Healthy & Biologically Diverse Seas Evidence Group
Technical Report Series:

Evaluation and gap analysis of current and potential indicators for Seabirds & Waterbirds

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Preface

The UK Marine Monitoring and Assessment Strategy (UKMMAS) aims to provide coordinated and integrated marine monitoring programmes which support periodic assessments of the state of the UK marine environment. The strategy aims to provide vital data and information necessary to help assess progress towards achieving the UK's vision of clean, healthy, safe, productive and biologically diverse seas. The overarching strategy is supported and delivered by four evidence groups; Clean and Safe Seas Evidence Group (CSSEG); Productive Seas Evidence Group (PSEG); Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) and Ocean Processes Evidence Group (OPEG). These groups are responsible for implementing monitoring and observations programmes to contribute to ecosystem-based assessments of marine environmental status.

As part of the HBDSEG programme of work, a series of reviews of environmental indicators was undertaken for the following marine ecosystem components:

1. Rock and biogenic reef habitats
2. Sediment habitats
3. Deep sea habitats
4. Seabirds and waterbirds
5. Cetaceans
6. Seals
7. Plankton
8. Microbes

The aim of the reviews was to evaluate a wide range of currently available and potential indicators for marine biodiversity monitoring and assessment. This task was undertaken particularly to inform future needs of the EU Marine Strategy Framework Directive (MSFD). The work was carried out by a group of consultants and contributors and was managed by JNCC.

Each review included a process to evaluate indicator effectiveness against a set of specified scientific and economic criteria. This process identified those indicators of activity, pressure, state change/impact and ecosystem structure and function that were considered to be scientifically robust and cost effective. The indicators which met these criteria were then assessed for inclusion within an overall indicator suite that the reviewers considered would collectively provide the best assessment of their ecosystem component's status. Within the review, authors also identified important gaps in indicator availability and suggested areas for future development in order to fill these gaps.

This report covers one of the ecosystem components listed above. It will be considered by HBDSEG, together with the other indicator reviews, in the further development of monitoring and assessment requirements under the MSFD and to meet other UK policy needs. Further steps in the process of identifying suitable indicators will be required to refine currently available indicators. Additional indicators may also need to be developed where significant gaps occur. Furthermore, as the framework within which these indicators will be used develops, there will be increasing focus and effort directed towards identifying those indicators which are able to address specific management objectives. There is no obligation for HBDSEG or UKMMAS to adopt any particular indicators at this stage, based on the content of this or any of the reports in this series.

This report has been through a scientific peer review and sign-off process by JNCC and HBDSEG. At this time it is considered to constitute a comprehensive review of a wide range of currently available and potential indicators for this marine ecosystem component.

Summary

- Indicators and individual species indices of seabirds and coastal waterbirds are reviewed as a contribution to the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) OSPAR / UKMMAS assessment framework. This review focuses on those currently in use in policy and regulatory mechanisms and those which could be developed with little additional effort.

- There are currently 10 indicators based on seabird and coastal waterbird populations in use, and nine in development. The majority of the indicators that are currently in use are generated from data collected as part of the Wetland Bird Survey (WeBS) or the Seabird Monitoring Programme (SMP), and are based on mean trends in the abundance or breeding success of a number of species at either a UK or regional scale.

- All bird indicators scored very highly in the scientific evaluation because data are collected and analysed according to strict, well established protocols producing accurate indicators in terms of their accuracy in measuring variation in bird numbers (although not all indicators are able to attribute these changes to a specific pressure or activity). Furthermore there are long-term datasets for most indicators. Waterbird indicators based on WeBS data were rated as good value in the economic evaluation because these data are largely collected by volunteers, whose time is costed as free. Seabird indicators based on SMP data were still relatively good value, but tended to be rated as moderate value in the economic evaluation because the SMP relies more heavily on professional fieldworkers, although it also has some input from volunteers.

- Most bird indicators in use or in development are indicators of state, and are not good indicators of single pressures, activities or their impacts because they include a wide range of species, each of which is affected by multiple pressures and activities. However, they tend to be good indicators of ecosystem structure and function because their association with a large number of habitats, their sensitivity to environmental change and their relationships with other species means that they often reflect changes in other taxa, and in ecological patterns generally.

- Of 36 pressures listed in the UKMMAS / OSPAR assessment framework matrix (version 12), 16 are assessed to some extent by the existing marine bird indicators, and a further four by those that are under development. However, as most of these indicators are affected by multiple pressures it may be difficult to disentangle the effect of one particular pressure in most circumstances. The exception to this is the oiled guillemots’ indicator (ID 1145) which provides a direct indicator of oil pollution in the marine environment. The indicators that are currently under development for organohalogen and mercury concentrations in seabird eggs (ID 1142 and 1145) and for plastics in seabird stomachs (ID 1141) will also provide direct indicators of particular pressures.

- Seven pressures that are not addressed by the current indicators, or those under-developments, could be addressed by new seabird and coastal waterbird indicators that have been proposed in this report. The majority of the proposed indicators could be generated from existing data

on coastal waterbirds and seabirds collected as part of WeBS and SMP. Many of the proposed indicators will be affected by multiple pressures, therefore we suggest that such indicators, rather than being direct indicators, could be used to flag up sites or regions where there is a problem worthy of further (and more costly) investigation, in a similar style to WeBS Alerts. This would reduce the need for carrying out more costly types of monitoring at all sites.

- Nine pressures cannot be addressed by any of the existing or proposed seabird and coastal waterbird indicators, either because there is insufficient evidence to quantify the impact of these pressures on marine birds, or because the pressures in question are better measured in other ways. The pressures not addressed are: pH changes, regional or national salinity changes, local temperature changes, radionuclide contamination, other substances released into the environment in accordance with community legislation or international conventions, electromagnetic changes, underwater noise, genetic modification and the introduction of microbial pathogens.

- There is considerable scope to make use of existing data collected at the national, regional and site-level to create new indicators for components of ecosystem structure and functioning. Of the 26 aspects of ecosystem structure and function identified by the HBDSEG assessment framework, only four can be monitored using existing seabird and coastal waterbird indicators. However, a further 11 can be monitored using the new indicators that have been proposed in this report, and six custom aspects of ecosystem structure and function can also be monitored. Seabird and coastal waterbird indicators are generally more effective at assessing the biotic and ecological aspects of ecosystem structure and function than the abiotic and physico-chemical aspects. As seabird and waterbird species use a wide range of marine habitats and are typically at the top of the marine food chain, changes in their populations are typically indicative of changes elsewhere in the ecosystem and thus they are good indicators of ecosystem structure and function.

- Seabird and waterbird populations are ideal for producing indicators of certain pressures and of ecosystem structure and functioning in the marine environment. The relative ease with which they can be counted and their tendency to congregate at key locations make them cost-effective to monitor. Consequently indicators based on seabirds and coastal waterbirds could be used as a means of monitoring the state of marine environments, pressures on marine environments and the success of initiatives designed to alleviate these pressures.

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1 Introduction

1.1 Aims & objectives of report

There are multiple policy drivers for effective monitoring and assessment of the marine environment, but there are significant gaps in our current biodiversity monitoring effort and the cost of comprehensive marine monitoring programmes are high. Therefore, it is desirable to work towards a single monitoring framework that will meet all national and international policy and legal commitments, while ensuring adequate scientific evidence is available to fully assess the state of the marine environment and any changes over time. The aim of this report is to assess the applicability of existing seabird and coastal waterbird indicators and monitoring programmes, to identify where modifications might be appropriate and to identify significant gaps. Indicators have been entered into the online Marine Indicators Database (http://www.jncc.gov.uk:80/MarineIndicators/); these are taken from a number of key policy mechanisms (e.g. EC Directives) and other sources. It is recognised that there are large numbers of indicators developed through research which could be considered; this review focuses on those in use in policy and regulatory mechanisms and those of potential practical use.

