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Effects of hypoxia and acidification on the swimming behavior of Calanus pacificus: Lethal and sublethal responses to stressors

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Effects of hypoxia and acidification on the swimming behavior of *Calanus pacificus*: Lethal and sublethal responses to stressors

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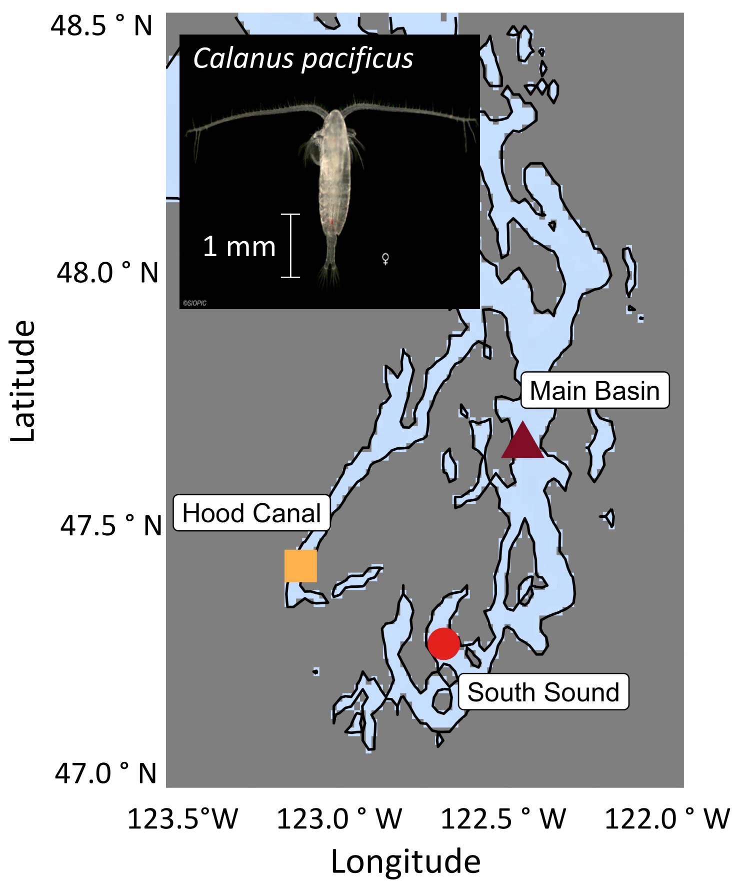
Background



Map of study site with stations where study organisms, C. pacificus, were collected.

- Chemical stressors resulting from ocean change, such as hypoxia (low oxygen) and acidification (low pH), are increasing in coastal waters.[1]
- Stressors vary among regions due to differences in productivity and circulation patterns.[1]
- Deeper waters are typically more stressful than surface waters due to limited mixing and bacterial respiration at the seafloor that consumes O_2 and releases CO_2.[2]
- Chemical stressors are known to affect many marine organisms, including copepods[3], a critical link in marine food webs.[4]
- Diel vertical migration (typically swimming downwards during the day and upwards at night) is an important predator-avoidance behavior for many copepods.[5]

