Environmental controls on pteropod phenology along the Western Antarctic Peninsula

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OBJECTIVE

To determine if a shift in pteropod (pelagic snail), *Limacina helicina antarctica*, phenology (life history) has occurred due to warming or other environmental controls–change that would have important implications for regional food web dynamics.

INTRODUCTION

Limacina helicina antarctica is one of the most abundant zooplankton taxa in the Western Antarctic Peninsula (WAP), a region affected by rapid climate warming (Figure 1a) (Thibodeau et al. *in review* L&O). However, little is known about *L. antarctica*'s annually occurring life history events (phenology). *L. antarctica* is commonly found in sediment traps that are used to measure the rate of particle export, due to their sinking behavior to escape predators (Figure 1b) (Gilmer and Harbison, 1986).

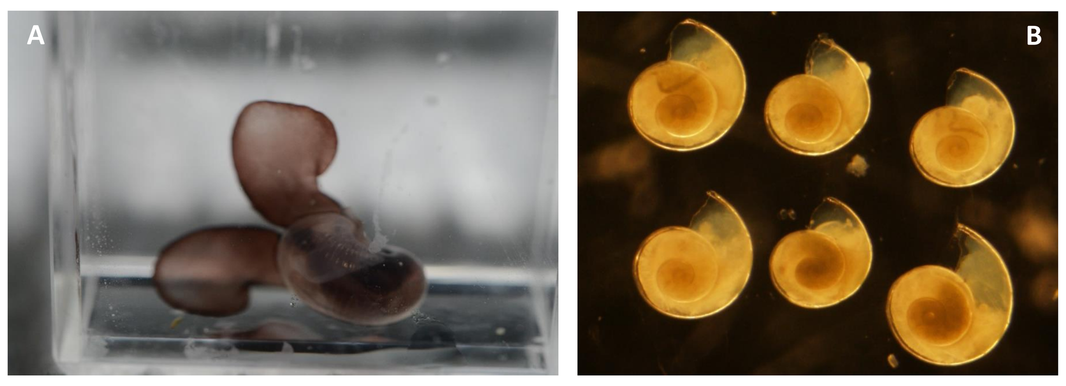


Figure 1. Live *Limacina helicina antarctica* collected onboard the PAL LTER annual January cruise (A) and preserved *L. antarctica* shells (B) collected from the year-round PAL LTER sediment trap.

The Palmer, Antarctica Long-Term Ecological Research (PAL LTER) program has deployed a short, conical-shaped sediment trap annually off the WAP since 1993 (Figure 2) (Ducklow et al., 2008).

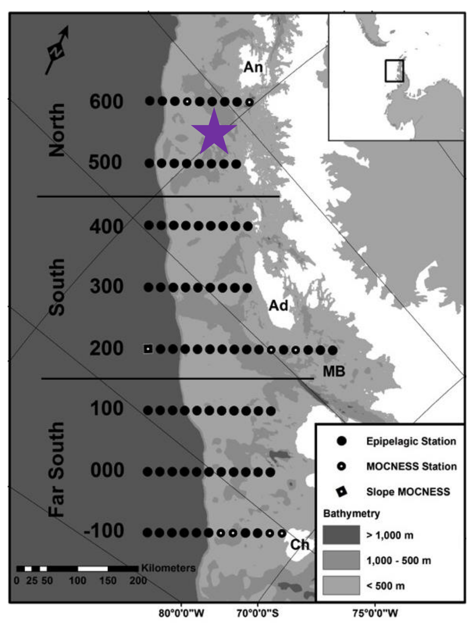
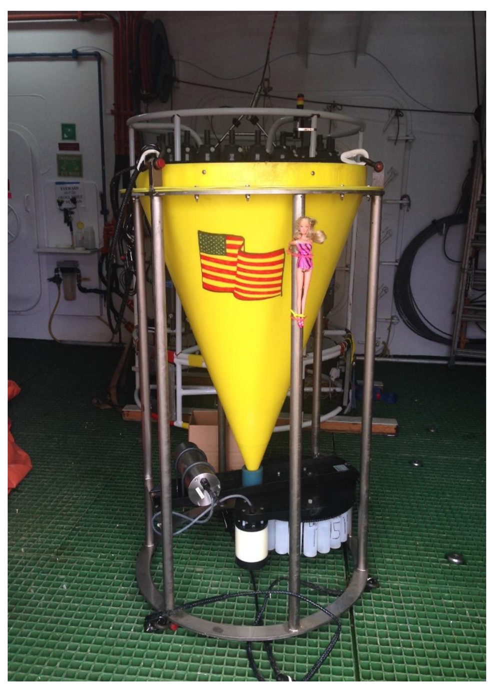


Figure 2. The Palmer LTER sampling grid along the Western Antarctic Peninsula (WAP). The location of Palmer LTER sediment trap is indicated by the purple star positioned of the WAP shelf.