1.2 Work undertaken in report

In order to achieve the aims set out above, the following work was undertaken:

- a review of the existing indicators for seabirds and waterbirds;
- an evaluation of the effectiveness of the indicators against standard scientific and economic criteria;
- a review of indicators against relevant pressures and important aspects of ecosystem structure and function;
- identification of significant gaps and any indicators that may be able to fill these gaps;
- recommendation of a set of indicators for seabirds and waterbirds that are effective scientifically and economically and could be used in future within an integrated monitoring and assessment programme.

1.3 Introduction to the ecosystem component of interest

In this report we focus on seabirds and coastal waterbirds. The project aims to identify the most effective indicators of marine ecosystem state, pressures and impacts to allow scientifically robust assessments of marine environmental status to be made. Birds are considered to be good indicators of the state of the environment as they occupy a wide range of habitats, are usually near the top of the food chain (Furness & Greenwood 1993) and long-term data are readily available to assess population changes.

A number of indicators based on seabirds and coastal waterbirds are already in place. Most of these provide an indication of the state of marine bird populations, as opposed to a proximate indicator of a pressure, or a direct indicator of the impact of a pressure. In this report we review the effectiveness of these existing indicators as components of a marine monitoring framework and suggest new indicators to fill any gaps.

Seabirds in this report are defined as petrels, gannets, cormorants, skuas, gulls, terns and auks (Gaston 2004; Schreiber & Burger 2002; Mitchell *et al* in prep.). There are 25 species of seabird that regularly breed in the UK (Mitchell *et al* 2004). These are listed in Table 1: Seabirds that do not breed in the UK but use the marine environment around the UK for feeding at any time of the year are also considered in this report where appropriate.

Table 1. English and scientific names of the 25 species of seabird that regularly breed in the UK. Short versions of English names that are used in this report are also given.

Full English Name	**Short English Name**	**Scientific Name**
Northern fulmar	Fulmar	*Fulmarus glacialis*
Manx shearwater		*Puffinus puffinus*
European storm petrel	Storm petrel	*Hydrobates pelagicus*
Leach’s storm petrel	Leach’s petrel	*Oceanodroma leucorhoa*
Northern gannet	Gannet	*Morus bassanus*
Great cormorant	Cormorant	*Phalacrocorax carbo*
European shag	Shag	*Phalacrocorax aristotelis*
Arctic skua		*Stercorarius parasiticus*
Great skua		*Stercorarius skua*
Black-legged kittiwake	Kittiwake	*Rissa tridactyla*
Black-headed gull		*Chroicocephalus ridibundus*
Mediterranean gull		*Larus melanocephalus*
Common gull		*Larus canus*
Lesser black-backed gull		*Larus fuscus*
Herring gull		*Larus argentatus*
Great black-backed gull		*Larus marinus*
Little tern		*Sterna albifrons*
Sandwich tern		*Sterna sandvicensis*
Common tern		*Sterna hirundo*
Roseate tern		*Sterna dougallii*
Arctic tern		*Sterna paradisaea*
Common guillemot	Guillemot	*Uria aalge*
Razorbill		*Alca torda*
Black guillemot		*Cepphus grylle*
Atlantic puffin	Puffin	*Fratercula arctica*

For the purposes of this review, the term coastal waterbirds refers to coastal populations of divers, grebes, herons, swans, geese, ducks, coots, and waders[3].

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[3] Some sources (e.g. Wetlands International 2006) also include cormorants, gulls and terns among waterbirds, as they are found in both marine and freshwater environments.

Table 2. English and scientific names of the 65 species and sub-species of waterbird that are regularly found in coastal areas of the UK, and have been considered as part of this review (although not all are included in current or proposed indicators). Short versions of English names that are used in this report are also given.

Full English Name	**Short English Name**	**Scientific Name**
Mute swan		*Cygnus olor*
Bewick's swan		*Cygnus columbianus*
Whooper swan		*Cygnus cygnus*
Pink-footed goose		*Anser brachyrhynchus*
European white-fronted goose		*Anser albifrons albifrons*
Greenland white-fronted goose		*Anser albifrons flavirostris*
Greylag goose		*Anser anser*
Barnacle goose		*Branta leucopsis*
Brent goose		*Branta bernicla hrota*
Dark bellied brent goose		*Branta bernicla bernicla*
Common shelduck	Shelduck	*Tadorna tadorna*
Eurasian wigeon	Wigeon	*Anas penelope*
Gadwall		*Anas strepera*
Common teal	Teal	*Anas crecca*
Mallard		*Anas platyrhynchos*
Northern pintail	Pintail	*Anas acuta*
Northern shoveler	Shoveler	*Anas clypeata*
Common pochard	Pochard	*Aythya ferina*
Tufted duck		*Aythya fuligula*
Greater scaup	Scaup	*Aythya marila*
Common eider	Eider	*Somateria mollissima*
Long-tailed duck		*Clangula hyemalis*
Common scoter		*Melanitta nigra*
Velvet scoter		*Melanitta fusca*
Common goldeneye	Goldeneye	*Bucephala clangula*
Red-breasted merganser		*Mergus serrator*
Goosander		*Mergus merganser*
Red-throated diver		*Gavia stellata*
Black-throated diver		*Gavia arctica*
Great northern diver		*Gavia immer*
Little grebe		*Tachybaptus ruficollis*
Great crested grebe		*Podiceps cristatus*
Red-necked grebe		*Podiceps grisegena*
Slavonian grebe		*Podiceps auritus*
Black-necked grebe		*Podiceps nigricollis*
Little egret		*Egretta garzetta*
Grey heron		*Ardea cinerea*
Eurasian spoonbill		*Platalea leucorodia*
Common coot	Coot	*Fulica atra*

Full English Name	**Short English Name**	**Scientific Name**
Eurasian oystercatcher	Oystercatcher	*Haematopus ostralegus*
Pied avocet	Avocet	*Recurvirostra avosetta*
Ringed plover	Ringed plover	*Charadrius hiaticula*
European golden plover	Golden plover	*Pluvialis apricaria*
Grey plover		*Pluvialis squatarola*
Northern lapwing	Lapwing	*Vanellus vanellus*
Red knot	Knot	*Calidris canutus*
Sanderling		*Calidris alba*
Little stint		*Calidris minuta*
Curlew sandpiper		*Calidris ferruginea*
Purple sandpiper		*Calidris maritima*
Dunlin		*Calidris alpina alpina*
Dunlin		*Calidris alpina schinzii*
Ruff		*Philomachus pugnax*
Common snipe	Snipe	*Gallinago gallinago*
Black-tailed godwit		*Limosa limosa limosa*
Black-tailed godwit		*Limosa limosa islandica*
Bar-tailed godwit		*Limosa lapponica*
Whimbrel		*Numenius phaeopus*
Eurasian curlew	Curlew	*Numenius arquata*
Spotted redshank		*Tringa erythropus*
Common greenshank	Greenshank	*Tringa nebularia*
Common redshank	Redshank	*Tringa totanus*
Ruddy turnstone	Turnstone	*Arenaria interpres*
Red-necked phalarope		*Phalaropus lobatus*
Grey phalarope		*Phalaropus fulicarius*

1.4 Policy background

1.4.1 National policy obligations

Following the last State of the Seas Report (Defra 2005), Defra embarked on the development of the UK Marine Monitoring and Assessment Strategy (UKMMAS) and the establishment of a new structure across Government, the Devolved Administrations and their Agencies to deliver the UK's future marine assessment and monitoring needs. This included the setting up of three 'evidence groups' who would be responsible for coordinating the work needed, and reporting to the Marine Assessment & Reporting Group (MARG). The Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) has a very broad remit to provide evidence on the state of the environment, including all biodiversity and oceanographic aspects, and complements the evidence groups for Clean and Safe Seas (CSSEG) and Productive Seas (PSEG). The Groups are required to evaluate assessment and monitoring needs that fulfil Government's overall policy goals and meet national and international obligations.