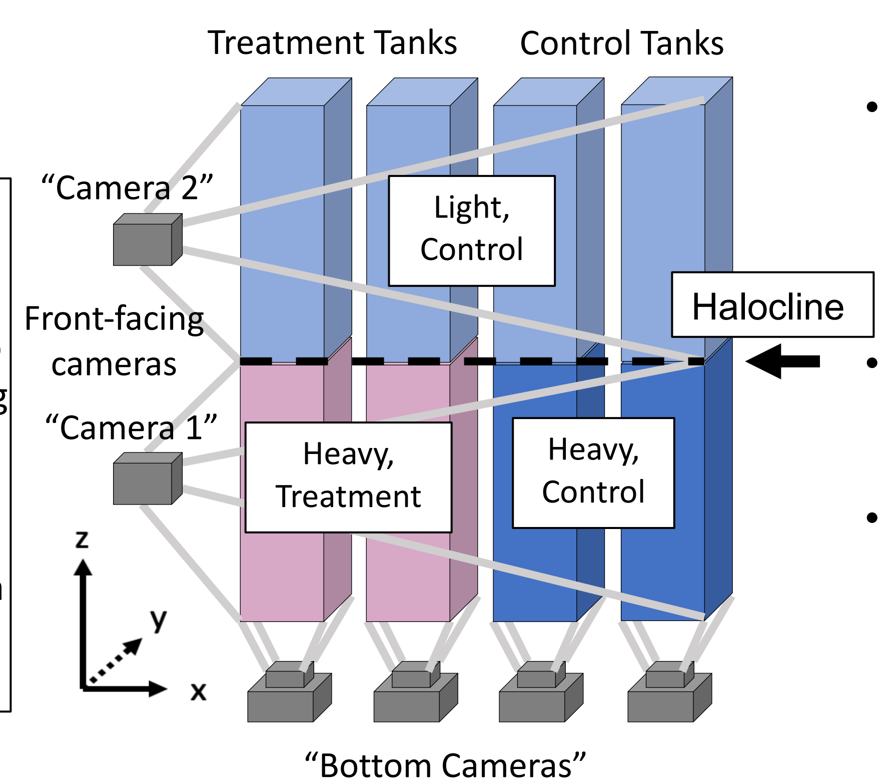
Research Questions & Hypothesis

- Questions: When exposed to bottom water stressors, do copepods avoid stressful conditions by modifying their normal downward migration or do they migrate into stressful bottom waters and exhibit signs of physiological stress? What roles do mortality and swimming behavior play in shaping the vertical distribution of copepods in the water column? Will the region copepods are collected from effect their behavior?
- Hypothesis: When exposed to stressful bottom waters, *C. pacificus* mortality rates will increase and swimming speeds within stressful waters will decline as a result of physiological stress and metabolic suppression.

Methods

Two sets of laboratory experiments were run with a bottom stressor of either low oxygen (0.65 mg/L dissolved O_2) or low pH (7.48 pH).

C. pacificus normally swim down when added to the top of tanks, allowing us to record changes in behavior when they encounter a stressful water layer at depth.



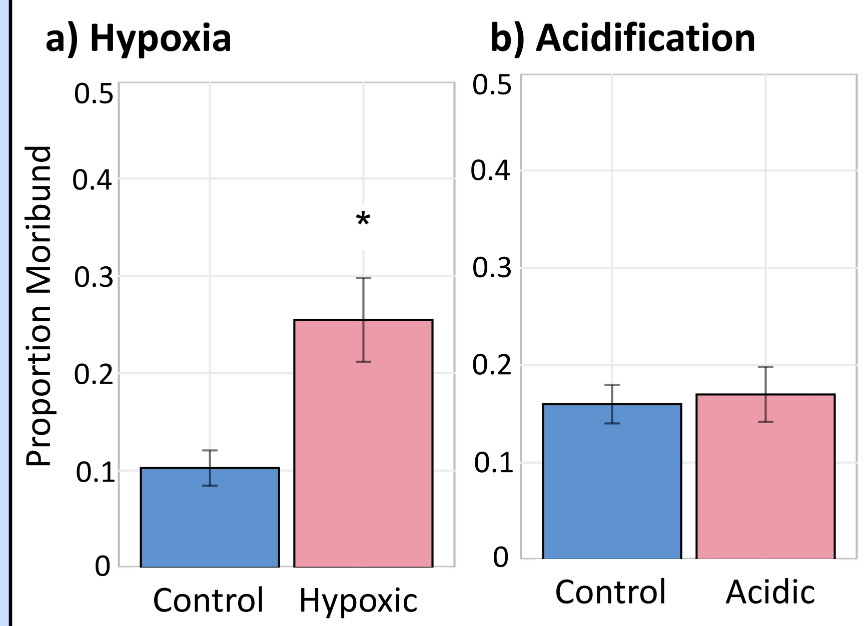
Experimental schematic highlighting the two-layer water columns and camera views.

