Decadal-scale changes in gastropod body size along a thermal gradient support the temperature-size rule

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Figures

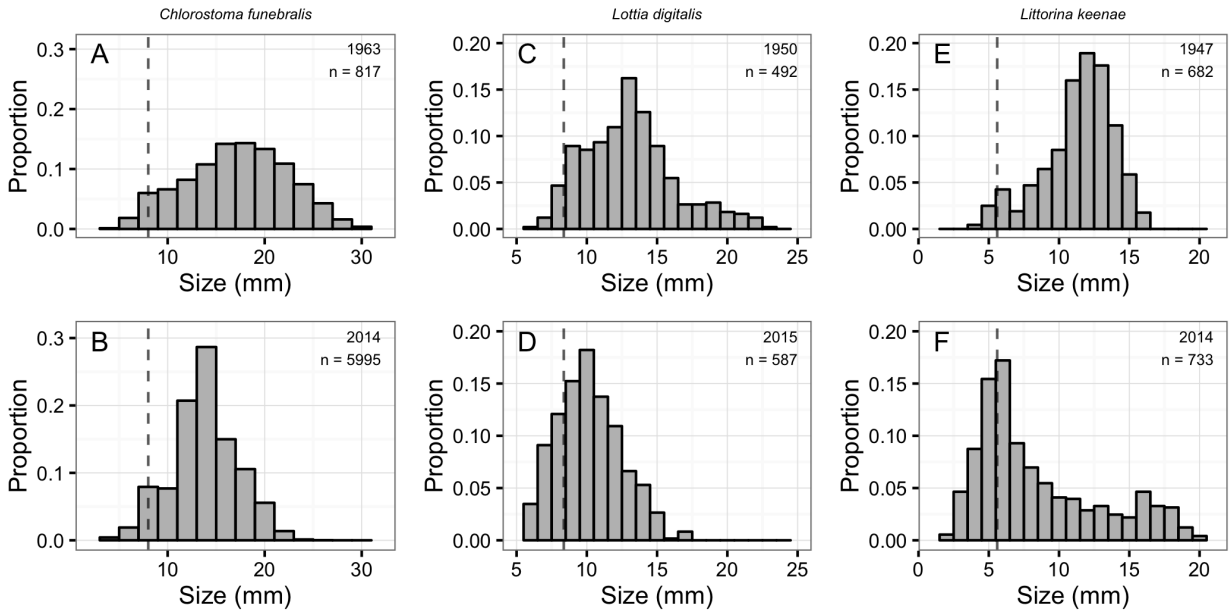

Figure 1: Size frequency distributions of three intertidal gastropods sampled in the past (A,C,E) and present (B,D,F). The vertical dashed line indicates the 5th percentile of size for each species in the past. Only gastropods larger than this threshold were included for all statistical tests and summary calculations. We did this to ensure a conservative test of declining body size; that is, it is possible that the previous investigators sampled the smallest individuals less carefully than we did.