1.4.2 International policy obligations

The OSPAR Commission's Biodiversity Committee (BDC) is delivering OSPAR's Biodiversity Strategy through a number of working streams, including Ecological Quality Objectives (EcoQOs), assessment of threats and declining species and habitats, designation of marine protected areas and the assessment of the impact of human activities. It has recently started to consider its biodiversity monitoring needs as a contribution to the Joint Assessment and Monitoring Programme (JAMP). The UK presented a proposal for a biodiversity monitoring strategy to the 2007 meeting of the BDC; it sets out a framework for assessing monitoring needs that takes account of pressures from human activities and could also fulfil Marine Strategy Framework Directive requirements. The proposal has subsequently been reviewed by OSPAR's Environmental Assessment and Monitoring Committee (ASMO) and by the ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO) and recommended for further development.

The European Union's Marine Strategy Framework Directive (MSFD) was adopted in June 2008. It requires the establishment of clear environmental targets and monitoring programmes for the marine environment, including its biodiversity, and an assessment of the pressures (from human activities) upon it, with the overall aim of achieving Good Environmental Status (GES) of the marine environment by 2021.

In addition to the MSFD, there are a number of other directives, including the Water Framework (WFD), Habitats and Birds Directives, and Conventions such as ASCOBANS that require assessment of different aspects of the marine environment.

1.5 OSPAR/UKMMAS assessment framework background

The assessment framework developed by JNCC was first presented to the OSPAR Convention's Biodiversity Committee in February 2007 and has since gained wide support across OSPAR as a tool to guide the development of a strategic approach to biodiversity monitoring. It has been particularly welcomed for its potential benefit in meeting the needs of the Marine Strategy Framework Directive (MSFD).

The framework takes the form of a matrix which relates ecosystem components (e.g. deep-seabed habitats) to the main pressures acting upon them (e.g. physical disturbance to the seabed). The ecosystem components have been correlated with components used by OSPAR and the MSFD. The columns of the matrix are a generic set of pressures on the marine environment, which are based on those used by OSPAR, MSFD and the Water Framework Directive (WFD). A 3-point scale of impact (low, moderate, high) reflects the degree of impact each pressure has on an ecosystem component. Each cell of the matrix has additionally been populated with a set of known indicators[4], derived from statutory and non-statutory sources, which are used to monitor and assess the state of that ecosystem component. The assessment matrix helps to

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[4] Note: cells of the matrix where impacts have been identified currently contain a number of species and habitats on protected lists (OSPAR, Habitats Directive), which could potentially be used as indicators of the wider status of the ecosystem component which they are listed against. Should this be appropriate, certain aspect of the species or habitat (e.g. its range, extent or condition) would need to be identified to monitor/assess.

highlight priorities for indicator development and monitoring programmes, based on the likely degree of each impact on the ecosystem component in question.

Since 2007 this approach has also been introduced to the UK's Marine Monitoring and Assessment Strategy (UKMMAS) and is being further developed by the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG). The intention has been to have parallel development at UK and OSPAR levels which will help ensure similar biodiversity strategies are developed at national and international levels. It is also envisaged that the development process will benefit from wide input across OSPAR Contracting Parties.

The overall goal of the UKMMAS is to implement a single monitoring framework that meets all national and international multiple policy commitments (UKMMAS, 2007). This will identify if there are any significant gaps in the current monitoring effort and aim to minimise costs by consolidating monitoring programmes. To help meet this goal, the assessment matrix has been developed with HBDSEG to provide a useful framework that analyses components of an ecosystem and their relationships to anthropogenic pressures. The framework aims to encompass three key issues: an assessment of the state of the ecosystem and how it is changing over space and time, an assessment of the anthropogenic pressures on the ecosystem and how they are changing over space and time, and an assessment of the management and regulatory mechanisms established to deal with the impacts.

The further development of the assessment framework has been divided into five shorter work packages: 1) assessment of pressures, 2) mapping existing indicators to the framework, 3) review of indicators and identification of gaps, 4) modifying or developing indicators and 5) review of current monitoring programmes. The following work will contribute to work package 3 and will critically review indicators, identify gaps and recommend an overall suite of the most effective indicators for the ecosystem component in question.

1.6 Definitions used in the report

Definitions of activity, pressure, state change/ecological impact and ecosystem structure and function are used within this report as follows (adapted from the 2008 CP2 methodology (Robinson *et al* 2008)):

Activity – Human social or economic actions or endeavours that may have an effect on the marine environment e.g. fishing, energy production.

Pressure - The mechanism (physical, chemical or biological) through which an activity has an effect on any part of the ecosystem e.g. physical disturbance to the seabed.

State change/ecological impact – Physical, chemical or biological condition change at any level of organisation within the system. This change may be due to natural variability or occurs as a consequence of a human pressure e.g. benthic invertebrate mortality.

Ecosystem structure and function – Ecosystem level aspects of the marine environment (i.e. structural properties, functional processes or functional surrogate aspects) which are measured to detect change at higher levels of organisation within the system (i.e. changes at ecosystem scales), that is not attributable to any pressure or impact from human activity e.g. natural changes in species' population sizes. Please see Annex 4.

1.6.1 Defined pressures list:

The standard list of pressures against which indicators for this ecosystem component are reviewed is taken from the generic pressures list in the latest version (v11) of the UKMMAS / OSPAR assessment framework. Those pressures which are relevant to the ecosystem component (i.e. those that cause any impact on it) are used within the critical indicators review, gap analysis and this report.

1.7 Abbreviations used in the report

ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas
ASMO	OSPAR's Environmental Assessment and Monitoring Committee
ASSI	Area of Special Scientific Interest
BDC	The OSPAR Commission's Biodiversity Committee
BTO	British Trust for Ornithology
CSSEG	Clean and Safe Seas Evidence Group
CP2	Charting Progress 2
EcoQO	Ecological Quality Objective
GES	Good Environmental Status
HBDSEG	Healthy and Biologically Diverse Seas Evidence Group
ICES	International Council for the Exploration of the Sea
JAMP	Joint Assessment and Monitoring Programme
JNCC	Joint Nature Conservation Committee
MARG	Marine Assessment and Reporting Group
MHWS	Mean High Water mark at Spring tide
MSFD	The European Union's Marine Strategy Framework Directive
OSPAR Convention	The Convention for the Protection of the Marine Environment of the North-East Atlantic
PSEG	Productive Seas Evidence Group
SMP	JNCC Seabird Monitoring Programme
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UKMMAS	United Kingdom Marine Monitoring and Assessment Strategy
WeBS	Wetland Bird Survey
WGECO	ICES Working Group on Ecosystem Effects of Fishing Activities
WFD	Water Framework Directive

2 Methods and data sources

Before completing the review of existing and potential indicators a meeting was held with waterbird and seabird scientists and monitoring specialists at the BTO. Each of the activities, pressures and impacts identified in the OSPAR HBDSEG assessment framework was assessed during the meeting and any existing or potential waterbird or seabird indicators were identified for each activity, pressure or impact. Additional scientific evidence for each indicator was gathered using publications previously known to the authors and by searching on Web of Knowledge (http://wok.mimas.ac.uk/) for relevant peer-reviewed articles. Work was undertaken for each of the specific tasks as outlined in sections 4.1 to 4.5 below.

For the purposes of this report we define a sample in one of two ways, dependent on the scale of the indicator. For indicators which rely on annual estimates of abundance or breeding success, we define a sample as the total annual estimate for the UK. For indicators that rely on measurements from individual birds, we consider each individual bird as a sample.

2.1 Review the existing indicators for seabirds and waterbirds

All the indicators currently in use were reviewed with respect to the purpose, parameters measured, the location of monitoring and the governmental or non-governmental body carrying out the monitoring. Relevant single-species indices were included. Each indicator was entered into the online database on the marine indicators website (http://www.jncc.gov.uk/MarineIndicators/) in a standardised format. References to support each indicator were entered into the online database but are also included in the reference list for this report.

2.2 Evaluate the effectiveness of the indicators against standard scientific and economic criteria

The effectiveness of each indicator was evaluated by entering responses to a standard set of questions in the online database on the marine indicators website.

