Effect of short-term exposure to low pH and low dissolved oxygen on swimming performance in juvenile rockfish

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Introduction

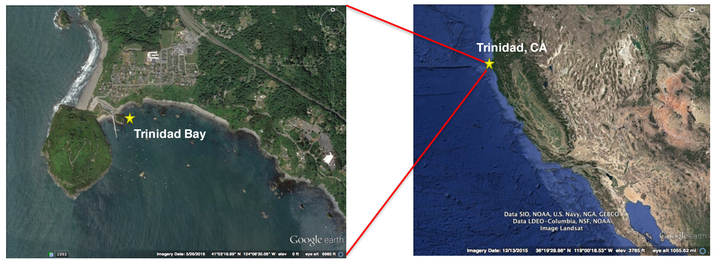


Figure 1. Juvenile rockfish collection site in Trinidad Bay, CA.

Upwelling in Trinidad Bay

It has been hypothesized that temperate reef fish in coastal upwelling regions might be more resilient to ocean acidification (OA) and hypoxia, having evolved under natural exposure to low pH and dissolved oxygen (DO) during upwelling events. Yet, how these fish are affected by natural variability in pH and DO over short time scales remains poorly understood, as do the effects of longer term trends in pH and DO driven by climate change.

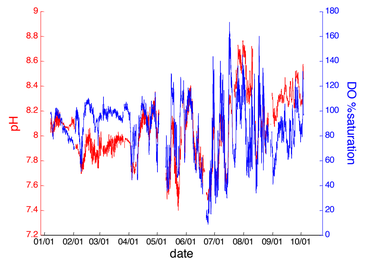


Figure 2. Example of coherent fluctuations in pH and dissolved oxygen observed during 2011 at Trinidad Wharf (near collection site indicated in Figure 1). Note for example, simultaneous decline in pH and DO during strong upwelling in mid-to-late June Data collected and processed with support from the Central and Northern California Ocean Observing System (CeNCOOS; www.cencoos.org).

Ecological Significance of Rockfish

- Rockfish (*Sebastes spp.*) comprise numerous ecologically and economically important species in Northern California.

Sebastes caurinus

Figure 3. Juvenile copper rockfish collected from Trinidad, Bay, California.

Critical Swimming Speed

- Critical swimming speed (Ucrit) is a measure of swimming performance that integrates speed and endurance.
- Scaled to body length, Ucrit can be used to compare relative swimming performance among fishes of differing body lengths (Kashef et al 2014).

Research Question

What is the effect of short-term exposure to low pH and low dissolved oxygen, typical of that expected during the onset of strong upwelling, on swimming performance of juvenile rockfish?

Hypotheses

- Short-term **exposure to low pH** will result in a **decline in Ucrit.**
- Short-term **exposure to low DO** will result in a **decline in Ucrit**.
- Short term **exposure to pH and DO** will result in a strong **decline in Ucrit.**

Methods

Materials

- pH and DO treatment tanks
- swimming flume (Loligo Systems model 10)
- digital flow meter
- digital pH meter
- CO_2 and nitrogen tanks
- stopwatch
- flashlight
- data sheets

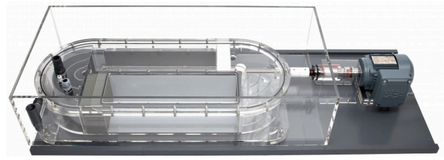


Figure 3. Model of swimming flume.

Swim Flume Design

The flume is a 10 L respirometer with a 400 L buffer tank. The respirometer contains a Plexiglas swim chamber (70×20×20 cm) that sits in a large water bath to maintain water temperatures at 11-12 C. Flow rates are adjusted by increasing power to a motorized water pump

Treatments

- control (pH ~8.0, 100% O_2 saturation)
- low pH (pH ~7.5, 100% O_2 saturation)
- low dissolved oxygen (pH ~8.0, 50% O_2 saturation)

Data Collection and Analysis

1. Calibrate swimming flume using digital flow meter.
2. Measure total length of fish. Calculate flow speed per bodylength increment using swimming flume calibration data.
3. Following acclimation to lab conditions, expose fish to treatment conditions for intervals of 0 (control), 1, 2, 4, 8, or 24 hours.
4. Measure the pH, DO, and temperature of treatment water in the swimming flume.
5. Place fish into the swimming flume at a flow speed of ½ bodylength/s and give 10 minutes to acclimate.
6. Following acclimation to treatment conditions, increase flow speed by one body length per second every 2 minutes.
7. End the trial when the fish becomes fatigued (can no longer maintain swimming position for entire 2 minutes) and record the time the fish spent swimming at the highest flow speed.
8. Ucrit = (penultimate speed + final speed*fraction of final period endured)/body length
9. Data analyzed using generalized additive models (GAMs; package mgcv in R; Wood 2006).

