An Alternative Framework to Assess Marine Ecosystem Functioning in Shelf Seas (AlterEco)

Summary

Continental shelf seas are typically less than 200m deep and can be described by the shallow ocean surrounding continental land masses. Due to their accessibility, shelf seas are commercially and economically important, with oil and gas extraction alone in UK shelf seas valued at £37B pa. Despite occupying only 7% of the surface ocean, shelf seas also play a major role in the global carbon cycle and marine ecosystem. Shelf seas are 3-4 times more productive than open-ocean, are estimated to support more than 40% of carbon sequestration and support 90% of global fish catches providing a critical food source for growing coastal populations. However, shelf seas are also exposed to climate driven and anthropogenic stress that could have a profound impact on their biological productivity and ecosystem function. Many processes contributing to this threat are related to regions that undergo vertical density stratification, when lower layers of our ocean become detached from the atmospherically ventilated near surface layer. In temperate shelf seas stratification predominantly occurs as solar heating outcompetes the tide and wind-driven mixing to produce a warm surface layer, resulting in seasonal stratification over large areas of the NW European shelf seas. A combination of physical detachment from the surface and increased biological oxygen consumption in the bottom layer, accentuated by the enhanced productivity that stratification also supports in the upper ocean, can result in drastically reduced oxygen concentration in the tidally mixed bottom layer. Oxygen levels have been observed to become so low to be classified as 'oxygen deficient', becoming problematic for benthic and pelagic marine organisms with a detrimental effect on ecosystem function.

A recognised global increase in the extent of shelf sea and coastal oxygen deficiency calls for an urgent need to increase the spatial and temporal measurement of oxygen and a better understanding of the processes that lead to oxygen deficiency in shelf sea bottom waters. This need is severely impeded by the natural complexity of ecosystem functioning, the impact of a changing climate, connectivity between different regions of our shelf seas and large-scale external forcing from ocean and atmosphere. Current methods are severely restricted in resolving this complexity, due to poor resolution in observational coverage, which calls for a new strategy for observing and monitoring marine ecosystem and environmental status. AlterEco seeks to address this challenge by the development of a novel monitoring framework to deliver improved understanding of key shelf sea ecosystem drivers. We will capitalise on recent UK investments in marine autonomous vehicles and planning capability to investigate an area of the North Sea throughout an entire seasonal cycle. The chosen area is known to undergo variable physical, chemical and biological conditioning and includes areas identified to experience low bottom layer oxygen levels during summer months.

The overarching aim of this proposal is to develop a novel monitoring framework to deliver improved spatio-temporal understanding of key shelf sea ecosystem drivers.

AlterEco deliverables;

i) utilise the latest autonomous technology to provide sufficiently high temporal and spatial resolution of meso and sub-mesoscale processes to better understand the impacts of inter-annual variability on the functioning of the shelf sea ecosystem,

ii) provide the tools necessary for informing operational forecast models of the *stressors on* and *consequences of* the environmental status of shelf seas, which in partnership with Challenge 2 will provide,

iii) a modular, integrated framework for an efficient, diagnostic monitoring regime for continental shelf seas that has global transferability.

Hypotheses to address:

We will address 4 hypotheses towards achieving the overarching aim of this proposal;
H1: To understand inter-annual variability across the shelf sea interior requires detailed knowledge of the connectivity between hydro-climatic forcing, seasonal and shorter time-scale cycles and meso to sub-mesoscale physical features.
H2: For systematic understanding of ecosystem function and health, key physical and biogeochemical drivers must be directly connected to ecosystem response. This requires sustained, high-resolution observations over temporally and spatially varying conditions.
H3: As the intensity and global area extent of oxygen depletion increases, there is an urgent need to better understand the relative importance of physical versus biological drivers of the development of oxygen deficient regions.
H4: Interpretation of current environmental status therefore requires an improved definition of *baselines* that incorporates the consequences of inter-annual variability in both pre-conditioning and seasonal development of ecosystems.