2.3 Review indicators against relevant pressures and important aspects of ecosystem structure and function

Each indicator was critically reviewed against the particular pressure or pressures that it was designed to measure, and the impact(s) of the pressure it was aimed at. For those indicators not intended to address a pressure, the aspect(s) of state change or ecosystem structure and function they address were identified. The suitability and effectiveness of each indicator with respect to the pressure, impacts, state change or aspects of ecosystem structure and function it is designed to measure were addressed.

2.4 Identify significant gaps and any indicators that may be able to fill these gaps

An assessment of pressures, impacts or aspects of ecosystem structure and function that were not adequately addressed by existing indicators is provided, making use of the gap matrix report provided on the marine indicators website. Critical gaps in the current indicators were identified and suggestions are made for indicators or areas of research that could be developed in the future to help to fill these gaps.

2.5 Recommend a set of indicators for seabirds and waterbirds that are effective scientifically and economically and could be used in future within an integrated monitoring and assessment programme

Having reviewed all the current and potential indicators for seabirds and coastal waterbirds, recommendations are made as to the most effective suite of indicators of marine ecosystem state, pressures and impacts to allow scientifically robust assessments of marine environmental status to be made in the future.

3 Review of the existing indicators and critical evaluation

3.1 Current indicators summary

The majority of migrant and wintering waterbirds and breeding bird species using the marine environment in the UK are widely monitored through the Wetland Bird Survey (WeBS) and the Seabird Monitoring Programme (SMP). Both surveys are carried out annually at sites distributed throughout the UK and are used to produce trends in abundance and breeding success (seabirds only) that can be used to assess the state of bird populations at individual sites, regionally and in the UK as a whole. The SMP has collected seabird abundance and breeding success data since 1986 from coastal and inland breeding colonies. Annually it receives information on 25 seabird species from up to 250 sites. WeBS surveys non-breeding waterbirds at both inland sites and coastal sites below MHWS and has run since 1975 (Austin *et al* 2008). Around 2000 WeBS sites are surveyed each year, and although coverage of inland sites may vary from year to year, almost all estuarine sites have been consistently surveyed in every year.

Most WeBS data and some SMP data are collected by volunteers. Although identification skills are not formally checked, WeBS surveys are co-ordinated by local organisers who are selected for their field experience and local knowledge. Local organisers select volunteers with the appropriate identification and counting abilities for surveys in their area. Most WeBS sites are counted by the same volunteer for several years in a row, but volunteers change from time to time. To ensure that any changes in the numbers of birds recorded are not due to recorder variance, strict data checking procedures are in place, with data checking conducted both by local organisers and by staff at the BTO, such that any major changes in bird numbers that coincides with a change in observer at a site would be identified. Minor differences (for example small differences in the estimated size of large flocks of birds) between observers are unlikely to be identified by this process, but because around 2000 WeBS sites are surveyed every year such minor changes between observers are likely to be insignificant at the scale of the whole country or region.

Neither WeBS nor SMP collect data on offshore aggregations of waterbirds and seabirds which are difficult, if not impossible, to count from land and require at-sea surveys from boats or aircraft. At-sea surveys can provide reliable estimates of the numbers and trends of localised inshore aggregations of, for example, wintering seaduck, but are unable to provide accurate estimates of, or trends in, the numbers of seabirds that are dispersed over large areas of sea.

The WeBS alerts monitoring scheme (Atkinson *et al* 2006; Maclean & Austin 2008) assesses species trends on a three year cycle (ID 1136). For WeBS alerts, population changes are calculated using smoothed trends over 5, 10 and 25 year periods. Alerts are issued where populations have undergone a change of 25 % or more over any given time period and a higher level of alert is given if that change is 50 % or more. In addition to monitoring species at a national level, WeBS alerts are used to monitor population changes at site level for all designated species on Special Protection Areas (SPAs) and Sites/Areas of Special Scientific Interest (SSSIs/ASSIs). Regional indices, based on the Environment Agency regions, are used to put these site specific trends into context.

Since 2003, as part of the UK Sustainable Development Strategy and Public Service Agreements, the ‘wild bird population indicator’ has been used as one of 20 UK Framework indicators (http://www.jncc.gov.uk/page-4229). There are two aspects to this indicator, reported here as two separate indicators, breeding seabird populations (ID 1153) and wintering waterbird populations (ID 1151). For breeding seabirds, a trend in the annual mean index of breeding abundance of 20 species since 1970 is calculated. For wintering waterbirds a trend in the annual mean index of wintering abundance since 1976 is calculated. Both of these indicators can be used to examine changes in the distribution, size and composition of communities of birds using the marine environment

In addition to the UK bird indicators, separate indicators have been developed for the state of seabird and waterbird populations in England and Scotland, as part of the national biodiversity strategies in place within each country. In England, the ‘Populations of wild birds: seabirds’ (ID 1156) and ‘Population of wild birds: wintering waterbirds’ (ID 1155) indicators have been in use since 2003 (http://www.defra.gov.uk/environment/quality/biodiversity/documents/indicator/200905m1.pdf). In Scotland the ‘abundance of wintering waterbirds’ (ID 1157) and ‘abundance of breeding seabirds’ (ID 1156) indicators have been in use since 2006 (http://www.jncc.gov.uk/page-4229). Both countries’ indicators are derived in a similar manner to the UK indicators: from trends in the annual mean index of abundance of a suite of species. The England seabird indicator has two derived indicators that show mean trends in abundance of a group of piscivorous species that feed just below the sea surface (ID 1204) and another group that actively dive in pursuit of fish at greater depths (ID 1203). Division of species into these feeding guilds may make these derived indicators more sensitive to pressures, such as climate change, which are likely to affect species with different foraging strategies in different ways, notably through the response of different food species. In 2009, trends in the mean annual index of breeding success were incorporated into the Scottish seabird indicator. Work is underway to develop similar indicators for the UK and England that are also derived from seabird breeding success data (ID 1188).

The OSPAR EcoQO for monitoring the proportion of oiled guillemots amongst those found dead or dying on beaches (ID 1145) has been in use since 2007. This provides an indicator of the magnitude of pressure from oil pollution in the North Sea (OSPAR 2007). Other indicators are currently under development under five OSPAR ecological quality elements on seabirds: mercury concentrations in seabird eggs (ID 1144), organohalogen concentrations in seabird eggs (ID 1142), plastic particles in seabird stomachs (ID 1141), local sandeel availability to black-legged kittiwakes (ID 1202) and seabird population trends as an index of seabird community health (ID 1140) (OSPAR 2006).

3.2 Evaluation of the effectiveness of indicators against standard scientific and economic criteria

3.2.1 Criteria used to evaluate indicators

In order to achieve a consistent critical appraisal of all indicators, the indicators for this ecosystem component have been reviewed and scored against the following set of criteria. These criteria have been built into the online indicators database application and the data has been stored electronically.

i *Scientific criteria*:

The criteria to assess the scientific 'effectiveness' of indicators are based on the ICES EcoQO criteria for 'good' indicators. The scoring system is based on that employed within the Netherlands assessment of indicators for GES (Langenberg & Troost 2008). A confidence score of 3 - High, 2 - Medium, 1 - Low is assigned for each question. A comment is given on the reasons for any low confidence ratings in the comment box provided within the database. All efforts have been made to seek the necessary information to answer criteria questions to a confidence level of medium or high.

INDICATOR EVALUATION:

1. Sensitivity: Does the indicator allow detection of any type of change against background variation or noise?

Score	3	2	1	Confidence
Options	Usually	Occasionally	Rarely	

2. Accuracy: Is the indicator measured with a low error rate?

Score	3	2	1	Confidence
Options	Usually	Occasionally	Rarely	

If the indicator scores 1 or 2 for question 1 or 2, conclude that it is ineffective and do not continue with the evaluation - the indicator will still be stored within the database as considered but will be flagged as 'insensitive, no further evaluation required'

3. Specificity: Does the indicator respond primarily to a particular human pressure, with low responsiveness to other causes of change?

