Summary of Cefas capability to support the NERC/Defra Shelf Sea Biogeochemistry Research Programme

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Version Control History

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Summary of Cefas capability to support NERC/Defra Shelf Sea Biogeochemistry Research Programme

Authors: Ruth Parker, Stefan Bolam, Rodney Forster, Clare Leech, Nigel Lyman, Thomas Maes, Steve Malcolm, Edmund McManus, David Mills, Suzanne Painting, David Sivyer, Jeroen van der Kooij Johan van der Molen, Keith Weston and Paul Whomersley

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1 Introduction

The Centre for Environment, Fisheries & Aquaculture Science (Cefas) is an executive agency of the Department for Environment, Food and Rural Affairs (Defra). Cefas makes an important contribution to securing healthy marine and freshwater environments, and the sustainable use of associated resources, that will enable current and future generations to prosper. Established for over 100 years, and with a turnover exceeding £50m, we employ over 500 people - primarily in Lowestoft and Weymouth. As the UK’s most diverse applied marine science laboratory, we provide leadership in many areas. We help to shape and implement policy through our internationally renowned science and through our collaborative relationships that span UK Government, EU, NGOs, research centres and industry.

Our core remit is to provide advice and support to UK Government and its agencies. Our work takes us from freshwater to the open ocean. Our influence and leadership spans the full spectrum of issues, including:

- marine nutrient and contaminant monitoring
- marine spatial planning and environmental licensing
- sustainable fisheries management
- marine biodiversity and habitats
- fish and shellfish health and hygiene
- climate change impacts and adaptation
- emergency response

This is supported by leading edge capabilities to collect, manage and interpret a breadth of environmental, biodiversity and fisheries data.

The UK shelf seas are increasingly under pressure from competing demands and decision making is complex, often international, relying on timely, integrated evidence and advice. In shaping future policy we need to have a much better understanding of ecosystem function and the issues we need to address span both basic research questions and applied science to align the outputs with policy needs. These big questions can only be answered by the UK marine community working in partnership. The NERC/Defra programme on Shelf Seas Biogeochemistry is an examplar of partnership working, bringing together Research Council resources with those of Government agencies and the wider academic community to meet the NERC vision of excellence with impact.

Purpose of this document

The document provides a starting point for dialogue between Cefas scientists and those from other organisations that will potentially bid into the NERC Shelf Seas Biogeochemistry Research Programme call. It summarises current and planned Cefas activity to provide a framework for research projects in the field, reducing the overall cost of the Programme, and providing synergies between Cefas and other organisations. The summary table provides a snapshot of Cefas monitoring programmes and past/present R&D programmes of relevance to this call. Brief information on duration and coverage, potential contribution to the Shelf Sea Biogeochemistry Programme is also included.

Briefly, the Cefas contribution to the partnership agreement is to extend our operational remit by:

- Providing collaborative research opportunities

Our operational work includes monitoring programmes that we undertake for Defra using the RV Cefas Endeavour to supply underpinning science to help Defra comply with national and international legislation. Some of this work is highly prescribed in nature with fixed point sampling e.g. fish stock evaluation but other programmes are more flexible. These monitoring programmes provide
opportunities to scientists to undertake discrete work packages alongside monitoring effort, and to extend operational cruises by adding research modules.

- Offering access to relevant data resources from our research

Past research programmes provide opportunities for data mining as baselines for new work or to address trends by adding new measurements. Cefas has carried out extensive work on carbon and nutrient flows and budgets, and has data for both water column and the sea bed. We have contrasted budgets at impacted areas through fishing, disposal and aggregate extraction activities for example, with those at largely undisturbed sites

- Enabling input via our ongoing research programmes

Ongoing work includes research on sea-bed integrity, nutrient flux, plankton dynamics, fishing impacts and ecohydrodynamics. Our SmartBuoy network provides opportunity to add additional sensor packages to make autonomous measurements. The RV Cefas Endeavour is also fitted with a ferry box to make continuous measurements of oceanographic parameters

- Our scientific participation in new programmes

For new programmes the skill base at Cefas is extensive with experts in areas ranging from acoustics and ecology, to biogeochemistry and ecosystem modelling. Our work is supported by bespoke electronics, and molecular biology, analytical chemistry and aquarium facilities.

An overview of relevant modelling capabilities is also provided at the back of this document.

