ICES Journal of
Marine Science

ICES CIEM International Council for the Exploration of the Sea / Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2012), 69(5), 776–783. doi:10.1093/icesjms/fss077

The Porcupine Abyssal Plain fixed-point sustained observatory (PAP-SO): variations and trends from the Northeast Atlantic fixed-point time-series

Susan E. Hartman[1]*, Richard S. Lampitt[1], Kate E. Larkin[1], Maureen Pagnani[1], Jon Campbell[1], Thanos Gkritzalis[1], Zong-Pei Jiang[1], Corinne A. Pebody[1], Henry A. Ruhl[1], Andrew J. Gooday[1], Brian J. Bett[1], David S. M. Billett[1], Paul Provost[1], Rob McLachlan[1], Jon D. Turton[2], and Steven Lankester[1]

[1]*National Oceanography Centre, Waterfront Campus, European Way, Southampton SO14 3ZH, UK*
[2]*UK Meteorological Office, FitzRoy Road, Exeter EX1 3PB, UK*

**Corresponding author: tel: +44 2380 596343; fax: +44 2380 596247; e-mail: suh@noc.ac.uk*

Hartman, S. E., Lampitt, R. S., Larkin, K. E., Pagnani, M., Campbell, J., Gkritzalis, T., Jiang, Z.-P., Pebody, C. A., Ruhl, H. A., Gooday, A. J., Bett, B. J., Billett, D. S. M., Provost, P., McLachlan, R., Turton, J. D., and Lankester, S. 2012. The Porcupine Abyssal Plain fixed-point sustained observatory (PAP-SO): variations and trends from the Northeast Atlantic fixed-point time-series. – ICES Journal of Marine Science, 69: 776–783.

Received 29 July 2011; accepted 14 March 2012; advance access publication 18 May 2012.

The Porcupine Abyssal Plain sustained observatory (PAP-SO) in the Northeast Atlantic (49°N 16.5°W; 4800 m) is the longest running open-ocean multidisciplinary observatory in the oceans around Europe. The site has produced high-resolution datasets integrating environmental and ecologically relevant variables from the surface to the seabed for >20 years. Since 2002, a full-depth mooring has been in place with autonomous sensors measuring temperature, salinity, chlorophyll-*a* fluorescence, nitrate, and pCO_2. These complement ongoing mesopelagic and seabed observations on downward particle flux and benthic ecosystem structure and function. With national and European funding, the observatory infrastructure has been advanced steadily, with the latest development in 2010 involving collaboration between the UK's Meteorological Office and Natural Environment Research Council. This resulted in the first simultaneous atmospheric and ocean datasets at the site. All PAP-SO datasets are open access in near real time through websites and as quality-controlled datasets for a range of remote users using ftp sites and uploaded daily to MyOcean and the global telecommunications system for use in modelling activities. The combined datasets capture short-term variation (daily–seasonal), longer term trends (climate-driven), and episodic events (e.g. spring-bloom events), and the data contribute to the Europe-wide move towards good environmental status of our seas, driven by the EU's Marine Strategy Framework Directive (http://ec.europa.eu/environment/water/marine).

Keywords: Northeast Atlantic, observatory, Porcupine Abyssal Plain, time-series.

The Porcupine Abyssal Plain sustained observatory

The Porcupine Abyssal Plain sustained observatory (PAP-SO) is situated in the subpolar Northeast Atlantic (49°N 16.5°W) at a water depth of 4800 m (Figure 1). This location is considered remote from the complexities of the continental slope and the Mid-Atlantic Ridge. It is the longest running multidisciplinary open-ocean time-series observatory in Europe and one of the longest in the world. Since 1989, it has produced high-resolution *in situ* time-series data of climatically and environmentally relevant variables from the entire water column and the seabed beneath. Historically, the measurements have been sampled from a research vessel. However, a fixed-point mooring has been in place since 2002, with a surface buoy being added in 2007. In 2010, collaboration between the UK's Natural Environment Research Council (NERC) and the Meteorological Office led to a redesigned infrastructure, deployed on 1 June 2010, and the first simultaneous monitoring of *in situ* meteorological and ocean variables at the PAP-SO (Table 1).

The multidisciplinary set of sensors on the mooring (Figure 2) have produced high-resolution *in situ* time-series datasets, including subsurface (~30 m depth) measurements of temperature, salinity, chlorophyll-*a* fluorescence, nitrate, and

pCO_2. Recent enhancements to the mixed layer variables include oxygen and irradiance, and a water sampler has been added to the sensor frame. A full list of the variables is provided in Table 1. Data are sent in near real time from the upper 1000 m through Iridium telemetry to the UK National Oceanography Centre (NOC). This full-depth observatory has allowed the analysis of trends in seasonal and interannual processes, and forms an integrated system from the euphotic zone to the benthic boundary layer and seabed.

