
Little tern	No data	High	Low	No data	12	Long	S
Common tern	No data	High	Low	No data	12	Long	S
Common kingfisher	No data	Low	Low	No data	2	Short	UK (few E)
Generalist wetland species							
Bewick's swan	Declining[2]	High	High	Low	9	Long	NE
Dark-bellied brent goose	Declining	High	High	High	11	Long	NE
Eurasian wigeon	Increasing	High	Low	Low	3	Long (short)	E
Eurasian teal	Increasing	High	Low	Low	3	Long (short)	E (some NW)
Mallard	Declining[2]	Low	Low	Low	3	Long / Short	E & UK

Species	Population Status[1]	Habitat Dependence[3]	Site Dependence[4]	Site Fidelity[5]	Typical Lifespan (years)[6]	Migration Distance[7]	Migration Direction[7]
Generalist wetland species (continued from previous page)							
Northern pintail	Declining	High	High	Low	3	Long (short)	E (some NW)
Northern shoveler	Declining	High	Low	Low	3	Long	E
Common pochard	Declining[2]	Low	Low	Low	3	Long (short)	E
Pied avocet	Increasing	High	High	High	No data	No data	No data
Northern lapwing	Declining	Low	Low	High	No data	Long	UK & E
Eurasian curlew	Declining	High	Low	High	5	Long (short)	UK & E
Black-tailed godwit	Increasing	Low	High	High	18	Long	NW
Birds of prey							
Hen harrier	No data	Low	No data	No data	7	Short	UK (some E/NE)
Short-eared owl	No data	Low	No data	No data	No data	Short	UK (some E/NE)
Merlin	No data	Low	No data	No data	3	Short (long)	UK (some NW)

[1] Whether the species has undergone a >25% decline (or >33% increase) over a 5-, 10- or 25-year period either on the Thames Estuary and Marshes SPA, Medway Estuary and Marshes SPA, or nationally (Cook *et al*. 2013).

[2] Species for which trends were only available at the national level.

[3] Qualitative assessment based on BTO expert judgement.

[4] Assessed using 2011/12 WeBS data: species for which 50% of the Great Britain population was found on 10 or fewer sites are classified as having High site dependence.

[5] Based on the 'WeBS Alerts Biological Filter' (Austin *et al*. 2003) in which a scoring system is used to assess the natural fluctuations in species' numbers between winters. Species with scores of five or below (for which a filter would be applied to 'High Alerts' in this system) are classified as typically exhibiting low site-fidelity, those with scores of 6-8 as typically exhibiting high site-fidelity. This method of defining site fidelity is a standard approach used in the WeBS Alerts system which monitors changes in the populations of designated waterbird species on SPAs and SSSIs (Austin *et al*. 2003).

[6] Longevity figures from "BirdFacts" (Robinson 2005).

[7] Migration distances and directions are taken from the Migration Atlas (Wernham *et al*. 2002) in conjunction with expert knowledge. Where two migration distances are stated, the first is the migration distance of the wintering population, with the second (in brackets) the breeding population. In most cases wintering populations are considerably larger than breeding populations, for example for many duck species. Migration direction is the direction the species moves from the greater Thames area in the breeding season. Species that move NW mostly breed in Greenland or Iceland, those that move NE breed in Fennoscandia or Russia, those that move E breed in Eurasia, UK indicates the species breeds elsewhere in the UK and winters in the greater Thames area.

3. REVIEW OF THE ABILITY OF BIRD POPULATIONS TO RESPOND TO THE LOSS OF HABITAT ASSOCIATED WITH LARGE SCALE DEVELOPMENTS, USING EXAMPLES TAKEN FROM AROUND THE WORLD

3.1 Introduction

Habitat loss and degradation are undoubtedly amongst the most important processes driving the declines of bird species. These processes are widespread due to different anthropogenic pressures across the world and affect a wide range of habitats and the species that rely on them. Coastal wetlands support large numbers of waterbirds particularly during the non-breeding season, providing them with the type and amount of resources needed to survive the winter months and/or refuel during migration (van de Kam *et al*. 2004). In fact, these habitats are crucial for the survival of many wetland bird species as very high proportions of their populations are reliant on them. As a consequence of the waterbirds and other wildlife that they support, many wetlands across the world have protected status, for example, under the Ramsar Convention on Wetlands of International Importance (http://www.ramsar.org/cda/ramsar/display/main/main.jsp?zn=ramsar&cp=1_4000_0__) and, in Europe, as Special Protection Areas under the EC Directive on the Conservation of Wild Birds (Directive 2009/147/EC – the codified version of Council Directive 79/409/EEC as amended – the 'Birds Directive'; http://jncc.defra.gov.uk/page-162).

However, despite their ecological importance, extensive areas of coastal wetlands have been and are being lost globally, through conversion into land for agriculture, industry, harbours, housing and other developments, as well as tidal power and amenity barrage schemes (Davidson *et al*. 1991, Boere *et al*. 2007). For example, over 146,000 ha of wetlands were lost in the Atlantic coast of United States between 1998 and 2004 (Stedman and Dahl 2008) and approximately 45,000 ha of offshore habitats, of which 21,800 ha was intertidal mudflat, were claimed between 1994 and 2010 in Bohai Bay, north-western Yellow Sea (Yang *et al*. 2011). In Europe, much intertidal habitat has also been lost through such processes historically, although development pressures remain (e.g. Hurley 2003, http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/shippingports/ports/dl/associatedbritishportsimming4915?page=3).

In addition to causing direct loss of habitat, such developments may also impact the quality of remaining coastal wetland habitat through changes to water and sediment flow and changes in nutrient inputs and water quality. Further to such land claim pressures, wetland habitat is also currently threatened by the effects of climate change, particularly by sea-level rise, which will most probably cause significant habitat loss (Watkinson *et al*. 2004, Jones *et al*. 2009). These habitat losses have put pressure on migrating and wintering waterbird populations and led to population declines of many species worldwide (International Wader Study Group 2003). As a consequence, a significant number of both theoretical and empirical studies have been carried out to understand the processes through which habitat loss may impact waterbird populations.

The impacts of habitat loss of local bird populations will be dependent on a number of factors, principally the availability and proximity of suitable habitat. Should alternative sites be limited in quantity or quality and already at or near capacity, increased densities may lead to intense competition for available resources (Goss-Custard 1985, Goss-Custard *et al.* 2002). Such increased competition may lead to a reduction in body condition for poorer competitors and consequently lead to impacts on an individual's 'fitness', most notably a decrease in survival rates. Local populations may also be impacted through emigration from the site, if resources for displaced birds are limited. Habitat loss may also impact the breeding success of waterbird species, either through the direct reduction in the extent of habitat or through changes in its quality.

Through impacts on survival rates and breeding success, and potentially increased emigration, habitat loss may thus directly lead to local population declines. Furthermore, for migratory species, the conditions experienced at one point of the annual cycle can be carried over into subsequent stages, reduced breeding success and survival, potentially therefore impacting populations both locally during one season and further afield in another.

Here, we provide a summary of theoretical studies of the impacts of habitat loss on waterbird populations, review empirical case studies of the impacts of the loss of intertidal habitat and roost sites on waterbirds, and discuss other potential impacts.

3.2 Modelling the impacts of habitat loss

Different models have been developed to estimate the population size that can be supported on sites and thus, assess changes in population abundance due to changes in environmental conditions. The most straightforward are habitat association models that predict bird numbers or density from habitat characteristics, such as prey density (e.g. Goss-Custard *et al*. 1991), habitat area (e.g. Rehfisch *et al.* 1997) or other variables that are good predictors of food availability (e.g. Goss-Custard & Yates 1992). However, despite the ease of predicting population abundance under new environmental conditions (e.g. reduction of area), these models may overestimate the effect of habitat loss on population size at local and global scale as they fail to predict the effect on fitness and demographic rates and individuals compensatory behaviour (e.g. individuals moving to another site after habitat loss) (Goss-Custard 2003).

Spatial depletion models have been also applied to predict the likely impact of habitat changes on the number of individuals that can be supported by the food available in a given area (i.e. carrying capacity) by changing the food abundance parameters. This approach has been widely used for wintering populations of wildfowl in the UK. For example, Percival *et al*. (1998) used depletion model to predict the effects of food loss due to intertidal habitat loss on the abundance of wildfowl and showed that the impact was dependent on the location of the loss, with greater impacts when food was lost from upper shore mudflats compared with an equivalent food loss from the lower shore, as a result of the longer exposure and thus accessibility of upper shore habitats. However, the results generated from another type of depletion model – a daily ration model, where the total amount of consumable food is divided by the daily food requirement of an individual bird – by Goss-Custard *et al*. (2003) for the same wildfowl species suggested that habitat loss reduces the total amount of prey available and thus the carrying capacity of the site, irrespective of prey location. Nevertheless, both studies predicted a general loss of the site's carrying capacity. Depletion models have been also applied to predict the abundance of black-tailed godwit at a range of spatial scales and, by incorporating different levels of prey density in the model, the effects on godwits' abundance of processes altering prey density, such as habitat loss and degradation, have been investigated (Gill *et al*. 2001b). However, depletion models assume all individuals to be identical and not to compete for food and, as with habitat association models, impacts on fitness and demographic rates (survival, breeding success) due to changes in environmental conditions cannot be predicted.

