Journal of Environmental Radioactivity xxx (2014) 1–12

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Linking the distribution of ^{210}Po and ^{210}Pb with plankton community along Line P, Northeast Subarctic Pacific

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ARTICLE INFO

Article history:
Received 16 May 2013
Received in revised form
17 February 2014
Accepted 17 February 2014
Available online xxx

Keywords:
Polonium
Plankton
Ocean Station Papa
Particle export

ABSTRACT

Depth profiles of ^{210}Po and ^{210}Pb activity and phytoplankton and zooplankton abundance were collected during two cruises along the Canadian time-series Line P in the Northeast Subarctic Pacific (ranging from 48o39 N to 50o00 N and 126o40 W to 145o00 W) in August 2010 and February 2011 to evaluate connections between the planktonic community and distributions of these radionuclides in the upper 500 m of the water column. Statistical analysis indicates that ^{210}Po is more effectively removed from the surface ocean when large (>0.1 mg ind^{-1} dry wt) zooplankton dominate, and is less effectively scavenged when the picoplankton *Synechococcus* is present at high concentrations (>1 × 10^5 cells ml^{-1}). While the zooplankton field data are consistent with previous lab studies and field observations, the phytoplankton results seem to conflict with recent evidence that small cells may contribute significantly to export in other oligotrophic regions. Differences in ecosystem mechanisms between the Subarctic Pacific and other oligotrophic systems that limit the contribution of small cells to sinking flux remain to be identified.

1. Introduction

The Northeast Subarctic Pacific represents a high-nutrient-low chlorophyll (HNLC) region of the open ocean. The physical circulation of this region consists of the Subarctic Current and Alaska Current, which form the Alaska Gyre. Ocean Station Papa (OSP, 50o00 N 145o00 W), which began in 1956, represents one of the oldest ocean time-series sites in the world (Charette et al., 1999; Mackas and Tsuda, 1999). Unlike other time series sites in the open ocean, at OSP there is a record of a direct correlation between biological productivity (measured by satellites or bottle experiments) and export flux to depth, as measured in sediment traps (Wong et al., 1999). Despite one of the highest primary production rates reported for open ocean systems, and relatively high export flux, there is a low and constant phytoplankton biomass that is thought to be controlled by zooplankton grazing and iron availability (Denman and Peña, 1999; Harrison, 2002; Lippiatt et al., 2011). The Subarctic Pacific is also a region with a strong pycnocline that limits the strength of the solubility pump (Thibault et al., 1999). As a result, this area of the ocean is a useful location to investigate plankton community structure and its effect on the biological pump.

While carbon can be redistributed from the surface ocean to depth via multiple routes (e.g. carbonate/ballast pump, dissolved carbon pump, and microbial pump), the "classic" biological pump is the export of organic carbon from primary production at the surface to the deep ocean in the form of particulate organic carbon (POC) (Volk and Hoffert, 1985). The biological pump plays an integral role in the global carbon budget by removing and retaining CO_2 from the atmosphere. Much of the particulate carbon in the ocean cannot sink on its own due to its similar density to seawater, and so the efficiency of the biological pump is driven by the aggregation and packaging of material done by the plankton community (Boyd and Newton, 1999; Boyd et al., 1999; Buesseler et al., 2007; Richardson and Jackson, 2007). For example, zooplankton can form dense, rapidly sinking fecal pellets, while phytoplankton can assist in gravitational settling via the incorporation of biomineral ballasts (Armstrong et al., 2001; Honjo et al., 2008). The efficiency of the biological pump to transport net primary production (NPP) below the euphotic zone varies from region to

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http://dx.doi.org/10.1016/j.jenvrad.2014.02.009
0265-931X/

region, ranging from 1 to 10% of NPP in central gyres to 30–100% in polar areas (Buesseler, 1998; Lutz et al., 2002; Moran et al., 2005; De La Rocha and Passow, 2007; Lutz et al., 2007).

Traditionally, larger phytoplankton cells and larger zooplankton are believed to contribute to more efficient export flux via gravitational settling of particulate matter through the water column. However, recent experimental (Pfannkuche and Lochte, 1993; Turley and Mackie, 1995; Thibault et al., 1999; Waite and Hill, 2006), modeling results (Richardson et al., 2004, 2006; Richardson and Jackson, 2007) and field studies (Fawcett et al., 2011; Lomas and Moran, 2011) have indicated that small phytoplankton cells and aggregates contribute to POC export in proportion to their contribution to total phytoplankton biomass. At OSP, small cells dominate the phytoplankton such that only ~6%, on average, of the plankton biomass is larger than 20 μm (Thibault et al., 1999). Thus, an important question is the extent to which export productivity in the NE Subarctic Pacific is driven by small phytoplankton with relatively low biomass yet high productivity.

Zooplankton also contribute significantly to downward POC flux by phytoplankton grazing in the upper waters and repackaging that biomass into fecal pellets that have a density dependent on the zooplankton species and diet (Turner and Ferrante, 1979; Bienfang, 1980; Carroll et al., 1998; Schnack-Schiel and Isla, 2005; Poulsen and Kiørboe, 2006; Wilson et al., 2008). Carroll et al. (1998) reported that despite the relatively low abundance of large copepods in the NW Mediterranean, their large cylindrical fecal pellets resulted in a large overall carbon flux. Salps also play an important part in vertical fecal pellet carbon flux, with an export of nearly 10.5 mg C m^{-2} d^{-1} observed in the North Pacific and 12 mg C m^{-2} d^{-1} in the North Atlantic (Wiebe et al., 1979; Iseki, 1981). Though copepod and salp fecal pellets are both thought to contribute significantly to sediment trap flux, salps are reported to have a large contribution to the temporal variation in particle flux (Andersen and Nival, 1988). Sinking fecal pellets can also be ingested, disaggregated by other zooplankton, or aggregated into marine snow (Wilson et al., 2008).