Score	3	2	1	Confidence
Options	Usually	Occasionally	Rarely	

4. Performance:

For questions 4a-f, if a score of 1 is given, please consider if the indicator is of real use. Please justify (within the report) continuing if a score of 1 is given.

The following criteria are arranged with descending importance:

a) Simplicity: Is the indicator easily measured?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

b) Responsiveness: Is the indicator able to act as an early warning signal?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

c) Spatial applicability: Is the indicator measurable over a large proportion of the geographical to which the indicator metric it to apply to e.g. if the indicator is used at a UK level, is it possible to measure the required parameter(s) across this entire range or is it localised to one small scale area?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

d) Management link: Is the indicator tightly linked to an activity which can be managed to reduce its negative effects on the indicator i.e. are the quantitative trends in cause and effect of change well known?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

e) Validity: Is the indicator based on an existing body or time series of data (either continuous or interrupted) to allow a realistic setting of objectives?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

f) Relatively easy to understand by non-scientists and those who will decide on their use:

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

Thresholds for scientifically poor, moderate and good indicators:

Combine indicator evaluation scores for:

1. Sensitivity
2. Accuracy
3. Specificity
4. Performance

Evaluation Score	Indicator 'Effectiveness' Category
22-27	**Good**
16-21	**Moderate**
9-15 OR not all questions completed due to expert judgement not to continue	Poor

Further economic evaluation required - see section B below

ii *Economic criteria:*

Having identified the most scientifically robust indicators using the above stated criteria, a further economic evaluation of those most effective indicators (i.e. those falling in the good or moderate categories) is carried out using the criteria stated below.

1. Platform requirements

Score	4	3	2	1
Options	None e.g. intertidal sampling	Limited e.g. coastal vessel	Moderate e.g. Ocean going vessel or light aircraft	Large e.g. satellite or several ocean going vessels

2. Equipment requirements for sample collection

Score	4	3	2	1
Options	Simple equipment requirements e.g. counting number of organisms	Limited equipment requirements e.g. using quadrats on the shoreline	Moderate equipment requirements e.g. measuring physiological parameters	Highly complex method e.g. technical equipment operation

3. Amount of staff time required to plan collection of a single sample

Score	4	3	2	1
Options	Hours	Days	Weeks	Months

4. Amount of staff time required to collect a single sample

Score	4	3	2	1
Options	Hours	Days	Weeks	Months

5. Amount of staff time required to process a single sample

Score	**4**	**3**	**2**	**1**
Options	Hours	Days	Weeks	Months

6. Amount of staff time required to analyse & interpret a single sample

Score	**4**	**3**	**2**	**1**
Options	Hours	Days	Weeks	Months

7. Amount of staff time required to QA / QC data from a single sample

Score	**4**	**3**	**2**	**1**
Options	Hours	Days	Weeks	Months

Thresholds for economically poor, moderate and good indicators:

Evaluation Score	**Indicator ‘Effectiveness’ Category**
24-28	**Good**
19-23	**Moderate**
7-18	Poor

Those indicators which fall within the **‘Good’** or **‘Moderate’** economic category will then be tagged within the summary database as ‘Recommended’ indicators. Indicators can also be ‘recommended’ via expert judgement even if the evaluation of the indicator does not score well enough to be automatically recommended. This judgement will be justified within the report text.

3.2.2 Additional information on the critical analysis of indicators

All waterbird and seabird indicators currently in use were rated as ‘good’ or ‘moderate’ for both scientific and economic criteria. All but one are based on two existing long-term monitoring programmes, WeBS and the SMP (see above). This means that the data are collected and analysed according to strict, well established protocols. These indicators are currently produced as part of existing legislative requirements, including the England Biodiversity Strategy, the Scotland Biodiversity Strategy and the UK Sustainable Development Strategy.

Despite similar effort being expended in the collection of both WeBS and SMP data, the waterbird indicators based on WeBS data scored consistently higher in the economic evaluation than the seabird indicators derived from SMP data. WeBS data are collected largely by volunteers, with only occasional gap-filling by professional fieldworkers. In contrast, SMP relies more heavily on professional fieldworkers, although it also has some input from volunteer observers. As volunteer time is, for the purposes of this report, costed as free, this accounts for most of the differences in the economic evaluation. However, it is important to note that both surveys give rise to multiple indicators, and therefore the economic costs of data collection would remain the same whether one or all of the indicators were chosen, although data analysis and reporting costs would have to be added for each indicator.

Currently, the WeBS-based indicators are not broken down at a habitat specific level. Consequently, these cannot be considered as indicators of solely the marine environment. However, it would be relatively straightforward to adapt them so that they include only coastal and marine habitats, indeed the development of a coastal waterbird composite species indicator (ID 1158) has been explored as part of Charting Progress 2 (Mitchell *et al* in prep.).

Existing multi-species waterbird and seabird indicators are based on long-term datasets. As these are collected as part of well established, long-running surveys, they are typically measured with a low error rate and capable of detecting change against background noise and variation. However, existing indicators are designed predominantly to indicate the state of populations at a variety of geographical and political scales. Consequently, rather than directly assessing the effects of the set of activities and pressure identified in this report, they proximately indicate the state of the marine environment. The degree to which they do this is dependent on how strongly changes in populations are affected by environmental changes (including those caused by human activities).

With the exception of the OSPAR EcoQO for monitoring oiling of guillemots, none of the existing indicators respond primarily to a single pressure. As a result, often they cannot be linked to a specific activity that can be managed to reduce its impacts on marine bird populations. This is largely because the species concerned are often affected by a number of different activities and pressures or to different degrees by a single activity or pressure, dependent on factors such as habitat (i.e. Goss-Custard *et al* 1995; Norris *et al* 1997).

A key function of ecological indicators is often to provide an early warning signal that can be attributed to a particular pressure. Most of the current indicators use population size to monitor ecological change. However, changes in population size of marine birds are often not obvious immediately as many of the species concerned do not reach maturity for several years. In contrast, the seabird indicators based on breeding success are more likely to provide an accurate indication of conditions at the time in question, and are therefore better able to act as an early warning signal of potentially chronic impacts on seabird populations. For instance, successive seasons of poor breeding success of some seabird species in the UK have resulted from not enough food being available, which in turn may have been caused by climate change impacts lower down the food chain and/or by over-exploitation of prey fish, namely sandeels, by industrial fishing in the North Sea (Furness & Tasker 2000; Fredriksen *et al* 2004, 2005, 2006, 2008; Wanless *et al* 2005; Parsons *et al* 2008).

4 Gap analysis - Review of indicators against relevant pressures and important aspects of ecosystem structure and function

4.1 Review of indicators against pressures and identification of gaps

4.1.1 Current indicators and identification of gaps

Please refer to the associated spreadsheet 'SeabirdWaterbirdGapMatrix.xls'. This gap matrix was produced as a tool to aid authors in identifying significant gaps in current or potential indicators i.e. where important pressures on the ecosystem component have no suitable indicators associated with them. All recommended indicators have been prefixed with [R] and the cells containing them are coloured green.

It should be noted that if a single indicator is associated with more than one pressure within the pressures gap matrix, it may mean that this indicator responds to a range of pressures or the synergistic effects of a combination of pressures. Such an indicator would not necessarily be able to detect change which can be attributed to each individual pressure.

Of the 36 environmental pressures identified by HBDSEG assessment framework, there are 16 for which indicators currently exist and a further four for which indicators are under development. However, as alluded to above, most of these indicators are affected by multiple pressures and it may be difficult to disentangle the effect of one particular pressure in most circumstances. Therefore although 16 different pressures would affect the indicator value of at least one of the current indicators, this does not necessarily mean that all of these pressures would be accurately or adequately measured using the current indicator suite.

