Two mechanisms of low oxygen stress to Hood Canal biota and their associated areas of risk

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In Hood Canal, there are two different types of oxygen stress that a marine organism may encounter, episodic and chronic. These types of stress, which will be explained more fully below, are driven by different mechanisms. The two figures below reflect where in Hood Canal the potential is greatest for each type of stress, as revealed by HCDOP-IAM data and analyses.

Oxygen is needed for most all animal forms of life, including aquatic organisms such as fish and shellfish. When oxygen concentrations fall below 3-5 mg/L, many marine organisms experience stress and fish may exhibit avoidance behavior. Other organisms, especially benthic forms, are more resistant and do not incur stress until concentrations are lower. When concentrations of oxygen fall to 1-2 mg/L, some organisms will experience severe stress or die. Anoxic conditions (no oxygen) can be inhabited only by some forms of bacteria.

Figure 1. Map of Hood Canal showing areas where risk of exposure to episodic low oxygen conditions caused by wind-mediated upwelling is greatest. Intensity of yellow indicates where deep water rises to surface most effectively during southerly wind events. This indicates where highest risk of biota stress and mortality due to episodic wind-driven low oxygen events occurs. Source: M. Kawase (UW) HCDOP model results and D. Gombert (WDFW) projection.

Figure 2. Map of Hood Canal showing areas where risk of exposure to chronically low oxygen is greatest. Intensity of red indicates where lowest oxygen concentrations are found, based on August 2006 measurements reflecting the typical pattern. This indicates where highest risk of biota stress and mortality due to chronic exposure to low oxygen occurs. Source: HCDOP Citizen Monitoring data and UW Spatial Analysis Lab projection.
Episodic: One type of oxygen stress observed in Hood Canal is the episodic fish kill event. Such events are often associated with the sudden appearance of dead fish and other marine life on beaches. Fish kill events have been recently recorded in the falls of 2002, 2003, 2004 and 2006 and spring of 2003. While the severity and dynamics of these events has varied, these typically occur in late summer to fall and are associated with processes that bring deep low-oxygen water to the surface. Upward movement of the oxygen minimum zone can be gradual, due to intrusion of newer, denser ocean water at depth or more rapid, due to southerly winds that push the surface layer in the mainstem of Hood Canal northwards, resulting in upwelling of deeper waters. Most of the fish kill events were documented with southerly winds.

To assess where risk for this type of oxygen stress is greatest in Hood Canal, output from the HCDOP IAM hydrodynamic model by Dr. Mitsuhiro Kawase (UW) is used to show where wind induced upwelling would be most effective in bringing deep water to the surface. This is seen in Figure 1 as where the change in surface salinity before and after the wind event is the greatest (yellow shading) indicating where wind-induced upwelling brings high salinity, low oxygen waters to the surface.

The major fish kill event in September 2006 was associated with southerly wind bursts after a long period of northerlies. The severity of the 2006 event was increased because offshore coastal ocean upwelling had contributed high density seawater to Hood Canal during the late summer. This intrusion displaced the deep water of the canal upwards, pushing low oxygen water to relatively shallow depths. WDFW divers led by Wayne Palsson noted more fish higher in the water column than usual prior to the fish kill event and the southerly wind bursts. Because the oxygen minimum zone was so shallow in 2006, the system was particularly poised for wind-induced upwelling to bring low oxygen water all the way to the surface. Fish essentially lost their shallow refuge as the entire upper water column became very low in oxygen. Underwater videography by WDFW captured this episodic condition.

Chronic: The other type of oxygen stress observed in Hood Canal is less obvious from the surface. It is the chronically low oxygen that worsens with distance from the mouth (north of Bangor) to the head of Hood Canal (in Lynch Cove). Risk for exposure to this type of oxygen stress is shown by the pattern in Figure 2, based on minimum oxygen concentrations measured during August 2006 at the sea-bed by the HCDOP-IAM Citizen Monitoring Program, led by the Hood Canal Salmon Enhancement Group and the Skokomish Tribe. This spatial pattern is consistent with that shown from previous historical and current data collected by UW (Collias et al., 1975; PRISM data at [http://www.psmem.org](http://www.psmem.org)) and Washington Department of Ecology PSAMP monitoring (e.g., Newton et al., 2002).

What has appeared to change is the persistence of how long oxygen remains below 3 mg/L in the southern Hood Canal and Lynch Cove areas (see [http://www.hoodcanal.washington.edu](http://www.hoodcanal.washington.edu)). Because the oxygen concentration stays so low (annual range at Lynch Cove sea-bed can be as little as 0-3 mg/L; HCDOP-IAM data), fish do not get caught suddenly in low oxygen waters, die and wash ashore, as they do in the episodic events. Rather, the species existing in these areas have either adapted to low oxygen conditions or have found a stable refuge in the surface waters.

It is within these chronically low oxygen waters that the Skokomish Tribe observed dead organisms, such as crab, and widespread bacterial mats during the summer of 2006.
Comparison: At times, both episodic and chronic low-oxygen waters comprise large areas in Hood Canal. However, it is important to note that low-oxygen stress from the episodic events is confined to lasting days to several weeks, whereas stress from the chronic conditions persists mostly throughout the year.

While the mechanisms involved and the areas for risk from these two types of oxygen stress are somewhat different, there is a relation between the two. An increase in the persistence of chronically low oxygen or a decrease in minimum oxygen concentrations will increase the odds that episodic wind-driven events will result in biota death. While the natural factors of wind-driven upwelling and oceanic intrusions facilitate the episodic events, if oxygen concentrations were higher, biota mortality would be less or not occur at all.

The reason why oxygen concentrations are so persistently low in Hood Canal and how or if humans are contributing to this is the topic of ongoing and active research in the HCDOP-IAM study. Funding for the study is primarily federal through Congressman Norm Dicks, with leveraged funds and resources from tribal, Washington state, local, and other sources.

Further details of the study are at http://www.hood canal.washington.edu)