Individual-based models (IBMs) have been developed to predict how changes in the quality, quantity and accessibility of food resources will impact the fitness of the individuals, through density-dependent processes. The models using a theoretical framework that follows the fitness-maximising decisions of individuals and information on food resources to predict impacts on demographic rates that determine population size (Stillman 2003, 2008, Stillman & Goss-Custard 2010, Stillman *et al.* 2007). For example, early work by Goss-Custard *et al*. (1994) predicted a mean increase in winter Eurasian oystercatcher mortality as a result of increased bird density and intensified competition following a reduction of feeding habitat available. Subsequently, IBMs have been developed for several waterbird species at several European sites, and have been shown to predict accurately overwinter mortality, and the foraging behaviour from which predictions are derived. They have been used to predict the effect on survival in coastal birds of habitat loss, sea-level rise, wind farm development, shellfishing and human disturbance (Stillman & Goss-Custard 2010). For example, a mean increase in winter mortality was predicted for common redshank following the loss of intertidal feeding habitat at Cardiff Bay, UK (Goss-Custard *et al*. 2006), where competition due to depletion or interference or both was suggested as the main causes of the increased observed mortality. Likewise, a study on the Humber Estuary using the IBM approach, accurately predicted the observed distributions of nine species of wader, and predicted decreased survival rates in five species (common redshank, grey plover, black-tailed godwit, bar-tailed godwit and Eurasian curlew) due to potential reductions in intertidal area of 2-8% that might be expected through sea level rise and industrial developments (Stillman *et al.* 2005).

3.3 Case studies

Case studies of the impacts of the loss of intertidal habitat and roost sites on waterbirds are reviewed below and summarised in Table 4, highlighting the species concerned and observed impacts.

3.3.1 Loss of intertidal feeding habitat

The case studies outlined below primarily concern the loss of habitat in the non-breeding seasons, i.e. sites used during the winter months or as staging sites on spring or autumn passage. Loss of habitat at these times, when birds need to spend much of their time feeding to meet energy demands (either because of winter weather or to store fat and increase muscle size for long-distance flights and, in spring, as insurance against food shortage on arrival at breeding grounds) (Evans *et al.* 1991), may directly impact birds' survival.

3.3.1.1. The East Atlantic Flyway

The impacts of historic losses of intertidal habitats in Europe on waterbird populations have been documented by Davidson *et al.* (1991), though knowledge is limited of the scale of these impacts is limited due to an absence of data from monitoring schemes (such as the Wetland Bird Survey). Nevertheless, there have been a number of applied studies in recent decades that have evaluated impacts in more detail. Typically, these, have been reliant on inferring impacts from count data alone, and only recently with the development of the theoretical frameworks described above have impacts on the mechanisms of population change, i.e. survival, breeding success, been investigated. However, most applied studies around the world have shown that observations are not far from model predictions and that the loss of waterbird habitats can lead to a decline in waterbird numbers.

In the UK, the impacts of a loss of 60% of an area of intertidal habitat on the Tees Estuary (previously much reduced historically through land claim) were studied by Evans (1978-79) and Evans *et al.* (1979). Critically in this case, not only was the extent of habitat reduced, but also the available feeding time across the tidal cycle. As a result, dunlin and common redshank on the estuary were forced to supplement their feeding in non-tidal areas over the high tide period, and when these areas became unavailable in cold winter weather, dunlin numbers fell (either due to increased mortality or emigration).

Similar impacts on local numbers of wintering waterbirds have been seen in other case studies in the UK and northwest Europe. For example, McLusky *et al.* (1992) recorded significant declines in the local populations of dunlin and bar-tailed godwit at Torry Bay on the Firth of Forth following loss of

20% of the intertidal habitat there in 1978-79. Similarly, in Denmark, Laursen *et al.* (1983) reported declines in the local populations of five wildfowl species and eight of 12 species of wader after a new dyke enclosed 11 km^2 of intertidal mudflats and saltmarsh. At Nordstrand Bay on the German Wadden Sea coast, following land claim of 33 km^2, numbers of wintering dark-bellied brent geese, shelduck and most waders (red knot, bar-tailed godwit, spotted redshank, common redshank and greenshank) all declined. In contrast, numbers of barnacle geese and Eurasian wigeon, that were able to use the embanked grassland habitat created, increased (Hötker 1997).

It is important to understand the mechanisms of behavioural responses and their causes and consequences to be able to improve our ability to predict the effects of human-induced environmental change on individuals and thus populations (Tuomainen & Candolin 2011). A major factor contributing largely to the declines of waterbirds is strong site fidelity within and between winters (Rehfisch *et al.* 1996, Burton *et al.* 1997, Burton 2000), a characteristic that is known to strongly influence patterns of occupancy (Jackson *et al*. 2004), particularly given the longevity of these birds. Individuals return to the same site every winter and, despite migrating long distances from breeding to wintering grounds, between year movements are limited as individuals benefit from the knowledge gained upon their return, in terms of territoriality, knowledge of spatial and temporal variation in resources, and improved ability to avoid predation (Rehfisch *et al*. 1996). Where birds show high levels of site fidelity the consequences of habitat loss are potentially more serious.

Depending on the strength of site fidelity of the species, individuals may change their behaviour in response to habitat loss and move into an alternative habitat. However, the ability to relocate into new sites depends on factors such as the proximity of new sites and whether these sites have enough resources to support the displaced birds (Goss-Custard *et al*. 2002), and prior knowledge and age (Burton & Armitage 2008). For example, following the loss of saltmarsh at Rodenäs Vorland, on the German Wadden Sea, long distance movements were more frequent amongst the displaced dark-bellied brent geese, and many of these birds moved to less preferred sites that were apparently below their carrying capacity and therefore able to support the increased densities without an apparent decline in survival (Ganter & Ebbinge 1997, Ganter et al. 1997).

Burton & Armitage (2008) showed that common redshank, a highly site faithful species (Rehfisch *et al*. 1996, Burton 2000), appeared to be reluctant to leave their wintering site following intertidal habitat loss from the construction of a barrage at Cardiff Bay, in the Severn Estuary. However, birds were forced to move from the bay in the winter following the loss of habitat and settled at the nearest alternative foraging sites, increasing the densities of birds at those sites. These processes were influenced by prior knowledge of the individuals, with young birds being less attached to the bay than older bids and so more plastic in their response to change.

Almost all the common shelduck, Eurasian oystercatcher, dunlin, Eurasian curlew and common redshank that formerly used the bay were displaced by its inundation (Burton 2006, Ferns & Reed 2008). Counts and observations of marked birds in the first winter following closure indicated that some displaced common shelduck, Eurasian oystercatcher, Eurasian curlew and common redshank settled at adjacent sites within 4 km. However, these increases were not sustained in following winters. It was not possible to determine whether displaced dunlin were able to settle elsewhere due to an ongoing decline of the local population.

The study at Cardiff Bay also evaluated the impacts of the displacement of common redshank on their fitness. Burton *et al*. (2006) showed that the loss of habitat in Cardiff Bay impacted the body condition and survival of the redshank wintering there before the loss. Displaced common redshank had difficulty maintaining their mass in the first winter post-barrage closure, with adults from Cardiff

Bay being significantly lighter than those from the recipient site, probably resulting from the combination of increased competition for food at the recipient site, as there was higher bird densities, and the lack of experience of displaced birds, as they were highly faithful to the bay and had less knowledge about the new site. Additionally, the survival rates of adult redshank displaced from the bay declined, whereas the survival of common redshank from the recipient site did not change, suggesting that the increased mortality resulted from their displacement. Without an increase in recruitment of juveniles into the local population, such increases in mortality rate will reduce the local population size.

Extensive study has also been made of the impacts of intertidal habitat loss on the waterbirds in the Dutch Delta region, notably that associated with the construction of a storm surge barrier on the Oosterschelde (Lambeck, Sandee & de Wolf 1989; Meire 1991, 1996; Schekkerman, Meininger & Meire 1994). Eurasian oystercatchers displaced by this loss of mudflats were significantly lighter than those originally ringed at other neighbouring sites (Lambeck 1991). The impact of this habitat loss on the survival of Eurasian oystercatcher was evaluated through an analysis of ringing data by Duriez *et al.* (2009). During mild winters, survival rates were very high, and similar to before the closure in both changed and unchanged sectors of the Oosterschelde. However, the combined effect of habitat loss with severe winters decreased the survival of birds from changed sectors and induced emigration.

These two case studies provide the best evidence to date for impacts on the mechanisms of population change, thereby clearly linking population changes to the recorded loss of habitat.

3.3.1.2 The East Asian-Australasian Flyway

In the present day, the most significant loss of intertidal habitat is occurring in the East Asian-Australasian Flyway, most notably in the Yellow Sea, where extensive areas of intertidal flat are being claimed for development each year.

At Saemangeum in the Republic of Korea, Moores *et al.* (2008) recorded a decline of 100,000 waders in their main study site, including 15 out of the most numerous 24 species, from 2006-2008 following conversion of two free-flowing estuaries and 40,100 ha of tidal-flats and sea-shallows into a vast reservoir and land, through the construction of a 33-km long seawall. This included 90,000 great knot; nine other species showed declines of 30% or more, including the spoon-billed sandpiper (listed as Critically Endangered under the IUCN Red list: http://www.iucnredlist.org/). The survey found no evidence that shorebirds lost to Saemangeum had relocated elsewhere within the Republic of Korea. Further, the MYSMA data reveal a large decline in Great Knot reaching Australian non-breeding grounds following closure of the Saemangeum sea-wall and analysis suggests that the global population of the great knot could already have declined by 20% due to this single land claim.

In Bohai Bay, China, there has been an increase of waterbird densities in the remaining intertidal mudflats following the loss of one third of the original area during 1994-2010 (Yang *et al*. 2011), which, as described earlier, is predicted to cause a decrease in the survival of birds forced to aggregate together or to relocate nearby.

3.3.2 Loss of roosting sites

Several other studies have linked local population declines with loss of high tide roosting sites. For example, in the Tagus estuary (Portugal) decreases of wintering populations of dunlin, grey plover and common redshank have been attributed to the loss and degradation of roost sites, as there were no changes in the quality of intertidal area that could explain such declines (Catry *et al*. 2011). In the north-east cost of England, roosting numbers of purple sandpiper, turnstone and red knot declined following a harbour redevelopment, although here there was no evidence that this impacted local populations as a whole (Burton *et al*. 1996).