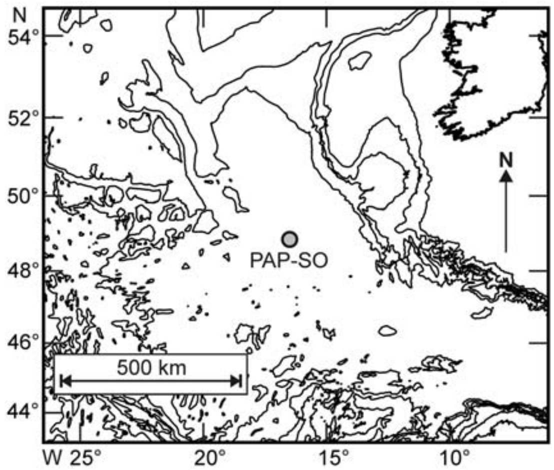

Figure 1. Location map of the Porcupine Abyssal Plain Sustained Observatory (PAP-SO). The depth contours shown are 200, 1000, 2000, 3000, and 4000 m.

Research to date at the PAP-SO site has focused on understanding surface processes (e.g. Hartman *et al*., 2010) and the link between upper ocean physical and biogeochemical processes, the supply of particulate organic carbon (POC) to the deep ocean (e.g. Lampitt *et al*., 2010a), and the response (in terms of biodiversity and ecosystem functioning) of the benthic fauna below (e.g. Billett *et al*., 2001, 2010; Wigham *et al*., 2003; Gooday *et al*., 2010; Kalogeropoulou *et al*., 2010; Soto *et al*., 2010). In some cases, community changes have been attributed to longer-term climate-driven changes (Ruhl *et al*., 2008). More details on the benthic biological observations and time-series from the PAP-SO site can be found in Glover *et al*. (2010), Lampitt *et al*. (2010b), and Larkin *et al*. (2010).

Upper ocean biogeochemistry

A three-year time-series (2003–2005) of physical and biogeochemical data was analysed for both seasonal and interannual variation (Hartman *et al*., 2010). Results from that analysis showed

Table 1. Sensor types, variables measured, and measurement frequency at the PAP-SO.

Depth	Parameters/variables	Sensor	Frequency
Atmospheric (UK Meteorological Office buoy)			
3.5 m above surface	Windspeed and direction	Gill acoustic sensor and revolution magnetic compass	Hourly (10 min mean)
2 m above surface	Relative humidity	Rotronic Hygroclip R/S sensor	Hourly (instantaneous reading)
2 m above surface	Air temperature	Electrical resistance thermometer (ERT)	Hourly (10 s mean)
1 m (subsurface)	Sea temperature	Electrical resistance thermometer (ERT)	Hourly (10 s mean)
1.75 m above surface	Atmospheric pressure	Druck RPT350 pressure sensor	Hourly (20 s mean)
Surface	Significant wave height and period	Datawell heave sensor; 17.5 min average	Hourly (over 17.5 min sample)
Surface ocean (fixed frame)			
30 m	CTD	Seabird MicroCAT	10 min
30 m	CTD + dissolved oxygen	Seabird MicroCAT IDO	30 min
30 m	Nitrate and nitrite (chemistry)	NAS	4 h
30 m	Nitrate and nitrite (UV absorption)	Satlantic ISUS	1 h
30 m	Chlorophyll	WETlabs (FLNTUSB) and Cyclops	6 h, 1 h
30 m	Dissolved oxygen	Aanderaa optode on Seaguard	1 h
30 m	Currents	DCS	1 h
30 m	CO_2 (IR absorbance after equilibration)	PRO-OCEANUS	12 h
30 m	Dissolved gases (gas tension device)	PRO-OCEANUS gas tension device	12 h
30 m	Radiance Lu upwelling radiance	Radiometer (Satlantic OCR, 7-channel with standard wavelengths)	1 h
30 m	Irradiance Ed, Eu downwelling irradiance	Radiometer (Satlantic OCR as above)	1 h
30 m	Irradiance Es total irradiance	Radiometer (Satlantic OCR as above)	1 h
30 m	Zooplankton sampler	McLane zooplankton sampler	Every 2 d
Deep ocean (subsurface mooring)			
25–1 000 m	CTD	Seabird MicroCAT	10 min
3 000 m	Particle flux (sediment traps)	McLane sediment trap	Variable (d)
3 000 m	Currents	Aanderaa RCM9	4 h
3 050 m	Particle flux (sediment traps)	McLane sediment trap	Variable (d)
100 m above seabed	Particle flux (sediment traps)	McLane sediment trap	Variable (d)
100 m above seabed	Currents	Aanderaa RCM9	4 h
Seabed (lander)			
Seabed (4 800 m)	Time-lapse photos	Imenco AS (SDS 12100) stills camera	8 h

