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Interactive comment on "Zooplankton faecal pellet transfer through the meso- and bathypelagic layers in the Southern Ocean in spring" *by* A. Belcher et al.

Response to reviewer #2

AC: Thank you for reviewing our manuscript and for taking the time to make suggestions for improvement, please find our responses below. Line numbers refer to the marked up version of the manuscript which has also been uploaded.

Anonymous Referee #2

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"Zooplankton fecal pellet transfer through the meso- and bathypelagic layers in the Southern Ocean in spring" by Belcher, A., Manno, C., Ward, P., Henson, S., Sanders, R., Tarling, G.

General comments
The manuscript by Belcher et al. compares estimates of copepod faecal pellet production in the epipelagic with those of faecal pellet abundances in the meso- and bathypelagial derived from Marine Snow Catcher (MSC) and sediment traps. The study was conducted in the Scotia Sea, Southern Ocean. Based on faecal pellet morphology and abundance, the main conclusion of this study is that small faecal pellets are in high abundance in the epipelagic but do not contribute much to export fluxes. Instead, repackaging of faecal pellets and de novo production take place in the meso- and bathypelagic. The manuscript is well written. The findings are in accordance with expectations derived from earlier studies on faecal pellet export in the ocean.

Specific comments
I suggest that the authors provide more information on their methods and measurements to allow for better evaluation of the data. I also suggest a more critical discussion on the comparability of data on faecal pellet fluxes derived from net tows, MSC and sediment traps.
1) Lines 89 and 90; here, an estimate for a mean current velocity at the study site of <10 m s-1 is given and Whitehouse et al. (2012) are cited to suggest that lateral advection can be neglected. It is not clear where the current velocity was measured and for what processes it can be neglected. I assume that a current meter was used in the cited study to estimate the trapping efficiency of the sediment traps, but this information should be given. Is the current velocity in the epi- and mesopelagic in the Scotia Sea in the same range? Does one have to consider lateral advection of faecal pellets in the water column? This is important to estimate how well samples from a MSC and deep traps can be compared.

AC: Thank you for drawing our attention to this, we realise that there was a typo and that mean velocities at the site are < 10 cm s^{-1}. This is based on the work of Whitehouse et al. 2012 for the study area, consistent with Manno et al. 2015 whose sediment trap data we have used for our comparisons. We additionally present current meter data from the P2 and P3 moorings collected between 2012 and 2014 (lines 101-134). Unfortunately we do not have current meter data from the mesopelagic to for comparison. However, Heywood and King, (2002) measured, geostrophic velocities in the upper 1000 m of Scotia Sea of <10 cm s^{-1} suggesting currents here are in the same range. Considering that zooplankton FP sink rapidly and that vertical shear is small below the mixed layer of the ACC (Firing et al., 2011), we do not think lateral advection will have significantly biased our results. See also response to point 4 of reviewer 2 where we add additional discussion on the uncertainties of the spatial and temporal resolutions of the different sampling techniques.

"Mean current velocities in December 2012 and 2013 (measured with a Nortek Aquadopp current meter deployed just below the ST) were 7.2 and 4.5 cm s^{-1}, and, 14.2 and 12.5 cm s^{-1}at P3 and P2 respectively. These data agree with mean current velocities at the depth of the ST at both sites of <10 cm s^{-1} observed by Whitehouse et al., (2012) in 2008, suggesting that the effects of lateral advection are minimal and as such they are not considered in this study."

2) 140ff.; please indicate how many splits were analyzed. Were the splits analyzed separately so that a sampling error can be given? How many pellets per split, or in total, were counted? So far only relative abundances are given in the manuscript and supplemental information. The authors may consider providing a table with absolute counts in the supplemental information. Please give this information also for faecal pellets determined in the MSC samples.
AC: We have added additional text to clarify our methods in terms of splits analysed.
Lines 177-178:
"All particles collected in the MSC tray were counted as it was not necessary to split the sample."

Lines 197-198
"Three replicates were analysed for ST FP, with all FP in each replicate counted (see supplementary table S1 for absolute counts)."

For the sediment trap samples splits were 1/16 and 1/160 of the total sample size for P2 and P3 respectively. Three replicate splits were calculated and following your advice we have detailed the mean and standard deviation of these counts in supplementary table S1. We have also included the absolute counts of FP collected in the MSC. This is the total number of FP in the MSC as it was not necessary to split the sample. We are aware that the sample size for the MSC is small at the P2 site which is controlled by the particle flux at the time of sampling. However, data from multiple deployments over two field campaigns increases our confidence in these values. These data are the best estimations available for comparison with the ST at our study sites and we believe they still provide insights into the transfer of FP through the mesopelagic.