Pressures that are not addressed by the current indicators or those under development are those linked to climate change (changes to pH and salinity levels and emergence regime and wave exposure changes), local hydrological changes (to temperature and emergence regime), pollution and other chemical changes (synthetic compounds, radionuclide contamination, de-oxygenation, nitrogen and phosphorus enrichment and organic enrichment), physical changes to the seabed, physical damage to the seabed, electromagnetic changes, underwater noise, genetic modification and the introduction of microbial pathogens. Whilst it is unlikely that waterbird and seabird indicators will be able to address all of the pressures in the HBDSEG assessment framework, it is possible to develop additional indicators that can fill many of these gaps, often by using data collected as part of existing monitoring programmes. Seabird and waterbird indicators fall into two categories, those which act as an indicator of the state of the environment and the impact a pressure has on it and those which directly measure the pressure itself.

Of those waterbird and seabird indicators currently in use only one, oiled guillemots (ID 1145), is designed to reflect the magnitude of single environmental pressure i.e. the extent of surface oil pollution in the North Sea. The other seabird and waterbird indicators currently in use reflect the sum of the impacts on UK or regional populations, of two or more pressures that may be acting at a combination of local, regional and national scales. These indicators rarely reflect the impact or magnitude or a single pressure (see section 5). Below we suggest some indicators that are currently in development or novel, which are more likely to reflect the impact or magnitude of single pressures.

4.1.2 Novel indicators to measure the impact or magnitude of single pressures

There are few indicators that could be developed to measure pressures directly. Currently only the OSPAR EcoQO for the proportion of oiled guillemots found dead or dying on the North Sea coast does this (ID 1145). This indicator could be improved by extending coverage to the UK coastline as a whole. In addition, the different foraging ecologies of seabirds means that by extending the scheme to include additional species it may be possible to gain a better understanding of the distribution of oil in marine habitats, at little extra cost. In addition to the OSPAR EcoQO for oiled guillemots, an additional EcoQO for monitoring litter in the marine environment using the quantity of plastic in the stomachs of fulmar is currently under development (ID 1141). This could be complemented by creating an indicator to monitor the amount of litter at seabird nests (ID 1215), which could be recorded as part of existing monitoring programmes and therefore would be cheaper to implement than monitoring the quantity of plastic in fulmar stomachs as it would not require the collection and dissection of dead seabirds.

Seabirds and waterbirds could be used to directly monitor other aspects of pollution in the marine environment. OSPAR EcoQOs have been proposed for monitoring the concentrations of organohalogens (ID 1142) and mercury (ID 1144) in seabird eggs. It would be possible to monitor additional heavy metal contamination, including those in other habitats, using tissues collected from wild birds. The seasonal shooting of wildfowl occurs between September and February each year in the UK; tissue samples could be collected from a subset of quarry birds (ID 1207). Wader species are common targets of ringing effort, and feather samples can also be used to monitor heavy metal concentrations in the area where the bird has grown its feathers (ID 1206)(Burger *et al* 1993). For each of these indicators it would be possible to carry out chemical analysis of tissues centrally, leading to a cost-effective method of gathering information on the distribution of chemical pollutants in the marine environment at a large spatial scale.

A potentially important area which is not addressed satisfactorily by existing indicators is the bycatch of seabirds by commercial fisheries. The impact of this on seabird populations in the North Sea is currently not fully understood, but some studies suggest it may be substantial (Pierce *et al* 2002; Osterblom *et al* 2002; Rogan & Mackey 2007). Again, this would be straightforward to monitor directly (ID 1124), and this could be done in conjunction with current legislative requirements for monitoring the bycatch of cetaceans. This would be an indicator of the impact of the HBDSEG pressure “over-exploitation by fisheries: non-target species” but could also measure the response to any management put in place to reduce seabird bycatch. In addition any carcasses could be collected and used to monitor marine pollution through the collection of tissue samples and the examination of stomach contents. A final indicator that could be used to directly assess a pressure would be to collect seabird corpses centrally for post mortem examination (ID 1186) to monitor the distribution of litter and synthetic and non-synthetic pollutants in the marine environment.

4.1.3 Novel indicators to flag up the impacts of pressures on seabirds and coastal waterbirds

For those pressures that cannot be directly measured using any current or proposed marine bird indicator, it is often possible to develop indicators to flag up the potential impacts of these pressures on bird populations using data that are collected as part of existing monitoring programmes. The use of well designed multi-species indicators, with a small set of species whose populations have been proven to respond to changes in a specific pressure, is likely to be more robust than that of single-species indicators, as each individual species is affected by multiple pressures. This can be illustrated by the following example: The population size of species 1 is known to be affected by changes in pressures A, B and C, while species 2 is affected by pressures A, D and E and species 3 is affected by pressures A, F and G. If the populations of all three species decline this is most likely a result of a change in pressure A rather than any of the other pressures. However, it is important to note that rather than indicating any pressure directly, these are indicators of the state of the marine environment and any impacts that a pressure is having on it. Therefore, it would be most appropriate to use this type of indicator to flag up instances where population changes exceed a pre-determined percentage, in a similar style to WeBS alerts. These “alerts” could be used to prompt more detailed investigations into the pressures occurring at specific sites, in a similar manner to the EcoQO on seabird population trends. For example, if the multi-species shellfish indicator (ID 1117) changed significantly at certain sites it may be worth conducting more detailed surveys at those sites to determine whether shellfish stocks had declined, the cause of any decline and potential management options. Further examples of this type of indicator are illustrated below.

At a local spatial scale, changes in salinity and water clarity often affect many species’ foraging ability (Camphuysen *et al* 1996, 2002; Smit *et al* 1998) and this may be reflected in a number of the existing indicators, although any changes in salinity caused by climate change are likely to be small compared with shorter-term tidal and seasonal changes. High levels of wave action are likely to resulting in coarser, more mobile sediments which prevent the invertebrate prey, on which many waterbird species rely, from settling (Rehfisch *et al* 1997). WeBS alerts (ID 1136) may provide a useful indicator for these pressures as they are based at the scale of single sites. However, as alerts do not necessarily respond to any particular pressure it is important to be aware that there could be alternative explanations for these changes and therefore WeBS alerts cannot be used as indicators for single pressures.

Offshore windfarms can impose a variety of pressures on seabird populations including the physical loss of habitat, barriers to movement, disturbance and death or injury by collision (Garthe & Huppop 2004). Although the effects of these pressures could be monitored using existing indicators, for example ‘wild bird populations-seabirds (breeding success)’ (ID 1188) and ‘wild bird populations-seabirds (breeding abundance) (ID 1153)’ these are unlikely to be good indicators of the pressures caused by offshore windfarms because multiple pressures act on these populations, so relating changes to specific pressures is likely to be difficult. In addition, these indicators will be unable to detect local changes in the distribution of seabirds. The impacts of windfarms are best monitored using boat-based or aerial surveys before and after the construction of the windfarm, a methodology currently undertaken as part of existing legislative requirements. However, such work had demonstrated that it is often difficult to measure the impacts of windfarms on inshore waterbirds.

Fisheries often impact both seabird and waterbird populations through the removal of target species, some of which the birds rely on as prey. Breeding success in a number of seabird species has been linked to the availability of sandeel, a species exploited commercially for animal feed and fertilizer production (Monaghan 1992; Furness & Tasker 2000; Fredriksen *et al* 2005). In areas where sandeel populations are low, the breeding success of a number of seabird species is often severely affected, although their overall abundance is often unaffected. Consequently, an OSPAR EcoQO has been proposed to use breeding success in the black-legged kittiwake to monitor sandeel populations in the North Sea (ID 1202). This could be extended to include the breeding success of additional species, for example auks, which are also dependent on sandeel populations for food (ID 1187). However, although extending this indicator to include the auks is ideal, breeding success is difficult to measure in guillemots and razorbills and thus historical data are only available from a small number of colonies and it would be difficult and costly to expand data collection for these species to additional colonies. It could also be extended to the rest of the UK coastline although this indicator is likely to be a less powerful measurement of changes in sandeel stocks on the west coast of the UK where seabirds are known to feed more widely on other prey species as well as sandeels. Breeding success in sandeel specialists may also indirectly reflect the health of other fish stocks, such as mackerel and galoids, which compete with seabirds for sandeel prey, and are lower in areas with high seabird breeding success (Furness 2002). However fish stocks are better measured directly rather than using a bird proxy which will be affected by many other pressures. These indicators could be developed using data currently collected as part of the SMP, however, it is important to note that seabird breeding success can also be influenced by a variety of other pressures, notable the abundance of introduced species like American mink (Craik 1997; Ratcliffe *et al* 2008), and that the distribution of sandeel populations themselves can be influenced by pressures related to climate change (Arnott & Ruxton 2002).