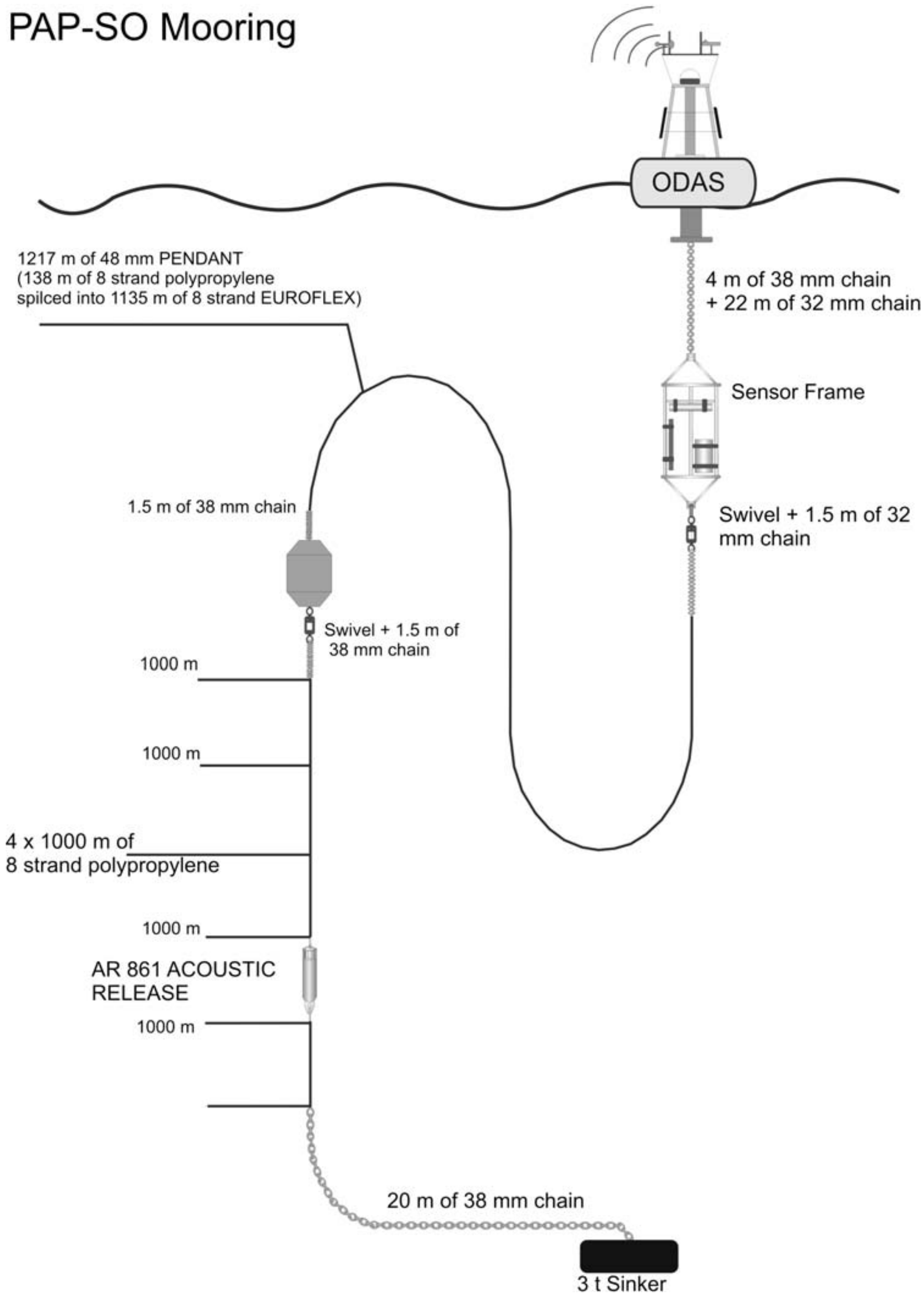

Figure 2. The PAP-SO full depth mooring design and Ocean Data Acquisition System (ODAS) surface buoy.

evidence of increased temperature and salinity signals in surface waters from 2003 to 2005, with increased stratification, decreased nitrate concentration (Figure 3) and consequent decline in productivity, and delay in the spring bloom (Hartman *et al*., 2010). In addition, indications of changes in surface circulation and mode waters supplying the region suggested that eddy activity and lateral advection cannot be ignored at the site (Hartman *et al*., 2010).

The variation in open ocean *in situ* data, of increasing temperature and salinity over a three-year period, confirms other observations including UK coastal *in situ* observations, e.g. the L4 buoy in the western English Channel (Smyth *et al*., 2010). Results from the PAP-SO also align with 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 (Gregg *et al*., 2003; Behrenfeld *et al*., 2006). Progressive warming at the PAP-SO site from winter 2003 to winter 2005 was observed in both the National Centre for Environmental Prediction (NCEP) sea surface temperature (SST) and subsurface (30 m) temperature records from the PAP-SO mooring. Associated decreases in nitrate concentrations and productivity (Behrenfeld *et al*., 2006)