To discuss collaboration with Cefas in this programme please contact Ed McManus by email (edmунd.mcmanus@cefas.co.uk) or telephone 01502-521312.
<table>
<thead>
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<th>Project name</th>
<th>Duration / coverage</th>
<th>Supporting contribution</th>
<th>Contact</th>
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<td><strong>Monitoring Programmes</strong></td>
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<td>Clean Seas Environmental Monitoring Programme</td>
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<td>Support OSPAR requirements, compliance with EC directives, local monitoring and R and D</td>
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<td>Data available on wide range of environmental variables including salinity, nutrients, chl, O2 and SPM. Mostly surface but also some sub-surface.</td>
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<td>RV Cefas Endeavour Cruise plans for Jan 2012 - Mar 2013</td>
<td>Ongoing - regional seas</td>
<td>Access to most areas of shelf seas within year / seasonally under Cefas monitoring cruise programme</td>
<td>Nigel Lyman</td>
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<td><strong>Past R&amp;D programmes</strong></td>
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<td>EMECO - European Marine Ecosystem Observatory and Western Shelf observatory (C3686)</td>
<td>North Sea and SW approaches. Past (2) and present (1) projects</td>
<td>Managing model and data outputs for health assessments and policy focused outputs</td>
<td>David Mills</td>
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<td>Integrated Survey (ME4157)</td>
<td>SW approaches. 2009 - 2011</td>
<td>Seasonal observations at three sites. High resolution SmartBuoy data (tether and landers), 1° and 2° production, seabed processes and fauna, carbon and nutrient flows &amp; budgets, at 2 sites. Transects 2008 in N North Sea, DCM work. Clustering of seabed regions into units of hydrography &amp; sediment. Ecosystem modelling developments to derive C budgets, existing limitations</td>
<td>Sven Kupschus, Ed McManus</td>
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<td>Research supporting an extended SmartBuoy network (ME3304) and supporting ‘Pixels to Policy’</td>
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<td>Observations and modelling of new production and carbon associated with the thermocline</td>
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<td>Seabed disturbance (AE1224)</td>
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<td>Benthic State and Change in UK Marine Waters (ME3112)</td>
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<td>Spatial distribution of the macrofaunal assemblages currently around the coast of England, Wales and the west coast of Scotland</td>
<td>Stefan Bolam</td>
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<td>JoNuS I and II - Joint nutrient studies</td>
<td>1990-1997</td>
<td>Improving the understanding of the input of nutrients to estuaries, the processes within estuaries that influence the output of nutrients to the sea and the impact of nutrients in coastal waters and more widely</td>
<td>Steve Malcolm</td>
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<td><strong>Present R&amp;D programmes</strong></td>
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<td>Seabed Integrity (E5301) - mapping structure, function and sensitivity of seabed</td>
<td>Channel and North Sea. 2009-2013</td>
<td>Seabed nutrient, redox, carbon and faunal measurements.</td>
<td>Ruth Parker, Roger Coggan</td>
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<td>Research supporting an extended SmartBuoy network (ME3304)</td>
<td>UK shelf.</td>
<td>Extension of SmartBuoy network to 2 further sites/ addition of biogeochemical sensors</td>
<td>David Sivyer</td>
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<tr>
<td>Ecosystem Health (E5302) and supporting ‘Pixels to Policy’</td>
<td>UK shelf. 2007-2012,</td>
<td>Data analysis 10 year time series SmartBuoy programme/ merging of data streams etc.</td>
<td>David Mills</td>
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<td>Capability to monitor climate indicators using thin scattering layers in the water-column</td>
<td>SW Approaches, North Sea - ongoing</td>
<td>Testing feasibility of using fisheries acoustic data (2000 to present day) to provide information on stratification and DCM production</td>
<td>Jeroen van der Kooij</td>
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<td>Productivity tools (C3273)</td>
<td>Regional seas. 2009-2012.</td>
<td>Develop and adapt technology to measure primary production of phytoplankton with automated optical techniques to place on ships of opportunity</td>
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<td>Fit for purpose monitoring (MES404)</td>
<td>All UK shelf seas. 2010 to 2014 with seatime in 2013.</td>
<td>MSFD scoping monitoring options for England and Wales</td>
<td>Edmund McManus</td>
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Table 1. Summary of relevant Cefas projects
2 Monitoring Programmes

In this section we highlight some of the relevant key monitoring programmes currently ongoing at Cefas, along with future cruise plans.

Developing a fit for purpose and cost effective Clean Safe Seas Environmental Monitoring Programme (CSEMP) for monitoring chemical related biological effects (contract E5203)

Thomas Maes and Paul Whomersley

The Clean Seas Environment Monitoring Programme (CSEMP), formerly known as NMP and NMMP, was implemented to address the continuing need to meet the UK’s marine monitoring commitments co-ordinated through the Oslo and Paris Commission (OSPAR). OSPAR’s Joint Assessment and Monitoring programme (JAMP) and the Nutrients Monitoring Programme (replaced by the Eutrophication Monitoring Programme in 2005) require contracting parties to monitor the marine environment. The programme was also designed to meet temporal trend monitoring requirements of OSPAR.

The main drivers for CSEMP are:

- To meet temporal trend monitoring requirements of the Oslo and Paris Commissions Co-ordinated Environmental Monitoring Programme (CEMP)
- To support compliance with EC Directives
- To support research and development needs
- For local monitoring

The CSEMP benthic monitoring programme is conducted to detect long-term spatial and temporal trends within infaunal benthic communities. This monitoring programme is conducted under the auspices of the hazardous substances evidence group of CSEMP and is currently the only annual offshore benthic monitoring programme being conducted.

The most recent monitoring survey (July 2011) adopted a stratified spatial approach based on Charting Progress sea areas (Figure 1). Sampling effort was concentrated in the North Sea and Eastern English Channel and in muddy sediments (>30% silt clay) to allow the detection of contaminant levels (metals and organics). To maintain the temporal aspect of this programme existing temporal stations (~15 years of data) were incorporated into the current monitoring programme design.
Figure 1. Benthic monitoring sampling design 2011

Sampling Procedure at each benthic station followed:

- At least 1 valid 0.1 m$^2$ Day Grabs
- At least 1 valid 0.1 m$^2$ Day Grabs (existing temporal stations only)
- At least 1 valid 0.1 m$^2$ Day Grabs
- At least 1 bottle of water from the continuous flow system. Filter 250 ml water

Sediment sub-sample (PSA, metals)
Macrofauna (remaining sediment)
Sediment sub-sample (PSA, metals)
Chl a sub-sample
Porosity sub-sample
Metals
Organics
Salinity
Chlorophyll
Fisheries Monitoring Surveys

Brian Harley

Fisheries stock monitoring surveys to fixed stations have been used in recent years to enable wide-scale surveys for biogeochemical measurements in UK shelf seas. Figure 2 shows the geographic coverage of the regular Research Vessel (RV) cruises (and single charter cruise) that support the present Fisheries programme and are visited on an annual basis. Samples for water column biogeochemical measurements (e.g. δ18O of water masses and dissolved organic matter) have been undertaken successfully during previous cruises, with sampling between stations possible using the on-line supply of seawater on the RV Cefas Endeavour.