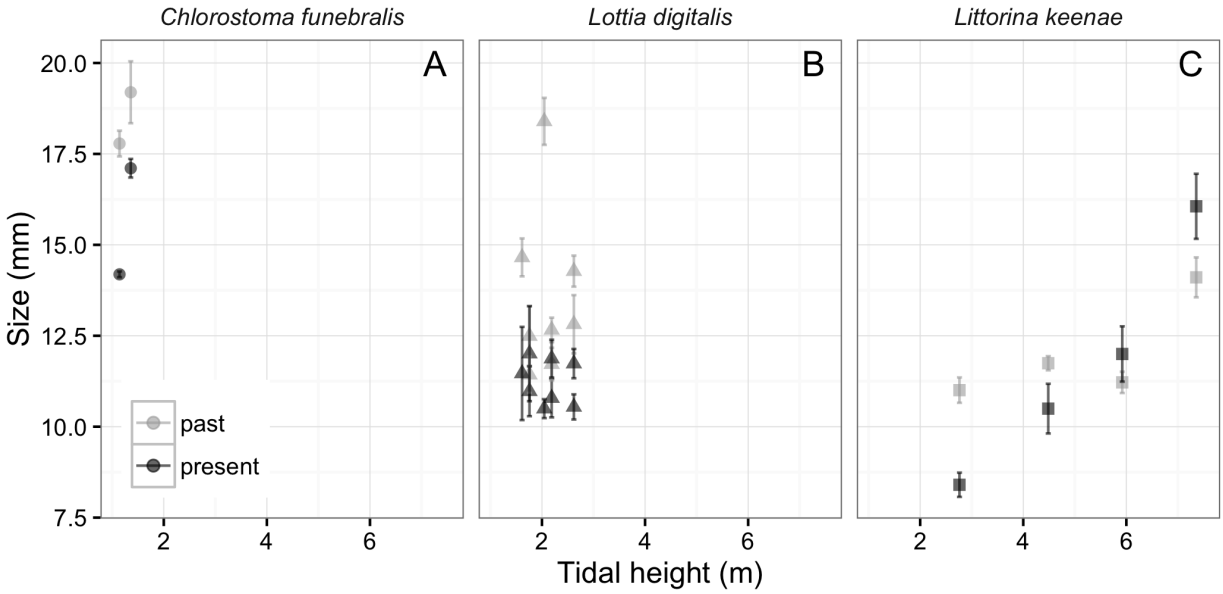

Figure 2: Body size (mean +- CI) of three intertidal gastropods plotted against tidal height. In general, mean body size has declined over six decades. However, *L. keenae* (C) has increased in mean body size in the high intertidal (sampling areas C and D in Figure 3).

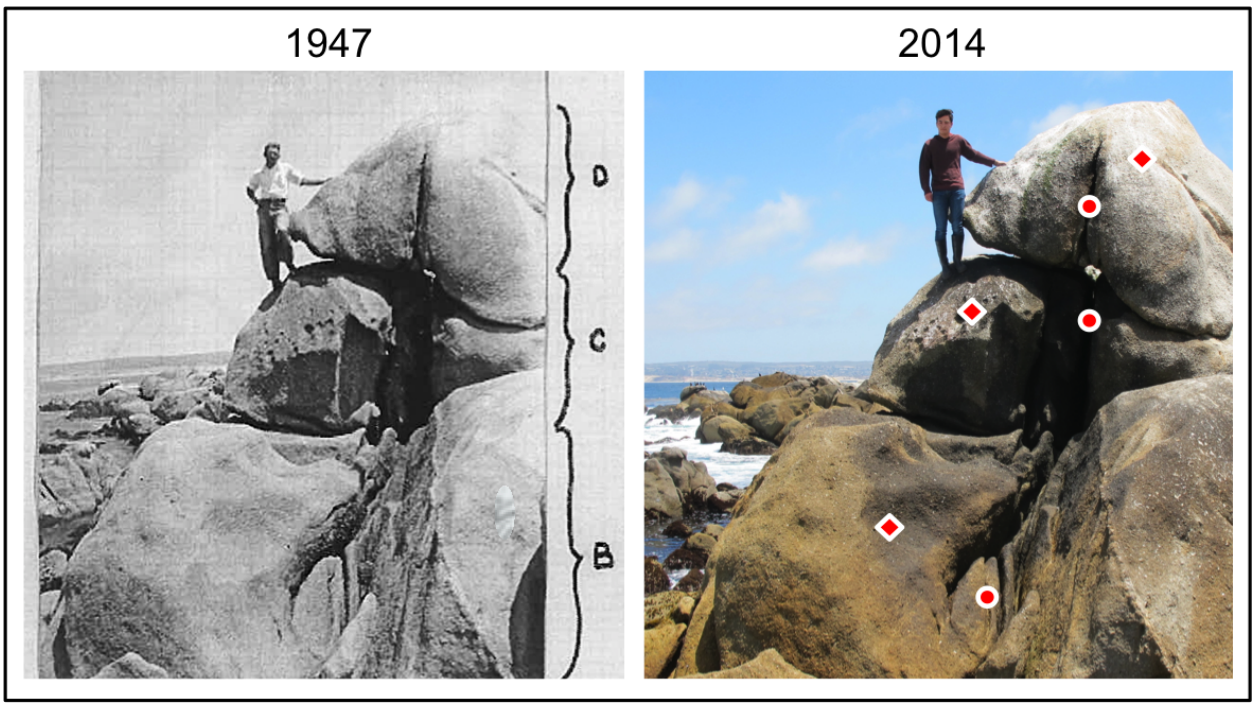

Figure 3: Historical comparison of three (out of four) sampling areas (B-D) for *Littorina keenae* on High Rock at Cabrillo Point in Pacific Grove, California. In the 2014 photo, the red diamonds and circles indicate the locations of temperature loggers on exposed rock faces and rock crevices, respectively. The lowest and highest loggers were situated at approximately 3.6 and 7.6m above mean lower low water.