The health of shellfish stocks could be indicated using waterbird species. Shellfish fisheries have been shown to have a detrimental affect on species such as oystercatcher, knot and shelduck, which feed on shellfish as a food source (Myers *et al* 1980; Atkinson *et al* 2000, 2003; Piersma *et al* 2001; Goss-Custard *et al* 2004; Stillman *et al* 2004; Verhulst *et al* 2004; Kaiser *et al* 2006; van Gils *et al* 2008). The impact of shellfish fisheries could be monitored using a multi-species indicator including these species (ID 1117). Shellfish stocks can also be negatively affected by activities such as dredging and substrate extraction. Changes in the sediment as a result of these activities adversely affect bivalves and benefit fast growing, mobile species, like polychaete worms (Frid *et al* 2000; Atkinson *et al* in press). While the multi-species shellfish specialist indicator could be used to monitor the effects of these activities, a more effective alternative would be to monitor the proportion of shellfish specialist waterbirds to worm specialist indicators (ID 1213).

Both sanderling and ringed plover are negatively impacted by human disturbance. Breeding ringed plover avoid beaches with high levels of disturbance (Liley & Sutherland 2007) and wintering sanderling spend less time on beaches heavily used by people (Thomas *et al* 2003). An indicator using ringed plover distribution during the summer and sanderling distribution during the winter could be used as an indicator of the effects of human disturbance and tourism (ID 1214).

Nutrient and organic matter enrichment can have both positive and negative impacts on waterbirds in coastal areas. Moderate levels of nutrient enrichment from sewerage or other outfalls can provide feeding opportunities for waterbirds (Green *et al* 1990, Hill *et al* 1993, Burton *et al* 2002). Diving ducks such as scaup *Aythya marila*, goldeneye *Bucephala clangula*, pochard *A. ferina* and tufted duck *A. fuligula* (Pounder 1976a, 1976b, Campbell 1978, 1984, Campbell *et al* 1986; Campbell & Milne 1977; Burton *et al* 2003) and some species of gulls (Ferns & Mudge 2000) have been shown to feed in the areas directly around sewage outfalls. Other species may benefit from an increase in the numbers of invertebrates caused by nutrient enrichment (Burton *et al* 2002). However, high nutrient input results in de-oxygenation, depleting waterbird food resources as few invertebrates can survive in the de-oxygenated sediment (Daywansa 1995; Burton *et al* 2002; Maclean *et al* 2006). The wealth of evidence linking bird numbers to nutrient and organic matter enrichment means that a bird indicator would be particularly appropriate for this pressure. Two separate multi-species indicators could be developed, the first monitoring the total abundance of species that feed directly on sewage and other outfalls (such as diving ducks or gulls) (ID 1198), and the second the total abundance of those species that feed on the invertebrates whose numbers may increase in areas of moderate and decrease in areas of high nutrient enrichment (for example many waders) (ID 1200). However, since monitoring protocols for sewage output are already in place under the Water Framework Directive it may be better to use indicators based on these data to measure this pressure, rather than using birds as a proxy.

Activities such as aquaculture and mariculture can affect the structure of benthic communities through pressures like smothering (Simenstad & Fresh 1995). This could be monitored using a multi-species indicator that assesses the average changes in the populations of a range of diving duck species (ID 1190). It may also be possible to use this indicator to detect the impacts of other activities, such as the dumping of waste from beach replenishment. Again it is important to note that this type of indicator is not a direct indicator of only one pressure, and so should only be used to flag up areas where further investigation is required.

Invasive species, like the zebra mussel and the grass, *Spartina anglica*, can have a severe impact on the UK marine environment (Goss-Custard & Moser 1988; Percival *et al* 1998; Aldridge *et al* 2004). It would be possible to develop multi-species indicators to monitor the spread of both of these species. Species of diving duck including pochard, tufted duck and scaup have been shown to be attracted to areas with high zebra mussel abundance (Burla & Ribi 1998; De Leeuw 1999; Werner *et al* 2005; van Nes *et al* 2008). A multi-species indicator involving these species (ID 1210) could be used to highlight areas in which zebra mussel abundance may have increased, which could then be the subject of further monitoring. In contrast, *S. anglica* has been shown to have a negative impact on populations of species including dunlin, redshank, knot and brent geese. Again, it would be straightforward to develop a multi-species indicator (ID 1211), involving these species, to highlight changes in the distribution of *S. anglica* using existing WeBS data. However, it is debateable whether this would be a more cost-effective approach than using remote sensing to measure the distribution directly.

Physical loss of, or damage to, inter-tidal habitats and changes to the siltation rate are pressures that can arise from a range of activities such as the construction of coastal defences, marinas and harbours, dredging and the extraction of sand and gravel. A variety of species, including waders and shelduck rely on these habitats for food (Lee 2001; Armitage *et al* 2003; Burton *et al* 2006; Burton & Maclean 2006; Clark 2006). A multi-species indicator using a common subset of these species (for example oystercatcher, redshank, curlew and shelduck) could be used to monitor the effect of these pressures on inter-tidal habitats.

4.1.4 Pressures for which seabirds and coastal waterbirds cannot provide indicators

There remain nine pressures for which waterbirds and seabirds cannot effectively be used to provide an indicator of either the magnitude of the pressure or the magnitude of the impact of the pressure. In some cases, for example pH and salinity changes linked to climate change, it may be possible to develop multi-species indicators. However, given the range of multiple interacting affects on these species, it is likely to be more cost effective and reliable to simply measure pH and salinity directly. For others, such as radionuclide contamination, the introduction of microbial pathogens, genetic modification, electromagnetic changes and underwater noise, there is insufficient information on any potential effects on birds to be able to provide a reliable indicator.

4.2 Review of indicators against ecosystem structure & function aspects and identification of gaps

As seabird and waterbird species are typically at the top of the marine food chain, changes in their populations are indicative of changes elsewhere in the ecosystem. However, the structure of ecosystems is often complex, with multiple, interacting direct and indirect relationships. For simplicity's sake, we consider only those aspects of ecosystem structure and function where there is a direct relationship with the indicator concerned. The nature of waterbird and seabird indicators means that the majority of ecosystem structure and function aspects with which they are associated are biotic or ecological rather than abiotic or physico-chemical.

Of the 26 aspects of ecosystem structure and function identified by the HBDSEG assessment framework, only 4 can be monitored using existing indicators. With the exception of the OSPAR EcoQO for monitoring the proportion of oiled guillemots received, all existing indicators are capable of monitoring the population size aspect of biotic ecosystem structure. In addition, the 'wild bird populations-seabirds (breeding success)' (ID 1188) indicator can also be used to monitor the reproduction and longevity aspect of biotic ecosystem structure and the delivery of recruiting organisms aspect of ecological ecosystem function. The link between species abundance and food availability means that many existing indicators could also be used to monitor the trophic complexity aspect of ecological ecosystem function. It is not possible to use existing indicators to monitor abiotic or physico-chemical aspects of ecosystem structure and function.

Currently breeding success in seabirds in monitored only in Scotland. Seabird breeding success indicators can be used an early warning signal for future changes in seabird populations (because many species delay breeding until they are two or three years old). If these indicators are considered important it would be useful to extend monitoring of seabird breeding success throughout the UK. Although breeding success can be affected by both predation and the weather, it is most strongly correlated with food supply. This relationship is particularly strong in the kittiwake (Tasker & Furness 1992). Consequently, breeding success is also likely to be affected by levels of primary and secondary production, although it is unlikely to be reliable or cost-effective to monitor these aspects of ecosystem function in this way.