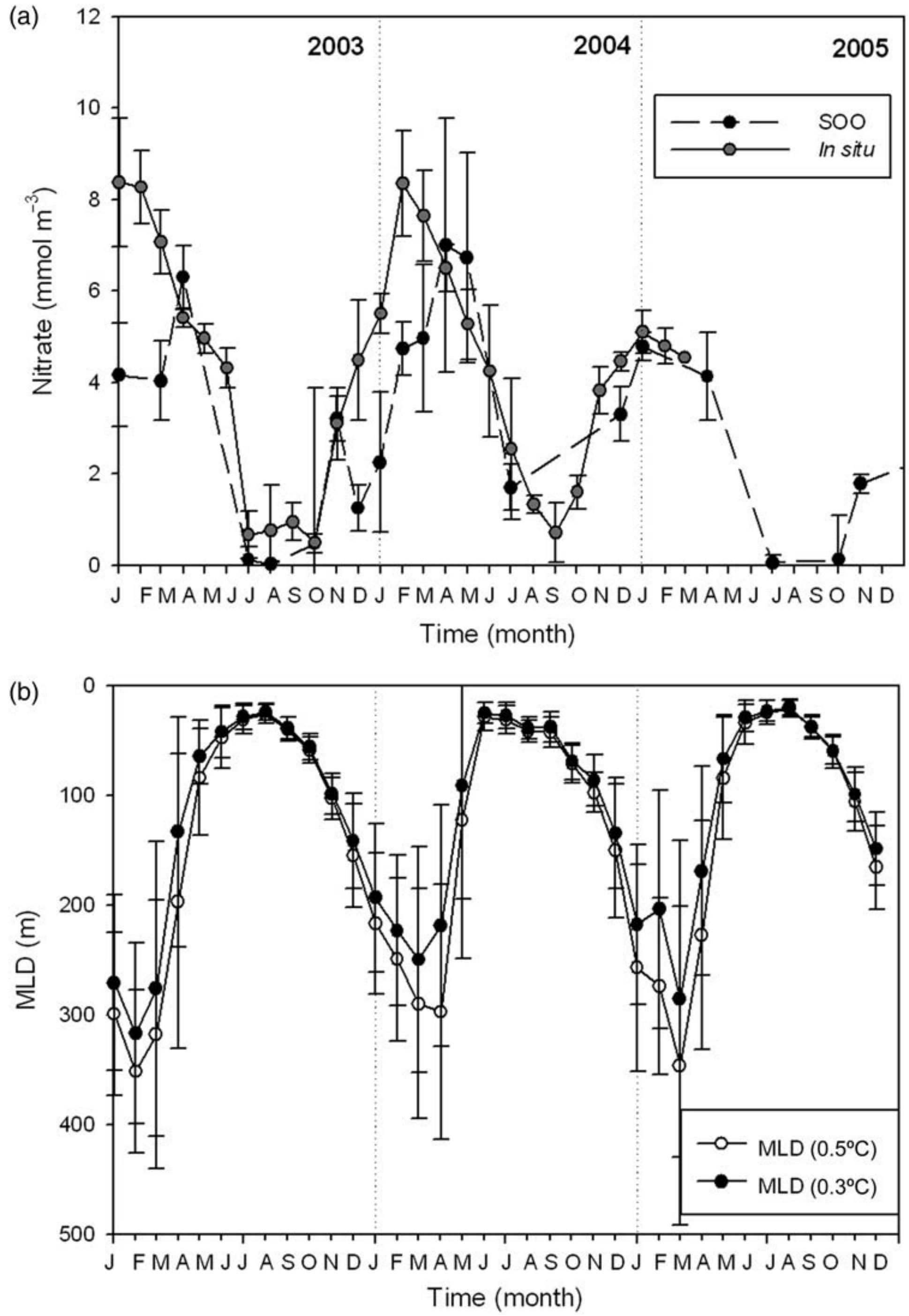

Figure 3. Nitrate concentrations and mixed layer depth (MLD) estimates at the PAP-SO site from 2003 to 2005 showing: (a) *in situ* monthly mean ($\pm$ 1 s.d.) nitrate concentrations (grey circles), compared with discrete samples taken from a ship of opportunity (black circles); and (b) monthly mean ($\pm$ 1 s.d.) MLD from Argo float profiles (across 45–52°N 26.08–8.92°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 Hartman *et al.*, 2010).

may be attributable to a combination of shallower convective mixing, changes in surface circulation, and mode waters supplying the region (Hartman *et al.*, 2010). These variations in the physical and biogeochemical processes in the Northeast Atlantic will have a notable impact on the pelagic (and benthic) ecosystems. This will cause a variability in zooplankton distribution and population size that ultimately relates to fish stock dynamics.