METHODS

- *L. antarctica* shell lengths were analyzed from samples collected in the Palmer, Antarctica Long-Term Ecological Research program (PAL LTER) year-round sediment trap from 2004 to 2016 (Figure 3).



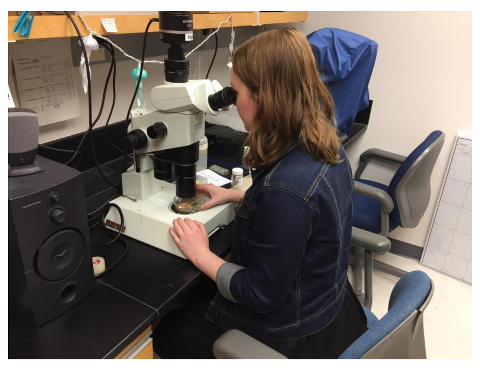


Figure 3. Design of the conical-shaped sediment trap deployed every year since 1993. The trap is bottom moored at 170m below the surface. Note the carousel with cups at the bottom which rotates approximately every month to collect a full year of samples.

Figure 4. Imaging pteropod shells with a dissecting microscope.

- Pteropods were picked from each sediment trap sample, counted, and photographed using a camera attachment on the microscope (Figure 4).

METHODS

- Specimens were measured from the opening of the shell aperture directly across the diameter of the shell with CellSens image processing system (Figure 5).
- Up to 120 pteropod shells were measured from each cup.
- Data analysis done with R statistical software.

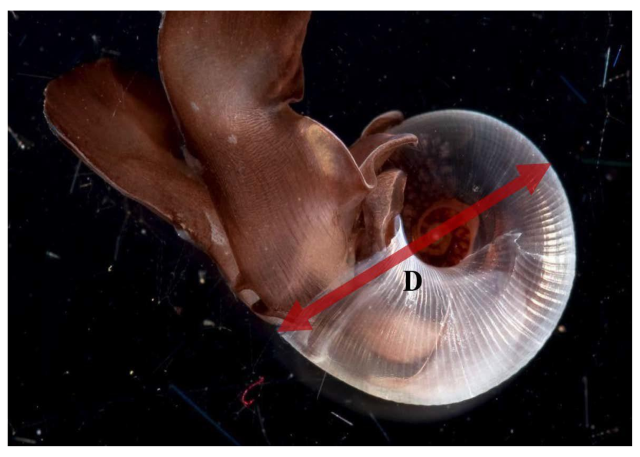


Figure 5. Shell diameter (D) measurement of *Limacina helicina* from Wang et al., 2017.

RESULTS

Size-frequency histograms were constructed to identify median shell size and time of appearance for each year of the time series. A new cohort of pteropods typically appears in May or June (austral fall to winter) and continues to grow throughout the winter season into the austral summer (Figure 6).

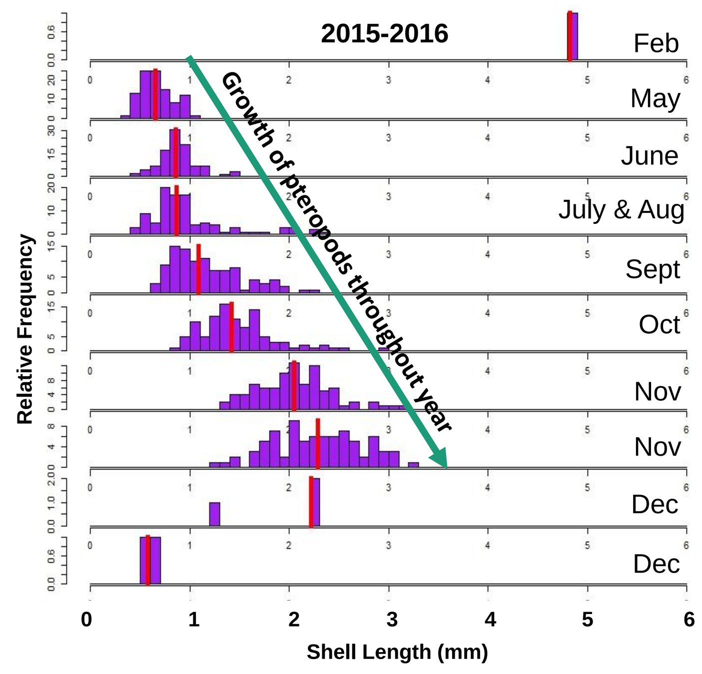


Figure 6. Size-frequency histogram for 2016. Similar histograms were constructed for each year of the time series (2004-2016). Months labeled on the right indicate the sampling month for that particular histogram of shells measured. Median shell length for each cup was determined (red bars).

