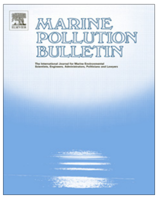
Marine Pollution Bulletin 73 (2013) 435–442

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul



Consequences of a simulated rapid ocean acidification event for benthic ecosystem processes and functions

Fiona Murray [a,*], Stephen Widdicombe [b], C. Louise McNeill [b], Martin Solan [a,1]

[a] Oceanlab, University of Aberdeen, Main Street, Newburgh, Aberdeenshire AB41 6AA, UK
[b] Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK

ARTICLE INFO

Keywords:
Amphiura filiformis
Carbon Capture and Storage (CCS)
Ocean acidification
Ecosystem function
Bioturbation
Bioirrigation

ABSTRACT

Whilst the biological consequences of long-term, gradual changes in acidity associated with the oceanic uptake of atmospheric carbon dioxide (CO_2) are increasingly studied, the potential effects of rapid acidification associated with a failure of sub-seabed carbon storage infrastructure have received less attention. This study investigates the effects of severe short-term (8 days) exposure to acidified seawater on infaunal mediation of ecosystem processes (bioirrigation and sediment particle redistribution) and functioning (nutrient concentrations). Following acidification, individuals of *Amphiura filiformis* exhibited emergent behaviour typical of a stress response, which resulted in altered bioturbation, but limited changes in nutrient cycling. Under acidified conditions, *A. filiformis* moved to shallower depths within the sediment and the variability in occupancy depth reduced considerably. This study indicated that rapid acidification events may not be lethal to benthic invertebrates, but may result in behavioural changes that could have longer-term implications for species survival, ecosystem structure and functioning.

1. Introduction

The potential and realised impacts of anthropogenic carbon dioxide (CO_2) emissions on the global environment are now well established (Hoegh-Guldberg and Bruno, 2010), leading to political, social and environmental pressure on governments to reduce carbon emissions. Consequently, many countries have opted to reduce carbon emissions within a limited timeframe (e.g. UK, 60% of 1990 levels by 2050; EU member states, 20% of 1990 levels by 2020; Russia, 15–25% of 1990 levels by 2020; USA, 17% of 2005 levels by 2050; Gough et al., 2010; Stern and Taylor, 2010). A principal method adopted by governments is to partially achieve such reductions through the use of Carbon Capture and Storage (CCS) technologies, a process whereby CO_2 is captured from a point emission source and stored in deep geological formations in order to prevent it from entering the atmosphere. This methodology has been endorsed as a key climate change mitigation option by the Intergovernmental Panel on Climate Change (IPCC, 2005), accelerating the development and implementation of the necessary infrastructure (Gibbins and Chalmers, 2008). Whilst CCS technology has the potential to reduce CO_2 emissions from fossil fuel power stations by 80–90% (Holloway, 2007), the delivery and storage of large volumes of CO_2 has raised concerns about the potential for stochastic leakage and associated environmental consequences (Blackford et al., 2008). Although probably very small, the risk of leakage remains largely unknown and unquantified (Koornneef et al., 2010), however, it is generally accepted that leakage will occur over time (Hawkins, 2004) and that it could have negative consequences for benthic organisms and communities (Harrison et al., 1995; Thistle et al., 2005, 2007).

The spatial extent of an acidification event will depend on the location of the CCS infrastructure and the nature of the release, making it difficult to form generic opinion and advisory conclusions on the likely impact. Nevertheless, seepage from sub-seabed storage is likely to lead to localised effects (Blackford et al., 2009), and, even where such effects are spatially constrained, there is evidence that significant point-source leaks will also simultaneously affect neighbouring ecosystems (including, for example, aquatic releases affecting terrestrial environments; Baxter et al., 1989). Evidence from naturally occurring CO_2 seeps suggest that associated changes in ocean chemistry (pH, HCO_3, etc.) can lead to pronounced biodiversity shifts, most notably the loss of calcifying organisms (Hall-Spencer et al., 2008; Hendriks et al., 2010). In addition, metabolic activity, fertility, growth and survival have all been shown to be negatively impacted by exposure to acidified seawater across a range of taxa (Fabry et al., 2008; Kroeker et al., 2010; Pörtner and Farrell, 2008). The magnitude and rate of effects vary greatly between species, but all calcifying species studied to

---

[*] Corresponding author. Tel.: +44 (0)1224 274401; fax: +44 (0)1224 274402.
E-mail address: fiona.murray@abdn.ac.uk (F. Murray).

[1] Present address: Ocean and Earth Science, National Oceanography Centre, Southampton, University of Southampton, Waterfront Campus, European Way, Southampton SO14 3ZH, UK.

0025-326X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2012.11.023

date have been shown to be negatively affected (Hendriks et al., 2010). Although acidification may not necessarily be lethal, elevated levels of CO_2 will affect many physiological processes and has the potential to lead to trade-offs between maintenance activities, such as respiration, growth or reproduction (Widdicombe and Spicer, 2008). In addition to physiological impacts, exposure to acidified seawater can also influence the activity and behaviour of marine invertebrates (e.g. de la Haye et al., 2011; Simpson et al., 2011), which may have significant consequences for ecosystem functioning.