Roost fidelity and preferences are variable among waders (Rehfisch *et al*. 2003, Conklin *et al*. 2008) and thus, the loss of roosting sites will have a greater negative effect in species that show strong roost fidelity (e.g. Eurasian oystercatcher, common ringed plover, purple sandpiper, common redshank). Loss of roost sites will increase the probability of birds having to undertake energetically demanding flights between feeding and roosting areas and this may impact their body condition and thus decrease their probability of survival (Rehfisch *et al*. 2003). Furthermore, there is evidence that the location of roosting sites is very important for the distribution of foraging waders, with bird density declining with distance from their roost (Dias *et al*., 2006), probably as a result of strategies to minimise the energy expenditure spent between foraging and roosting sites (Luís *et al*., 2001, Rogers, 2003). In addition, the pattern of use of intertidal areas for some species can result from a trade-off between the distance from roosting sites and the quality of foraging locations (van Gils *et al*. 2006) or safe feeding grounds (Rehfisch *et al*. 1996, Rogers *et al*. 2006). Thus, the loss of high tide roosts may increase the inaccessibility to important intertidal areas to birds, and high quality areas may become too far away to be exploited (Dias *et al*. 2006, van Gils *et al*. 2006), which may force birds to feed in lower quality areas and ultimately influence their fitness and overwinter survival.

Table 4. Summary of the observed impacts on waterbirds due to habitat loss and degradation.

Study	Species	Observed impact
Loss of intertidal feeding habitat		
Evans (1978-79) Evans *et al.* (1979)	Common shelduck, grey plover, dunlin, bar-tailed godwit, Eurasian curlew, common redshank	Displacement and local population declines
McLusky *et al.* (1992)	Dunlin, bar-tailed godwit	Displacement and local population declines
Laursen *et al.* (1983)	Common shelduck, mallard, Eurasian teal, Eurasian wigeon, northern pintail, grey plover, golden plover, dunlin, bar-tailed godwit, Eurasian curlew, spotted redshank, common redshank, common greenshank	Displacement and local population declines
Hötker 1997)	Dark-bellied brent goose, shelduck, red knot, bar-tailed godwit, spotted redshank, common redshank, greenshank	Displacement and local population declines
	Barnacle goose, Eurasian wigeon	Local population increases (due to associated habitat creation)
Ganter & Ebbinge (1997) Ganter, Prokosch & Ebbinge (1997)	Dark-bellied brent goose	Displacement into less preferred sites, no apparent impact on survival
Burton & Armitage (2008) Burton *et al*. (2006) Ferns & Reed (2008)	Common shelduck, Eurasian oystercatcher, dunlin, Eurasian curlew and common redshank	Displacement and local population declines; for common redshank, decreased body condition & survival
Duriez *et al.* (2009), Lambeck (1991), Lambeck, Sandee & de Wolf (1989), Meire (1991, 1996), Schekkerman, Meininger & Meire (1994)	Eurasian oystercatcher and other wader species	Displacement and local population declines; for Eurasian oystercatcher, decreased body condition & survival
Moores *et al*. (2008)	Eurasian oystercatcher, Kentish plover, lesser sand plover, great knot, red knot, red-necked stint, dunlin, sharp-tailed sandpiper, spoon-billed sandpiper, black-tailed godwit, bar-tailed godwit, far eastern curlew, common greenshank, Nordmann's greenshank, ruddy turnstone	Local population declines; for great knot, global population decline
Yang *et al*. (2011)	Red knot, curlew sandpiper	Displacement and local population increases in the remaining habitat
Loss of roosting sites		
Catry *et al*. (2011)	Grey plover, dunlin, redshank	Local population declines
Burton *et al*. (1996)	Red knot, purple sandpiper, turnstone	Displacement

3.4 Other impacts

3.4.1 Loss of breeding habitat

Freshwater wetland habitats associated with estuaries are also crucial for many wintering and breeding waterbirds species, and have also historically been under significant pressure from both urban development and agricultural intensification (Wilson *et al.* 2004, 2005, Fuller & Ausden 2008, Sutherland *et al*. 2012).

Many breeding waders of lowland wet grasslands have undergone dramatic population declines. For instance, breeding northern lapwing, common snipe and common redshank have declined by 29, 38 and 61%, respectively over the last 20 years in England, and 64% of all grassland-breeding waders have become restricted into few key sites (Wilson *et al*. 2005). These declines are primarily driven by habitat loss and degradation through the conversion into arable land and agriculture intensification, such as re-seeding, use of artificial fertilizers, changes in water levels, cutting date and grazing, all decreasing the suitability of grassland for most breeding wader species (Sutherland *et al*. 2012 and references therein). For example, increased use of fertilizer combined with warmer temperatures allows earlier cutting and grazing dates for some grasslands (Kleijn *et al*. 2010), resulting on increases of nest loss and chick mortality and so, decreases in the overall productivity (Kruk *et al*. 1996). The advances on time of mowing and grazing can also affect chick-rearing habitat that may lead to a further reduction on chick survival (Schekkerman *et al*. 2008). Agricultural intensification is also normally accompanied with a decrease in invertebrate size and densities, which can decrease the intake rates and the profitability of prey items for chicks and therefore reducing chick survival (Beintema *et al*. 1991). The proportion of nest lost through trampling have also increased due to increase in domestic stock densities (Beintema & Muskens 1987), which also can alter the habitat structure, reducing the availability of tussocky grassland preferred by nesting species such as common redshank (Milsom *et al*. 2000).

Direct studies of lowland wet grassland habitat loss through urban development, rather than change due to agricultural intensification are lacking. However, direct habitat loss has the potential to impact the breeding success of waterbird species, either through the direct reduction in the extent of habitat or through changes in its quality, and the effects associated with agricultural intensification are, as such relevant.

3.4.2 Carry-over effects

Migratory species depend on multiple locations during their annual cycle that can spread over different continents and thereby encompass very different environmental conditions (Newton 2008). Large-scale variation in local weather conditions and in the quality and quantity of resources can result in different costs and benefits for individuals and have future implication for their fitness. The conditions experienced during one part of the annual cycle can carry over into subsequent stages (reviewed in Harrison *et al*. 2011). For example, variation in environmental conditions experienced in the winter can drive variation in individual survival and subsequent breeding success, or both, as shown for the black-tailed godwit. In Icelandic godwits, studies have shown that early arrival to the breeding grounds is positively related to breeding success (Gunnarsson *et al*. 2005, 2006). Individuals wintering in good quality habitats also tend to occupy good quality habitats at the breeding grounds, while individuals wintering in less favourable sites tend to occupy poor quality breeding habitats (Gill *et al*. 2001a, Gunnarsson *et al*. 2005), with males in poor quality breeding sites being more likely to be unpaired and experience lower breeding success than males in good quality sites (Gunnarsson *et al*. 2012). Furthermore, higher energy costs experienced in winter due to less favourable environmental conditions are associated with lower survival (Alves *et al*. 2013), and delayed arrival in Iceland, thus lower probability of occupying good quality breeding habitat.

Inger *et al*. (2010) have studied carry over effects in light-bellied brent goose in relation to reproductive success. Adults with families use lower quality resources than non-breeders in wintering grounds, likely constrained by the low foraging efficiency of juveniles. So, parental adults end the winter in poorer body conditions than adult non-breeders, leading to a late arrival on the breeding grounds, and hence a reduced probability of successful breeding the following year. This suggests that the conditions that adults experience during the non-breeding season are carried over into the breeding season.

Thus, the consequences of habitat loss and degradation at any point of the species' migratory cycle can not only have negative consequences for the individual at that point but the effects can be carried over to the subsequent periods, and can therefore have far-reaching consequences for the entire population.

4. HIGH-LEVEL REVIEW OF POTENTIAL HABITAT CREATION MITIGATION AND COMPENSATION MEASURES AVAILABLE AND ASSOCIATED ISSUES, AND THE APPROXIMATE COSTS PER UNIT AREA OR BIRD OF SUCH MEASURES

4.1 The need for mitigation or compensation measures

Under the Planning Act (2008), when preparing an application for a nationally significant infrastructure project (NSIP), developers should consider the potential effects on protected sites. If a NSIP – such as an airport development on the Thames Estuary – is likely to affect a European site or European marine site – such as the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA – the developer must (under the 2010 Habitats Directive: 92/43/EEC) undertake a Habitats Regulations Assessment (HRA) to enable the decision maker to make an appropriate assessment as to any 'likely significant effects' following any proposed mitigation (http://infrastructure.independent.gov.uk/wp-content/uploads/2011/04/Advice-note-10-HRA-web.pdf).

Mitigation measures could include changes to the design of the development to reduce the impacts on birds, or the creation of new habitat for birds in the local area (i.e. within the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA).

Article 6(4) of the EC Habitats Directive allows plans or projects which may have an adverse effect on the integrity of a European site or European marine site to go ahead on grounds of 'imperative reasons of overriding public interest' (IROPI) when there are no alternative solutions and compensatory measures have been secured. Compensation is normally only considered where it is not possible to provide sufficient mitigation locally to account for the magnitude of the predicted impacts. In the case of an airport development on the Thames Estuary, compensation measures might involve the creation of new habitat further afield – either adjoining or at a distance from the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA.

4.2 Potential habitat creation mitigation or compensation measures and their scope

The potential mitigation and compensation measures considered here involve habitat creation either within the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA, close to these estuaries or at a distance.

Mitigation measures might include:

1. Intertidal habitat creation within the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA to replace lost feeding habitat (e.g. through topographical modification);
2. Creation of roost sites where might be lost, e.g. due to loss of saltmarsh or coastal freshwater marsh.

