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The distribution and vertical flux of fecal pellets from large zooplankton in Monterey bay and coastal California

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ABSTRACT

We sampled zooplankton and fecal pellets in the upper 200 m of Monterey Bay and nearby coastal regions in California, USA. On several occasions, we observed high concentrations of large pellets that appeared to be produced during night-time by dielly migrating euphausiids. High concentrations of pellets were found in near-surface waters only when euphausiids co-occurred with high concentrations of large (> 10 μm) phytoplankton. Peak concentrations of pellets at mid-depth (100 or 150 m) during the day were consistent with the calculated sinking speeds of pellets produced near the surface at night. At these high flux locations (HI group), pellet concentrations declined below mid-depth. In contrast, at locations where the phytoplankton assemblage was dominated by small phytoplankton cells (< 10 μm), pellet production and flux were low (LO group) whether or not euphausiid populations were high. Protozooplankton concentrations did not affect this pattern. We concluded that the day and night differences in pellet concentration and flux in the HI profiles were mostly due to sinking of dielly-pulsed inputs in the surface layer, and that small zooplankton (*Oithona*, *Oncaea*), heterotrophic dinoflagellates, and bacterial activity probably caused some pellet degradation or consumption below 100 m. We estimated that consumption of sinking pellets by large copepods was insignificant. High fluxes of pellets were episodic because they required both high concentrations of large phytoplankton and large stocks of euphausiids. Under these conditions, flux events overwhelmed retention mechanisms, resulting in large exports of organic matter from the upper 200 m.

1. Introduction

Fecal pellets from large zooplankton such as copepods and euphausiids can dominate the downward flux of organic matter in the ocean (e.g., Legendre and Michaud, 1998; Thibault et al., 1999; Roy et al., 2000; Vargas et al., 2002; Wexels Riser et al., 2008; Kobari et al. 2010; González et al., 2011). Many factors contribute to high variability in this flux component, including biological conditions such as the concentration, type and composition of food, the size and species composition of the zooplankton, and the predator to prey size ratio. Physical conditions such as stratification and mixing also affect fecal flux (Alldredge et al., 1987). Although much of the organic matter flux is derived from pellets, most pellets typically do not sink far (Wassmann, 1998) but are modified by microbial degradation (Hansen and Bech, 1996; Hansen et al. 1996) and zooplankton activities that include pellet ingestion and destruction (Noji et al., 1991; Urban-Rich 1999; Poulsen and Iversen, 2008). Consequently, the dynamics of fecal pellet degradation significantly affect the dynamics of vertical flux (Turner, 2002).

Zooplankton can modify sinking pellets by direct consumption (González and Smetacek, 1994; Huskin et al., 2004) or by breaking up the pellets into smaller, slower sinking particles (Noji et al., 1991). Breakage also enhances microbial access to pellet contents (Lampitt et al., 1990). Small ubiquitous copepods such as *Oithona* spp. and *Oncaea* spp. have been proposed as important modifiers of pellet flux, e.g. the "*Oithona* filter" (González and Smetacek, 1994; Svensen and Nejstgaard, 2003). Also, protozooplankton can be important consumers of pellets (Poulsen and Iversen, 2008; Poulsen et al., 2011). Euphausiids, which are strong diel migrators, have been observed to feed at depth during the day (e.g. Hamame and Antezana, 2010) where they may consume fecal pellets and thereby reduce flux. Alternatively, large zooplankton, especially swarming kinds like euphausiids and salps, have high filtration rates and produce large, rapidly sinking pellets; they can overwhelm degradation and recycling processes near the surface, resulting in high flux events.

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In addition to fecal pellets, other materials such as phytoplankton, mucous and gelatinous remains can aggregate to form major components of the vertical flux of organic matter (e.g. Silver and Gowing 1991; Silver et al. 1998; Jackson and Checkley, 2011). Flux is often in the form of aggregates of particles from a variety of sources, including fecal pellets, and all these materials are commonly observed at various levels of decomposition and degradation.

We are attempting to measure the magnitude of zooplankton consumption of these sinking materials, a process we call "gate-keeper activity", in the region immediately below the euphotic zone. Our goals are to determine the zooplankton contribution to the overall retention efficiency of pellets and other sinking organic matter, and to understand the conditions under which flux-consumption by zooplankton is an important determinant of the flux profile (Petrik et al., 2013). In this paper, we present information on the size frequency distribution of large fecal pellets, operationally defined as those retained on a 60 μm mesh, in the upper 200 m during a 14-day study in or near Monterey Bay, California. Our specific objectives here are to show the vertical distribution of large fecal pellets and to determine some of the factors controlling the production and losses of these large pellets in the upper 200 m.

2. Material and methods

2.1. Study area and sampling

We spent July 10–23, 2010 aboard the RV New Horizon in or just offshore to the west of Monterey Bay, CA (Fig. 1). Shipboard sampling was done near a free drifting SOLOPC float set to cycle through the upper 100 m at approximately hourly intervals. SOLOPC floats are fully described in Checkley et al. (2008), Jackson and Checkley (2011) and Petrik et al. (2013).

