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Interactive comment on "Role of zooplankton in determining the efficiency of the biological carbon pump" *by* Emma L. Cavan et al.

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Thank you for this positive response to our study. We carried out a sensitivity analysis as suggested using other literature conversion factors available that were relative to this study. Note the following section on conversion factors is also in the response to reviewer #1. We acknowledge that we should expand the method section on conversion factors in the revised manuscript to make it clear exactly what was done.

Conversion factors:

In this study we used two different conversion factors (CFs) from Alldredge (1998), one for generic marine aggregates and one for faecal material. For POC Alldredge (1998) found 3 different relationships for different particle types; larvacean, diatom and faecal. These were non-linear, forming the equation m = aVb, where m is mass of POC and V

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the volume of the particle. For the 3 types of particle described a ranged from 0.97-1.09 and b from 0.39-0.52. In this study the following CFs were used:

1. Phytodetrital aggregates m = 1.09 * V0.52 2. Faecal m = 1.05 * V0.51

These particles were collected from the sub-tropical Santa-Barbara channel, California. As with all methods using CFs does produce some uncertainties in the results. However we believe our method is robust and will show this through 1) a sensitivity analysis, 2) explaining the theory behind the Alldredge 1998 CFs and finally 3) that is a widely-used method in particle flux analysis. We will include more detail on which CFs were used for different particles and justifications for using them in the manuscript.

1. Sensitivity analysis

There are very few published studies that have produced a relationship between carbon content and particle size in the oceans, hence the Alldredge (1998) CFs are commonly used. These others studies have only produced conversion factors for faecal pellets (FPs) such as Gonzalez & Smetacek (1994) on one copepod species' FPs and Manno et al. (2015) on Southern Ocean FPs. As the study by Manno et al. (2015) was done on Southern Ocean FPs we used these CFs to compare with Alldredge (1998) faecal CFs for our Southern Ocean data. For cylindrical pellets (which were the type of pellet found in the Southern Ocean, images will be included in the revised manuscript) Manno et al. (2105) found 18 ug C mm-3. Fig. 1 shows the total mass (ug C) for each sample (n = 40, 20 stations and 2 depths) calculated using the Alldredge and Manno methods in the Southern Ocean only with the linear regression shown.

The slope of the regression was close to 1 at 0.96 showing neither CF consistently over- or underestimated mass of POC relative to each other. There was no statistical difference (t-test, t = 0.2537, df = 77.232, p-value = 0.8004) between the mean masses of the two methods with Manno calculations producing a mean mass of POC per sample of 11 μg C and Alldredge calculations producing a mean of 8.4 μg C.

We then used both values from Fig. 1 to compute particle export efficiency (PEeff). Comparing PEeff calculated including Manno CFs for FPs in the Southern Ocean with fluxes calculated using Alldredge for all fast sinking particles still results in the same trend (Fig. 2), an inverse relationship between PEeff and primary production. We also calculated the mean transfer efficiency (used in Fig. 4a in manuscript) using both CFs, which in the Southern Ocean was 1.9 when using Alldredge and Manno CFs for faecal pellets. Therefore we can conclude that using the Alldredge conversion factors gives comparable estimates of mass of carbon and using a different conversion factor does not alter trends observed or our conclusions. As stated we shall include more detail in the revised manuscript about the conversion factors used and the assumptions they are based on.

2. Theory of Alldredge (1998) conversion factors

Even though the CFs used by Alldredge are from shallow depths, the relationship accounts for the fractal nature of particles, such that as particles get larger in volume, porosity increases and thus the relative proportion of carbon decreases (Alldredge 1998). This is represented by Fig. 3, which shows the Alldredge relationship between size and POC mass, dry mass and POC mass as a percentage of dry mass with size, using faecal pellets as an example. Note that the percentage of POC of dry mass decreases with particle size.

We have shown that using the fractal Alldredge relationship or the linear relationship of Manno for FPs produce statistically similar results suggesting that the different environments particles were taken from (polar and sub-tropical) does not effect the relationship between size and POC. Additionally the different particles within the Alldredge study (see equations 1 and 2) had extremely similar CFs, thus the relationship between carbon content and size is conserved over the different particles described in this study and the area sampled from globally.