Figure 2. Geographical coverage of cruises supporting the fisheries programme

Key publications:


Eutrophication Monitoring, including SmartBuoy and FerryBox

Dave Sivyer

Cefas has collected environmental and nutrient data throughout UK waters using instrumented buoys (SmartBuoy) for many years and these are available to collaborators. The SmartBuoy programme has run continuously since 1999, providing high frequency data from several key sites and supplemented by R&D programmes in various locations (Figure 3). The data Cefas collects is quality assured and play a key role in our assessment of eutrophication. Observations are typically collected at the surface but Cefas has sampled subsurface and, by using bottom landers, at the benthic boundary layer. A SmartBuoy at the Oyster Ground has been sampling at the surface, thermocline (34m depth) and seabed (45 m) since 2006. Multiple moorings can be used to increase spatial coverage.

Quantitative measurement of the following parameters are routinely obtained from SmartBuoy:

- Temperature, pressure and conductivity
- TON (nitrate and nitrite) using an automated in situ nutrient analyser
- TON, silicate and phosphate using preserved samples collected by water sampler (up to 50 samples)
- Chlorophyll fluorescence
- SPM derived from measurements of optical backscatter
- Underwater light attenuation coefficient (Kd) from measurements of downwelling PAR irradiance, with at least 2 sensors spaced beneath the buoy in the water column
- Dissolved oxygen using optodes
- SPM and phytoplankton species composition and abundance, can be determined from preserved water samples.

The sensor package routinely collects data for 10 minutes every 30 minutes but is easily varied according to scientific need and length of deployment. New sensors can be integrated into the package as the system logger is built and maintained in Cefas. All the existing SmartBuoy locations have spare payload capacity for collaborator’s sensors or instruments and any new locations can be configured to suit most requirements.

Similar sensors to those on SmartBuoy are installed in a FerryBox on RV Cefas Endeavour which collects continuous surface water data – see figure 4 for cruise track in 2010. The FerryBox also has a refrigerated automated water sampler. In addition on most fisheries surveys another profiling system is deployed up to 4 times per day.

Figure 3. Current and historic SmartBuoy locations (red dots show current locations, black dots are historic locations)
High frequency observations from SmartBuoy have enabled detailed investigation into the temporal dynamics of oxygen, chlorophyll and nutrients at many sites in UK waters. These measurements have provided estimates of primary and net community production over multiple years, and generated unique insights into the variability in carbon cycling in the water column of shelf seas. In addition, the measurements have been used to improving understanding of the physical forcing in shelf seas challenge and improve ecosystem models and for validation of remote sensing data.

Figure 4. RV Cefas Endeavour FerryBox 2010 cruise track.

Key publications:


The Research Vessel Cefas Endeavour and SmartBuoy (for continuous monitoring):
Cruise plans for January 2012 to March 2013

Nigel Lyman

Below is a summary of the cruise programme for the RV Cefas Endeavour from January 2012 to March 2013. There may be opportunities to place individual scientists on board Endeavour for discrete workpackages alongside monitoring effort, or extending operational cruises to add research modules.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>From</th>
<th>To</th>
<th>Duration (days)</th>
<th>Area</th>
<th>Aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cend 1_12</td>
<td>05 January 2012</td>
<td>06 January 2012</td>
<td>2</td>
<td>North Sea</td>
<td>Landers</td>
</tr>
<tr>
<td>Cend 2/12</td>
<td>08 January 2012</td>
<td>21 January 2012</td>
<td>14</td>
<td>TBA</td>
<td>Mapping</td>
</tr>
<tr>
<td>Cend 3/12</td>
<td>25 January 2012</td>
<td>03 February 2012</td>
<td>10</td>
<td>North sea</td>
<td>Nutrients</td>
</tr>
<tr>
<td>Cend 4/12</td>
<td>06 February 2012</td>
<td>19 February 2012</td>
<td>14</td>
<td>TBA</td>
<td>Mapping</td>
</tr>
<tr>
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<td>20 February 2012</td>
<td>11 March 2012</td>
<td>21</td>
<td>Lowestoft</td>
<td>Engine</td>
</tr>
<tr>
<td>Cend 5/12</td>
<td>14 March 2012</td>
<td>27 March 2012</td>
<td>14</td>
<td>Channel</td>
<td>Beam Trawl</td>
</tr>
<tr>
<td>Cend 6/12</td>
<td>10 June 2012</td>
<td>27 June 2012</td>
<td>18</td>
<td>North Sea</td>
<td>Clean Seas Environment Monitoring Programme</td>
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<td>Cend 7/12</td>
<td>21 July 2012</td>
<td>04 August 2012</td>
<td>15</td>
<td>Channel</td>
<td>Beam Trawl</td>
</tr>
<tr>
<td>Cend 8/12</td>
<td>07 August 2012</td>
<td>05 September 2012</td>
<td>30</td>
<td>North Sea</td>
<td>International bottom trawl survey</td>
</tr>
<tr>
<td>Cend 9/12</td>
<td>13 September 2012</td>
<td>02 October 2012</td>
<td>20</td>
<td>Irish Sea</td>
<td>International bottom trawl survey</td>
</tr>
<tr>
<td>Cend 10/12</td>
<td>07 October 2012</td>
<td>14 October 2012</td>
<td>8</td>
<td>North Sea</td>
<td>Nephrops</td>
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<tr>
<td>Cend 11/12</td>
<td>03 November 2012</td>
<td>02 December 2012</td>
<td>30</td>
<td>Celtic Sea</td>
<td>Q4 Ground Fish Survey</td>
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<tr>
<td>Cend 1/13</td>
<td>01 February 2013</td>
<td>10 February 2013</td>
<td>10</td>
<td>North Sea</td>
<td>Nutrients</td>
</tr>
<tr>
<td>Cend 2/13</td>
<td>14 March 2013</td>
<td>27 March 2013</td>
<td>14</td>
<td>Channel</td>
<td>Beam Trawl</td>
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</table>

Table 2. Cruise programme for RV Cefas Endeavour from January 2012 to March 2013
3 Past R&D programmes

In this section we highlight some key Cefas projects which have now been completed (except for the latest part of the EMECO project) of relevance to this Call. Projects that have been most recently completed are listed first.