- A stable, 2-layer water column was created using salinity differences ('heavy' and 'light' water).
- Six 5-megapixel IR cameras recorded swimming behavior.
- Videos were processed to extract pixel coordinates which were stitched into swimming trajectories.[6]

Results

Moribundity – *Are there consequences of unmodified swimming?*

- Moribundity, a proxy for mortality, was significantly higher in hypoxic but not acidic tanks relative to control tanks.

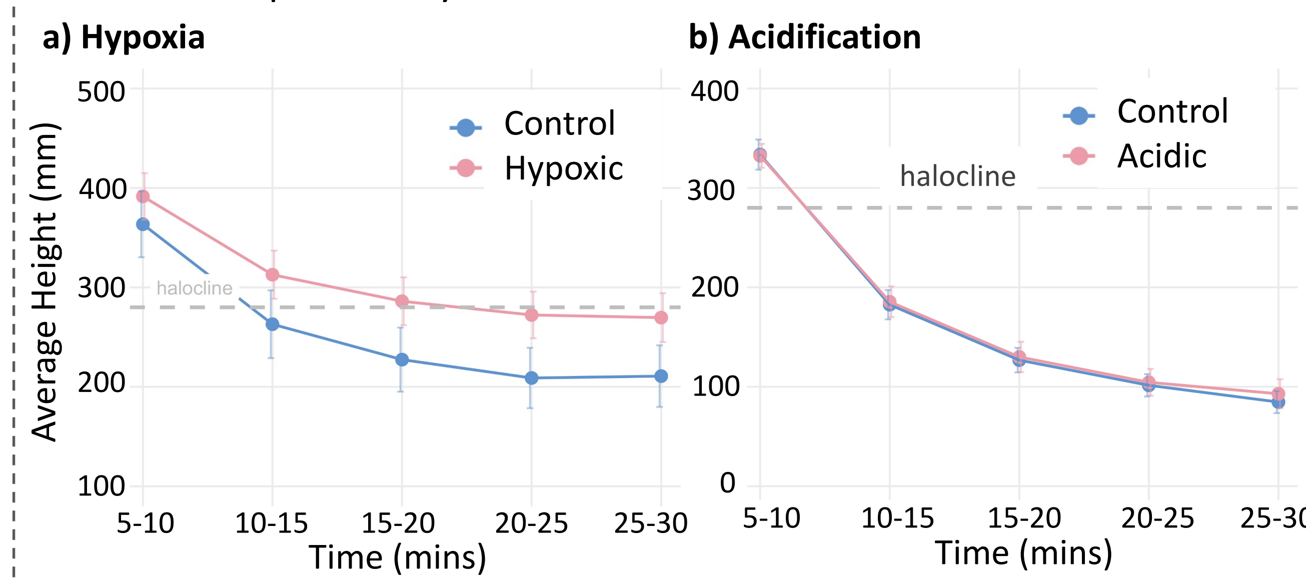


Moribund = remain stationary at the bottom of the tank through the last 2 minutes of the experiment
- Used as a proxy for mortality

The average proportion of immobilized or dead copepods in stressor and control tanks from a video-based metric estimating moribundity at the end of all experiments.