Aboard ship, whole water samples were collected for mesozooplankton fecal pellets using a simple method modified from that described in Wassmann et al. (1999) and Wexels Riser et al. (2001). For each collection, a CTD-rosette sampler fit with twelve 10-L Niskin bottles was used to collect water from six depths (Fig. 1, Table 1). In several cases, day and night samples at the same location were collected within a 24 h period (CTD 14/15, 25/26, 31/33 and 37/39). On deck, contents of Niskin bottles were gently drained into 10-L polycarbonate carboys. In the ship's laboratory, the entire content of each carboy, approximately 9.2 L, was filtered through a 60-μm mesh sieve. This mesh size was selected because smaller ones sometimes resulted in retention of too many contaminating particles for practical analysis of samples. Retained particles were backwashed into a small container and preserved in 5% Formalin–seawater solution. Final sample volume was between 150 and 250 ml. Preserved samples were kept in the dark and returned to a shore-based laboratory for analysis. Particles passing through the 60-μm sieve were not analyzed.

Table 1
Information for fecal pellet CTD casts.

CTD	Date	Time	Latitude (°N)	Longitude (°W)
14	13-Jul	01:08	36.74	122.01
15	13-Jul	12:02	36.74	122.01
25	15-Jul	02:02	37.03	123.37
26	15-Jul	15:00	37.03	123.37
31	17-Jul	14:05	36.77	122.08
33	17-Jul	23:06	36.74	122.05
37	19-Jul	14:47	36.72	122.00
39	20-Jul	01:26	36.74	122.04
42	21-Jul	14:16	36.68	122.03
46	23-Jul	02:22	36.44	123.33
48	23-Jul	15:33	36.43	122.21

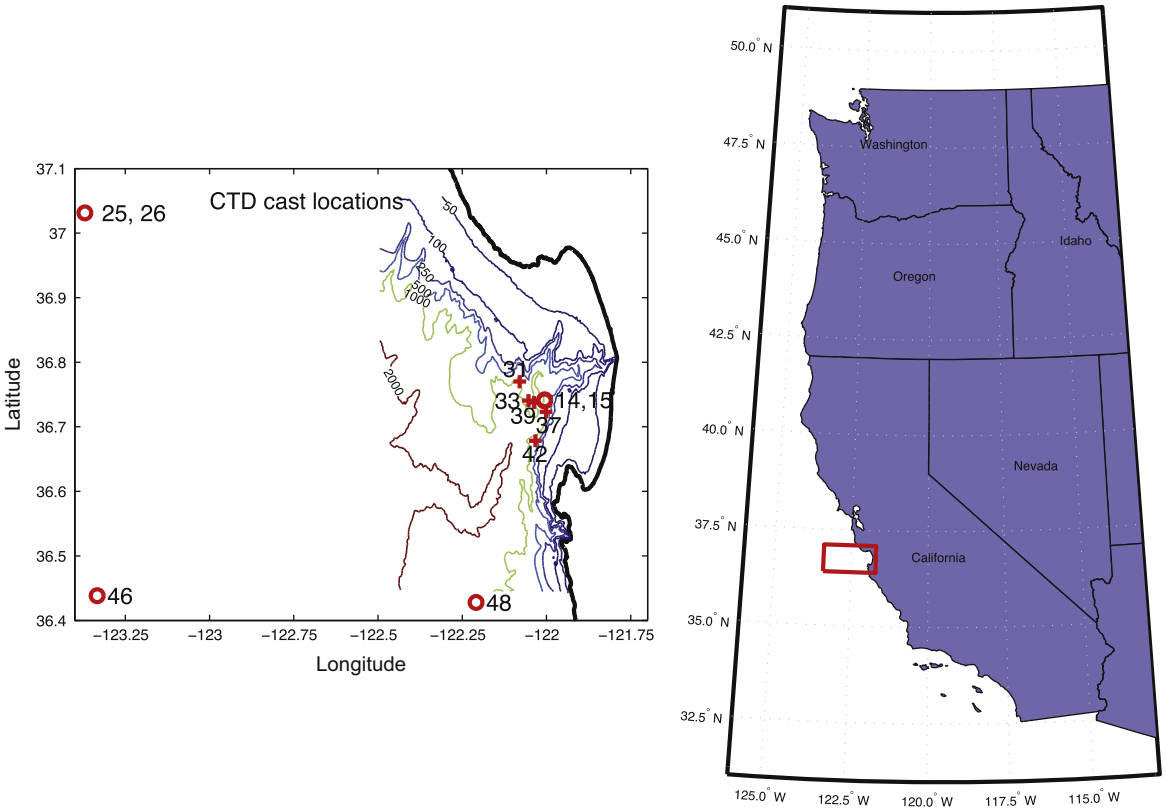

Fig. 1. The study area, showing the sampling locations for zooplankton fecal pellets. Depth contours in m. Open symbols=LO group, plus symbols=HI group.