EMECO – European Marine Ecosystem Observatory. *Both past and current projects.*

*David Mills*

Under this heading three strongly linked projects are described; one current and 2 completed projects. The European Marine Ecosystem Observatory (EMECO) and the Western Shelf Observatory (see figure 5) have been built on regional partnerships to collaborate, identify gaps, co-ordinate and to integrate large and complex data sets. Using internet technologies (the EMECO Datatool: [www.emecodata.net](http://www.emecodata.net)) they provide an open and transparent system that supports wider community engagement for increasing understanding and more tailored evidence for policy use.

The initial focus of the EMECO Datatool was on eutrophication but further development to produce a common system for assessment of Good Environmental Status for the Marine Strategy Framework Directive (MSFD) will focus work on specific descriptors; litter and commercial fisheries. The initial partnership was focussed on the North Sea ([www.emecogroup.org](http://www.emecogroup.org)) and was extended to the Western Shelf Region through the Western Shelf Observatory ([www.westernshelfobservatory.org](http://www.westernshelfobservatory.org)). Currently funded work supports the observatory infrastructure.

![Figure 5. Overview of EMECO and Western Shelf Observatory related programmes](image)

Key publication:

Integrated Survey (contract ME4157). 2008-2011

Ed McManus

This project was a cross-divisional, multi agency, survey designed to consider the logistical synergies, survey strata and issues to multi disciplinary work. Activities and measurements were planned against the Good Environmental Status (GES) descriptors. The survey (see Figure 6 below, which includes strata and stations) included fisheries (as part of the routine survey work), sea birds/mammals, macro-benthos, nutrients, sediments, acoustic / video surveys of habitats at and between stations.

Figure 6. Environmental data collected within fisheries strata (March 2009)

Marine Ecosystem Connections: indicators for essential indicators of healthy, productive and biologically diverse seas (contract ME3205). 2006-2011

Ruth Parker and Suzanne Painting

This project ran from 2006 to 2011 and was undertaken in the North Sea. This project focused on improving the understanding of the generation, cycling and fate of carbon, nutrients and oxygen in the North Sea, and how these pools and flows (including water column and seabed coupling – see Figure 7) were altered by trawling and climate change. These aims were achieved using a combination of observation and modelling approaches. Three sites which represented contrasting ecohydrodynamic regions of the shelf (Southern Bight, Oyster Grounds and North of the Dogger Bank) were observed (see Figure 7) over five seasons relevant to carbon generation. High temporal resolution buoy and lander measurements deployed continuously from 2007 and 2008 were coupled with remote sensing techniques. Transects were also run in 2008. The state and process measurements included hydrography, light climate, primary and secondary production, benthic assemblage biomass and production and biogeochemical rates. New observational approaches using SPI (Sediment Profile Imagery), primary production (using PAM) and secondary production were tested and developed.
Annual carbon budgets for these sites have been constructed and controlling processes identified for the contrasting sites using observational and modelling approaches. 1D ecosystem modelling and spatial modelling using GIS has investigated the impact of trawling at a regional scale on nutrient fluxes and ecosystem state and rate variables and carbon pools and flows.

Publications resulting from this project will appear in a Special Issue of Biogeochemistry – currently in preparation for publication in 2011.

Key publications


Figure 7. Study Sites in the North Sea, shown superimposed on a composite of surface chlorophyll during the last week of March 2007. Red dots indicate the main sampling sites in the southern Bight (SB, 53.17°N 2.81°E), at the Oyster Grounds (OG, 54.41°N 4.04°E) and north of the Dogger Bank (ND, 55.68°N 2.28°E). Conceptual diagram of carbon pools and flows addressed within Marine Ecosystem Connections programme.

Liam Fernand

The aim of these projects was to quantify the role of the Deep Chlorophyll Maximum observed in the UK shelf seas (Figure 8 and Table 3) and assess its importance in sustaining fisheries production.

The project combined modelling (GETM ERSEM) and observations and used existing observational data, focusing on the North Sea. It also used the GETM ERSEM model coupled to a size based model to investigate the effect on higher trophic levels.

The observations (from the thin layers project) consisted of estimates of primary production from the Dogger Bank into the heavily stratified area of the North Sea (Weston et al., 2005) and chlorophyll derived from an extensive spatial coverage using a towed undulator. Observations from the Marine Ecosystems Connections project were also incorporated.

The modelling work undertook simulations over 20 years using Hindcast meteorological data and used the observation data for validation. It demonstrated that the DCM is the dominant supply of new production after the spring bloom and helps sustain higher trophic levels.

Publications resulting from this project will appear in a Special Issue of Biogeochemistry – currently in preparation for publication in 2011.

![Graph showing contribution of production at depth to total new production in the Northern North Sea](image)

**Figure 8. Contribution of production at depth to total new production in the Northern North Sea**

<table>
<thead>
<tr>
<th>NNS</th>
<th>production gC/m²/y</th>
<th>% of total production</th>
<th>new production gC/m²/y</th>
<th>% of total new production</th>
</tr>
</thead>
<tbody>
<tr>
<td>spring bloom</td>
<td>35.8 (5)</td>
<td>24</td>
<td>34.5 (5)</td>
<td>36</td>
</tr>
<tr>
<td>DCM</td>
<td>33.6 (8)</td>
<td>23</td>
<td>38.2 (9)</td>
<td>39</td>
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</tbody>
</table>

*Table 3. Estimated, spatially averaged primary production in the Northern North Sea (NNS). The standard deviation of the 21 year run is given in brackets. Note the production in the Deep Chlorophyll Maximum is equivalent to the spring bloom.*

Key publication:

The ecosystem consequences of seabed disturbance (contract AE1224). 2002-2006

Ruth Parker

This project ran from 2002 to 2006 and its aims were to assess the effect of sediment disturbance on biogeochemical functioning of shelf sediments. A key aim was to assess the relative magnitude of sediment disturbance due to natural (storms and tides) and human (dredging, fishing and construction) activities, at both local and regional scales and develop a conceptual model of the consequences of sediment disturbance to support impact assessments and the development of activity-related ecological targets. Fieldwork was carried out in 2002 / 2003 in the Thames Embayment, Outer Silver Pit and Tyne regions to look at the response of sediment biogeochemical state and processes to impact. Measurements of sediment characteristics, carbon, fauna and biogeochemistry were measured at 14 sites across these regions.