Median shell size for each cup of each year was determined to identify long-term trends in pteropod growth (Figure 7). Growth rates were determined by log-adjusting median shell sizes for each year of the time series and constructing linear models (Figure 8). There was no long-term, directional change in time of appearance or growth rate (Figure 9).

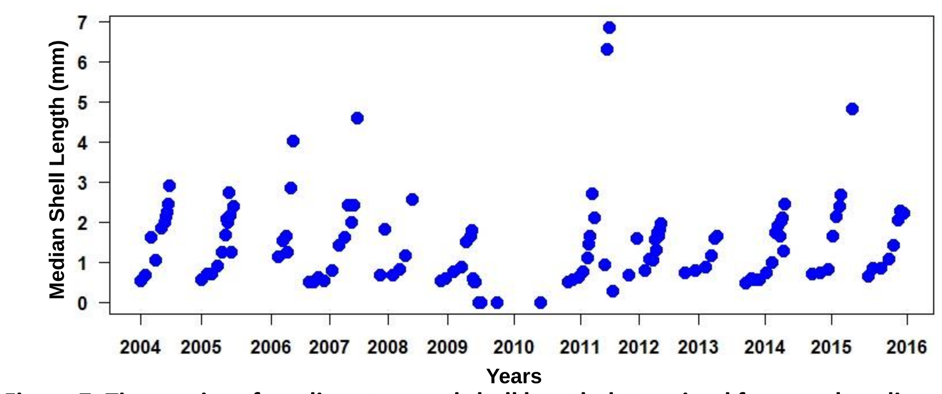


Figure 7. Time series of median pteropod shell length determined from each sediment trap cup during a particular year from 2004-2016. No data is available in 2010 due to a trap failure.

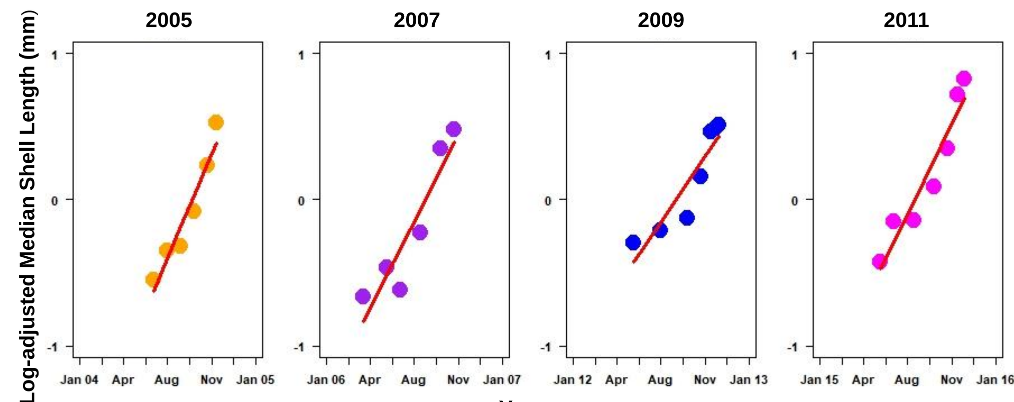


Figure 8. Growth rates determined by constructing linear models on log-adjusted data for select years (2005, 2007, 2013, 2016) of the entire time series (2004-2016). All models significant ($p < 0.05$) in time series with R^2 range from 0.65-0.90 except 2008 ($p > 0.05$).