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 (Körtzinger *et al.*, 2008). This makes this a region of great importance in the global carbon cycle. The 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,

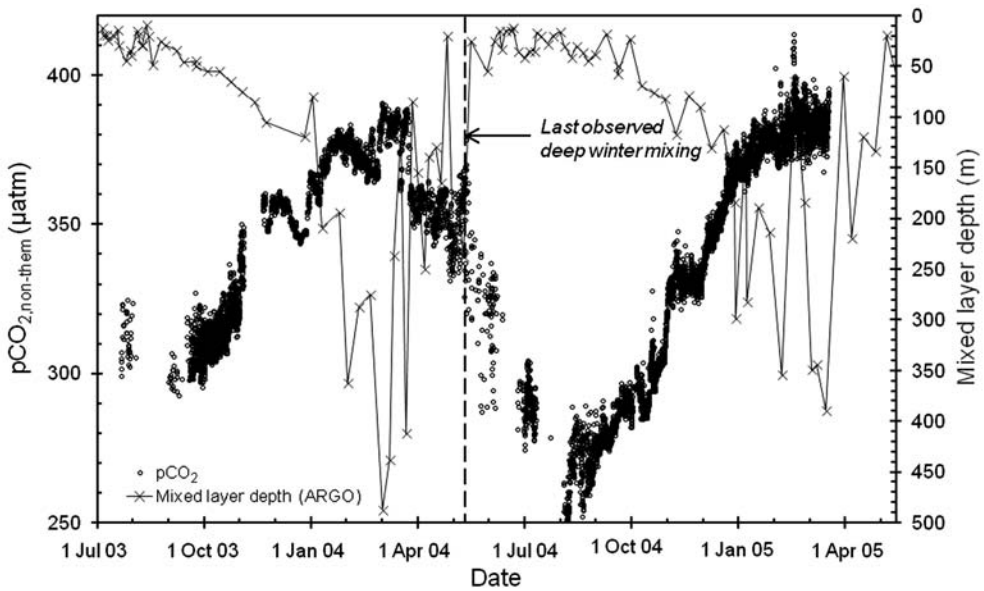

Figure 4. Observed pCO_2 corrected to the annual mean SST of 2004 and estimated MLD. Reproduced from Körtzinger *et al.* (2008).

there is evidence for a trend of less CO_2 being absorbed into the oceans for the period 2003/2004 (Körtzinger *et al.*, 2008). This demonstrates the need to monitor temporal changes in the ocean in a sustained way on oceanographic and ecologically relevant time-scales. Changes in the amount of CO_2 absorbed into the ocean may have implications for the global carbon cycle and importance of the oceans as a carbon sink in the future. To assist in making these estimates, pCO_2 data are available from the site in near real time (Figure 4).

Deep ocean and benthic studies

The PAP-SO is the only long-term time-series site in the Atlantic to combine sustained water column and benthic biological sampling effort. This dataset is vital for understanding environmental change. For example, carbon sequestration from the upper ocean is monitored through an understanding of the changes in the downward flux of particulate material in the deep-sea environment. At the PAP-SO site, mesopelagic particle flux samples have been collected from the mooring for more than 20 years using sediment traps at depths between 3000 and 4700 m (Figure 5). Results show that the site is characterized by a relatively high level of flux of organic carbon with high seasonal and inter-annual variability (Lampitt *et al.*, 2001, 2010a). The causes and trends for this long-term variability of downward particle flux in the region are discussed in Lampitt *et al.* (2010a). These include indications that substantial variation in the date of the spring change in mixing (shoaling) may have a large effect on the biogeochemistry of the remainder of the productive season and the resulting carbon sequestration.

The PAP-SO site is an important long-term reference site across the global ocean for benthic biological community studies. The benthic studies carried out at the site are reviewed in Glover *et al.* (2010) and Lampitt *et al.* (2010b), and summarized together with other key benthic biological time-series in Larkin *et al.* (2010). More than 20 years of sampling the abyssal seabed (4800 m) at the PAP-SO site has permitted studies of benthic biodiversity, rate processes, and ecosystem change in the deep seabed.

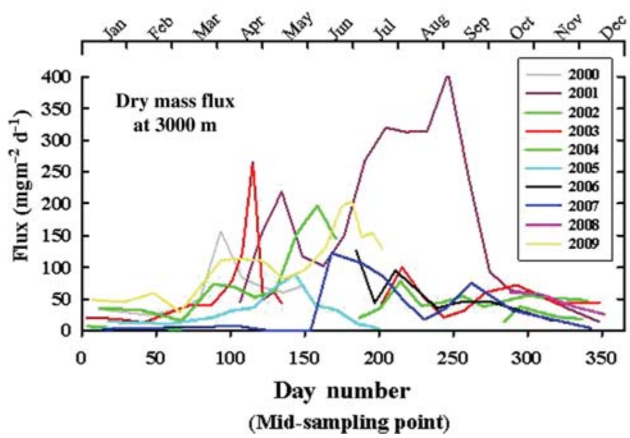

Figure 5. Time-series of particle flux (dry mass), 2000 – 2009, showing clear interannual and seasonal variation.

Results have revealed that benthic ecosystems and geochemistry are intimately linked with ocean-surface processes through variations in POC flux quantity and/or quality arriving on the seabed. The responsiveness of benthic biological communities to climatic drivers and shifts makes them powerful indicators of biogeochemical and other environmental change in the oceans. Results 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. For example, biodiversity at depth may be linked to seasonal variability in productivity and the resultant flux of organic material at the surface (Wigham *et al.*, 2003; Billett *et al.*, 2010).