Key publication:


Benthic State and Change in UK Marine Waters. Phase II: The English Channel and Celtic Seas (contract ME3112). 2000-2002

Stefan Bolam

The main purpose of this project was to assess the spatial distribution of the macrofaunal assemblages currently around the coast of England, Wales and the west coast of Scotland, together with an assessment of the factors affecting such assemblages. Estimates of the benthic productivity associated with such communities were also derived, for the first time, at this large spatial scale.

This was primarily achieved by sampling the biological and physical characteristics of 155 stations (Figure 9) in the English Channel, Celtic Seas and the North Sea (the latter being previously sampled under AE1143). Parallel environmental information obtained for each sampling station included sediment granulometry, bathymetry (except North Sea and western Scotland), stratification, bottom temperature, wave and tidal bed stress and surface chlorophyll.
The results from this project have particular benefit in providing a wider context for the assessment of environmental quality status and change, thereby addressing a range of UK, European and International needs. For example, information from this project was used in the formulation of policy for the management of the marine environment, including the implementation of the Marine Strategy Framework Directive (MSFD), reporting for Charting Progress II and OSPAR, and will provide valuable information to help inform the selection of Marine Protected Areas in UK waters. In addition, the data were used by JNCC as part of the re-evaluation of biotopes in offshore environments where such data have previously been relatively sparse. Finally, the data are being used as a basis for the formulation of a number of other R&D-focused projects with national and international remits.

Key publications:


JoNuS (Joint Nutrient Studies) I and II. 1990-1997

Steve Malcolm

These projects ran from 1990 to 1997 and were focused in the southern North Sea and eastern Irish Sea. The projects focused on improving the understanding of the input of nutrients to estuaries, the processes within estuaries that influence the output of nutrients to the sea and the impact of nutrients in coastal waters and more widely. The programmes were carried out by Cefas, AFBINI, the Universities of East Anglia and Essex and the Plymouth Marine Laboratory as well as a range of PhD students and through links to Netherlands Institute for Sea Research.

JoNuS I had a strong focus on what happens to nutrients that are discharged into contrasting estuarine environments, using the Humber and The Wash for extensive field surveys. The programmes found that the geomorphology (shape) had a profound effect on the delivery of nutrients.
to the sea through processes such as nitrification and denitrification of nitrogen and particle related process interacting with salinity change for phosphorus. Insight into the growth of phytoplankton in turbid environments was also delivered. JoNuS II followed on from this to investigate the impact of nutrients on the phytoplankton and other organisms in the outer Thames estuary and Liverpool Bay, providing information about the extent to which the communities were altered by enhanced nutrient availability.

A database of observations from the estuaries, coastal waters and from repeated surveys in the southern North Sea is available together with the knowledge of several members of staff who still work at Cefas.

Key publications:


4 Present R&D programmes

In this section we highlight ongoing Cefas R & D projects of particular relevance to this call.

**Mapping the structure, function and sensitivity of seabed sediment habitats to support assessment of the seafloor status and broad scale monitoring and management of the benthic environment (contract ME5301)**

*Clare Leech*

This project aims to develop quantitative measures of the ecological function of seabed substrates and habitats, and apply these to map habitat sensitivity which, when combined with maps of anthropogenic pressures, will enable evidence-based assessments of the health of the seabed. In the context of the Marine Strategy Framework Directive (MSFD) the project is addressing Descriptor 6 ‘seafloor integrity’ and so is focusing on sensitivity of the seabed to physical disturbance, the most widespread source of which is demersal trawling/dredging. The project builds on recent work that has studied the biogeochemical processes and functioning of sediments at selected sites in the North Sea (Marine Ecosystem Connections – ME3205). Ecohydrodynamic units developed in ME3205 have been refined using GIS modelling techniques to define spatial assessment units in the North Sea and English Channel. Biological, sediment and geochemistry samples collected on 3 cruises are being used to validate these units. A new approach to modelling the spatial distribution of surficial sediment composition has been developed. The resulting maps will form the basis for an assessment of significant fishing pressure (MSFD indicator 6.1.2) and will inform the assessment of habitat sensitivity. Biological Traits Analysis has been used to understand the functional diversity among the biota that live in the sediments. Methods to assess the sensitivity of seabed habitats, are currently being developed along with recommendations for alternative metrics targets and indicators for the MSFD for assessing Good Environmental Status. The project began in 2009 and will run until 2013.

**Extended SmartBuoy network (contract ME5304)**

*David Mills*

The main objectives of this programme are to extend the SmartBuoy network, to evaluate SmartBuoy data in the context of policy requirements for assessments of eutrophication and ecosystem health, test new indicators of ecosystem health and carry out research related to ecosystem response to anthropogenic pressures. Two additional SmartBuoy have been successfully deployed; at Dowsing in the North Sea and at the Celtic Deep in the Celtic Seas. The Celtic Deep buoy is operated collaboratively with AFBI. Real time buoy data and historic data can be accessed via the Cefas website: [http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/monitoring-sites.aspx](http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/monitoring-sites.aspx). Initial results confirm the relatively high level of turbidity in the Humber/Wash region and their potential for reducing the risk of anthropogenic eutrophication although not sufficient to suppress all phytoplankton growth. The Celtic Deep buoy provides important contextual information about environmental status in a region of our shelf seas distant from major anthropogenic nutrient inputs.

