Victoria Assad
California State University, Monterey Bay

Study of *Tergivelum baldwinae*, a benthic acorn worm's behavior and population densities

Synopsis: This study investigates the observed rise of *Tergivelum baldwinae* populations in relation to carbon inputs and potential predictors of *T. baldwinae's* behavior of fecal trails.

INTRODUCTION

Tergivelum baldwinae is a benthic hemichordate, or enteropneusta, belonging to the torquaratorid family and is known for distinct fecal trails (Holland et al., 2012). These fecal patterns are often found in either a spiral or "switchback" pattern and are created while feeding on the seafloor. It has been theorized that in more nutrient rich areas, specific patterns such as the spiral would cover a greater surface area (Priede et al., 2012). It has also been hypothesized that taxon specificity are influential, as different species have specific fecal trails (Priede et al., 2012). These trails have also been found throughout the fossil record, indicating that behavior could be a result of both ecology and anatomy (Jones and Alt, 2013). If behavior is linked to nutrient supply, this could be compared to fossil records and enteropneust behavior could be used as an indication for benthic conditions of specific time periods.

T. baldwinae has been increasing in abundance at a time-series site off the California coast (Station M, 4000 m depth), possibly related to increasing food supply (Smith et al., 2005). There have been changes in sinking particulate food supply, particularly particulate organic carbon (POC) influencing deep-sea communities at Sta. M (Smith et al., 2014). POC flux has been linked to changing climate. Increased wind stress within the California Upwelling system is associated with increased mixing and greater primary production. It's important to keep in mind why these population densities may be rising and the potential implications for their rise, as POC flux and other carbon inputs such as detrital aggregates continue to rise because of changing climate, *T. baldwinae* population densities could be rising too, which brings in larger implications for community structure. This study examines the relationship between *T. baldwinae* population increase and the influence of food supply vs. area of individual (or individual size) on behavior. We hypothesize:

Hypothesis 1: There is no significant correlation ($p<0.05$) between population density and food quantity (detrital aggregate percent cover on the seafloor), and quality (POC flux).

Hypothesis 2: There is no significant correlation ($p < 0.05$) between number of *T. baldwinae* number of spiral trails and greater food supply.

Hypothesis 3: There is no significant correlation ($p< 0.05$) between *T. baldwinae* body size and number of spiral or switchback trails.

METHODS

The Study Site: Station M

Station M, with its time-lapse cameras and sediment traps, is located on the Monterey Canyon abyssal fan (34o 50’N, 123o 00’W) at 4,000 m depth. For this study, hourly sea-floor images from the time-lapse cameras were analyzed. Images from the years 1989-2004 and 2011-2017 were annotated.

Observations & Data Analysis

Tergivelum baldwinae observations of number, size and behavior were images were observed using VARS (Video Annotation & Referencing System) for Images system through the Monterey Bay Aquarium Research Institute.

Each image with an enteropneust appearance was annotated during the first and last sighting point, the tracking of the trail, and measurements made on the individual body size of the enteropneust. Data from deployments during 2011-2017 were collected. Date of arrival and departure was noted, as well as which trail they had created. *T. baldwinae* population sightings were found through the same method as behavior observations.

Relative change in the amount of food available to the benthic community was estimated separately by measuring the percent cover of detrital aggregates on the sea-floor. Detrital aggregate percent cover at the time of arrival of the enteropneust was compared to fecal trail characteristics.

Once annotated, all data collected was exported to Microsoft Excel. Data was sorted and a carbon time lag was accounted for. R Studio was used to run cross-correlations between population counts and potential food source ie. POC flux and detrital aggregates. A Brian-Pypers correlation test was performed to find p-values.

Data obtained from Smith et al. 2005 on population was used for this study to find changes in population from 1989 until 2017. Though there was a gap from late 2004 until 2011 it was accounted for in the data. The same methods in R Studio and Brian-Pypers correlation test were run.