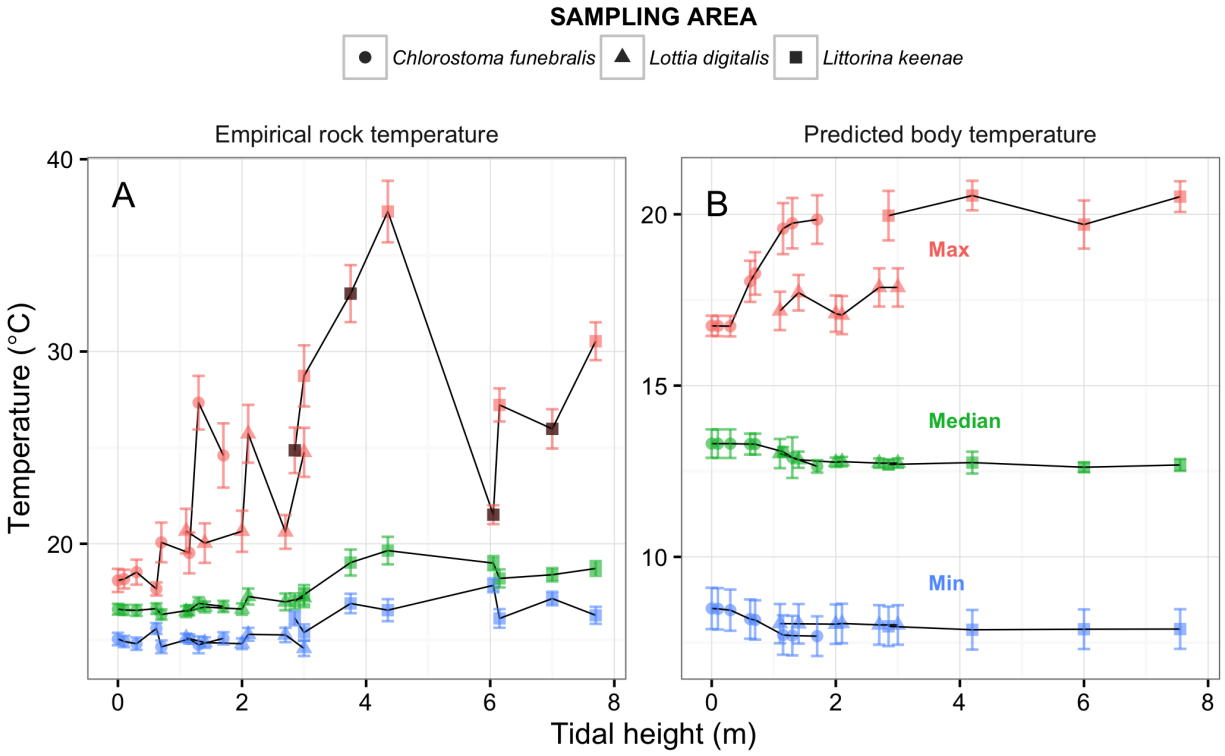

Figure 4: Empirical rock temperatures quantified from 6-week deployments of temperature loggers in the gastropod sampling areas (A), and predictions of body temperature from heat budget models {mean +- CI of daily maximum (red), median (green), and minimum (blue)}. Predictions are for a 30mm limpet (*Lottia gigantea*) from the same areas sampled for the three gastropods (*C. funebralis*, *L. digitalis*, *L. keenae*). The four black squares represent measurements from loggers placed in crevices where we sampled *L. keenae* (but not indicated for median and minimum temperatures for clarity). Black lines connect measurements from different sampling areas. Note the different y-axes between panels. See Methods for details of measurements.