In conjunction with the project E5302 (see below), primary and secondary production has been measured at a range of locations in the western UK shelf region from Liverpool Bay to the shelf edge in the South-west Approaches. Some results are shown below from this study (Figure 10) and comparative data from the North Sea supplied by Dutch colleagues.
Figure 10. Regression between log-transformed primary production (mgC m\(^2\) d\(^{-1}\)) and secondary production (mgC m\(^2\) d\(^{-1}\)) derived from measurements carried out during the May and July cruises, combined with measurements from Dutch coastal waters derived during an independent study (data provided by NIOO; in the legend, monthly measurements starting with ‘D-’).


Work is also being carried out to examine the extent to which temporal variability in nutrient concentrations at the shelf edge influence nutrient status of the inner shelf.

**Research to improve understanding and assessment of ecosystem health (contract ME5302)**

*David Mills*

This is a five year thematic programme ending in October 2012, and is a broad research and development programme of work designed to meet a range of Defra’s future requirements particularly for sound science to underpin the monitoring and assessment of Good Environmental Status required by the Marine Strategy Framework Directive.

Work to develop and refine a theory of ecosystem health is underway and will be reported shortly. This underpins the development of potentially new indicators of ecosystem health based on measuring shifts in plankton community structure. Work on indicators is being carried out through field work in the Irish and Celtic Seas and use of models. Field measurements include primary and secondary production from a range of ecohydrodynamic regimes. Measurements are being carried out using traditional and novel techniques including an enzyme bioassay for secondary (crustacean) production. Preliminary results show a significant linear relationship between primary and secondary production for the Irish Sea. Collaborators in the North Sea found a similar relationship using the same approaches but with a different slope. Analysis of a 50 yr hindcast of 3D coupled hydrodynamic models is being used to define ecohydrodynamic regions (Figure 11) in the North Sea. The outcome from this work can provide a sound theoretical basis the design of future monitoring of environmental status. This work is being extended to include all UK waters. Theme 2 of this project ‘Pixels to Policy’ is described in the following section.

Under this programme work is being carried out to progress to publication the results from analysis of nearly 10 years of observations from the Cefas SmartBuoy programme. A number of publications are already in press with others in preparation.
Figure 11. Different hydrodynamic regions in the North Sea, defined by density stratification derived from a hindcast of the Cefas 3D GETM-ERSEM model. The median values of the period 1958-2008 were used. ROFI is short for Region Of Fresh water Influence.

Research supporting improved understanding and assessment of ecosystem health: (2) Pixels to Policy (contract ME5302)

Rodney Forster

The overall aim of the Ecosystem Health thematic is to improve our ability to support policy requirements for assessment of eutrophication in the context of current policy drivers and the future needs of the Marine Strategy Framework Directive and to ensure the supply of data for verification, assessment and improved understanding of marine ecosystem health. The second part of the project ‘Pixels to Policy’ aims to assess the availability, accuracy and coverage of the operational products created by the GMES MyOcean service, and other service providers. This is done by analysing spatial and temporal oceanographic and biological time-series data from MyOcean and other service providers to produce new insights in ecosystem health (Figure 12).

There are links between this project and the NERC-NCOF consortium which provides model and ocean colour data to MyOcean.

Figure 12. Trends in growing-season averaged chlorophyll-a for UK shelf seas (from Charting Progress II – the State of UK Seas, Defra, 2010).
Capability to monitor climate indicators using thin scattering layers in the water-column (Cefas seedcorn project)

Jeroen van der Kooij

Fisheries acoustics have been recorded on the Cefas North Sea International Bottom Trawl Survey (IBTS) undertaken during August and September since 2000, providing a 10 year time series of high resolution insight into the watercolumn along the survey tracks. Apart from the strong acoustic marks from fish schools, weaker layers of sound scatterings associated with small organisms such as plankton are also often observed.

This project is investigating these wide scale coverage datasets to establish the feasibility of using fisheries acoustics to extract vertical and horizontal information on stratification (pycnocline, chlorophyll) and to explore trends in stratification and acoustic density distribution (of thin scattering layers) of the North Sea over the last 10 years and relate this to climatic variability.

Productivity Tools: Automated Tools to Measure Primary Productivity in European Seas. A New Autonomous Monitoring Tool to Measure the Primary Production of Major European Seas (contract C3273)

Rodney Forster
UK PIs: Dave Suggett (U Essex), Denise Smythe-Wright (NOC-S)

This FP7 project runs from 2009 to 2012 and will develop and adapt technology to measure primary production of phytoplankton with automated optical techniques, so that they can be placed on ships of opportunity (SOOP, ferries, container ships). The complete ProTool module will consist of a fluorometer measuring the rate of photosynthesis (using the variable fluorescence approach), an algal absorption meter and a hyperspectral reflectance unit to obtain water quality parameters like chlorophyll and suspended matter concentrations and the light attenuation coefficients. The design is modular so that the individual units can also be used in existing FerryBox systems. Cefas are testing the protocol approach on RV Cefas Endeavour by comparing results obtained with different variable fluorescence instruments (PAM, FRRF, PSI), and with 14-C based productivity. The test sites are the North Sea, Irish Sea and Celtic Sea. The project is linked to the NERC Pelagic Ocean Acidification project via PI Suggett (U Essex), with staff using ProTool methods on both Cefas and NERC cruises around the UK in spring-summer 2011.

Deliverables will be validated maps of phytoplankton biomass, underwater optical conditions and gross primary production for the North Sea.
Fit for purpose monitoring (contract ME5404)

Ed McManus

This project started in April 2010 and has an end date of March 2014 (Sea time: To trial integrated options in 2013). This project was originally scoping monitoring options for the East and West, but may now feed into a larger UKMMAS monitoring strategy for all of UK (to be confirmed).

The goal of the UK marine monitoring and assessment strategy is to ensure the cost-effective provision of the information needed for policy and management decisions to deliver the UK marine vision.