All components and size classes constituting the benthic ecosystem communities have shown a response to bentho-pelagic coupling. Since the 1980s, an autonomous time-lapse camera system, Bathysnap, has been used to take 4-hourly still benthic images. Benthic research at the site has revealed significant variations in faunal densities and community composition over

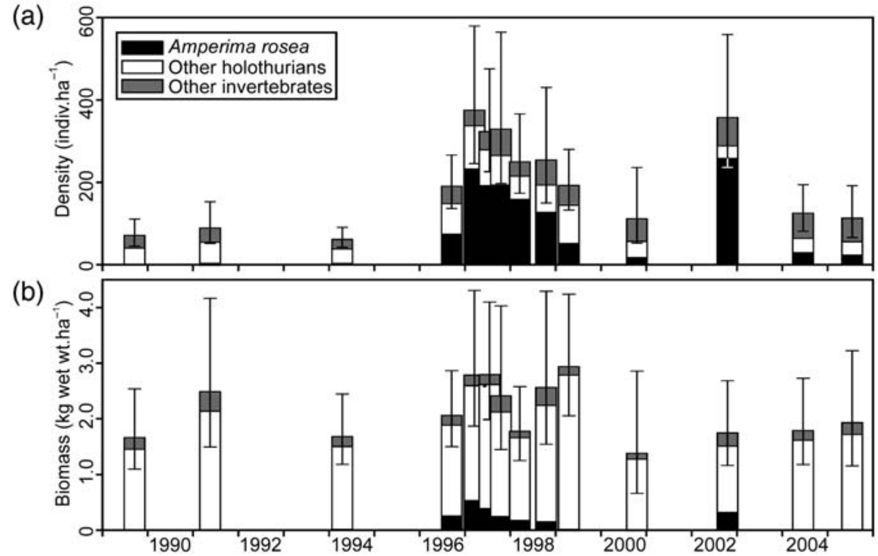

Figure 6. Histograms illustrating temporal variations in the (a) abundance and (b) biomass of selected megafaunal groups at the PAP-SO site (means and 95% confidence intervals). Adapted from Wigham *et al.* (2003).

seasonal and interannual time-scales, from small meiofauna to larger macro- and megafaunal size classes. Often, this impact can be related to food quality and quantity (Wigham *et al.*, 2003; Billett *et al.*, 2010). In particular, the quality and quantity of the organic matter were shown to influence benthic ecosystem functioning and resulted in radical changes in the density and species diversity of benthic fauna, in particular of large invertebrates (megafauna), as documented in a population explosion of holothurians dominated by the species *Amperima rosea* in 1997 and 2002, in the latter case, following a notable peak in particle flux (Figure 6). Community shifts and population changes were also seen in other size classes, e.g. the macrofauna. Significant differences were observed in some trophic groups (predators, surface deposit-feeders, and burrowers) and in the dominant families (Cirratulidae, Spionidae, and Opheliidae). Studies of benthic foraminifera have shown a significant increase in total densities from 1996 to 2002 compared to 1989–1994, together with changes in assemblage composition at the species and higher taxon levels (Gooday *et al*., 2010).

Community changes at the PAP-SO site have been attributed to climate-driven changes in POC flux quantity and quality. The North Atlantic Oscillation (NAO), for example, was linked to POC fluxes to the seabed with a time-lag of several months, as well as to megafauna community composition (Billett *et al*., 2010). Notably, the observed ecosystem changes at the PAP-SO were linked to qualitative variations in the biochemistry of particulate organic matter (Wigham *et al*., 2003) that are believed to be critical to the reproductive and recruitment success of key species such as *A. rosea* (FitzGeorge-Balfour *et al*., 2010).

European and global context

The PAP-SO is funded by the UK National Environment Research Council (NERC) with dedicated webpages (www.noc.soton.ac.uk/pap). In addition, the site has been supported by a number of earlier European projects, including BENGAL, ANIMATE, MERSEA, and MarBEF. Most recently, the PAP-SO has become a key open-ocean time-series site contributing to the EuroSITES network (www.eurosites.info). Within the EuroSITES FP7 Collaborative Project (2008–2011), the PAP-SO was maintained and enhanced with additional sensors, including measurements of carbon dioxide and meteorological variables, thereby increasing its capacity to monitor environmentally and climatically relevant variables (Table 1). Further maintenance will be supported largely by national funding (NERC) together with support for benthic research by the European project HERMIONE.

As a European platform, PAP-SO has been used for science missions and the development and testing of novel sensors. These include the IODA6000 for *in situ* oxygen consumption (developed by CNRS: University of Marseille) and the research and development for enhancing long-term capabilities of a mesozooplankton sampler. Strong links exist between EuroSITES and other European initiatives, e.g. ESONET (European Sea Observatory Network). For example, ESONET funded a collaboration design study to enhance the seabed observation infrastructure at the PAP-SO site. This utilized the existing water-column mooring to send multidisciplinary data in near real time via an acoustic link from a lander at 4800 m to the surface and to shore. The PAP-SO is also a key site in the European Multidisciplinary Seabed Observatory (EMSO) planning that aims to establish a long-term governance entity for operating observatories in Europe.