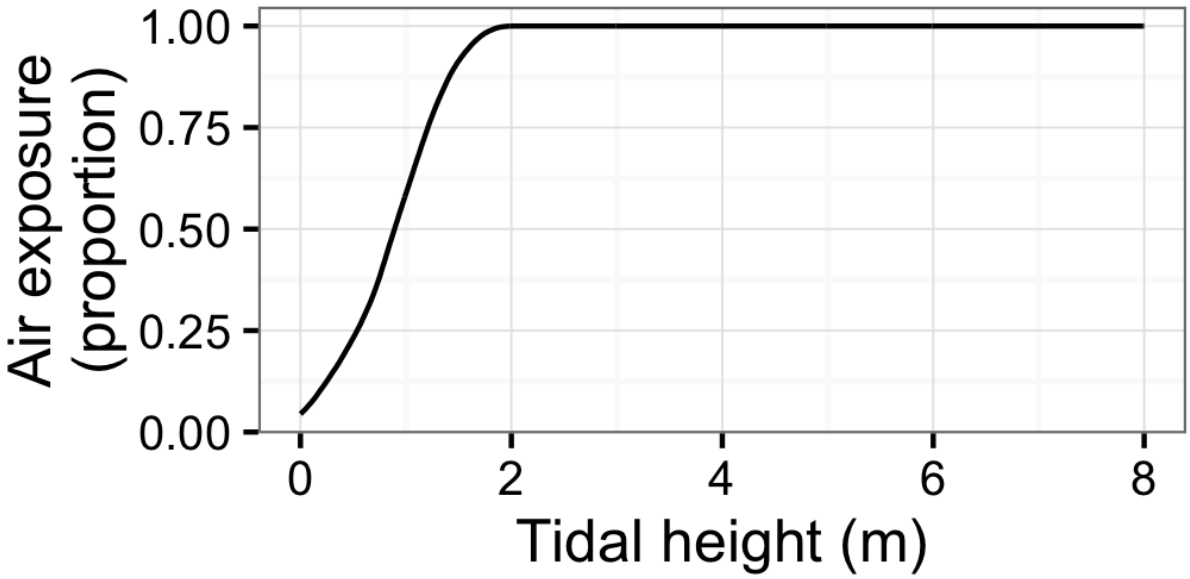

Figure 5: Annual air exposure increases rapidly with tidal height up to 2m above mean lower low water. Beyond 2m above mllw, intertidal rocky shores in Monterey are never submerged, but still receive wave splash. Data are from the NOAA tidal station in Monterey Harbor, 2015.