Compensation measures might include:

1. Managed realignment adjoining the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA to create intertidal habitat;
2. Managed realignment at a distance from the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA to create intertidal habitat;
3. Creation of freshwater wetland habitat close to the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA.

4.3 Factors that may limit the effectiveness of mitigation or compensation measures

A range of factors is likely to influence the effectiveness of mitigation or compensation measures. These include:

- Optimising the design of intertidal habitat creation for birds;
- The need for ecologically linked areas;
- Site-fidelity and habitat equivalency;
- Implications for flyway populations.

These issues are discussed in detail below.

4.3.1 Design criteria for optimising intertidal habitat creation for SPA birds

The science behind the restoration and creation of many terrestrial habitats is well advanced. However, intertidal habitats pose special problems for restoration because they are topographically and ecologically complex and they support many species of animals, some of which require specific habitats and linkages to other terrestrial or marine habitats. Moreover they exist and evolve within dynamic coastal settings, subject to changing tidal levels, salinities and long term mechanical processes that are associated with sea-level rise and climate change. Often these complexities are ignored and there has been a tendency for created coastal habitats to lack the diversity seen in natural areas and support only generalist species.

In northwest Europe, experience of creating new wetland habitat, especially mudflats, is fairly limited but expanding at a rapid rate. It has included the use of dredged material or managed realignment to create or restore areas. Until recently, relatively few studies had monitored the impact on waterbirds and the majority of published literature on managed realignment in the UK has concerned non-biological processes such as geo-chemical changes, tidal exchange, persistence of saltmarsh in unmanaged retreat sites and policy related to managed realignment (http://www.abpmer.net/omreg/). However some notable studies published in the last decade have assessed how biodiversity, including birds, respond to the creation of new intertidal habitat (e.g. Atkinson *et al*. 2004, Garbutt *et al*. 2006, Mander *et al*. 2007, Mossman *et al*. 2012, Spencer *et al*. 2012).

It is perhaps not surprising that relatively little has been published in the peer-reviewed literature on the long-term biological development of created intertidal habitat (though see Garbutt *et al*. 2006 and Mossman *et al*. 2012), as sites at which habitat creation or restoration has been practised in the UK are relatively young and generally less than 15 years old. Within this short timeframe, the potential for ecological communities to develop and change is relatively limited. Elsewhere in north-west Europe, large areas of man-made marshes and mudflats are found in the Wadden Sea. Although only a fraction of the area present prior to human intervention, these intertidal habitats are still the largest contiguous area of saltmarsh in Europe. In the Netherlands alone, there are over 17,000 ha of man-made saltmarshes, created specifically for flood defence purposes rather than for any other environmental benefit (Esselink 1998). This policy is changing and saltmarshes on the North Sea coasts of Germany, Belgium, the Netherlands and Denmark, which are of high conservation importance because of the large concentrations of wintering, passage and breeding waterbirds that they support, are now increasingly being managed for nature conservation purposes (Esselink 2000). Again little has been published in the peer-reviewed literature although the created marshes at Sieperda in the Netherlands are a notable exception (Castelijns *et al*. 1997, Eertmann *et al*. 2002).

Elsewhere in the world, Japan has led the way in creating tidal mudflats and, according to the Environment Agency of Japan, 37 areas covering approximately 900 ha were created between 1973 and 1998 (WAVE 2001a, 2001b). This is small compared to the loss of nearly 4,000 ha (42% to reclamation) over the same time period (WAVE 2001a, 2001b), and most of the sites are also relatively small in scale.

Research has therefore been geographically rather limited and focussed on particular habitats or ecosystems. One of the largest issues, rarely tackled, has been a detailed assessment of the physical, temporal and biological factors that determine the resulting habitats and communities and how these relate to the range of variation found in natural areas. Most studies have simply described the biological communities and the changes within them. Restoration schemes have also generally been small (both in extent and number) compared with surrounding 'natural' areas and their scale will affect the use made of such areas by birds in ways independent from the type and quality of habitat created. Where comparisons are made, differences in sampled attributes between created and restored sites are often masked by the high natural variability in these attributes between different. This means that results from many studies may not be applicable at a larger (i.e. regional rather than site) scale.

This makes the definition of a 'successful' restoration quite difficult, given that natural habitats are very varied and restoration sites have tended to be small. It may be that we can only create a subset of coastal wetland habitats. To be able to restore or create habitats for birds successfully, they should exhibit the functions and processes within the variation found in surrounding natural habitats at a range of spatial scales. In many cases, this will mean allowing dynamic change to take place, e.g. allowing habitats to shift upshore in relation to sea level rise. In estuaries, it means taking a strategic approach at the flood plain level, using the whole estuary as a functional unit rather than concentrating on particular vulnerable areas within the estuary. This type of approach has the advantage of allowing ephemeral habitats such as saline lagoons and fresh/brackish water transitional habitats, which are important for waterbirds, to remain.

4.3.1.1 Are created/restored saltmarshes equivalent to natural marshes?

Experience from the both the UK and United States has led to the conclusion that created saltmarshes provide an approximation of the habitat required by the target birds, but do not necessarily lead to the development of the same plant, invertebrate or bird species assemblage as is to be found on surrounding natural saltmarshes (Edwards & Proffitt 2003, Darnell & Smith 2004, Nottage & Robertson 2005, Mossman *et al*. 2012, Spencer *et al*. 2012). The reasons for these differences are often due to the nature of the sites. Created marshes tend to be on land that was previously used for agriculture. This land has tended to be smooth, flat or gently sloping, and microhabitats that are important for many bird species such as ephemeral pools and creeks were rare. Often restored/created marshes were at an overall higher elevation, had less edge habitat and where present, creeks or channels tended to be deep and steep-sided (Crooks *et al*. 2002, Garbutt *et al*. 2006).

Given the very different soil characteristics, one frequent difference between restored and natural marshes in both the UK and US, is the consolidated nature of the sediments in restored and created saltmarshes (soil structure collapses due to re-wetting with salt water), as well as their lack of natural creek systems, smooth topography and poor drainage (Crooks *et al*. 2002, Fearnley *et al*. 2008). Re-wetted sediments in the UK tend to be extremely hard and tabular in form and, thus, if sediment does not come in from the surrounding area and settle, these hard mud habitats are inhospitable environments for invertebrates and plants. This has led to reduced structural diversity and differences in vegetation communities on some of the naturally-regenerated marshes in SE England (Garbutt & Wolters 2009, Mossman *et al*. 2012).

Some kinds of saltmarsh can never be created. The ancient saltmarshes of North Norfolk, which may be 10,000 years old, feature a very intricate topography of pools and creeks. The pools are remnants of old creeks and as a result of this very varied topography these marshes are amongst the most species-rich in the UK. In contrast, marshes in higher energy, sandier, environments such as the Severn Estuary tend to be species-poor and dominated by species such as *Puccinellia*. This forms an important food source for many species of wildfowl. These marshes are probably easier to recreate in a suitable tidal environment.

4.3.1.2 Do created mudflats function in a similar manner to 'natural' ones?

Mudflat creation is most highly developed in Japan (WAVE 2001a, 2001b), but there are few accessible reports of bird usage from there and success has to be inferred from studies of benthic invertebrates. The best examples of how birds use areas of created or restored mudflats are from UK studies.

Much of the realignment in the UK has been in low energy environments on the east coast. At two of the most intensively studied managed realignment sites in the UK (Tollesbury and Orplands on the Blackwater Estuary in Essex), the sediments became consolidated as re-wetting with saltwater occurred (Garbutt *et al*. 2006). However, accretion of soft sediments was quite rapid and benthic invertebrates colonized relatively quickly and shorebirds and wildfowl soon began to use the site. Common shelduck, dunlin, grey plover and common redshank probably exploited the polychaetes and *Hydrobia* that initially colonised the sites. In three to four years the bivalve *Macoma balthica* colonised and, particularly at Tollesbury, this coincided with increasing usage by red knot, a bivalve specialist. Other species such as Eurasian oystercatcher, which feed mainly on larger bivalves such as cockles and mussels, tended to show very low usage of the site (Atkinson *et al*. 2004). Studies of managed realignment sites on the Wash and the Humber Estuary also suggest that waterbirds colonise within about three years (Badley & Allcorn 2006; Mander *et al*. 2007).

Many more studies look at changes in invertebrate numbers. The speed with which invertebrates colonise these sites tends to be in line with what can be predicted through knowledge of life history traits. Mobile species, and those that have a planktonic larval phase, such as *Nereis* and other polychaetes, and *Hydrobia* colonise in the first year or two. Bivalves and other species that have no planktonic larval phase or take time to grow to a suitable size, such as oligochaetes and larger bivalves, either fail to colonise or take several years to appear (Evans *et al*. 1999,). This has implications for the rates of colonisation by particular guilds of birds, so that species that feed on small polychaetes are likely to colonise before those that feed on large bivalves, a feature observed at various UK realignment sites (Atkinson 2003, Atkinson *et al*. 2004, Mander *et al*. 2007).

Apart from realignment, another common way in which intertidal mudflats are created is through the use of dredged material. These mudflats have been created in a number of countries and invertebrates rapidly colonise these if they are in the correct position in the tidal frame. The exact nature of the invertebrate assemblage is determined by the make-up of the sediment used (sand/silt/mud content); often invertebrate assemblages are different to surrounding reference areas and both higher and lower densities of invertebrate prey have been reported (Bolam & Whomersley 2005, Widdows *et al*. 2006).

4.3.1.3 How can new habitat creation schemes maximise benefits to waterbirds?

Coastal intertidal habitats can be created or restored. The majority of cases where habitat has been recreated involved coastal sites that were created for reasons other than supporting wildlife and success, however it was measured, was often a very hit or miss affair. Most sites supported populations of waterbirds, but often failed to capture the diversity observed on natural areas (Atkinson 2003).

