LONG-TERM BIOGEOCHEMICAL TIME-SERIES FROM THE PORCUPINE ABYSSAL PLAIN DEEP OCEAN OBSERVATORY, NORTH EAST ATLANTIC

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ABSTRACT
The Porcupine Abyssal Plain (PAP) fixed-point observatory in the Northeast Atlantic (49ºN, 16.5ºW) is the longest running open ocean multidisciplinary observatory in the oceans around Europe. It has produced a high resolution *in situ* time-series dataset of climatically and environmentally relevant variables from the euphotic zone to the seafloor beneath (4800 m) for over twenty years. Data include ship-based sampling and autonomous measurements from a fixed-point mooring of temperature and salinity (to 1000 m), biogeochemical data at 30 m (including nitrate, chlorophyll and pCO_2) and deep ocean studies from deep sediment traps, benthic time-lapse photography and repeated sampling of the benthic biota. Current and future developments of the PAP site are in a National, European and international context including contributions to EuroSITES, an EU FP7 project to integrate European deep ocean observatories, to ESONET to enhance the seafloor capabilities of the site and as a European contribution to the OceanSITES worldwide system of deep water reference stations.

1. INTRODUCTION

1.1. Rationale

Fixed-point time-series are vital for investigating and understanding a range of temporal processes. These include short-term (daily to seasonal) variation and longer-term trends (climate driven). In addition, a continuous high resolution time-series allows episodic events, which are otherwise missed, to be sampled. These episodic events e.g. storm surges, eddies and phytoplankton blooms, often significantly shape the marine environment and ecosystem. The Porcupine Abyssal Plain (PAP) fixed-point observatory in the Northeast Atlantic (49ºN, 16.5ºW) has produced a high resolution *in situ* multidisciplinary time-series dataset of climatically and environmentally relevant variables from the euphotic zone to the benthic boundary layer since 1989. Historically these measurements have been sampled from a research ship. However, since 2002, a fixed-point mooring has been in place and most recently (2007), a surface buoy has been added. Data are sent in near real-time from the upper 1000m through Iridium telemetry to shore stations. A full depth observation programme has enabled the seasonal and inter-annual processes and trends to be analysed as an integrated system from the euphotic zone to the benthic boundary layer and seafloor. Research to date at the Porcupine Abyssal Plain Sustained Observatory site has therefore focused on understanding surface processes (e.g. [1]) and the link between upper ocean physical and biogeochemical processes, the supply of particulate organic carbon (POC) to the deep ocean (e.g. [2]), and the response (in terms of biodiversity and ecosystem functioning) of the benthic fauna below (e.g. [3,4,5,6,7,8]). In some cases community changes have been attributed to longer-term climate-driven changes [9]. More details on the benthic biological observations and time-series from the PAP site and other key

reference stations can be found in [10] and [11]. The European and international context of time-series research at the PAP site, is discussed as contributing both to the subsea component of GMES (Global Monitoring for Environment and Security) and to the Global Earth Observation System of Systems (GEOSS) through the OceanSITES deep water reference stations and the Global Ocean Observing System (GOOS).

2. RESULTS

2.1. Upper ocean biogeochemistry

A three year time period (2003-2005) of physical and biogeochemical data has been analysed particularly intensively for both seasonal and inter-annual trends [1]. Trends from 2003 to 2005 indicate a higher temperature and salinity signal in surface waters from 2003 to 2005 with increased stratification, decreased nitrate concentration (Fig. 1) and consequent decline in productivity and delay in the spring bloom. The trend from open ocean *in situ* data of increasing temperature and salinity confirms other observations including UK coastal *in situ* observations e.g. from the Smart buoy (CEFAS) project and extends the trend documented from remote (satellite) observations of chlorophyll-a fluorescence across the North Atlantic showing a progressive decline in primary production in the open ocean from 1999 to 2004 [12,13]. The progressive warming, at the PAP site from winter 2003 to 2005 (seen in both the NCEP SST and subsurface (30 m) temperature records from the PAP mooring), associated with a decrease in nitrate concentrations and productivity [13] may be due to a combination of shallower convective mixing and changes in surface circulation and mode waters supplying the region [1]. These trends in the physical and biogeochemical processes in the Northeast Atlantic will clearly have an impact on the pelagic (and benthic) ecosystems and will cause variability in plankton distribution and population size which will ultimately impact on fish stocks.