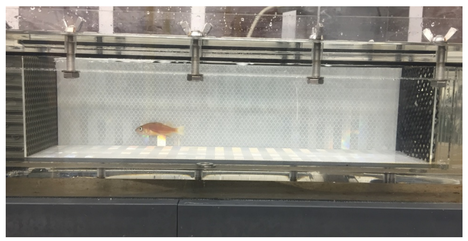


Figure 5. Juvenile rockfish during critical swimming speed trial.

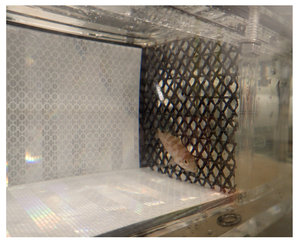


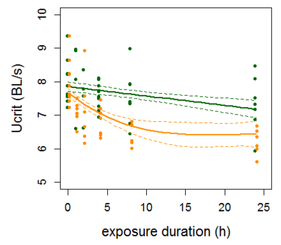
Figure 6. Juvenile rockfish at fatigue.

References

Wood, S.N. (2006) Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC.; Kashef, Neosha S., et al. (2014) Ontogeny of critical swimming speeds for larval and pelagic juvenile rockfishes (Sebastes spp., family Scorpaenidae). *Marine Ecology Progress Series* 500: 231-243.

Results

Ucrit v. pH exposure



Ucrit v. DO exposure

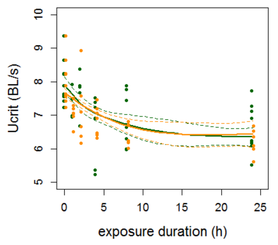


Figure 7. Left panel: response of Ucrit over exposures of varying length to pH 7.5. Right panel: response of Ucrit over exposures of varying length to DO 4.0 ml/l. Points indicate individuals' estimated Ucrit values. Solid lines indicate fitted relationship (dashed lines are +/-1 s.e.). Green indicates results for exposure to reduced pH (left panel) or DO (right panel) with the other parameter near ambient conditions. Orange represents simultaneous exposure to pH 7.5 and DO 4.0 ml/l.

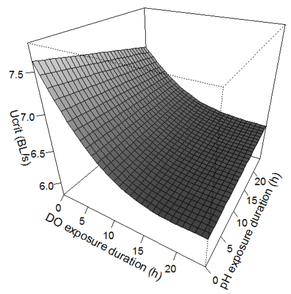


Figure 8. Joint effects of exposure to reduced pH or DO on Ucrit of juvenile copper rockfish. surface (dark mesh) +/- 1 s.e. (grey mesh). Note that fit is based on exposures to one stressor (along upper left, and lower left edges of surface) or to simultaneous exposure to both stressors (diagonal sloping across surface from peak at zero exposure).

Table 1. Summary of results from fitted GAMs (generalized additive models, accounting for individual length, and temperature, DO, and pH recorded during Ucrit trials.

Reduced DO exposure: Adj. R^2 = 0.306	Deviance explained = 35.1%
DO exposure	$p < 0.002$
Length, Temperature, pH	n.s.
Reduced pH exposure: Adj. R^2 = 0.131	Deviance explained = 22.6%
pH exposure	$p < 0.05$
DO	$p = 0.068$
Length, Temperature, DO	n.s.
Reduced pH and DO exposure: Adj. R^2 = 0.306	Deviance explained = 39.5%
pH and DO exposure	$p < 0.001$;
Temperature	$p = 0.069$
Length, DO, pH	n.s.

Conclusion

- Juvenile rockfish exposed to low DO showed a decline in uCrit that rapidly developed over short exposures (1-4 h).
- Juvenile rockfish exposed to low pH showed a weaker decline in uCrit, with effects developing over course of 24 h exposures.
- Effects of reduced DO on Ucrit dominate those of reduced pH.
- Swimming performance remains depressed over longer exposures, but it is possible that recovery from initial handling stress might partially offset continued declines in swimming performance.
- Insights from this study address the potential ecological effects of upwelling events, for these ecologically and economically important species, as well as the potential consequences of global ocean acidification predicted under ongoing climate change.

Acknowledgements

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