Polonium-210 (half-life of 138.4 days) is the final, naturally occurring radioactive element in the uranium-238 decay series. It is a useful tracer for quantifying oceanic processes due to its radiological timescale being on the order of a few months. Processing ^{210}Po samples is relatively straightforward, requiring basic wet chemistry, spontaneous silver plating, and analysis by alpha spectrometry (Bacon et al., 1976). However, determining ^{210}Po activity does have some caveats such as complicated calculations, especially of uncertainty, time-intensive methods, and differing methods of chemical separation (e.g. Rigaud et al., 2013). While both ^{210}Po and its radioactive grandmother ^{210}Pb are particle-reactive, a disequilibrium exists between dissolved ^{210}Po and ^{210}Pb in the surface ocean due to ^{210}Po's more bioactive nature (Friedrich and Rutgers van der Loeff, 2002; Murray et al., 2005; Stewart et al., 2007a, 2007b).

There is a large body of literature on the enrichment of ^{210}Po in phytoplankton and zooplankton (e.g. Folsom and Beasley, 1973; Cherry et al., 1975; Fisher et al., 1983; Krishnaswami et al., 1985; Jeffree et al., 1997; Stewart et al., 2005), which accounts for a typical dissolved ^{210}Po deficiency in the surface ocean and makes the ^{210}Po/^{210}Pb pair an effective tracer of organic carbon flux (Friedrich and Rutgers van der Loeff, 2002; Verdeny et al., 2009). The application of this tracer pair requires a few assumptions: first, that the deficit of ^{210}Po in the surface ocean is caused by the sinking of biogenic material, which is also carrying particulate carbon out of the surface ocean; second, that the system is in steady-state on a timescale so that the deficit measured today reflects export that has happened recently or continues to occur; and third, that there is little or no lateral advection of particles (Murray et al., 2005). Indeed, ^{210}Po has been shown to correlate with organic carbon and nitrogen in natural sinking particles (Sarin et al., 1999; Kim and Church, 2001; Friedrich and Rutgers van der Loeff, 2002; Murray et al., 2005) and has been successfully applied as a tracer proxy, when compared to sediment trap material.

Understanding the relationship between the plankton community and the efficiency of the biological pump, both spatially and temporally, is important in developing predictive models of the vertical transport of POC through the water column. The main objective of this study is to explore the relationship between variations in plankton community structure (size and species diversity) through space and time in the NE Subarctic Pacific and the corresponding variations in the export of ^{210}Po, of interest as a unique and biomagnified isotope and also as a possible POC flux tracer.

2. Sampling and methods

2.1. Sampling site

Seawater and plankton samples were collected at five stations along the Line P transect aboard CCGS John P Tully during two cruises in August 20–27, 2010 and February 11–14, 2011 (Fig. 1). The stations sampled range from relatively shallow coastal settings (P4, 48o39′N 126o40′W, 1300 m and P12, 48o58′N 130o40′W, 3300 m), to transition zones (P16, 49o17′N 134o40‘W, 3550 m and P20, 49o34‘N 138o40′W, 3890 m) to the HNLC open ocean station, Ocean Station Papa (P26, 50o00‘N 145o00‘W, 4300 m). Seawater samples from P4 and P26 were not collected in February 2011, due to adverse weather conditions. A complete list of sampling locations, dates, and depths is provided in Table 1.

2.2. Zooplankton and phytoplankton sampling

Zooplankton samples were collected via vertical net hauls from 250 m to the surface with a set of 236 μm Bongo nets at each station to collect mesozooplankton for community structure analysis. The hauls were conducted following the methods of the Line P zooplankton sampling (c.f. Mackas and Tsuda, 1999). Unfortunately, we could not do all of our zooplankton trawls at night (to maximize the abundance of vertical migrators), so some variation in our results may be due to the variable time of day trawls were conducted. Zooplankton were identified using microscopy after preservation in buffered formalin (10%). Lengths were measured using an optical micrometer, samples were divided into size classes using sieves and biomass was assessed after drying. Zooplankton were identified to genus level at Queens College and to species level at the Institute of Ocean Sciences in Sidney BC. The zooplankton size and mass analyses can be found at http://www.pac.dfo-mpo.gc.ca/science/.

Samples for characterizing the phytoplankton community were collected at seven (7) depths throughout and slightly below the euphotic zone. In August 2010, sample depths were 5, 10, 20, 30, 50, and 75 m at each station, with an additional sample at the deep chlorophyll maximum (DCM) that ranged from 21 to 40 m depending upon the station. In February 2011, samples were collected at 1, 35, 43, 48, 55, 60 and 65 m at station P12 and 1, 7, 13, 20, 24 (DCM), 72, and 95 m at station P16. From each depth, small volume (5 ml) samples for pico- and nanophytoplankton were analyzed by flow cytometry following the methods of Frankel et al. (1990), Durand and Olson (1996), and Durand et al. (2001). Samples were fixed in para-formaldehyde (0.5% final concentration), stored at −80 °C (Sieracki et al., 1993), and analyzed at the BIOS Marine Particle Imaging Lab using the volume analyzed method (e.g. Sieracki et al., 1993). Additional samples (4L) from these depths were filtered onto GF/F filters and stored in liquid nitrogen until

Please cite this article in press as: Choi, H.Y., et al., Linking the distribution of ^{210}Po and ^{210}Pb with plankton community along Line P, Northeast Subarctic Pacific, Journal of Environmental Radioactivity (2014), http://dx.doi.org/10.1016/j.jenvrad.2014.02.009