Why the Strait of Georgia is not a Dead Zone

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Google Earth has awarded the Strait of Georgia a dead fish.

Based on Diaz classification:
Eutrophic, hypoxic, dead zone

http://www.vims.edu/research/topics/dead_zones/
Nutrient concentrations are high in the Strait, but not due to local human activities.

Sutton et al., in press, Biogeosciences
Dissolved oxygen is declining in coastal seas around the world.

- imported from open ocean
- warming
- local discharge of wastewater / agricultural runoff (eutrophication)
$O_2$ has declined in the Strait of Georgia since the 1970s.

Oxygen was sometimes lower 1951-1970 than in 1980s.
Thresholds of Tolerance

Johannessen & Macdonald, 2009, Climate Research
Adapted from: Vaquer-Sunyer & Duarte 2008. PNAS
and Gilbert et al. 2007 Le Naturaliste Canadien
Seasonal oxygen profiles (2001-2009)
Deep Juan de Fuca Strait hypoxic seasonally
Deep SoG approaches hypoxia

[O_2] conversion: 
1 mL/L = 45 μmol/L
Assess seasonal and short-term variability in oxygen
Using moorings
Moorings 2008-2012

- sediment traps
- fluorometer
- Seabird CTD
- RCM current meter
- Sonde $O_2$
- ADCP
- RCM current meter
- RBR $O_2$ and pH
- Anchor (train wheel)

- 50 m
- 51.6 m
- 53.2 m
- 150 m
- bottom +50 m
- bottom +12.6 m
- bottom +10 m
- 310 m
The concentration of oxygen at 300m at the northern and southern moorings, April 2009 – November 2011

followed by
diffusive mixing: eddy
coeff. $1.1 \times 10^{-3}$ m$^2$s$^{-1}$
Masson, 2002, ECSS

Johannessen et al., in press, Limnology and Oceanography
Why the Strait of Georgia is different from the Gulf of Mexico...

Johannessen et al., in press, Limnology and Oceanography
Possible explanations for $O_2$ decline

*Increased $O_2$ Drawdown within the Strait of Georgia*
Higher influx from coast due to wastewater, pulp mills etc.
Higher Productivity (respiration)
Higher proportion fluxes to bottom (grazing mismatch)
Enhanced $O_2$ drawdown at bottom of SofG because of warming/microbial activity (benthic demand)

*Decreased $O_2$ in incoming water*
  Increased T
  Decreased mixing in Haro Strait
  $O_2$ decline in upwelled source water
Is the flux of organic C into the Strait increasing?

An increase of about 40\(g\ C/m^2/\text{year}\) required over 40 years at 200m depth

- Municipal wastewater: \(\sim 2 \ gC/m^2/\text{year total...}\) at the surface
- Pulp mills reduced biochemical \(O_2\) demand by 88% over 1990s

Increased organic C flux from local discharges cannot explain the decline in \(O_2\).
Primary production and remineralization

Primary production: \(~ 280 \text{ gC/m}^2/\text{year} \) (Harrison et al., 1983)… at the surface.

But \(~96\% \) organic matter remineralized before reaches bottom

An increase of \(40 \text{ gCm}^{-2}\text{yr}^{-1}\) at 300 m implies an increase of \(~1000 \text{ gCm}^{-2}\text{yr}^{-1}\)

Increased primary production inside the Strait of Georgia cannot explain the decline in O\(_2\).
The concentration of oxygen in upwelled water at 125 m at the mouth of Juan de Fuca Strait (in summer) has decreased at **0.02 mL/L/year** since 1978.
The concentration of oxygen in upwelled water at 125 m at the mouth of Juan de Fuca Strait (in summer)

Extremely low $O_2$: Leverage almost gone
Model: Anoxic Juan de Fuca inflow would reduce deep SoG $O_2$ to $\sim 2$ mL/L

Johannessen, Masson and Macdonald, submitted
Conclusions

1. Deep-water renewal, tidal mixing and diffusion largely govern the concentration of oxygen in the deep Strait. (balance with remineralization)

2. Dissolved oxygen is declining in the deep Strait of Georgia, due to decline in upwelled source water, and is approaching biological tolerance thresholds.

3. Even if source water becomes anoxic, the deep Strait of Georgia likely will not because of mixing in Haro Strait.

The Strait of Georgia is not a Dead Zone and is unlikely to become one.
## Acknowledgements

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<th>Field and lab</th>
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The officers and crew of the *CCGS Vector*; the community who collected long-term data

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