PAP-SO ocean and atmospheric data are sent in near real time from the upper 1000 m through Iridium telemetry to NOC (Southampton), acting as the PAP-SO and EuroSITES Data Assembly Centre. Data are available through the EuroSITES website (www.eurosites.info). Internationally, the site contributes to the OceanSITES global array (www.oceansites.org), complementing other *in situ* observing systems (e.g. Argo, CPR, Ships of Opportunity) that monitor the region. In line with other time-series sites within this network, there is an open access policy to data that are available through the CORIOLIS ftp site (ftp://ftp.ifremer.fr/ifremer/oceansites). Physical datasets (temperature and salinity) are also sent to the global telecommunication system.

As a component of EuroSITES and OceanSITES, the PAP-SO is a key data provider to MyOcean (European Marine Core Services). In future, it is envisaged that more near real-time data will be utilized by modelling and reanalysis activities to produce services and products for society. The PAP-SO is located in international waters, but in proximity to four member-state European economic zones. It is also an associated site in the Western Shelf Observatory (http://www.westernshelfobservatory.org/). The PAP-SO time-series datasets from the open ocean North Atlantic are invaluable as an early warning system for the European shelf and coastal waters at a regional level. Research at the PAP-SO site contributes 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).

Many science themes benefit from data supplied by ocean observatories (Ruhl *et al.*, 2011), and PAP-SO scientists regularly inform government policy on strategic issues, e.g. marine processes and climate, marine habitats and species (biodiversity in the deep sea), open ocean productivity, ocean governance, geo-engineering, and ocean fertilization. Regular advice is provided to the Royal Society, the Department of Environment, Food and Rural Affairs (Defra), the UN International Seabed Authority, and the European Commission (EC). The PAP-SO is also detailed as an existing *in situ* infrastructure for ocean observation contributing to the Group on Earth Observation (GEO) in Lampitt *et al*. (2010c) and related outputs from the OceanObs'09 conference. The combined datasets obtained enable short-term (daily–seasonal) and longer-term (climate-driven) trends to be captured, contributing to the Europe-wide initiative for good environmental status of our seas by the EU Marine Strategy Framework Directive (http://ec.europa.eu/environment/water/marine/).

Summary and conclusions

The PAP-SO in the Northeast Atlantic at 49°N 16.5°W is the longest running multidisciplinary open ocean time-series observatory in Europe and has produced a high-resolution *in situ* multidisciplinary time-series dataset of climatically and environmentally relevant variables from the euphotic zone to the seabed beneath (4800 m) for >20 years. More than 225 peer-reviewed papers have been published on the PAP-SO since 1975, including a recent special issue in Deep Sea Research (Volume 57, Issue 15) that details recent water column and seabed studies at the PAP-SO.

Results from the time-series have proven vital for understanding a range of ocean processes at different temporal scales, including an integrated understanding of seasonal and interannual surface processes and how these affect the deep ocean and seabed communities. Results have also highlighted the potential role of deep-sea benthic communities as indicators of climate change. As technology allows the measurement of 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. There is therefore a growing need for developing and maintaining long-term time-series sites to provide important *in situ* ocean datasets. However, sustaining these time-series through long-term funding commitments is an ongoing challenge.

Acknowledgements

The research leading to these results received support from the European Community's 7th Framework Programme FP7/2007-2013 under EuroSITES, grant agreement 202955, and under the HERMIONE project, grant agreement 226354 (see Article II.30. of the grant agreement), as well as from the European Community's 7th Framework Programme (FP7/2007-2013).

References

Behrenfeld, M. J., O'Malley, R. T., Siegel, D. A., McClain, C. R., Sarmiento, J. L., Feldman, G. C., Milligan, A. J., *et al.* 2006. Climate-driven trends in contemporary ocean productivity. Nature, 444: 752–755.

Billett, D. S. M., Bett, B. J., Reid, W. D. K., Boorman, B., and Priede, M. 2010. Long-term change in the abyssal NE Atlantic: the "Amperima Event" revisited. Deep Sea Research II, 57: 1406–1417.

Billett, D. S. M., Bett, B. J., Rice, A. L., Thurston, M. L., Galéron, J., Sibuet, M., and Wolff, G. A. 2001. Long-term change in the megabenthos of the Porcupine Abyssal Plain (NE Atlantic). Progress in Oceanography, 50: 325–348.

FitzGeorge-Balfour, T., Billett, D. S. M., Wolff, G. A., Thompson, A., and Tyler, P. A. 2010. Phytopigments as biomarkers of selectivity in abyssal holothurians; inter-species differences in responses to a changing food supply. Deep Sea Research II, 57: 1418–1428.