A persistent feature of the North Atlantic is undersaturation of CO_2 in surface waters throughout the year which gives rise to a perennial CO_2 sink [14]. This makes this region of high global importance in the global carbon cycle. This continuous undersaturation is characteristic of the entire subpolar North Atlantic resulting from the general cooling of surface waters during their passage from low to high latitudes. However, there is evidence for a trend of less CO_2 being absorbed into the oceans (for the period 2003 to 2004) [14]. This may have future implications for the global carbon cycle and importance of the oceans as a carbon sink and shows that we need to monitor in a sustained way the temporal changes which take place in the oceans.

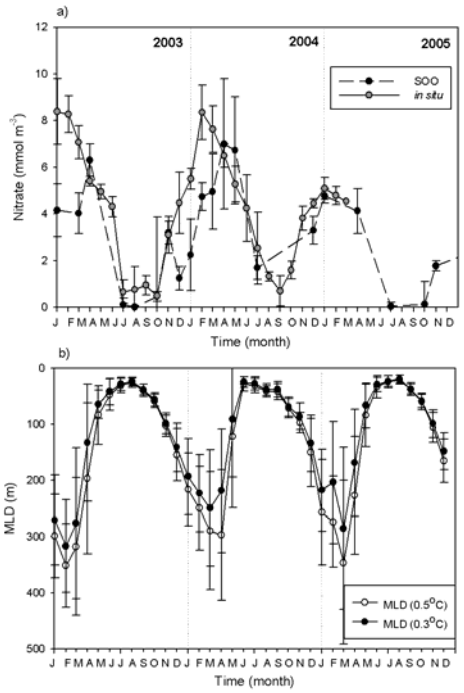

Figure 1. Nitrate concentrations and Mixed Layer Depth (MLD) estimates at the PAP observatory site from 2003 to 2005 showing: a) in situ monthly mean (± 1 standard deviation) NAS nitrate concentrations (grey circles), compared with discrete samples taken from a ship of opportunity (SOO, black circles); and b) monthly mean (± 1 standard deviation) MLD from Argo float profiles (across 45°N to 52°N and 26.08°W to 8.92°W) calculated using a temperature difference criterion of 0.5°C (open circles), compared with a 0.3°C criterion (black circles). Tick marks indicate the start of the month (from [1]).

2.2. Deep ocean and benthic studies

The Porcupine Abyssal Plain Sustained Observatory site is a key long-term reference site across the global Ocean for benthic biological community studies. The benthic work carried out at this site are reviewed in [10] (see Section 2, Fig. 1, 2 and Tab. 1) and [11]. Results from time-series studies of benthic communities suggest that biodiversity and ecosystem functioning are likely to be closely coupled (and in some cases driven) by global changes in the atmosphere and surface ocean e.g. productivity, biodiversity and community structure of

plankton [3,5]. Benthic research at the site has indeed revealed significant variations in faunal densities and community composition over seasonal and interannual timescales from small meiofauna to larger macro and megafaunal size classes. In many cases this impact can be related to the food quality and quality [3,5]. In particular, the quality and quantity of the organic matter is shown to influence the benthic ecosystem functioning and can result in radical changes in the density and species diversity of benthic fauna, in particular in large invertebrates (megafauna) as seen in a population explosion of holothurians dominated by the species *Amperima rosea* in 2002 following a particularly large peak in particle flux (Fig. 2). Community shifts and population changes were also seen in other size classes, e.g. the macrofauna, where significant differences were observed in some trophic groups (predators, surface deposit-feeders and burrowers) and the dominant families (Cirratulidae, Spionidae and Opheliidae). Studies of benthic foraminifera have shown a significant increase from 1989-2002 [6].