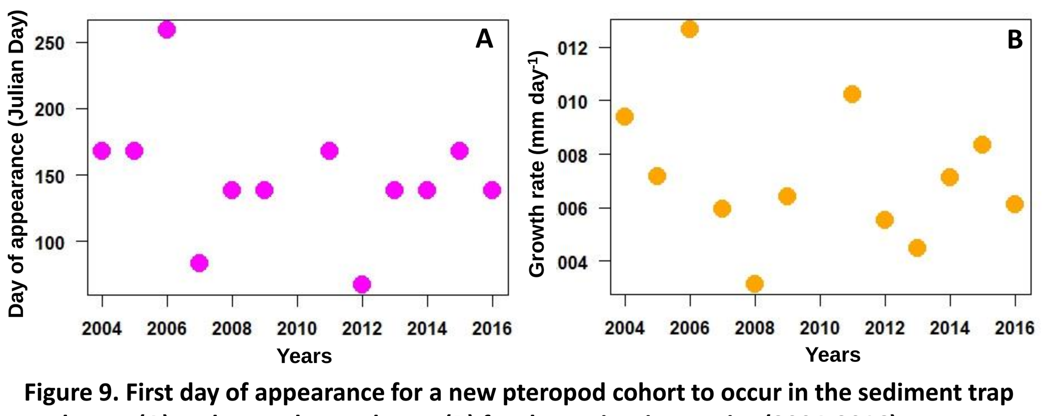


Figure 9. First day of appearance for a new pteropod cohort to occur in the sediment trap each year (A) and annual growth rate (B) for the entire time series (2004-2016)

RESULTS

Environmental parameters controlling pteropod phenology were determined with general linear models (GLM's) (Table 1). Earlier *L. antarctica* appearance and faster growth rates corresponded with warm waters in austral fall and more ice-free in the preceding year (Figure 10).

Table 1. GLM results addressing the effect of environmental, climate, and food on WAP pteropod phenology. Explanatory variables and statistical scores obtained from the best model, identified by the highest R^2 value.

Phenology parameter	n	Coefficient	SE	P
Time of Appearance (R^2 adjusted = 0.702, p = 0.004)	16			
Autumn SST (no lag)		-766.464	212.311	= 0.006
Primary Production (1-year lag)		-96.79	28.693	= 0.009
MEI (1-year lag)		22.411	13.552	= 0.13
Growth (R^2 adjusted = 0.622, p = 0.013)	14			
Open Water Area (1-year lag)		0.016	0.004	= 0.009
Autumn SST (1-year lag)		0.022	0.008	= 0.041

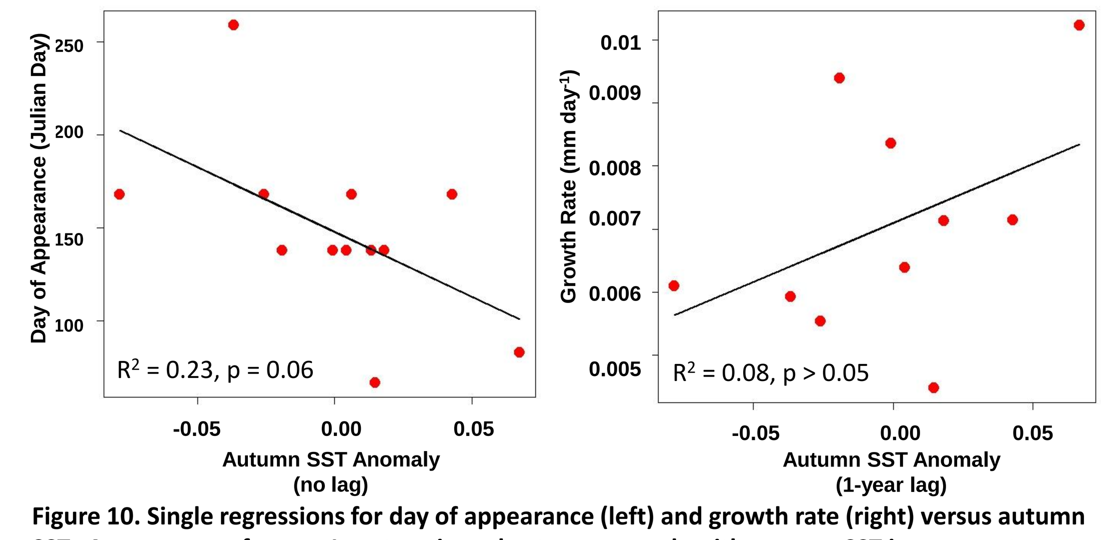


Figure 10. Single regressions for day of appearance (left) and growth rate (right) versus autumn SST. Appearance of a new *L. antarctica* cohort corresponds with warmer SST in same autumn (positive anomaly). Faster growth rates correspond to warmer SST in the year prior.

CONCLUSIONS

- Only study in Southern Ocean to illustrate pteropod shell growth during the ice-covered winter season.
- Strong interannual variability in the time of appearance of each new *L. antarctica* cohort (~200 days).
- Currently, no long-term pteropod phenology shifts in the WAP as indicated by time of appearance and growth rate.
- Most rapid growth occurs in November (austral summer) corresponding to a time of high biological productivity.
- Pteropod phenology may shift in the near future due to effects of warmer, ice-free waters on cohort appearance and growth rate. These changes have unknown consequences for food web.

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