Most studies looking at the processes underlying restoration/creation have been carried out at small scales in comparison with surrounding areas and often fail to capture the range of natural variation found at the larger scales at which migratory waterbirds usually operate. Successful restoration/creation may take time but, once the general roles of hydrodynamics, sediment dynamics and other forcing factors are understood, then wetland habitats can be created. An adequate supply of sediment is crucial to success. On the east coast of the UK, there is a plentiful supply of sediment and therefore it has been possible to recreate functioning mudflats that support waterbirds in three to five years. For example, at a managed realignment site at Paull Holme Strays on the Humber Estuary, a waterbird assemblage of similar composition to that of adjacent existing intertidal areas was supported within three years of creation (Mander *et al*. 2007). Despite this there are still many uncertainties surrounding the methods required to create habitats that will support specific waterbird species.

Studies of the beneficial use of dredged material have shown that as the sediments de-water and consolidate, invertebrates colonise and over time this may lead to the development of the varied assemblages found on a natural mudflat (Bolam & Whomersley 2005, Widdows *et al*. 2006). In the Thames and Medway Estuaries, if dredged material was to be used to create mudflats, the success of this may well depend on the subsequent movement of sediment in the area through processes such as dredging, erosion or deposition – i.e. will new sediment be deposited and/or will existing sediment be re-suspended and deposited through tidal action. As sediments are deposited, they will de-water and consolidate and the makeup of the sediment as well as availability of soft sediment (through deposition, re-suspension and deposition or bio-turbation) is important in determining invertebrate assemblages and densities. If sediment is re-suspended or slumps lower in the tidal frame then these mudflats may not be viable in the long term. In managed realignment areas on the east coast of England, there has been a sufficient supply of new sediment being deposited in these newly-created areas through the sediment cells in the North Sea that bring new supplies of sediment down the east coast of the UK. Vertical accretion of these new areas has meant that there has been sufficient new soft sediment for invertebrates to colonise rapidly. Were an airport development to go ahead in the Thames Estuary, detailed sediment modelling will be required to predict the range and areas of different types of sediment that will result. Sediment is key to any creation/restoration attempts and an understanding of the resulting types will give more confidence to the prediction of the impacts on benthic invertebrates and birds. Changes to water currents and sediment transport as a result of building an airport in the Thames Estuary may lead to intertidal habitats that support different assemblages or different densities of invertebrates (either higher or lower densities than the present habitats, depending on how the sediments change) which are likely to support different relative densities of wetland bird species than they do now.

Engineering of any created mudflat or saltmarsh is also key to success; it is important that small-scale habitat diversity is recreated. Restored sites have often lacked this range of micro-habitats and tend not to show such habitat diversity at a fine-scale. More recent (and larger scale) realignments have undertaken such surface modifications and have shown that if environmental conditions are suitable and there is a varied topography, the outcome is one where there is a complex mix of microhabitats that support a wide range of waterbirds. A successful outcome is therefore largely a case of 'getting the recipe right'. Whatever the case, to maximise the likelihood of creating a fully functioning wetland encompassing the range of variation found in natural areas, it is thought that larger-scale projects with a varied topography are more likely to be successful (Atkinson *et al*. 2001, Atkinson *et al*. 2004). At present, our knowledge is limited and it is essential that new projects adopt an experimental approach and ensure that adequate monitoring is carried out at appropriate timescales.

Generally, once habitats are created, benthic fauna and birds respond fairly quickly if conditions are suitable. This is because coastal wetlands are often high-energy environments, at low elevations, and with high soil-water tables. As such, they are likely to resemble the surrounding natural environment in a relatively short time-frame, i.e. years rather than centuries. For example, created marshes in the high energy sandy environments of the Severn Estuary are virtually indistinguishable from surrounding marshes (e.g. Cone Pill in Gloucestershire). However, marshes in the muddy, lower-energy environments of some estuaries in southeast England are often of a very different structure and support different vegetation types than surrounding natural marshes.

The track record in creating good quality habitats has, until recently, not been particularly good in terms of their biodiversity benefit, often because this has not been the primary reason for the work, as most realignment schemes have tended to be for flood protection purposes. In particular saltmarsh creation has not happened as predicted, often producing habitats of much lower quality and species diversity than surrounding natural marshes. This is because many early realignment schemes tended to make holes in sea walls without undertaking the engineering required to develop the creek systems that are needed to create habitats of high conservation value. In the longer term, a partnership is needed between ecologists, conservation bodies, governments and engineers. Only in this way will it be possible to set up the kind of large capital projects required to take the science forward and reach an understanding, not only of how to create coastal habitats, but also the impact they will have on waterbird populations. The ongoing RSPB project to create large areas of intertidal habitat of high conservation value at Wallasea Island is currently developing and testing coastal habitat creation methods (see http://www.rspb.org.uk/ourwork/casework/details.aspx?id=tcm:9-235089), though the long-term success of this project in creating high quality habitat is yet to be seen. However, it would be important to keep up-to-date with and learn from this experience, in addition to the existing evidence outlined here, in determining whether or not it will be feasible to find or create suitable sites, and the feasibility and cost of developing suitable habitat for birds, should managed realignment be part of any mitigation or compensation measures if the proposed airport goes ahead.

In summary, sediment is key to any restoration process. Having a good understanding of the sediment dynamics post-development will allow a much better prediction of the likely outcome of mudflat or saltmarsh creation in terms of its value to waterbirds and long-term persistence. There is sufficient knowledge to undertake the engineering to create habitats through managed realignment and some knowledge of how to modify them (for example including small scale topographic variation) but as this is a relatively new science taking an experimental approach and following up with longer-term monitoring is important if this science is to develop. In terms of the large-scale creation of mudflats in estuaries through use of dredged material there is less experience of this in northwest Europe and bringing in expertise from other parts of the world will be necessary (e.g. Japan).

4.3.2 The need for ecologically linked areas

For the purpose of this study, the ecological functional unit for SPA birds is taken to be the existing SPAs of the Thames Estuary and Marshes and Medway Estuary and Marshes together with areas that are adjacent or close and actually or potentially (through compensation measures) ecologically linked (e.g. the Swale SPA, the Benfleet and Southend Marshes SPA and the Foulness (Mid-Essex Coast Phase 5) SPA). Note that for each of the species guilds described below (and in Table 3) generalisations have been made based on available information. Were an airport development to be taken forward it would be possible to provide more detailed information regarding the within-winter and through-the-tide movements of species from existing bird ringing and recovery data, and through detailed studies of waterbird movements on the Thames and Medway and elsewhere including colour-marking and resighting and using radio, satellite or GPS tracking techniques. Such a study would be key to optimising the design of mitigation or compensatory measures.

4.3.2.1 Primarily intertidal mudflat invertebrate feeders and intertidal mudflat bivalve specialists

Species in the guilds that primarily use intertidal habitat (intertidal invertebrate feeders and intertidal bivalve specialists) require areas of habitat to support their populations at all stages of the tidal cycle. This means that areas of intertidal feeding habitat that are exposed at low tide must be ecologically linked (i.e. in relatively close proximity, and preferably adjacent) to intertidal feeding sites that can be used by birds on the rising or falling tide. Birds also require relatively undisturbed high-tide roost sites either on saltmarsh, farmland or on other habitats adjacent to the intertidal feeding area. The creation of intertidal habitat that is exposed at low tide away from areas where there is intertidal habitat exposed on the rising and falling tide and suitable high-tide roost sites is therefore unlikely to provide satisfactory mitigation or compensation, particularly for species that are primarily intertidal invertebrate feeders or intertidal bivalve specialists.

4.3.2.2 Generalist wetland species

Generalist wetland species also use intertidal habitat at some stages of the tidal cycle. However, these species are likely to use freshwater habitats adjacent to (or within one or two kilometres of) the estuary at stages of the tidal cycle where intertidal habitat is not available. It is therefore more likely that the provision of freshwater habitats adjacent to intertidal areas as part of any mitigation or compensation package at sites either close to or far from the Thames Estuary and Marshes / Medway Estuary and Marshes SPAs could be of benefit for species in these guilds.

4.3.2.3 Piscivores

These species use a wide range of marine and freshwater habitats and are therefore less affected by intertidal loss as a result of development than other species. However, they may be affected by any loss of freshwater habitats in adjacent terrestrial areas, and local breeding species such as the terns would be affected by loss of any terrestrial breeding sites in the area.

4.3.3.4 Birds of prey

The birds of prey for which the Thames and Medway Estuaries are important use a wide range of coastal habitats, including foraging over both freshwater and intertidal habitats. However, individuals tend to have relatively large home-ranges and therefore need a large extent of habitat to be available to support them. These species would be affected by both terrestrial and intertidal habitat loss as a result of any development, but this could be compensated for by the creation of either new intertidal or freshwater marsh habitats, if the design of these sites allowed sufficient prey to be available and the sites were large enough to support the large home-ranges of these species.

4.3.3 Site-fidelity and habitat equivalency

In this report, site-fidelity has been assessed using the 'WeBS Alerts Biological Filter' (Maclean & Austin 2008). This scoring system is used to assess the natural fluctuations in species' numbers within and between winters, and is calculated using a combination of measures of population size fluctuation, longevity, between-winter movements of birds and within-winter movements of birds.

The score assigned reflects the typical behaviour of each species at a UK level. Species with the lowest scores are those that tend to have fluctuating population sizes, are short-lived and are highly mobile (i.e. large between- and within-winter movements). Conversely species with the highest scores are those that tend to have relatively stable populations, are long-lived and are site-faithful (i.e. small between- and within-winter movements). Species with scores of five or below are classified as typically exhibiting low site-fidelity, those with scores of 6-8 as typically exhibiting high site-fidelity (Table 3).