RESULTS

Results of the logistic regression between type of trail and detrital cover suggest no correlation ($p=0.8377$, $\alpha=0.05$). Type of trail and POC flux suggests no correlation ($p=0.5025$). Results of the logistic regression between body size of individual and type of trail suggest no correlation ($p=0.458$). Results of the cross-correlations and Brian-Pypers tests with recent population data (ie. 2011-2017) showed significance. POC flux were not statistically significant ($p=0.9483$, $\alpha=0.05$). Detrital cover were statistically significant ($p=0.0263$, $\alpha=0.05$). Results of the cross-correlations and Brian-Pypers tests with long term population data showed statistical significance. POC flux results were statistically significant ($p=0.0197$, $\alpha=0.05$). Detrital cover results were not statistically significant ($p=0.7413$, $\alpha=0.05$).

DISCUSSION

Based upon these results ($p>0.05$), type of path created is not correlated with the body size of an individual. Therefore, Hypothesis 3 is confirmed. These results seem to refute previous theories on what influences enteropneust behavior. Hypothesis 2 being confirmed ($p>0.05$), POC flux and detrital aggregate cover did not show to have an influence on individual behavior, suggesting that food supply does not result in a particular path. This refutes theories stating that areas of high concentration food supply would result in a spiral to cover more surface area while switchbacks were a searching behavior. These results lead to the question if there may be other influences on *T. baldwinae* behavior than what has been previously theorized. There is a possibility that another nutrient may be an influence on behavior that is not measured at the moment, or there could be an evolutionary influence that the fossil record does not account for.

With p-values <0.05, Hypothesis 1 was rejected within different time frames. Over the time frame of 2011 – 2017, detrital aggregate cover showed to have a significant correlation with population rise. When including the 1989-2004 dataset, this significance was not found. Instead, POC flux showed to have a statistically significant correlation with p-values < 0.05. Due to the difference in significance over time, these results seem to suggest either a focus on specific food sources in specific time frames or importance of food sources that sustain *T. baldwinae*. Short term results seem to suggest detrital aggregates may be *T. baldwinae's* immediate food source. In long-term time periods, POC flux may be the main food source that sustains, and potentially even grows, *T. baldwinae* population densities.

CONCLUSIONS AND FUTURE DIRECTIONS

Though no correlations were found between *T. baldwinae* behavior and food supply or body size, this study was able to focus on food source and body size as an influence and frames future study questions. *T. baldwinae* population densities are clearly increasing over time as a result of carbon supply, leading us to see that changing climate is further influencing deep sea community structures. Future directions including calculating bioturbation rates of *T. baldwinae* to further understand their role in the carbon cycle.

BROADER IMPACTS

Tergivelum baldwinae is clearly being influenced by climate change processes. With increasing numbers of *T. baldwinae* there comes a change in benthic community structure at Station M. This also means that in future years, as climate change increases, more and more changes will be arriving to the deep sea. This study helps get an understanding of what these changes are thus far. Though no connections were found in *T. baldwinae* behavior processes, we have still arrived towards a better idea of what does not influence their behavior, allowing us to ask more focused questions and potentially use the fossil record to find indications of climate and benthic conditions of specified times.

APPENDIX

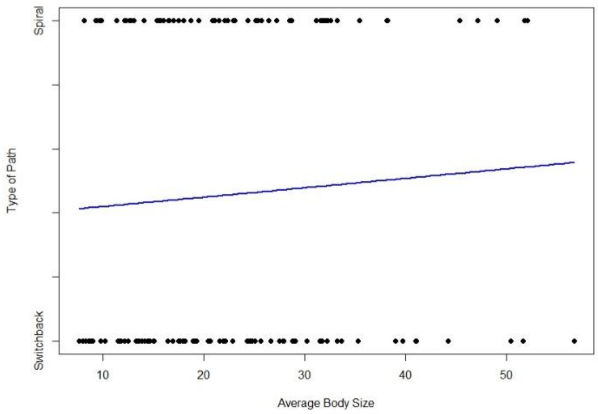

Figure 1. Logistic regression of average body size vs. type of path. P-value = 0.458