Waders and shelduck are closely associated with inter-tidal habitats. The multi-species inter-tidal indicator (ID 1115) proposed above could therefore be used to monitor the ecosystem structure aspects for the distribution and extent of this habitat. Similary, the range and extent of shellfish beds could be monitored using the multi-species shellfish specialist indicator (ID 1117). The distribution of invasive species, for example zebra mussels and *S. anglica* could be monitored using the diving duck zebra mussel and *S. anglica* waterbirds indicators. However, in these cases, it should be noted that there may be alternative explanations for the distribution of the indicator species.

It may also be possible to use waterbird indicators to flag changes in species diversity and richness and community structure. For example, the proposed EcoQO on seabird population trends (ID 1140) has been proposed to flag up any unusual changes in seabird community health. Elsewhere, extreme changes in the ratio of shellfish specialists to worm specialists (ID 1213) are likely to represent a switch from one community type to another, often following activities such as dredging. More subtle changes in the ratio of shellfish specialists to worm specialist may represent a change in the prey species diversity and richness, with ratios at or close to 50:50 representing a more diverse community.

Relationships with abiotic aspects of ecosystem structure are less straightforward. The Oxygen level of the water column is likely to be reflected by both the general multi-species nutrient input indicator (ID 1198) and the specific diving duck and gull nutrient input indicator (ID 1200). In areas with moderate nutrient input, the indicator species are likely to increase in number as a result of an increase in invertebrate populations, however, where nutrient input is high, the oxygen levels will be too low for the invertebrate populations to persist, so the indicator species will decrease in number. IT may also be possible to use these indicators to measure the nutrient exchange aspect of physico-chemical ecosystem function. These indicators will only allow crude estimates of oxygen levels and nutrient exchange; however, they could be used to highlight areas where closer inspection is required.

Changes in seabed and sediment types and in the rates of sedimentation and tidal flow are likely to be reflected in changes in waterbird populations. Changes in seabed and sediment types are likely to result in changes in the benthic fauna of these habitats (Quammen 1982; Yates *et al* 1993, 1996). Consequently, these aspects of abiotic ecosystem structure could be monitored using the diving duck smothering indicator (ID 1190) as changes in these media are likely to be reflected in changes in diving duck populations. Clearly these changes would be more accurately measured by direct measurement of changes in the benthic taxa but if this is not possible in all parts of the UK's marine environment the diving duck smothering indicator could be used to flag those areas where diving duck numbers have changed (possibly as a result of changes in the benthic fauna) and where detailed monitoring of the benthic environment could focus.

Heavy wave action results in coarser more mobile sediments, which in turn prevent the invertebrate prey, on which many waterbird species rely, from settling (Rehfisch *et al* 1997). It would therefore be possible to provide an indicator of the rate of tidal flow and consequent changes in wave action, and possibly also the rates of sedimentation using a multi-species indicator of fetch (wave action) (ID 1126). As rates of sedimentation can affect invertebrate distribution, it is possible they could also be reflected by the multi-species inter-tidal indicator (ID 1115).

There remain a number of aspects of ecosystem structure and function for which waterbirds and seabirds are unable to provide a suitable indicator. Some aspects, such as primary and secondary production, are likely to affect birds. However, the complex interactions involved are likely to make it difficult to disentangle any direct effects. For others, such as propagule dispersal and gas exchange insufficient data exist to describe any relationships.

5 Conclusions and recommendations

5.1 Database report tables

Database report tables are presented in two excel spreadsheets that accompany this report. For documentation of indicators of pressures and identification of gaps, please see the spreadsheet SeabirdWaterbirdGapMatrix.xls; for documentation of indicators of ecosystem structure and function, please see the spreadsheet SeabirdWaterbirdStructureFunctionReport.xls.

5.2 Identification of an effective indicator set

Please see the excel spreadsheet SeabirdWaterbirdReport.xls which accompanies this report.

5.3 Recommendations for areas of development to address significant gaps

Seabirds and waterbirds are currently the subjects of long-term monitoring programmes and as such provide accurate, reliable information on the state of the populations. In general, existing indicators respond to a variety of pressures and as such cannot be considered good indicators of single activities or pressures, but are useful indicators of ecosystem structure and function. Despite this, under the economic and scientific assessment frameworks in section 5.2.1, all indicators scored as good under scientific evaluation and moderate or good under the economic evaluation. Differences in the evaluation of economic criteria arose because waterbird indicators are largely based on data collected by volunteers, whose time is costed as zero, and there is a greater input from professional fieldworkers in collecting data for the seabird indicators.

The majority of existing seabird and waterbird indicators are likely to act as indicators of state or impact, and any changes are likely to reflect changes in a suite of pressures including atmospheric climate change, regional temperature changes, water flow changes, salinity changes, changes in water clarity, the introduction of synthetic and non-synthetic compounds into the environment, physical loss of habitat, litter, barriers to movement, death or injury by collision, visual disturbance and the removal of target or non-target species. The wide variety of, often interacting, pressures affecting waterbirds and seabirds makes it difficult to link any changes in their populations to specific pressures. However, the OSPAR EcoQO for monitoring the proportion of oiled guillemots is one indicator which can directly monitor changes linked to a specific pressure. The same is true of the proposed QSPAR EcoQOs for monitoring the quantity of plastic in the stomachs of fulmar the concentration of mercury and organo-halogens in seabird eggs.

It would be possible to develop indicators to measure a number of other pressures directly. Concentrations of heavy metals and organic compound could be monitored by collecting tissue samples from wildfowl quarry species and the feathers of waders. In addition to monitoring plastics in seabird stomachs, it would be possible for observers at seabird colonies to note the quantity of litter at nest in addition to carrying out their regular surveys. It would also be relatively straightforward to monitor seabird bycatch in the North Sea whilst fulfilling existing legislative requirements for the monitoring of cetacean bycatch.

It would be possible to develop a suite of multi-species indicators that could be used to flag up areas where a particular pressure may be having an impact. These pressures include the exploitation of shellfish, the spread of invasive species, like zebra mussels and *S. anglica*, changes in the siltation rate, changes and damage to sediment, organic, nitrogen and phosphorus enrichment, deoxygenation and changes to wave exposure, tidal flow and emergence regimes. In each of these instances there exist proven relationships between changes and waterbird or seabird species. By using a carefully selected group of species, a multi-species indicator could be used to identify areas in which changes in these pressures may have occurred, and which should be priorities for further investigation. These indicators would be straightforward to produce from existing databases using well-established analytical procedures.

Unsurprisingly, there are several pressures for which seabirds and waterbirds do not provide useful indicators, irrespective of the habitat in question. These include electro-magnetic changes, underwater noise disturbance, pH changes (although this may affect waterbirds it would be difficult to disentangle from other factors, and would be easier to measure directly), salinity changes, local temperature changes, contamination by munitions and radionuclide contamination, genetic modification and the introduction of microbial pathogens.

Existing indicators can be used to monitor the population size and reproduction and longevity aspects of ecosystem structure and the trophic complexity and delivery of recruiting organisms' aspects of ecosystem function. Using the proposed multi-species indicators it would also be possible to monitor the community structure, species richness and diversity and the seabed and sediment type aspects of ecosystem structure and the nutrient exchange, sedimentation and tidal flow aspects of ecosystem functioning. The nature of these indicators means that they are more effective at monitoring the biotic and ecological aspects of ecosystem structure and functioning than the abiotic and physico-chemical aspects.

In general, populations of seabirds and waterbirds are ideal for the purposes of producing indicators of ecosystem structure and function in the marine environment. Their association with a large number of habitats, sensitivity to environmental change and the extent to which they respond similarly to other species means that they often indicate changes that might be expected in other taxa or changes in ecological patterns generally. The relative ease with which they can be counted and their tendency to congregate at key locations make them cost-effective to monitor. Furthermore, many of these indicators would be based on data from existing monitoring schemes, reducing the cost of data collection still further.

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