Populations of site-faithful bird species are likely to take longer than other species to respond to any compensatory measures provided away from the Thames Estuary and Marshes SPA or Medway Estuary and Marshes SPA. Birds that are not site-faithful are likely to move to other sites within or away from the Thames and Medway fairly quickly if habitat were lost as a result of an airport development, as it is thought that such species distribute themselves in response to food resources. However, it is uncertain how far birds would be likely to move or what differences there might be between species with differing migration strategies. Conversely, it is likely that individual birds of site-faithful species would not move far within the Thames and Medway Estuaries even if habitat were lost as a result of an airport development. Instead, colonisation of any new habitat provided away from the site would be most likely to occur through the recruitment of first-winter birds of these species, and the reduction of the populations on the Thames and Medway is likely to occur through increased mortality of adult birds. Such limited movements and increased mortality was observed in common redshank following the closure of the Cardiff Bay Barrage (Burton *et al*. 2006; Burton & Armitage 2008), and we assume that other site-faithful species would behave in a similar way, although this is uncertain. This also means that populations of relatively short-lived site-faithful species may develop at new sites more quickly than populations of longer-lived site-faithful species. It is likely that there would be an initial decline in the SPA and national (and possibly the flyway) populations of site-faithful species following the construction of an airport in the Thames Estuary, although it is possible that the populations may recover in the longer term as any new sites provided away from the Thames and Medway are colonised. In order to minimise the likelihood of such population declines it would be necessary to provide any mitigatory or compensatory habitat creation at sites far from the Thames Estuary several years in advance of option implementation. The typical lifespan of the bird species that the habitat is targeted to (given in Table 3) should provide a reasonable guide to the likely time for species with high site-fidelity to colonise a new site. However, it is important to note that in the case of newly created intertidal habitat, intertidal bivalve specialists would be likely to colonise several years after other intertidal invertebrate feeders as their bivalve prey have been shown to take several years to colonise such habitats; therefore, it may be several years before the habitat is suitable for specialist bivalve feeders.

Site-fidelity of each species is summarised in Table 3. At a guild level, almost all species that are primarily intertidal invertebrate feeders have high site-fidelity. Within the other species guilds there is a mixture of species with low and high site-fidelity, although in general waders tend to have high site-fidelity while wildfowl tend to have low site-fidelity. The exceptions to this general pattern are dark-bellied brent goose (which has high site-fidelity) and red knot (which has low site-fidelity). This guild-level pattern suggests that any compensatory intertidal habitat created at a distance from the Thames would only slowly be colonised by those species that most depend on intertidal habitat for feeding (intertidal invertebrate feeders and some intertidal bivalve specialists). Site-faithful birds that winter on the Thames and Medway Estuaries immediately prior to the construction of an airport would be likely to return to the site but experience increased mortality in the years following construction until a stable population size, which could be supported on the modified estuary following development, is reached.

Mitigation and compensation measures based on managed realignment and topographic modification aim to mitigate or compensate for the intertidal habitats lost as a result of option implementation. The relative functionality of managed realignment compared to natural intertidal areas is outlined in section 4.3.1 above. Topographic modification is untested at the scale that would be required to mitigate for an airport development therefore the likelihood of creating functional intertidal habitat using this method is unknown.

4.3.3.1 Freshwater wetland creation

One potential compensatory measure is the creation of freshwater wetland habitat at sites close to the Thames and Medway Estuaries. This measure was used as compensation for the impoundment of Cardiff Bay, through the creation of the Newport Wetlands Reserve, which does support important numbers of some generalist wetland species (Austin *et al*. 2006). The creation of freshwater wetlands could not compensate for the predicted losses of intertidal invertebrate feeders or intertidal bivalve specialists. It could potentially provide mitigation for some of the losses of coastal freshwater and brackish marsh habitat that would occur if an airport were built on the Isle of Grain and may also provide compensation for predicted losses of the generalist wetland species from intertidal areas (Austin *et al*. 2006).

The likely effectiveness of this measure as compensation for the loss of intertidal habitat (for the guilds that also use freshwater habitats) can be summarised by the proportions of UK sites supporting internationally or nationally important numbers of each species that are primarily freshwater habitat (Austin *et al*. 2014). Species in the generalist wetland species guild tend to be found in reasonable numbers at freshwater sites, with the proportion of nationally or internationally important sites that are freshwater ranging from 9% to 85% for these species. It is important to also note that even at estuarine sites some these species may be using freshwater wetlands adjacent to the estuary as well as tidal areas. Therefore the creation of freshwater wetlands close to the Thames and Medway Estuaries may be at least partially effective as a compensation measure for the following designated SPA species: Bewick's swan, dark-bellied brent goose, Eurasian wigeon, Eurasian teal, mallard, northern pintail, northern shoveler, common pochard, pied avocet, northern lapwing, Eurasian curlew and black-tailed godwit. If the creation of freshwater wetlands were considered as a compensatory measure once development proposals were at a later stage, it would be possible to conduct more detailed analyses of WeBS data to calculate the proportion of these species' populations that are recorded on freshwater sites, the size of freshwater sites supporting each species, and estimates of the average density of each species supported at freshwater and intertidal sites. This would reduce the uncertainty regarding the habitat equivalency of freshwater wetlands compared to intertidal sites for these species.

The majority of species in the two intertidal guilds (primarily intertidal invertebrate feeders and bivalve specialists) rarely use freshwater habitats; therefore there are no nationally or internationally important freshwater sites in the UK for these species. Although a number of the species in these guilds will use freshwater habitats at some times of the year, or at certain stages of the tidal cycle, they are only supported at very low densities on freshwater sites in comparison to intertidal habitat. The creation of freshwater wetlands would not provide equivalent habitat for species in these guilds to compensate for the intertidal habitat that would be lost as a result of and airport development. This means that for several key SPA species that feed on intertidal habitat (e.g. common shelduck, common ringed plover, grey plover, ruddy turnstone, dunlin, common greenshank, common redshank, Eurasian oystercatcher and red knot) the only habitat creation measures that are likely to provide effective mitigation/compensation are a combination of topographic modification and managed realignment within/adjoining the Thames and Medway Estuaries, or managed realignment at a distance from the site to create new mudflats.

4.3.4 Implications for flyway populations of delivering compensatory habitat elsewhere

If compensatory habitat were delivered at a distance from the Thames and Medway Estuaries (i.e. in other parts of the UK) then there is considerable uncertainty as to whether it would be colonised by the bird populations currently using the habitat that would be lost on the Thames and Medway Estuaries if an airport were built. Creating new sites at a distance from the site is arguably not within the scope of current guidance on compensation, therefore consideration would also need to be given as to the legal implications of providing compensatory habitat elsewhere and would probably need to be agreed at ministerial level.

Species that are site-faithful (those with high site-fidelity scores in Table 3) include most intertidal invertebrate feeders and some intertidal bivalve specialists. The generalist wetland waders also largely fall into this category. Site-faithful species currently supported on the Thames and Medway Estuaries include more than 1 % of the international populations of dark-bellied brent goose, common shelduck, northern pintail, common ringed plover, grey plover, dunlin, red knot, black-tailed godwit and common redshank, and more than 1 % of the national populations of Eurasian wigeon, Eurasian teal, hen harrier, pied avocet, Eurasian oystercatcher, Eurasian curlew, common greenshank and little tern.

All of these site-faithful species are likely to respond rather differently from the mobile species to habitat creation in other parts of the UK. It is thought that most site-faithful species colonise a site in their first winter based on a range of factors (e.g. food supply, winter temperature, and migration distance from the breeding grounds). There is some evidence from colour-ringing and resighting of black-tailed godwits that first-winter birds sample a range of sites before settling. Thereafter, most individuals will return to the site where they settled during their first winter in every subsequent year of life (Wernham *et al*. 2002). If there were significant loss of habitat, and therefore a reduction in the carrying capacity on the Thames and Medway as a result of airport development, it is likely that adults of site-faithful species would continue to spend winters in these estuaries. Reductions in food availability would most likely lead to increases in mortality rates of these individuals. The colonisation of any new habitat provided in other parts of the UK would most likely be driven by the recruitment of first-year birds. The first individuals to colonise such new sites may have relatively high survival rates due to high food abundance (assuming the site did not immediately reach carrying capacity). Because the redistribution of site-faithful species depends on demographic processes such as recruitment and survival, rather than simply individual birds moving to other sites, the colonisation rate of compensatory habitat provided at a distance from the Thames and Medway Estuaries is likely to be much slower for these site-faithful species than for more mobile species. There is, therefore, less certainty in the likelihood of success of such measures for site-faithful species (including dunlin, redshank, ringed plover, grey plover, whimbrel and curlew) and a higher risk associated with providing compensatory habitat for these species at a distance from the site.

One example of site-faithful species staying in the vicinity of a site rather than moving a great distance following habitat loss is redshank in Cardiff Bay. Following the closure of the barrage redshank were displaced to other nearby sites, but mortality rates increased for at least three years afterwards (Burton 2006; Burton *et al*. 2006; Burton & Armitage 2008).

Although most wader species are site-faithful, the distributions of several species have been shown to shift towards the north-east in response to climate change in recent decades (Austin & Rehfisch 2005; Maclean *et al*. 2008). The provision of compensatory intertidal habitat creation at sites to the east or north of the Thames and Medway Estuaries, may therefore be beneficial for these species, although it may several years for such sites to be colonised and achieve stable population sizes. If populations of some species continue to move east and north in response to further predicted climate change (UKCP09 2009) then the potential benefit of newly created sites in these areas could increase in the future. However this is highly uncertain, not least because birds may continue to move east and north to sites outside the UK.

It is possible that the flyways of some species may not be supported by providing compensatory habitat at a distance from the Thames and Medway, for example further north on the east coast of England such as in Essex or elsewhere in East Anglia, as suggested by Foster and partners.