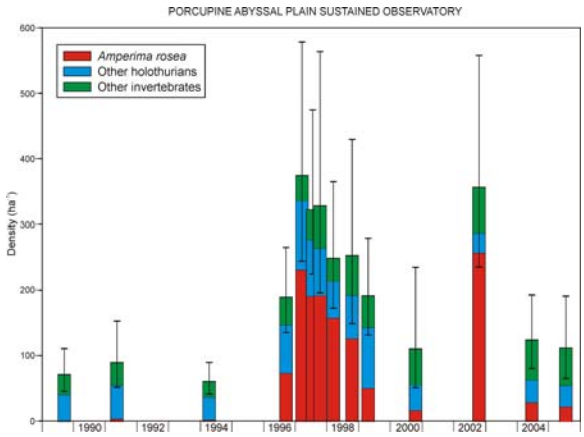

Figure. 2. *Abundance of benthic megafauna at PAP Sustained Observatory (1990-2004) (adapted from [3]).*

Community changes at the PAP site have been attributed to climate-driven changes in particulate organic carbon (POC) flux quantity and quality. The North Atlantic Oscillation, for example, was linked to POC fluxes to the seafloor with a time lag of several months, as well as to megafauna community composition [5]. Notably, the observed ecosystem changes at PAP were linked with qualitative variations in the biochemistry of particulate organic matter (POM) [3] which are believed to be critical to the reproductive and recruitment success of key species such as *Amperima rosea* [15].

3. EUROPEAN AND GLOBAL CONTEXT

The PAP observatory is currently funded in part by the UK National Environment Research Council (NERC) as a named site SO2 (Sustained Observatory 2) within the Oceans2025 Theme on Sustained Observations. The PAP site is also one of 9 key deep-ocean time-series sites contributing to the EuroSITES network (www.eurosites.info). Within the EuroSITES FP7 Collaborative Project (2008-2011) PAPis maintained and enhanced with additional sensors increasing it's capacity to monitor environmentally and climatically relevant variables. Strong links exist between EuroSITES and other European initiatives e.g. ESONET (European Sea Observatory Network). One tangible example of this is that ESONET has funded a collaboration demonstration mission, MODOO, which will enhance the seafloor observation infrastructure at the PAP site, utilizing the existing water column mooring to send multidisciplinary data in near real-time via acoustic link from a lander at 4800 m to the surface and to shore. The MODOO project will also include the addition of a bottom pressure sensor at the site in a demonstration project as a pre-operational tsunami warning system with the view of being part of an operational network in the future. Other future plans include a synergy between NERC and the UK Met Office to deploy an ODAS observing station at the site to provide contemporaneous meteorological data and a platform for additional sensors just above the sea surface fir studies of air-sea exchange.

The PAP sustained observatory is also part of the OceanSITES international network of open ocean reference stations. Data from PAP and other time-series sites within the OceanSITES network have an open access policy to data. Over the coming years this is set to increase both the potential users of these datasets e.g. modelers and to increase the societal benefit of these data through services and products. For instance PAP data (as a component of EuroSITES and OceanSITES) is a key data provider to MyOcean (European Marine Core Services). In the future, it is envisaged that more near real-time data will be utilized by modeling and reanalysis activities to produce services and products for society.

4. SUMMARY AND CONCLUSION

The Porcupine Abyssal Plain (PAP) fixed-point observatory in the Northeast Atlantic (49ºN, 16.5ºW) is the longest running open ocean time-series observatory in Europe and has produced high resolution

in situ multidisciplinary time-series dataset of climatically and environmentally relevant variables from the euphotic zone to the seafloor beneath (4800 m) for over twenty years. Results from the time-series have proven vital for understanding a range of ocean processes at different temporal scales. This has included an integrated understanding of seasonal and inter-annual surface processes and how these affect the deep ocean and seafloor communities. Results have also highlighted the potential role of deep-sea benthic communities as indicators of climate change. As technology enables more variables to be available in near real-time from the open and deep ocean the potential for societal benefit from these datasets in terms of products and services is set to increase exponentially. However, sustaining these time-series through long-term funding commitments and moving these from research towards an operational service is an ongoing challenge.

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