Approach: Improving on the Current Ecosystem Health Assessment Strategy

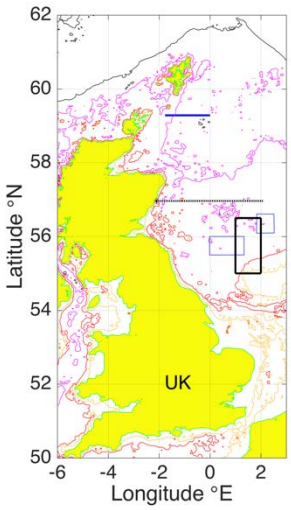
(i) Experiment design: To effectively address the stated hypotheses within a framework of available sensors and systems a sustained experiment will be undertaken in an area of the North Sea (figure 1) that displays characteristics of the dominant processes driving common ecosystem functioning in European shelf seas. To address inter-annual, seasonal and baseline characteristics this observational campaign will cover a winter-to-winter period (see table 1), providing repeat transects of an area in the North Sea that has been previously identified to undergo seasonally varying conditions and includes both permanently and periodically mixed states, high levels of biological productivity and regions experiencing seasonal oxygen depletion.

AlterEco will utilise a modular framework based upon small fleets of submarine and surface autonomous vehicles combined with ongoing North Sea observational programmes to provide atmosphere-thru-ocean coverage of physical conditions and forcing over a large area. The combined observational campaign will encompass mesoscale shelf sea features (order 100-150 km) while at a resolution sufficient to enable resolution of submesoscale features order 100s of metres. We will include the following vehicles and sensors:

- **Ocean gliders**: for vertical profiles of temperature, conductivity (for salinity) and depth (CTD), optical sensors measuring chlorophyll *a* (chl *a*), optical backscatter, photosynthetically active radiation (PAR) and an oxygen sensor. Estimates of tidal velocity will also be made using glider track.
- **Ocean Microstructure Glider** (OMG): for measurements of ocean mixing rates and fluxes, which are key to understanding the role of air-sea exchange, transfer across stratified interfaces, across the benthic-pelagic interface and variable tidal and meteorological forcing on physical and biogeochemical cycling.
- **Nutrient sensors enabled gliders**: Micro-fluidic sensors mounted on ocean gliders have been shown to provide an effective method for measurement of nutrient concentration over extended periods to assess winter nutrient stocks, organic matter remineralisation and benthic-pelagic exchanges.
- **Wavegliders**: Provides a platform for meteorological sensors and biological echo-sounders. We aim to use an advanced split beam echosounder to provide full water-column coverage that will have variable strength acoustic returns dependent on the target, enabling both mapping and quantification of zooplankton and small pelagic fish.

Experience gained from multiple glider deployments in the recent strategic programmes has demonstrated how these platforms can be used effectively in strong tidal regimes to provide high-value, long-term coverage of multiple parameters through repeat sampling over large areas. Gliders can effectively measure mesoscale and submesoscale (hundreds of metres to kilometres) hydrographic and biogeochemical variability in the ocean. Vertical glider profiles within shallow shelf seas are typically only a few hundred metres apart so small scale processes will be quantified from simultaneous measurements of the physics (temperature, salinity, current velocity, turbulent mixing) through the biogeochemistry (oxygen and nutrients) to the ecology (phytoplankton and zooplankton abundance and patchiness). Ocean gliders will therefore provide the backbone of our observational programme.

Figure 1: shows the proposed area of operation (black box) leading from shallow water north of Dogger Bank (DB), through nearby Marine Conservation Zones (MCZs) into deeper regions that undergo periods of prolonged stratification and deficient oxygen levels throughout summer months. For reference, depth contours are orange (30m), red (50m), pink (100m) and black (200m, indicating the shelf break). The JONSIS monitoring transect line, south of Orkney is shown in blue and the planned offshore extension of the Stonehaven monitoring follows the black dashed line.