In order to implement the European Marine Strategy Framework Directive (MSFD), the UK will need to work towards a position where it can report in 2014 on the implementation of coordinated monitoring programmes for the ongoing assessment of environmental quality status of UK waters, in particular addressing the need to monitor progress towards Good Environmental Status (GES) in UK waters in relation to the issues covered by the eleven MSFD descriptors of Good Environmental Status (GES) and in the context of prevailing conditions.

UKMMAS will need to define and in collaboration with funding bodies implement a monitoring strategy to meet requirements set out under the MSFD that is informed by the indicator, targets and measures currently being developed for reporting to the European Commission in July 2012.

Defra has supported a research project with Cefas to deliver a flexible, fit-for-purpose monitoring strategy for key parts of UK monitoring requirements (and specifically in relation to providing advice on contaminant monitoring) that directs and supports current and future monitoring activities providing meaningful state and trend data as needed. It will make use of data from field sampling, including existing data from current programmes, in order to assess the extent to which these currently meet the requirements of the MSFD. In particular, it will work with the UKMMAS Evidence Groups, Environment Agencies, Country Agencies and the JNCC to:

- Outline the requirements that are not currently met, but which will be necessary to demonstrate that GES is achieved,
- Realize monitoring efficiencies, and
- Provide recommendations on sampling protocols and sample optimisation.
5 Modelling capability

In this section we describe the key modelling experience and capabilities within Cefas of relevance to this call. Rather than provide a list according to specific projects (as in previous sections) a more holistic view is taken of overall capabilities.

Coupled physical-biogeochemical models

Johan van der Molen

Cefas uses the coupled physical-biogeochemical model GOTM-ERSEM-BFM and GOTM-ERSEM-BFM. GOTM (General Ocean Turbulence Model) is a public domain, one-dimensional Finite Difference hydrodynamical water column model designed initially for testing turbulence closure models (Burchard et al., 1999; www.gotm.net). It solves the 1DV partial differential equations for conservation of mass, momentum, salt and heat. GETM (General Estuarine Transport Model) is its three-dimensional equivalent (www.getm.eu). The biogeochemical model ERSEM-BFM (European Regional Seas Ecosystem Model - Biogeochemical Flux Methodology) is a development of the model ERSEM III (see Baretta et al., 1995; Ruardij & van Raaphorst, 1995; Ruardij et al., 1997; Vichi et al., 2004; Ruardij et al., 2005; www.nioz.nl/northsea_model, see also Figure 14) and describes the dynamics of the biogeochemical fluxes within the pelagic and benthic environment. The ERSEM-BFM model simulates the cycles of carbon, nitrogen, phosphorus, silicate and oxygen and allows for variable internal nutrient ratios inside organisms, based on external availability and physiological status. The model applies a functional group approach and contains four phytoplankton groups, four zooplankton groups and five benthic groups, the latter including four macrofauna and one meiofauna groups. Pelagic and benthic aerobic and anaerobic bacteria are also included. It also includes a 3-layer benthic module comprising 53 state variables, which enables it to resolve substantially more benthic processes and more detailed benthic-pelagic coupling than other biogeochemical models recently applied to the North Sea (Radach & Moll, 2006; Lenhart et al., 2010).

![Figure 14. Schematic of functional groups and carbon and nutrient flows in ERSEM-BFM in pelagic (left) and benthic (right) systems.](image-url)
ERSEM-BFM has been extended recently with (i) a CO$_2$ module, (ii) a *Phaeocystis* functional group, (iii) TEP production and enhanced sinking of diatoms leading to improved benthic-pelagic coupling, and (iv) filter-feeder larvae transport, (v) a local, wave-driven SPM concentration model for dynamic light climate predictions. GETM-ERSEM-BFM also allows for tracking of nutrients from a specific source.

To improve simulations of the under-water light climate, a multiple grain size SPM resuspension model for combined currents and waves has been developed and tested with 1D GOTM at the Liverpool Bay and West Gabbard SmartBuoy sites (van der Molen et al., 2009). This SPM model has recently been coupled with GOTM-ERSEM-BFM, and will be extended to 3D with GETM-ERSEM-BFM.

GOTM-ERSEM-BFM has been coupled to the higher trophic level foodweb model ECOPATH-ECOSYM, and GETM-ERSEM-BFM has been coupled to a size-based higher trophic level model. Also associated with GETM is a particle tracking Individual Behaviour Model for eggs and larvae of marine fauna.

**Model setups**

Cefas currently has the following model setups (see also Figure 15):

- **GOTM-ERSEM-BFM** 1D setups for SmartBuoy sites at Liverpool Bay, Sean Gasfield in the southern Bight, Oyster Grounds and a site north of Dogger Bank
- **GOTM** 1D setups at the Warp Anchorage and West Gabbard SmartBuoy sites
- **GETM** shelf-wide setup, 2 nautical miles resolution, 2D barotropic, used to provide tidal boundary conditions for 3D setups
- **GETM** Irish Sea setup, 2 nautical miles resolution, 3D with temperature and salinity, used for particle tracking IBM
- **GETM** North Sea setup, 2 nautical miles resolution, 3D with temperature and salinity
- **GETM** English Channel setup, 1 km resolution, 3D with temperature and salinity, under development
- **GETM-ERSEM-BFM** North Sea setup, 6 nautical miles resolution, 3D with temperature, salinity and biogeochemistry
Figure 15. GETM model domains with bathymetry.

**Boundary conditions and forcing**

Atmospheric forcing for the models was derived from the ECMWF ERA40 and Operational Hindcast data sets. Boundary conditions for temperature and salinity were based on climatologies derived from the World Ocean Data Base. Tidal boundary conditions were derived from Topex-Poseidon satellite altimetry. Boundary conditions for nutrients were based on literature values. Realistic data on riverine runoff and nutrient (N, P and Si) inputs were used. To this end, a UK riverine nutrient input database was developed at Cefas based on gauged data. This data set was improved using estimated terrestrial sources of nutrients from ungauged areas. The data have been used together with new data from Denmark and Baltic states to augment an existing continental riverine nutrient database. The combined database is now recognized as the best source of riverine nutrient input data for the North Sea.