Height off Bottom – *Do copepods avoid stressful bottom waters?*

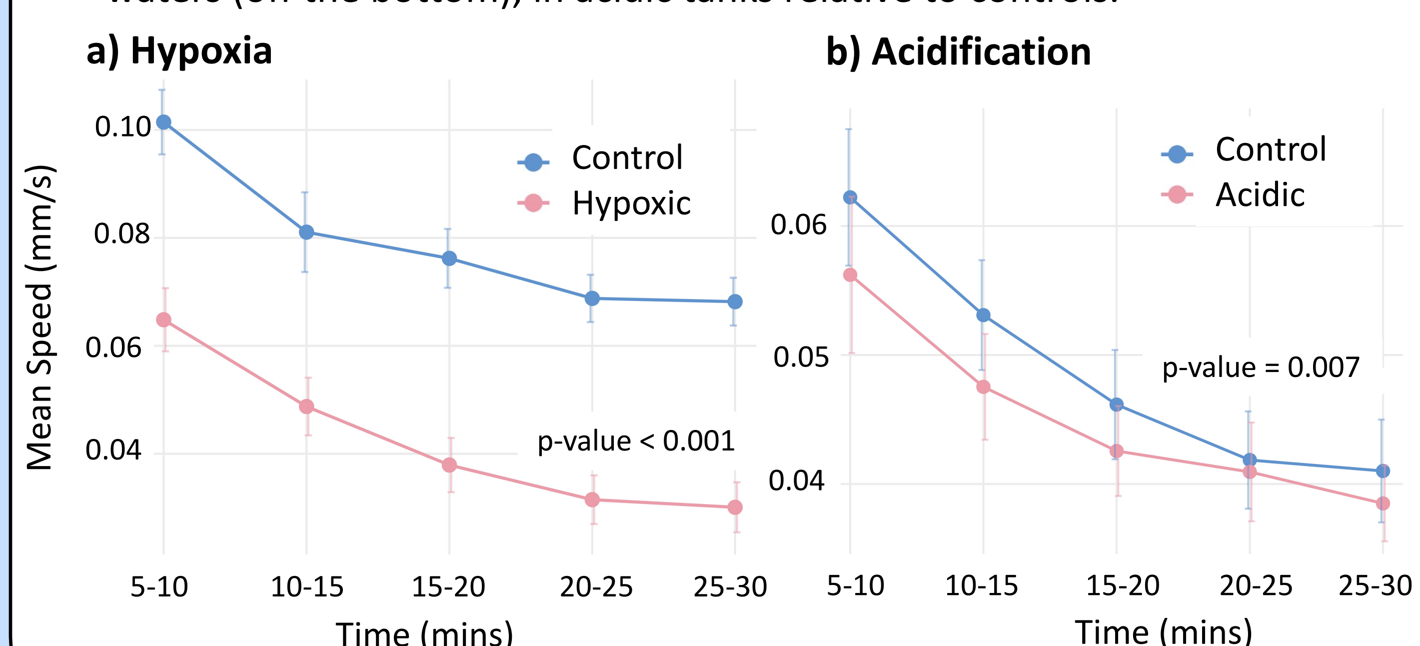
- Copepods avoided deep hypoxic layers by staying higher in the water column in hypoxic tanks relative to control tanks. Copepods did not avoid deep acidic layers.



Average height above bottom (+/- SE) of copepods over 5-minute intervals for control (blue lines) and stressor (red lines) tanks. Grey dashed line is the locations of the halocline separating heavy and light water.

Swimming Speed – *What behavioral changes underlie position shifts?*

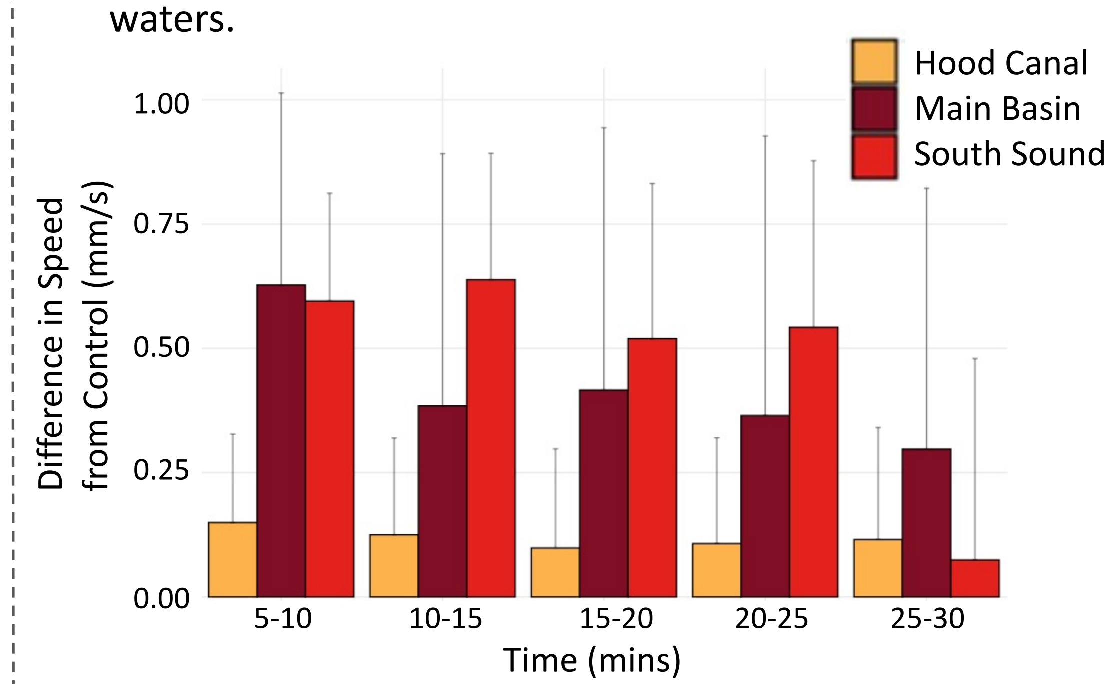
- Copepods swam faster above hypoxic waters and slower within hypoxic waters (both at (**shown below**) and off the bottom of the tank) in hypoxic tanks relative to controls.
- Copepods swam slower above acidic waters and at the bottom of the tank (**shown below**) but showed no difference in swimming speed within acidic waters (off the bottom), in acidic tanks relative to controls.