4.3.5 Compensation ratios

Habitats Directive guidance suggests that the area of compensatory habitat provided should be at least twice the area lost. However, the ratio of compensatory habitat compared to lost habitat that would need to be provided to compensate for waterbird losses (i.e. support the number of waterbirds predicted to be lost) depends on a range of factors and is therefore uncertain. As on any estuary there are considerably different densities of waterbirds in different parts of the estuary, and, further, each species tends to use particular parts of the estuary. This means that there are substantial areas of the estuary with few birds, and therefore compensation for the numbers of birds lost needs to provide habitat in an appropriate part of an estuary with the appropriate sediment type for the species in question. The density of birds on the area lost and the area created will determine the compensation ratio that is required. Necessarily, defining the ratio of compensatory habitat requires an understanding of the number of each species that needs to be supported and the likely density that would be supported on the habitat that will be created. Furthermore, the most crucial factor is likely to be our ability to engineer and successfully retain the exact sorts of habitats the individual species require. Understanding of how to achieve this is currently limited (see section 4.3.1 above) so the density of each bird species that would be supported on newly created habitat is highly uncertain. It is therefore realistic to anticipate that if an airport development were to go ahead in the Thames any compensatory habitat requirements would involve creating new areas of inter-tidal that were larger than those lost to maximise the chance of suitable habitat developing to support the number of birds lost.

4.3.6 Gaps in knowledge

There are a number of areas of uncertainty in this work, including:

- The numbers of birds of each species likely to be lost from the Thames and Medway Estuaries were an airport development to go ahead (a more detailed airport proposal and Environmental Impact Assessment (EIA) and HRA would be required to establish this);
- How to create optimal intertidal habitat for birds through managed realignment or topographic modification, and our ability to engineer the required types of intertidal habitat;
- The density of waterbirds of each species likely to be supported on created intertidal habitat, compared to natural intertidal habitat (and therefore the ratio of compensatory habitat that would need to be provided), and how long it would take to reach this density after creation;
- The density of waterbirds of each species likely to be supported on freshwater habitats, relative to intertidal habitats that would be lost (and therefore the ratio of compensatory habitat that would need to be provided if freshwater wetlands were used as mitigation for lost intertidal habitat);
- Through-the-tide movement distances of birds (for example from high-tide roosts to mid-tide feeding sites, to low-tide feeding sites). This limits our ability to define the distance within which all of these requirements need to be sited in any compensation packages;
- Within- and between-winter movements of birds between estuaries in the UK (and beyond). This is important in understanding the likelihood of new habitat created at a distance from

the Thames and Medway Estuaries being colonised by the same individual birds that currently use the site, and the rate at which this might happen;
- Colonisation rates of new sites by new birds, and demography of site-faithful species. This is important in understanding how long it might take for new populations of site-faithful species to build up on newly created habitat at a distance from the Thames and Medway Estuaries;
- The rate at which the wintering distributions of some bird species might change in response to future climate change.

Many of these uncertainties could be addressed through further research. Suggested methods to achieve this are given in the following sections.

4.3.6.1 Numbers of birds likely to be lost from the Thames and Medway due to the development

At this stage, while the precise airport proposals (and therefore area of habitat that would be lost) are uncertain, it is not possible to make precise predictions about the numbers of birds that would be lost from the area. A better estimate of these figures would be possible if a development goes forward and more detailed plans are developed, and EIA/HRA methods would allow this. As part of this, generating good predictions regarding the type of sediments in the estuaries following the construction of an airport, and predictions of the types and densities of invertebrates likely to occur in that sediment, would be extremely valuable in improving predictions for changes to waterbirds, for example through individual-based modelling. This is likely to require a collaborative approach involving experts in sediment transport modelling, and in benthic ecology.

4.3.6.2 How to create optimal intertidal mudflat habitat for waterbirds, and densities of waterbirds supported on created compared to natural intertidal habitat

Our understanding of the best areas and methods to create new intertidal mudflats for birds could be greatly improved through a detailed investigation and review of all situations where intertidal mudflat has been created either inadvertently or by design. Such a study could compare the densities of different waterbird species supported on created mudflats and on natural mudflats in nearby estuaries. The long-term development of created mudflats and their bird populations (over decades) could be studied in situations where new mudflat has been created inadvertently. This includes many east-coast estuaries where sea walls were breached in the 1953 floods and not rebuilt in the same places. For example, the Alde-Ore Estuary SPA has relatively new mudflats dating from this time. Studies of more recent managed realignment sites (where bird numbers have been monitored) could help to determine the time before a stable density of birds is achieved. Improving our understanding of the effects of changes to estuaries on birds would be very valuable in informing a wide range of future conservation management including managed realignment, not just in relation to airport development on the Thames.

Developing habitat association modelling to predict waterbird densities at a mudflat level (rather than the whole-estuary scale as has been done in previous studies (Severn Tidal Power 2010a) would improve our understanding of the within-estuary distribution of birds and may enable predictions of the capacity of topographic modification areas at given locations in the estuary. The advantage of this approach over individual-based models is that where it is difficult to predict future invertebrate densities, using estuary morphology as a proxy means that realistic predictions of future waterbird densities can still be generated. Habitat association models can also be used to predict the likely future densities of a wider range of waterbird species than individual-based models.

4.3.6.3 The density of waterbirds supported on freshwater wetlands compared to intertidal habitat

The creation of freshwater wetlands could potentially provide mitigation for some of the losses of coastal freshwater and brackish marsh habitat that would occur if an airport were built on the Isle of Grain and may also provide compensation for predicted losses of the generalist wetland species from intertidal areas. As outlined above it could not compensate for the predicted losses of intertidal invertebrate feeders or intertidal bivalve specialists. If the creation of freshwater wetlands were considered as a compensatory measure for the loss of intertidal habitat for generalist wetland species, it would be possible to conduct more detailed analyses of existing Wetland Bird Survey data to calculate the proportion of these species' populations that are recorded on freshwater sites, and estimates of the average density of each species supported at freshwater and intertidal sites. This would reduce the uncertainty regarding the habitat equivalency of freshwater wetlands compared to intertidal sites for this species guild and allow recommendations to be made regarding the ratio of the area of freshwater habitat creation compared to the area of intertidal habitat loss that would be required to support equivalent numbers of each species. Such a study would be relatively straightforward as the data required already exist.

4.3.6.4 Through-the-tide movement distances of birds

For intertidal feeding species (e.g. common shelduck, dunlin, common redshank, ringed plover, grey plover) in particular, it is important that a range of ecologically-linked sites that support the needs of the species at different stages of the tidal cycle are provided close together (within the distance that the birds would normally move during a tidal cycle). Were an airport development to be taken forward it would be possible to provide more detailed information regarding through-the-tide movement distances of birds through detailed studies of waterbird movements. GPS tracking techniques using tags that record almost continuously would be the best method to use for such a study because very regular information on the location of birds would be required to establish movement patterns within a single tidal cycle. However other techniques such as colour-ringing and resighting or radio-tracking could also provide useful (although less detailed) information. Ideally, movement patterns should be studied on a range of estuaries, including the Thames and Medway, to establish the range of distances that birds will move between roosting sites and feeding sites at different stages of the tidal cycle.

4.3.6.5 Within- and between-winter movements of waterbirds

If the creation of new intertidal habitats at a distance from the Thames and Medway Estuaries is to be considered, it would be valuable to investigate the within- and between-winter movements of the key waterbird species that the measure is targeted for. This analysis could be done using existing ringing data (although there may not be sufficient data for all species). This would help to determine the likelihood of birds of non-site-faithful species colonising compensatory habitat at a distance from the Thames and Medway Estuaries if they were displaced following airport construction. It would also reduce the uncertainty as to which of the more site-faithful species are unlikely to move to sites created at a distance.

4.3.6.6 Colonisation rates of new sites and demography of site-faithful species

The colonisation rates of new sites and the demography of site-faithful species in relation to changing distributions are uncertain as they depend on a range of factors. These include the rate of change of distributions in response to climate change, settlement patterns of first-winter birds and the typical lifespan of the species in question. Reducing uncertainty around some of these issues has been described elsewhere, but further reducing uncertainty regarding colonisation rates of new sites could be undertaken through studies of changes in bird numbers on existing or planned (in the near future) habitat creation schemes such as managed realignment.

4.4 Costs of mitigation and compensation options

The cost of creating new coastal wetland habitat, for example through managed realignment, will vary depending on a variety of site-specific issues. However, a 2010 study examined the average costs across a number of managed realignment sites and suggested that although there was a wide variation in costs, the average cost was between £70,000 and £75,000 per hectare. This represents the average of 11 separate site studies at three locations covering a range of size of managed realignments between 500ha and 11,500ha. (5 sq km to 115 sq km) (Severn Tidal Power 2010).

In addition to the monetary cost of mitigation and compensation there is also a time cost to be considered. As stated above, newly created habitat such as managed realignment would take a few years to become established and provide the conditions that coastal birds require. It is therefore likely that statutory agencies may require new habitat to be provided in advance of airport construction, which may lead to delays with the project. In the event that new compensatory habitat is created at a distance from the development site (for example in Essex or elsewhere in East Anglia, as proposed by Foster and partners) it is likely that there would be further delays in the effectiveness of this compensation due to the time it would take for birds to colonise the new site(s) (see section 4.3.6.6 above).