In marine sediment systems, infaunal macro-invertebrates are particularly important in influencing generative and regenerative microbial-mediated processes, such as nutrient transformation and decomposition, vital to maintaining ecosystem condition (e.g. Emmerson et al., 2001; Godbold et al., 2009; Ieno et al., 2006; Laverock et al., 2011; Marinelli and Williams, 2003; Mermillod-Blondin et al., 2004; Norling et al., 2007). In UK and European shelf sea sediments, the brittlestar *Amphiura filiformis* is highly abundant and, where it is present, can be responsible for up to 80% of particle redistribution below the sediment–water interface (Solan and Kennedy, 2002; Vopel et al., 2003). Reduction in seawater pH has been shown to induce muscle wastage in *A. filiformis* and increase rates of metabolism (Wood et al., 2008), potentially leading to changes in activity levels and burrowing capacity. Given the intimate link between infaunal behaviour and nutrient cycling, any widespread effect on the efficiency of bioturbation activity by *A. filiformis* is likely to have ecological consequences for ecosystem function in shelf sea sediment systems (Solan et al., 2004a, 2012). This study experimentally generated a short-term acidification (to pH 6.5) event to investigate the immediate effects of rapid acidification on benthic processes (bioturbation and bioirrigation) and, in turn, ecosystem functioning (nutrient concentration). Visual observations of burrowing behaviour will also indicate whether there are aspects of behavioural response that, following further investigation, may provide a means to identify the presence and spatial extent of CO_2 leakage in areas dominated by this species.

2. Materials and methods

2.1. Sediment and fauna collection

Individuals of *Amphiura filiformis* were collected from Plymouth Sound (~15 m water depth, 50°21.05′N, 04°07.8′W and 50°20.7′N, 04°07.78′W) using an anchor grab. Sediment was collected from Cawsand, Plymouth Sound (~15 m water depth, 50°19.8′N, 04°11.5′W) using an anchor grab. Sediment was sieved (500 μm mesh) in a seawater bath to remove macrofauna, allowed to settle to retain the fine fraction and homogenised by stirring, before being added to individual cores (capped PVC cores, 100 mm diameter, 200 mm tall) to a depth of 150 mm and overlain by 50 mm seawater. All cores were held in a recirculating seawater system until they were used in the exposure trials.

2.2. Seawater acidification and exposure

CO_2 gas was bubbled through natural seawater (salinity ~35) enabling the gas to dissolve rapidly into solution. Release of CO_2 gas, to maintain the pH, was controlled *via* a solenoid valve connected to the gas cylinder and monitored using a pH controller (Aqua Digital pH-201, accuracy ±0.1% + 0.02) which was cross checked weekly against values given by a regularly calibrated pH metre (InLab® 413SG, Mettler-Toledo). The reservoir electrodes did not require calibration over the course of the study. Two $1 m^3$ tanks, one containing the acidified sea water and one containing ambient seawater were used to acclimatise both the *A. filiformis* and the sediment (including meiofauna and microorganisms) prior to the experiment. Cores containing individuals of *A. filiformis* ($n = 5$ mesocosm^{-1}, density equivalent to 640 individuals m^{-2}) or sediment with no macrofauna were positioned randomly in the acclimatisation tanks for 96 h prior to the start of the experiment (Fig. 1). Salinity, temperature and alkalinity in both tanks were monitored three times per week (Monday, Wednesday and Friday) throughout the duration of the experiment. Unmeasured carbonate parameters were calculated from these data using constants supplied by Lueker et al. (2000) and Millero (2010) with CO_2 calc., an application developed by the U.S. Geological Survey Florida Shelf Ecosystems Response to Climate Change Project (Robbins et al., 2010).

2.3. Observation of species activity and behaviour

Following the acclimatisation period, sediment and fauna were transferred into rectangular thin-walled (5 mm) Perspex aquaria (33 × 10 × 10 cm, density equivalent to 500 individuals m^{-2}). Each aquarium was maintained in a temperature controlled room (10 °C) and supplied with seawater (on a flow through system from the acclimatisation tanks) at the appropriate pH level and at a rate of ~10 ml min^{-1} using a peristaltic pump (Watson–Marlow 323). The faunal redistribution of sediment particles was measured non-invasively using a time lapse sediment profile imaging system (f-SPI, following Solan et al., 2004b), optically modified to preferentially visualise fluorescent dyed sediment particles (luminophores, see Maire et al., 2008) housed in a UV illuminated imaging box (32 × 87 × 62 cm with Phillips blacklight, 8 W, Schiffers et al., 2011). The camera (Canon 400D, 3900 × 2600 pixels, i.e. 10 megapixels, effective resolution = 64 × 64 μm per pixel) was set for an

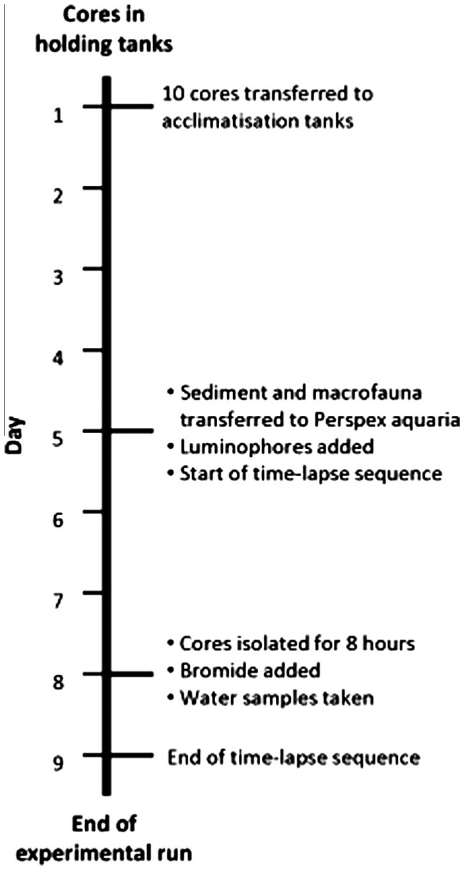


Fig. 1. Timeline diagram of experimental procedure.