Glover, A. G., Gooday, A. J., Bailey, D. M., Billett, D. S. M., Chevaldonné, P., Colaço, A., Copley, J., *et al.* 2010. Climatic and geological drivers of long-term temporal change in deep-sea ecosystems. Advances in Marine Biology, 58: 1–95.

Gooday, A. J., Malzone, M. G., Bett, B. J., and Lamont, P. A. 2010. Decadal-scale changes in shallow-infaunal foraminiferal assemblages at the Porcupine Abyssal Plain, NE Atlantic. Deep Sea Research II, 57: 1362–1382.

Gregg, W. W., Conkright, M. E., Ginoux, P., O'Reilly, J. E., and Casey, N. W. 2003. Ocean primary production and climate: global decadal changes. Geophysical Research Letters, 30: 1809. doi:10.1029/2003GL016889

Hartman, S. E., Larkin, K. E., Lampitt, R. S., Lankhorst, M., and Hydes, D. J. 2010. Seasonal and inter-annual biogeochemical variations in the Porcupine Abyssal Plain 2003–2005 associated with winter mixing and surface circulation. Deep Sea Research II, 57: 1303–1312.

Kalogeropoulou, V., Bett, B. J., Gooday, A. J., Lampadariou, N., Martinez Arbizu, P., and Vanreusel, A. 2010. Temporal changes (1989–1999) in deep-sea metazoan meiofaunal assemblages on the Porcupine Abyssal Plain, NE Atlantic. Deep Sea Research II, 57: 1383–1395.

Körtzinger, A., Send, U., Lampitt, R. S., Hartman, S., Wallace, D. W. R., Karstensen, J., Villagarcia, M. G., *et al.* 2008. The seasonal pCO_2 cycle at 49°N/16.5°W in the northeastern Atlantic Ocean and what it tells us about biological productivity. Journal of Geophysical Research, 113: C04020.

Lampitt, R. S., Bett, B. J., Kiriakoulis, K., Popova, E., Ragueneau, O., Vangriesheim, A., and Wolff, G. A. 2001. Material supply to the abyssal seafloor in the Northeast Atlantic. Progress in Oceanography, 50: 27–63.

Lampitt, R. S., Billett, D. S. M., Larkin, K. E., Hartman, S. E., Pebody, C., Pagnani, M., and Gooday, A. J. 2010c. Long-term biogeochemical time-series from the Porcupine Abyssal Plain Deep Ocean Observatory, North East Atlantic. *In* Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Annex), Venice, Italy, 21–25 September 2009, pp. 1–6. Ed. by J. Hall, D. E. Harrison, and D. Stammer. ESA Publication WPP-306.

Lampitt, R. S., Billett, D. S. M., and Martin, A. P. 2010b. The sustained observatory over the Porcupine Abyssal Plain (PAP): insights from time series observations and process studies. Deep Sea Research II, 57: 1267–1271.

Lampitt, R. S., Salter, I., de Cuevas, B. A., Hartman, S., Larkin, K. E., and Pebody, C. A. 2010a. Long-term variability of downward particle flux in the deep Northeast Atlantic: causes and trends. Deep Sea Research II, 57: 1346–1361.

Larkin, K., Ruhl, H., Bagley, P., Benn, A., Bett, B., Billett, D., Boetius, A., *et al.* 2010. Benthic biology time-series in the deep sea: indicators of change. *In* Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Annex), Venice, Italy, 21–25 September 2009, pp. 1–6. Ed. by J. Hall, D. E. Harrison, and D. Stammer. ESA Publication WPP-306.

Ruhl, H. A., Andre, M., Beranzoli, L., Cağatay, M. N., Colaco, A., Cannat, M., Danobeitia, J. J., *et al.* 2011. Societal need for improved understanding of climate change, anthropogenic impacts, and geo-hazard warning drive development of ocean observatories in European Seas. Progress in Oceanography, 91: 1–33.

Ruhl, H. A., Ellena, J. A., and Smith, K. L. 2008. Connections between climate, food limitation, and carbon cycling in abyssal sediment communities. Proceedings of the National Academy of Sciences of the USA, 105: 17006–17011.

Smyth, T. J., Fishwick, J. R., Al-Moosawi, L., Cummings, D. G., Harris, C., Kitidis, V., Rees, A., *et al.* 2010. A broad spatio-temporal view in the western English Channel observatory. Journal of Plankton Research, 32: 585–601.

Soto, E. H., Paterson, G. L. J., Billett, D. S. M., Hawkins, L. E., Galéron, J., and Sibuet, M. 2010. Temporal variability in polychaete assemblages of the abyssal NE Atlantic Ocean. Deep Sea Research II, 57: 1396–1405.

Wigham, B. D., Hudson, I. R., Billett, D. S. M., and Wolff, G. A. 2003. Is long-term change in the abyssal Northeast Atlantic driven by qualitative changes in export flux? Evidence from selective feeding in deep-sea holothurians. Progress in Oceanography, 59: 409–441.

Handling editor: Dr Bill Turrell