5. DISCUSSION

5.1 Impacts of habitat loss were an airport to be built on the Isle of Grain

Were an airport development to go ahead in the Hoo Peninsula / Isle of Grain area it would cause a significant loss of both freshwater and intertidal coastal wetland habitat, largely within the Thames Estuary and Marshes SPA, though probably also with some habitat loss to the Medway Estuary and Marshes SPA. The area of habitat that would be lost has been estimated by Foster and partners to be around 1700 hectares, and the proposed location of the development currently supports over 21,000 birds, which is approximately 25% of the total waterbird population of the two SPAs combined (the Thames Estuary and Marshes SPA and Medway Estuary and Marshes SPA). Significant proportions of the designated SPA bird populations occur in this area; the proportion of each species population supported by the proposed development area varies, but is up to 85% of the total population of the two SPAs for some species (Table 2). Coastal wetland habitat loss of this type has been widely shown to have significant impacts on bird populations in various parts of the world, as demonstrated by the review in section 3 of this report. We can therefore be confident that the habitat loss due to airport development would have significant negative impacts on the bird populations that depend on the areas lost, and it is likely that most of the 21,000 waterbirds currently using the area would be displaced. Under the 2010 Habitats Directive (92/43/EEC), an appropriate assessment would be required to determine any 'likely significant effects' to the SPAs following any proposed mitigation. Article 6(4) of the EC Habitats Directive allows plans or projects which may have an adverse effect on the integrity of a European site or European marine site to go ahead on grounds of 'imperative reasons of overriding public interest' (IROPI) when there are no alternative solutions, but only if compensatory measures have been secured. This means that as part of any airport development it is highly likely that mitigation and compensation would be required to provide alternative habitat for displaced birds. Further details of potential mitigation and compensation options are provided below.

5.2 Mitigation and compensation

The likely effectiveness of each mitigation or compensation measure for the designated SPA species in each species guild is summarised in Table 5. It should be noted that we have not considered the availability of suitable sites within the Thames Estuary in the suggestions below, and this will be an important consideration that will need to be taken into account in determining which of the suggested mitigation and compensation measures are feasible.

Topographic modification to create intertidal habitat within the Thames and Medway Estuaries is likely to be partially effective in mitigating the effects of intertidal habitat loss for intertidal invertebrate feeders, intertidal bivalve specialists and generalist wetland species. It is unlikely to have any significant benefits for piscivores or birds of prey. This measure has only been used at a relatively small scale in the past. Therefore, the likely success of this measure is relatively uncertain.

The introduction of new refuges or roosting sites where roosting areas have been lost is an established method that has been used elsewhere for waterbirds with some success, for example in Cardiff Bay (Burton *et al*. 2003) and Teesmouth (Burton *et al.* 1996). Although this has not regularly been used as mitigation or compensation for SPAs, it is likely to be effective or partially effective in replacing lost roosting sites for all species.

Managed realignment at sites adjacent to the Thames and Medway Estuaries may be effective compensation for the loss of intertidal habitat, though depending on the sites chosen it is uncertain whether it would be possible to create largely saltmarsh, largely mudflat, or a combination of the two, and it is important that any habitat created as compensation for an airport development should, as far as possible, aim to replicate the proportions of saltmarsh and mudflat that will be lost. Were saltmarsh created, this measure is likely to be effective or partially effective compensation only for generalist wetland species that feed on saltmarsh (for example Bewick's swan, Eurasian wigeon), or for intertidal mudflat feeding species that require such areas as high-tide roost sites. Birds of prey may also benefit, but piscivores are unlikely to be affected by this measure. Were mudflat habitats created by managed realignment, this could provide feeding opportunities for intertidal mudflat feeding species (e.g. common shelduck, common ringed plover, grey plover, ruddy turnstone, dunlin, common greenshank and common redshank). Managed realignment is an established method that can create good quality habitat (e.g. Badley & Allcorn 2006). However there are many examples where the habitat created has been of lower quality or diversity than natural intertidal habitat in the area, and thus supports lower densities of birds. It is therefore important to carefully design any areas of managed realignment to provide the best possible habitat quality. The web-based ABPmer managed realignment guide (http://www.abpmer.net/omreg/) provides useful information on techniques that can be used to achieve this. It is important to note that species in the intertidal bivalve specialist guild (Eurasian oystercatcher and red knot) are likely to colonise newly created intertidal habitat several years later than other intertidal invertebrate feeders. This is because the bivalve prey on which such species depend take several years to colonise newly created habitats, and thus these habitats are not suitable for bivalve feeding waterbirds in the early years. The same species guilds are likely to benefit from managed realignment at distance from the Thames and Medway Estuaries, however it is likely that this would only be partially effective, and would take longer to compensate for the loss of habitat due to the length of time required for colonisation (see below).

Creation of freshwater wetlands is an established practice for SPA compensation or mitigation and methods for creating high quality freshwater habitats are generally better established than those for creating intertidal areas. The creation of new freshwater wetland habitats adjacent to the Thames or Medway Estuary would be effective in providing compensation for the losses of coastal freshwater marsh that would occur on the Isle of Grain were an airport to be built. This is likely to be either completely or partially effective for generalist wetland species and birds of prey. If areas of open water were created it may also be partially effective for some species of piscivores. However, there would only be likely to be very low-level benefits for intertidal invertebrate feeders and intertidal bivalve specialists, as freshwater habitats generally only support low densities of these species. It would be important to consider the distance between such habitat creation and the remaining intertidal habitat in the area, to ensure a reasonable commuting distance for generalist wetland species which use both habitat types.

The creation of new habitats at distance from the Thames Estuary and Marshes and Medway Estuary and Marshes SPAs (for example in Essex and East Anglia, as proposed by Foster and partners), either through managed realignment, topographic modification, or the creation of freshwater wetlands, is likely to be less effective than providing such habitats locally, although it could still be partially effective for several species guilds. However, many of the intertidal invertebrate feeders, intertidal bivalve specialists and generalist wetland species that would benefit from these measures are very site-faithful. Thus the re-distribution of these species to new sites could take many years and, for site-faithful species, is likely to be driven by high mortality rates on the Thames Estuary and Marshes and Medway Estuary and Marshes SPAs, combined with recruitment of first-year birds to newly created sites elsewhere. Many of the intertidal invertebrate feeders and intertidal bivalve specialists also have high site dependence (50% or more of the Great Britain population is found on 10 or fewer sites). Populations of these species with high site dependence are likely to be affected more strongly by any negative effects of habitat loss due to an airport development than populations of species with more widespread distributions. Thus, it is likely that the recovery of species populations that are site dependent would take longer than other species, and may further reduce the rate of colonisation of any new habitat created at a distance. However, despite these limitations it is likely that intertidal habitat creation at sites elsewhere in the UK could be partially effective for a range of species, but this conclusion is based on expert judgement only as there is absolutely no precedent for such measures. Therefore there is considerable uncertainty surrounding this conclusion and a risk that compensatory habitat provided at a distance may not be effective. The uncertainty and risk surrounding this measure could be reduced (but not eliminated) through the further studies described in section 4 above, and we suggest that such studies would be essential before this measure could be recommended.

Table 5. Summary of the effectiveness of proposed compensation measures for each SPA waterbird guild. "Established methods" are those that have been proven to be successful elsewhere in compensating for the effects of developments on waterbirds. "Established practice" refers to whether the measure is an established mitigation or compensation measure.

Measure	Guild	Effectiveness[1]	Established method?	Example(s)	Established practice?
Topographic modification (intertidal habitat creation) to prevent or reduce effects of intertidal loss.	Intertidal invertebrate feeders	2	Not at this scale (but some small scale projects)	Parkstone, Poole Harbour (see Topographic modification report)	NO
	Intertidal bivalve specialists	2			
	Piscivores	N/A			
	Generalist wetland species	2			
	Birds of prey	1			
Introduction of new refuges and/or bird roost sites within the estuary where roosting areas have been lost.	Intertidal invertebrate feeders	3	YES Has been used elsewhere with some success	Cardiff Bay (Burton *et al.* 2003) Teesmouth (Burton *et al.* 1996)	NO (not regularly used)
	Intertidal bivalve specialists	3			
	Piscivores	2			
	Generalist wetland species	3			
	Birds of prey	2			
Managed re-alignment adjoining the Thames Estuary and Marshes and Medway Estuary and Marshes SPAs to create intertidal habitat	Intertidal invertebrate feeders	2	YES	Freiston Shore on the Wash - 66 ha intertidal habitat created (Badley & Allcorn 2006)	YES
	Intertidal bivalve specialists	2			
	Piscivores	1			
	Generalist wetland species	3			
	Birds of prey	3			
Managed re-alignment at distance from the Thames Estuary and Marshes and Medway Estuary and Marshes SPAs to create intertidal habitat	Intertidal invertebrate feeders	2	YES	Freiston Shore on the Wash - 66 ha intertidal habitat created (Badley & Allcorn 2006)	NO
	Intertidal bivalve specialists	2			
	Piscivores	1			
	Generalist wetland species	2			
	Birds of prey	2			
Creation of freshwater wetland habitat close to the Thames Estuary and Marshes and Medway Estuary and Marshes SPAs	Intertidal invertebrate feeders	1	YES	Newport Wetlands Reserve (compensation for Cardiff Bay barrage)	YES
	Intertidal bivalve specialists	1			
	Piscivores	2			
	Generalist wetland species	3			
	Birds of prey	3			

[1] Effectiveness is scored on a five-point scale where:
0 = ineffective
1 = effective at a very low level (e.g. new habitat that may support a low density of some SPA species)
2 = partially effective for some SPA species in the guild
3 = effective for some SPA species in the guild, partially effective for other SPA species in the guild
4 = completely effective for all SPA species in the guild

ACKNOWLEDGEMENTS

This work was funded by Medway Council and Kent County Council via Instinctif Partners. We thank Robin Cooper of Medway Council, Elizabeth Milne of Kent County Council, and James Nason and Paul Gaffney of Instinctif Partners for useful suggestions both at the start up meeting and in providing feedback on the draft report. We are also grateful to Nigel Clark and Phil Atkinson of the British Trust for Ornithology for helpful discussions sharing their advice and expertise regarding mitigation and compensation options for coastal birds.

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