RV Cefas Endeavour will assist in deployment and recovery of vehicles and will provide calibration capability under planned operational cruises (e.g. servicing of the North Sea SmartBuoy network). Additional vessel support will be provided by available smaller vessels such as the Newcastle University research vessel, RV The Princes Royal, or ships-of-opportunity. The survey area is designed to cover a diverse range of depths and physical regimes, including 1) shallow ~30m waters on the north side of the Dogger Bank (55^{o}N, 2^{o}E), which is a Marine Protected Area (MPA) that is nearly permanently well mixed by tidal stirring, 2) the frontal system delimiting seasonally stratified waters north of Dogger Bank, and 3) deeper seasonally stratified waters that include the tow Marine Conservation Zones (Fulmar and Swallow Sand).

(ii) ***Optimised planning and navigation*:** Simulated missions will be run through the experimental area within a state-of-the-art operational ecosystem model of the North Sea region (NEMO-ERSEM provided by partners UKMO) to test optimal sampling strategies under variable conditions. During the experimental period real-time and forecast data from the operational model will be combined with near real-time satellite data supplied by NEODAAS to identify physical (sea surface temperature (SST), colour and turbidity) and biological (ocean colour and chlorophyll fluorescence) features to tailor day-to-day sampling strategies. Navigation will be assisted from tidal prediction data and near real-time data feeds from the UKMO North Sea meteorological network, partner monitoring stations and deployed gliders. It is anticipated that this project will also benefit from ongoing development of an enhanced command-and-control system for gliders and other autonomous platforms, that is part of an ongoing NERC investment of £25M into the NERC Marine Autonomous and Robotic Systems (MARS) fleet centred on NOC and SAMS.

(iii) Delivery of data: Our glider fleets will provide subsets of collected data in near-real-time (during surfacing of submarine gliders). These data will delivered to the Global Telecommunication Service (GTS) via project partners UKMO for global dissemination. AlterEco will adopt the glider data format designed by EGO (Everyones Glider

Observatories, http://www.ego-network.org). The EGO format permits the inclusion of biogeochemical parameters, which traditionally sit outside of the current GTS accepted temperature, salinity and oxygen. These enhanced data products will enable immediate use by UKMO and other public users.
Following recovery of vehicles, full, high-resolution data will undergo data quality control and managed by BODC to ensure appropriate future data management.

Cruises	CEFAS						C1		C2				C3		C4		
	Newcastle		C1			C2						C3					C4
			2017		2018												2019
Provider	**Vehicle**	**Sensors**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**
NOC	NOC1	CTD, optics, O2															
	NOC2	CTD, optics, O2															
	OMG1	CTD, O2, Mixing															
	NSEG	CTD, Optics, Nutrients															
UEA	SG1	standard															
	SG2	standard															
CEFAS	WaveG	CT, Meteo, Acoustics															
SAMS	SAMS1	CTD, optics, O2															
	SAMS2	CTD, optics, O2															

Table 1: Glider deployment schedule with a short summary of vehicles and sensors available. Planned deployment, recovery and calibration cruises (C_) using CEFAS and Newcastle vessels are shown for reference but are subject to change.

Synthesis and delivery

AlterEco will be managed through four workpackages (WP). WP1-3 are aligned with hypotheses H1-3 to address key scientific challenges. A final synthesis workpackage WP4 will draw together results to address the overarching aim of this proposal and will coordinate AlterEco with challenge 2 to provide the key deliverables of this call. WP4 therefore has the following objectives;

a) *bring together the physical, chemical and biological results and findings from WP1-3 to address* ***H4.***
b) *assess the effectiveness of the chosen methodology to deliver the AlterEco overarching aim "****to develop a novel monitoring framework to deliver improved spatio-temporal understanding of key shelf sea ecosystem drivers."***
c) *deliver key datasets and knowledge to Challenge 2 of this call to contribute to efforts to "****more effectively predict and monitor the status of the shelf sea ecosystem."***
d) *work with Challenge 2 to achieve the overarching aim of the call to* ***"accelerate the use of autonomous measurements and combined observational-model outputs in meeting long-term science need and statutory policy requirements."***