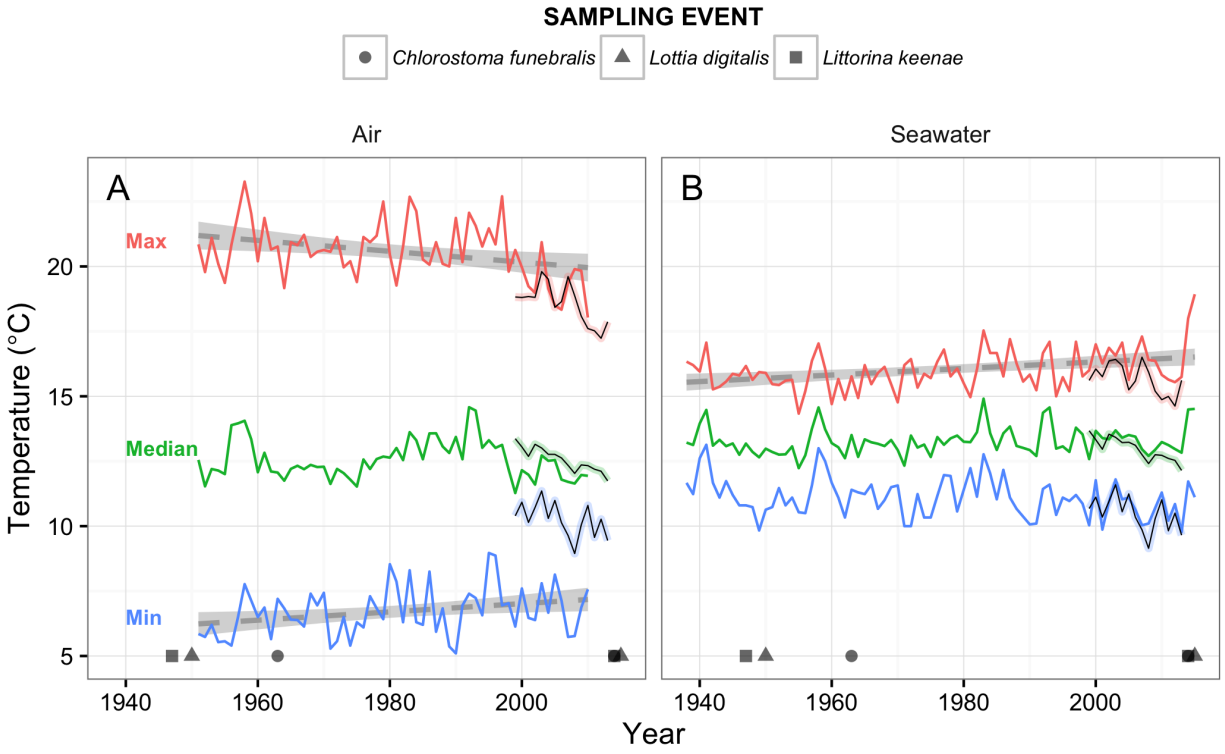

Figure 6: Air temperatures (A) from a weather station in Monterey (36.6, -121.9; 2.44km south of the sampling sites; 117m above sea level), and seawater temperatures (B) from Hopkins Marine Station, Pacific Grove. Gray dashed lines and confidence intervals are plotted for time-series if the trend was significant ($P < 0.05$). In (A), the black lines represent time-series of predicted body temperatures for a sampling location low (1.1m above mean lower low water (mllw)) in the intertidal. In (B), the black lines represent time-series of predicted body temperatures for a sampling location high (7.6m above mllw) in the intertidal. Note that maximum air temperature coincides with predictions of body temperature high in the intertidal, but maximum seawater temperature coincides with predictions low in the intertidal. Gray symbols next to the x-axis represent the years during which snails were sampled.

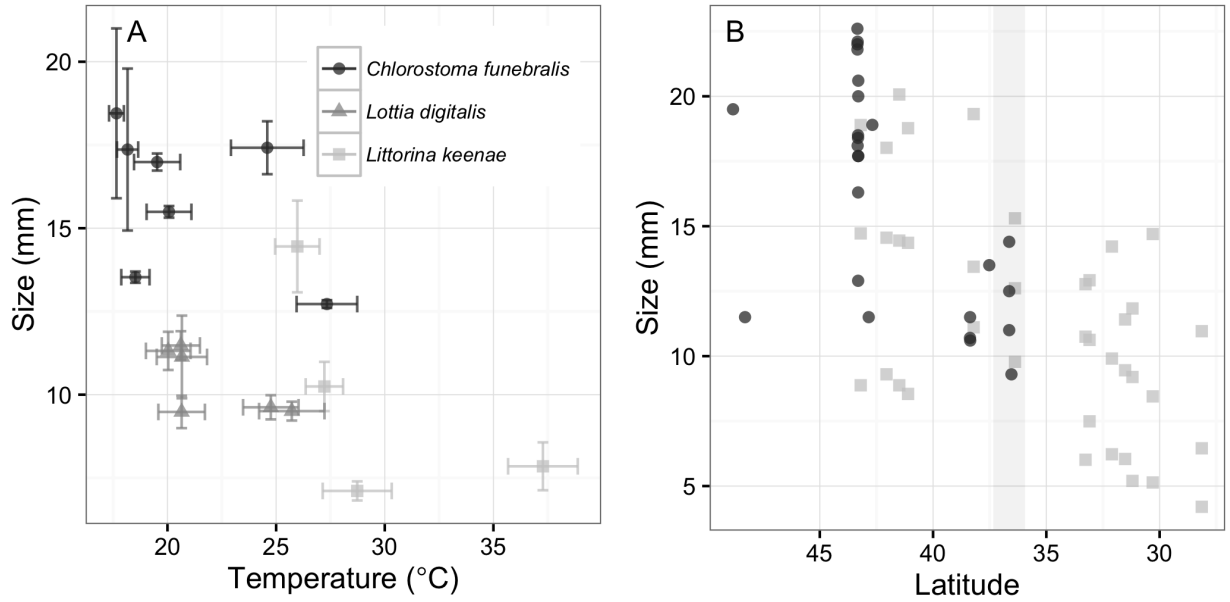

Figure 7: Microhabitat (A) and macroecological (B) spatial evidence for the temperature-size rule in intertidal gastropods. In (A), body size (mean + CI) is plotted against daily maximum rock temperature (mean +- CI) for all three species. In (B), body size of two gastropods sampled along the west coast of North America is plotted against latitude. For *C. funebralis*, points represent mean body size from Frank (1975). For *L. keenae*, points represent maximum, minimum, and estimated size for each latitude from Lee and Boulding (2010). Size was estimated using a quadratic regression in Lee and Boulding (2010). The gray vertical bar in (B) represents the latitudinal range relevant to the present study.