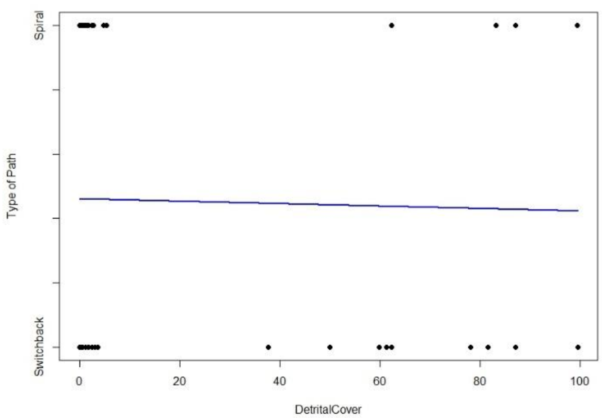

Figure 2. Logistic regression of detrital cover vs. type of path. P-value=0.8377

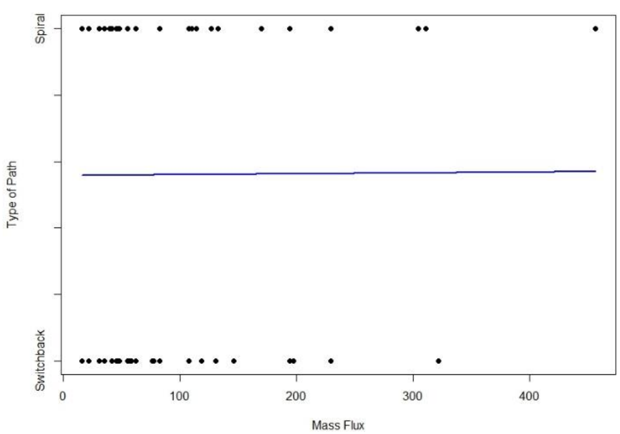

Figure 3. Logistic regression of mass flux vs. type of path. P-value=0.9656

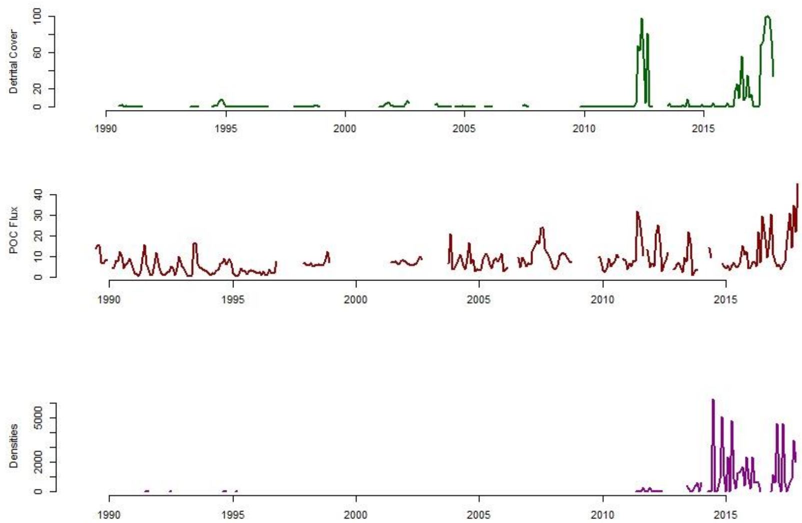

Figure 4. Cross correlation of Detrital Cover & POC flux to densities of *T. baldwinae*. Features years 1989-2004 & 2011-2017. P-value of detrital cover = 0.0263. P-value of POC flux = 0.9483 from years 2011-2017. From all years p-value of detrital cover = 0.7413 and POC flux = 0.0197.

LITERATURE CITED

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