Further at all sites particle size on average increased with depth, thus changes in the amount of POC would be accounted for at deeper depths than those measured by Alldredge. As shown above altering the CF did not effect the transfer efficiency of POC with depth. Another important point is that the marine snow catchers allow collection of particles relatively undamaged or altered compared to sediment traps (other than gel traps), making the use of conversion factors more reliable as particle shapes reflect those measured in situ (Romero-Ibarra & Silverberg 2011).

3. Alldredge (1998) is a comparable method

The Alldredge CFs have been used frequently in many other peer-reviewed particle flux studies and is considered a robust method to use. It allows results from our study to be compared with many others. Most studies that have used Alldredge's CFs did so at deeper depths than that of Alldredge have also used this relationship to infer carbon content. For instance Ebersbach & Trull (2008) used gel traps deployed at depths between 100 and 400 m and the fractal relationship by Alldredge to convert size to carbon content to infer zooplankton control on export fluxes. However for smaller (< 0.004 mm3) particles Ebersbach and Trull (2008) used a linear relationship. In our data < 1 % of fast particles fit into this smaller size category and thus this split in applied conversion factors is unnecessary for our study.

Other studies using the Alldredge CF to estimate particle carbon content from size include (Guidi et al. 2007) using an underwater video profiler to 1000 m, Laurenceau et al. (2015) using gel traps to 430 m and other marine snow catcher studies in the upper mesopelagic zone (Riley et al. 2012; Cavan et al. 2015; Belcher et al. 2016). The use of Alldredge's CF values is reflected in the lack of other CF data on organic sinking particles in the literature. Also the export depths (50 % of data) were mostly ~40 m, very close to those measured by Alldredge 1998 (20 m).

We are confident in our use of the literature CF values and conclude that using a different CF may alter the absolute values of POC, but does not alter the patterns and trends observed in our dataset. Whilst we do appreciate there are limitations to using conversion factors and we will include some more detail in the methods regarding the use of these particular factors, we believe our data set is robust and our observations, combined with the model output, can be used to infer the role of zooplankton processes in the biological carbon pump.

Other comments

We have data for each region on the relative contribution of phytodetrital aggregates and faecal pellets to total flux. We will add this into the revised manuscript with images from each site to show the composition of flux. Unfortunately there is no in situ data available on the dominant phytoplankton type for each area. However we agree some detailed discussion on the potential influence of phytoplankton type on particle type and zooplankton community structure, and thus transfer efficiency, would improve our manuscript. In the final discussion section on the efficiency of the biological carbon pump we will add a section on phytoplankton and zooplankton community structure and its influence on the biological carbon pump.

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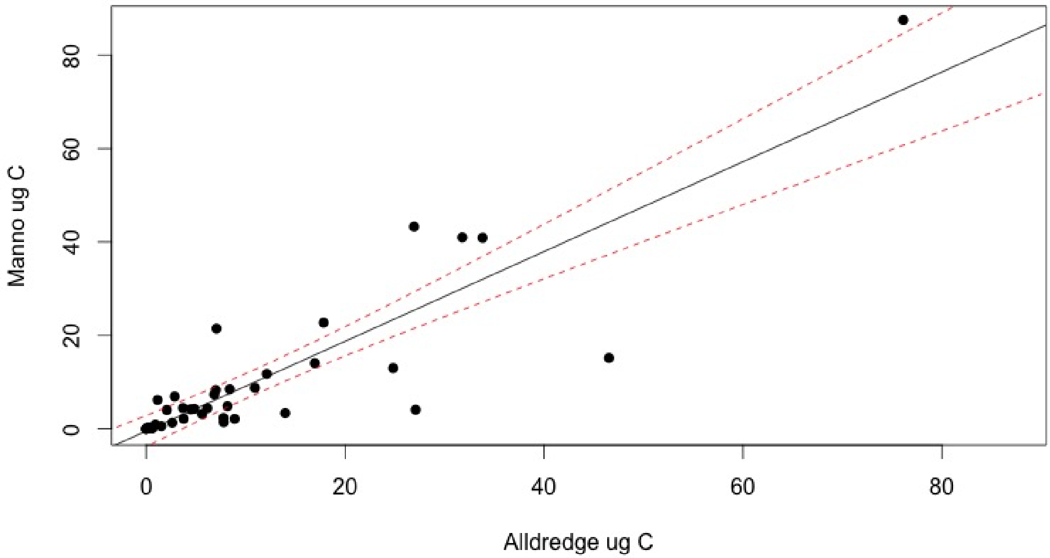

