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## Does ocean acidification affect the bioenergetics and susceptibility to pathogenic disease in juvenile Pacific herring (*Clupea pallasii*)?

Christopher Murray  
*University Of Washington*

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# Does ocean acidification affect the bioenergetics and susceptibility to viral disease in Pacific herring?



Murray, C.S.<sup>1\*</sup>, Gregg, J.<sup>2</sup>, Mackenzie, A.<sup>2</sup>, Jayasekera, H.<sup>2</sup>, Richards, W.<sup>2</sup>, Malloy, A.<sup>3</sup>, Hershberger, P.<sup>2</sup>

## Introduction

In fish, sublethal environmental stressors can compromise aerobic performance and immune function. The Salish Sea ecosystem is particularly vulnerable to ocean acidification, but whether near-future  $p\text{CO}_2$  levels reduce growth and increase susceptibility to pathogenic disease in marine fish remains understudied. Pacific herring (*Clupea pallasii*) is a keystone forage fish that is highly vulnerable to epizootic outbreaks of viral hemorrhagic septicemia virus (VHSV). To this end, we monitored the growth of juvenile herring reared under predicted future  $p\text{CO}_2$  levels, measured juvenile critical swim speed, and tested their resilience to an induced VHSV infection.

## Methods

Wild Pacific herring were reared at the USGS Marrowstone Marine Field Station from hatch under three  $p\text{CO}_2$  conditions: low (500  $\mu\text{atm}$ ); intermediate (1500  $\mu\text{atm}$ ); and high (3000  $\mu\text{atm}$ ). Fish were subsampled for size measurements every 3-5 days and juveniles were tested for critical swim speed ( $U_{\text{crit}}$ ) 90-105 days-post hatch (dph) using a Blazka-type swim flume. After 98 dph, groups of 60 fish (three groups per  $p\text{CO}_2$  treatment) were treated with VHSV (mean waterborne exposure levels were tittered at 807 PFU  $\text{mL}^{-1}$ ) for 2 h before the tanks were flushed. Mortalities were collected for 28 days post-infection (dpi) and tissues from all mortalities and survivors were measured for viral titer in kidney / spleen pools by plaque assay onto polyethylene glycol-pretreated EPC cells.

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 Author Affiliations

<sup>1</sup> School of Marine and Environmental Affairs and Washington Ocean Acidification Center, University of Washington, 3710 Brooklyn Ave NE, Seattle, WA 98105

<sup>2</sup> Western Fisheries Research Center, Marrowstone Marine Field Station United States Geological Survey, Biological Resources Discipline, 616 Marrowstone Point Road, Nordland, Washington 98358, USA

<sup>3</sup> Marine and Coastal Sciences, Western Washington University, 516 High Street, Bellingham, WA 98225, USA

## Virus Challenge

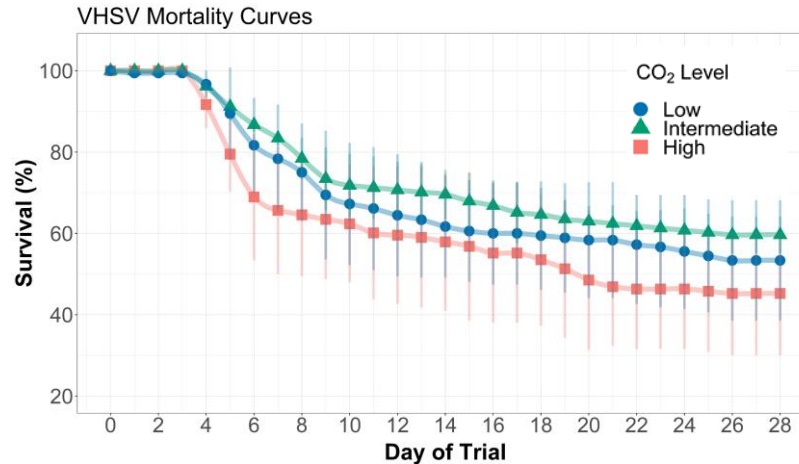


Fig. 1: Juvenile herring survival post-VHSV exposure. Colored shapes show daily mean survival percentages per  $\text{CO}_2$  treatment. Vertical lines denote  $\pm 1$  s.d.