Average speed (mm/s) from the upwards-looking bottom camera (+/-SE) in control (blue lines) and stressor (red lines) tanks.

Collection Site – *Does behavior change with collection site?*

- When exposed to hypoxic bottom waters, copepods collected from Hood Canal (a seasonally hypoxic inlet) showed the smallest response within hypoxic waters (**shown below**), and the largest response above hypoxic waters.



Difference in the average speed (mm/s) of copepods below the halocline in hypoxic tanks and control tanks (+/-SE), sorted by copepods collected from different sites (color).

Discussion & Implications

- In 90-minute experiments designed to test how copepods would modify normal downward migrations when exposed to stressful bottom water, we recorded lethal and sublethal responses to hypoxia as well as sublethal responses to acidic bottom waters.
- An increase in moribundity (proxy for mortality) and an upward shift in the vertical position of copepods could result in a decrease in overall abundances[7], shifts in community composition due to species-specific responses to chemical stressors[8], and changes in predator-prey overlap.[9]
- Changes in swimming speed have important energetic implications. Reducing swimming speed within stressors could be an important mechanism in conserving energy. However, an increase in swimming speed could be a mechanism used by copepods to avoid chemical stressors.
- Local adaptation could be an indication of the resilience of marine organisms to chemical stresses exacerbated by climate change.
- Monitoring *in situ* changes in swimming speed could serve as a useful proxy of sub-lethal stress in marine systems in the future.

References: (1) Doney, S. C. (2010). *328*(10058), 1512–1516. **(2)** Breitburg, D., Levin, L. A., Oschlies, A., Grégoire, M., Chavez, F. P., Conley, D. J., Zhang, J. (2018). *Science*, *359*(6371). **(3)** Wu, R. S. S. (2002). *Marine Pollution Bulletin*, *45*(1–12), 35–45. **(4)** Verity, P. G., & Smetacek, V. (1996). *Marine Ecology Progress Series*, *130*(1–3), 277–293. **(5)** Frost, B. W. (1988). *Bulletin of Marine Science*, *43*(3), 675–694. **(6)** Chan, K. Y. K., & Grunbaum, D. (2010). *Marine Ecology Progress Seriese*, *415*, 49–59. **(7)** Roman, M. R., Gauzens, A. L., Rhinehart, W. K., & White, J. R. (1993). *Limnology and Oceanography*, *38*(8), 1603–1614. **(8)** Uye, S. ichi. (1994). *Hydrobiologia*, *292–293*(1), 513–519. **(9)** Roman, M. R., Brandt, S. B., Houde, E. D., & Pierson, J. J. (2019). *Frontiers in Marine Science, 6(139).*

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