Fig. 1. Comparison of fast sinking particulate organic carbon mass from Southern Ocean stations calculated using Allredge (1998) and Manno (2015) conversion factors. Solid line is linear regression (slope = 0

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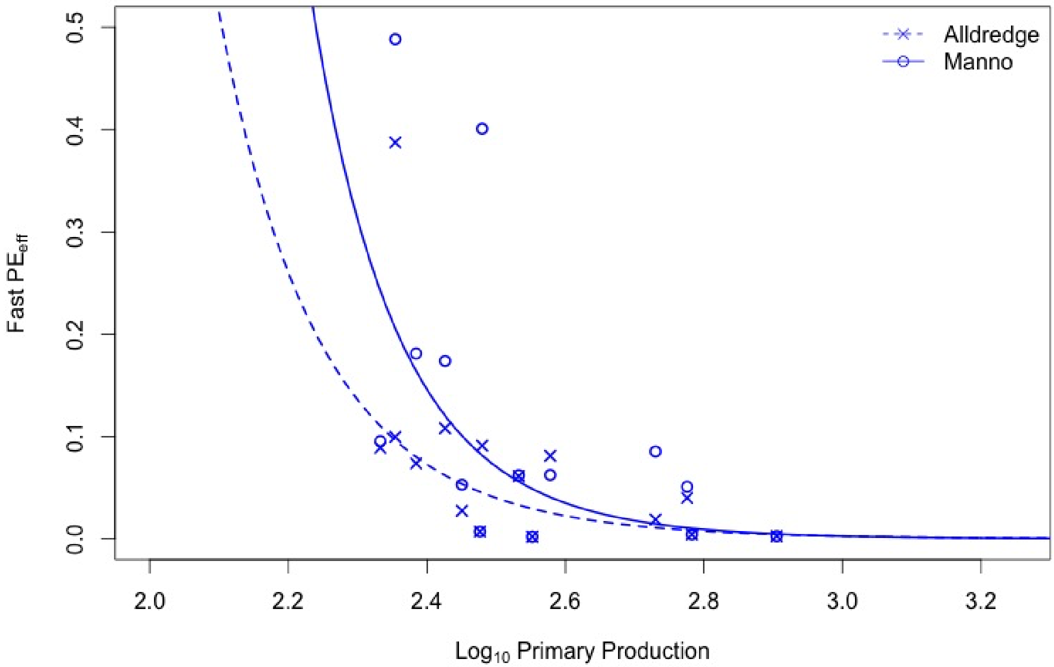

Fig. 2. Comparison of fast sinking Particle Export Efficiency (PEeff) for the Southern Ocean using Manno conversion factors for FPs (circle, solid line) and Alldredge conversion factors for FPs (cross, dashed

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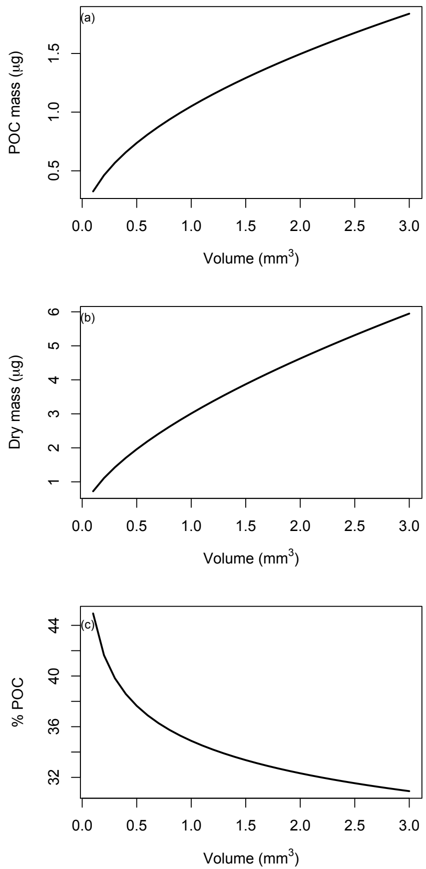

Fig. 3. Alldredge 1998 fractal relationship of POC content and size, using faecal pellets (FP) as the example. a) FP POC with size, b) FP dry mass with size and c) FP POC as a percentage of FP dry mass.