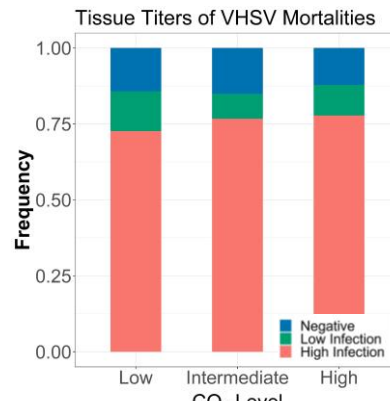


Fig. 2: The frequency of viral titers binned into three categories: fish negative for VHSV at time of death, showing low infections (<400 PFU  $\text{g}^{-1}$ ), and high infections (>400 PFU  $\text{g}^{-1}$ )

- Herring from all  $p\text{CO}_2$  treatment were susceptible to VHSV.
- Initial mortality rates 4-8 dpi slightly faster under high  $p\text{CO}_2$ .
- Second mortality wave (18-21 dpi) under high  $p\text{CO}_2$  hinted at a longer infectious period.
- However, no significant difference in survival at day 28.
- No difference in viral titers taken from tissues of VHSV mortalities.

## Growth & Critical Swim Speed

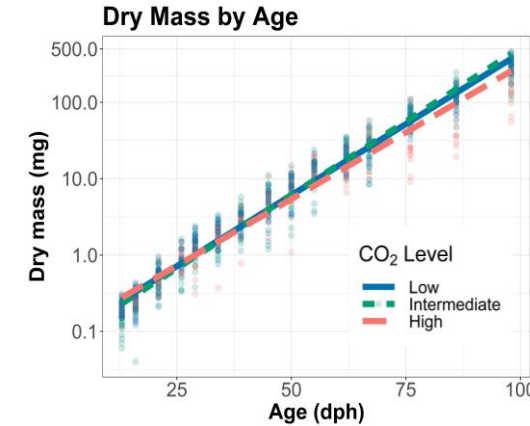


Fig. 3: Dry mass (mg) of fish sampled from 1 to 98 dph. Colored circles show individual fish. Colored hashed lines represent linear regression fits for log(dry mass) by age per  $p\text{CO}_2$  treatment.

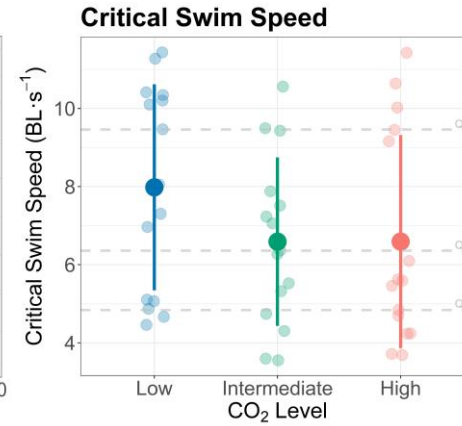


Fig. 4: Critical swim speed (scaled to body lengths per second) of juveniles measured between 90-105 dph. Large circles show treatment means and vertical lines denote  $\pm 1$  s.d. Small circles show individual fish. Horizontal dashed lines identify quartiles calculated on combined  $\text{CO}_2$  data.

- Long-term growth rate (dry mass) under high  $p\text{CO}_2$  showed a small (and not significant) reduction (-6.2%) compared to control fish.
- Juveniles from both elevated  $p\text{CO}_2$  treatments showed an average reduction in  $U_{\text{crit}}$  (scaled to body lengths per second) but high variability precluded a statistically significant result.

## Conclusions

- Juvenile Pacific herring were relatively tolerant to  $p\text{CO}_2$  levels 3x and 6x current spring/summer surface ocean conditions in the Salish Sea.
- Early life growth was largely insensitive to  $p\text{CO}_2$  level.
- A general trend of slower critical swim speed under elevated  $p\text{CO}_2$ , with most poor performing individuals from high  $p\text{CO}_2$ .
- High  $p\text{CO}_2$  induced an increase in initial VHSV mortalities, but final survival was not significantly different between treatments.