3) 159 ff.: The quality of the faecal pellet sinking velocity measurement and therewith of the faecal pellet fluxes cannot be evaluated. The authors state that they used two different approaches to determine faecal pellet sinking velocity and that there were no significant differences between the methods. But how reliable are the obtained sinking velocities? The range of sinking velocities given in line 246 is rather large (24- 950 m d^{-1}). The ranges given in lines 248-249 are much smaller. How do these numbers compare? What was the variability of sinking velocity within each approach? What was the variability within each size class? Since these data are used to calculate the faecal pellet flux (FPF), the original data should be given in the manuscript and their accuracy assessed critically. Please add more information.
AC: We have amended section 3.4 to include only the sinking velocities of non-krill FP as these are the data utilised in this study, and the high sinking velocity (950 m d^{-1}) of one particularly large krill FP is the cause of the large range that you mention. The text now reads as follows (lines 311-314):

"Sinking velocities of FP (excluding krill FP) collected in the MSC ranged from 52 to 382 m d^{-1} at P2 and 13 to 227 m d^{-1} at P3 reflecting the range in FP shapes and sizes. Generally small FP had lower sinking velocities than larger FP. We measured FP sinking rates (excluding krill FP) of 47-120 m d^{-1} for FP <0.002 mm^3, and 36-270 m d^{-1} for FP >0.02 mm^3 (supplementary table S2). Rates measured in this study are consistent with the range of 5-220 m d^{-1} given by Turner (2002) for copepod FP."

Both techniques used in this study have been used to measure sinking velocities of FP and other sinking particles in other published studies, e.g. Cavan et al. (2015), Iversen and Ploug (2013), Iversen et al. (2010), Ploug et al. (2008), Riley et al. (2012) and Small et al. (1979), and hence we believe that these methods are justified in their use in this study. There are inevitably limitations when carrying out sinking velocity measurements in the field, but care was taken to ensure that measurements were not made in rough conditions when significant movement of the research vessel could have impacted results. We have included the sinking velocity data measured in this study in supplementary data S2 for transparency to show clearly the range in sinking velocities measured. This range in sinking velocities is not unexpected considering the range in size

and type of FP that we observed and is consistent with previous literature (review of Turner (2002) gives a range of 5-220 m d^{-1} for copepod FP).

4) The authors conclude that small FP that sink more slowly are not transferred efficiently to depth as they are subject to remineralization and coprophagy for a much longer period of time than fast sinking large particles. This is very well comprehensible. However, I would like to see a more critical discussion of the comparability of data from net tows, MSC and sediment traps, which takes into account the spatio-temporal variability in that region, the three-dimensional flow field and the current velocities. In addition to biogenic loss process, slowly sinking fecal pellets found in the MSC of stations P 2 and P3 may not be represented well in the sediment traps at 1500 and 2000m depth, because the traps collect particles from a much wider area (e.g. Waniek et al. 2000) and integrate over a longer, and different, time period.

AC: The differences in the temporal and spatial resolutions of the three sampling methods is indeed an important consideration. We have followed your recommendation and added the following text (Lines 458-451) to discuss the various scales and acknowledge the uncertainties.

"When comparing datasets collected via different methods (in this case Bongo nets, MSC and ST), it is important to consider the different time and space scales over which they measure. The zooplankton Bongo net samples integrated vertically over the top 200 m and temporally over the period over which replicate samples were taken (a few days at each site for both cruises). MSC samples were an instantaneous snapshot of the particle flux and, at a deployment depth of 110 m below the mixed layer, they integrate over spatial scales of tens of kilometres (based on median sinking rates at P2 and P3 and a current speed of 10 cm s^{-1}). Conversely ST samples captured the flux over a 15 day period and at a deployment depth of 1500 and 2000 m had a potential sample collection area on spatial scales of hundreds of kilometres (based on the same conditions). If zooplankton communities vary significantly over tens of kilometres then this would reduce the direct comparability of MSC and ST data. Previous studies in the region suggest that much of the Scotia Sea is populated by a single zooplankton 'community', but there are regional differences in the stage of phenological development. (Ward et al., 2006), implying that the species composition may not vary on short spatial scales. Changes in the species stage are likely tied to changes in phytoplankton productivity, as for much of the time, Southern Ocean zooplankton are food limited (Ward et al., 2006). Cluster analysis of phytoplankton in the Scotia Sea reveals distinct communities (in terms of abundance, community structure and productivity) on spatial scales of hundreds of kilometres (Korb et al., 2012), and hence we would not expect significant changes in the stage-structure of zooplankton on the spatial resolution of the MSC, making these results more comparable to those of the ST. The high sinking rates of zooplankton FP means that their occurrence in ST is representative of the conditions directly above the ST (Buesseler et al., 2007). Slow-sinking particles spread out more as they sink which increases our uncertainty in depth comparisons of smaller FP. However, the spatial scale of zooplankton variability at our study site means that slow-sinking FP particles reaching the ST likely reflect the same zooplankton community structure as occurring directly above the ST. For each of our three methods (nets, MSC and ST), we take averages over multiple years which should also reduce the uncertainties associated with the various spatial and temporal resolutions of the three methods. However, we acknowledge that the different spatial and temporal scales of measurement could also contribute to some of the vertical changes in FP shape and size structure that we observed."

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