**Post-processing**

Cefas has a range of postprocessing tools for GOTM-ERSEM-BFM and GETM-ERSEM-BFM model output, written primarily in Matlab and Python. These include tidal harmonic analysis and tidal validation routines for both elevations and currents, skill test mapping tools for 3D variables such as temperature and salinity, and various other generic and purpose built visualisation and analysis tools.
Recent applications

1D GOTM-ERSEM-BFM has been applied recently to three contrasting sites in the North Sea as part of the Marine Ecosystems Connections programme to investigate the response of the lower trophic levels of the ecosystem to the impacts of greenhouse-gas driven climate change and demersal trawling (figure 16), with emphasis on benthic-pelagic coupling and carbon cycling. The main impacts of climate change were (i) a temperature-driven increase in pelagic metabolic rates and nutrient cycling, (ii) an increase in primary production fuelled by recycled nutrients, (iii) a decrease in benthic biomass due to increased benthic metabolic rates and decreased food supply as a result of the increased pelagic cycling, and (iv) a decrease in near-bed oxygen concentrations primarily due to decreased solubility in warmer water, but with a contribution by increased consumption. The main impacts of trawling were (i) reduced benthic biomass due to the increased mortality, and (ii) the increased benthic-pelagic nutrient fluxes, with these effects counteracting each other, and relatively small changes in other variables. One important consequence was a large decrease in the denitrification flux predicted at the two summer-stratified sites because less benthic nitrate was available. The effects of trawling scaled linearly with fishing effort, with greatest sensitivity to fishing in summer compared to fishing in winter. The impacts of climate change and trawling were additive, suggesting little or no non-linear interactions between these disturbances.

Figure 16. Thirty-year averages for gross primary production (a), zoobenthos biomass (b) and near-bed oxygen concentration (c) for the three sites (colours), for the base-line run without climate change (solid line), for the climate-change run (dashed line), and for combined climate change and trawling (dotted line).

3D GETM-ERSEM-BFM was used to assess the effectiveness of riverine nutrient reduction scenarios and the magnitude of trans-boundary transport of nutrients (TBNT) for OSPAR ICG-EMO together with partners in the European Union. Eight models were applied by different national institutes in seven countries for the nutrient reduction scenarios and 5 models from 4 countries for the transboundary nutrient flux calculations. For the UK, Cefas and the Proudman Oceanographic Laboratory (POL) both applied their own models to these questions. The nutrient reduction scenarios showed that reductions of riverine inputs of nutrients beyond 50% and, in some cases, beyond 70%, compared to the riverine input levels of 1985, are needed to reduce specific indicators (e.g. levels of chlorophyll, phytoplankton indicator species numbers and oxygen) of eutrophication below agreed levels. The results showed that some indicators were more responsive than others with the degree of responsiveness dependent on proximity to the riverine nutrient sources. In general, winter nutrient concentrations of inorganic nitrogen and phosphorous were most responsive in coastal water bodies (defined as having salinity 30 to 34.5). The mean summer chlorophyll concentration was less responsive to nutrient load reduction than nitrogen or phosphorous and generally had a similar response in offshore waters. Oxygen concentration was the least responsive of all the modelled indicators but most responsive offshore, although it was found to be effected by weather conditions and summer time thermal vertical stratification of the water. As a result of this work OSPAR amended its strategy for combating eutrophication. The strategy now takes into account the possibility that the OSPAR recommended reduction of nutrients by 50% of the riverine input levels of 1985 may not be enough to eradicate eutrophication where it has been found.
The results obtained from work on calculating transboundary nutrient fluxes (Figure 17) showed that the modelled transport of water and nutrients is aligned with the known general circulation in the North Sea. A pattern emerged in the results, with continental based riverine sources dominating the riverine contributions near the continental coast and sources from the UK dominating near the UK coast and in the central North Sea. Sources originating in the English Channel emerged into the centre of the southern Bight of the North Sea and from there into the central North Sea. The relative influence of a specific river source decreased with distance from the source. The largest contribution to the amounts of nutrients offshore was from the Atlantic (i.e. non-anthropogenic) whereas the nutrients of coastal areas were primarily made up of a combination of local riverine sources and Atlantic sources including the English Channel. An important question addressed in this work was the extent of the contribution of anthropogenic nutrients, mainly nitrogen, from one country to another. For the German maritime area approximately two thirds of the total nutrient content was derived from riverine sources, made up of contributions from Germany (28%), the Netherlands (23%), French (8%) and UK (5%). For the Dutch maritime area approximately half of the total nutrient content was derived from riverine sources, made up of contributions from the Netherlands (30%), France (10%) and UK (7%). For the Belgian maritime area approximately half of the total nutrient content was derived from riverine sources, made up of contributions from the France (23%), the Netherlands (21%), Belgium (12%) and UK (3%).

Figure 17. Tracked annual mean pelagic total Nitrogen content for the year 2002, as percentage from all pelagic total Nitrogen, originating from the river groups UK1, UK2, NL1, NL2, F1 and D.

3D GETM-ERSEM-BFM was also used to produce a 50-year hind cast (1958 – 2008) for the North Sea. These model results have yet to be analysed in detail, but some results are already available:

- An analysis of primary production at the thermocline indicated a contribution of up to 10% of the total for the North Sea
- A clear change in ecosystem function, manifested by shifts in functional group abundances, has occurred in response to the reduced riverine nutrient loads in continental coastal areas after the mid 1980s
- The model results show considerable interannual variability in most physical and biological variables
Hardware

The models are run on our in-house 64 bit parallel computing Linux cluster DeepBlue, consisting of 16 dual quad core nodes and 10 single quad core nodes. DeepBlue has about 50 Tb disk storage.

Key references:


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