Explanation of thresholds used on Baynes Sound Ecosystem Monitoring

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The effects of some environmental parameters on the physiology of marine organisms have been the object of study for decades, and the particular effects of temperature, pH, and calcite saturation are an active area of current research. However, even with the insight provided by physiological research studies, the definition of clear environmental thresholds with predictable physiological effects is complex.

The Pacific Oyster (*Crassostrea gigas*) is considered to be a thermotolerant species, or a species capable of tolerating a wide range of temperatures without suffering physiological stress. However, temperatures that can be considered physiological extremes of 25 – 30 °C are known to stress some populations of *C. gigas* (Le Gall and Olivier 1988, Bougier et al. 1995). These temperatures do periodically occur in summer months in the Salish Sea.

Independent of organismal physiology, long-term observations of seawater temperature lend themselves to definitions of extremes or anomalies as a method of discerning from typical conditions (Hobday et al. 2018). In Baynes Sound, daily surface temperature observations have been collected at the Chrome Island lighthouse since January 1961 (available through Fisheries and Oceans Canada). Despite being 8 kilometres apart, daily temperature measurements from Chrome Island show good agreement with the five minute averaged temperature data from Fanny Bay Oysters (Figure 1). Therefore, we use statistics derived from the long-term Chrome Island temperature record (Jan-1961 to Nov-2019) to identify marine heatwaves (anomalously warm) and coldwaves (anomalously cold) in the Fanny Bay Oysters temperature record. While these events may be extreme compared to historic conditions on any given day of the year, it should be noted that anomalous seawater temperatures do not necessarily indicate that temperatures are at the extreme high or low

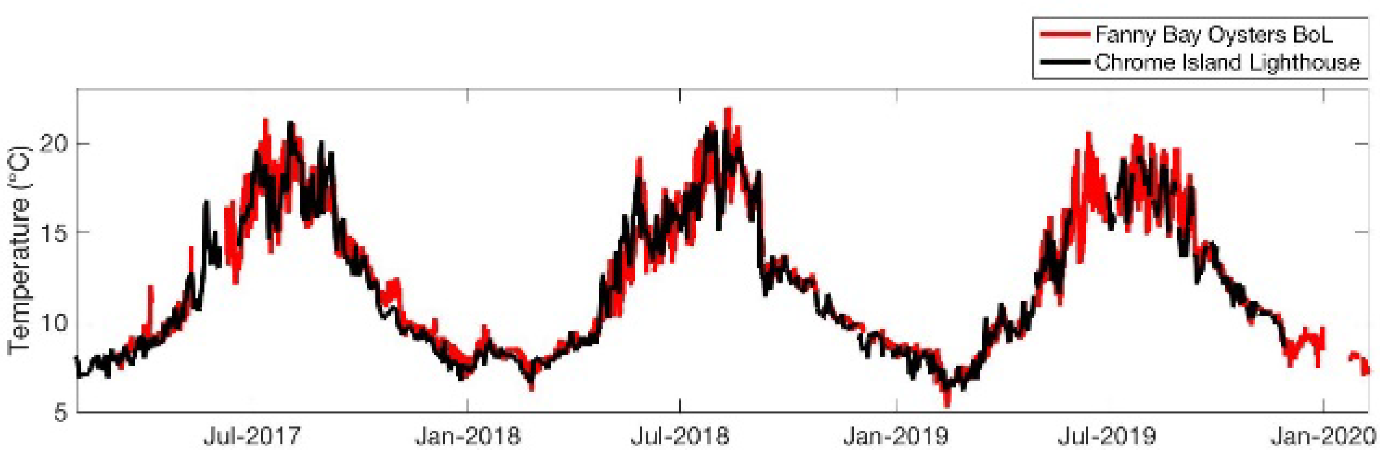

Figure 1. Daily measurements of surface seawater temperature made at Chrome Island Lighthouse compared to five minute averaged temperatures from the Burke-o-Lator (BoL) installed at Fanny Bay Oysters in Baynes Sound, BC.

end of the relatively thermally tolerant *C. gigas* oyster. For example, an extreme marine heatwave in winter is likely not at the upper thermal range of *C. gigas* in the same way as anomalous warmth at the peak of summer.

The biological thresholds applied for both pH and calcite saturation state (Ω_{Ca}) have been identified in carefully controlled laboratory experiments. Based on the total hydrogen ion concentration scale, we chose a threshold of pH < 7.69 because it corresponds to acute developmental effects on euphausiid early life stages (McLaskey et al., 2016). Euphausiids are a type of zooplankton krill at the base of many marine food webs, including many ecosystems in the Salish Sea. Though more research is needed, adult Pacific oysters seemed to display altered metabolism after being exposed to slightly lower values. For instance, exposure to pH < 7.63 for a month caused proteomic changes and disrupted calcification resulting in fragile and brittle shells (Timmins-Schiffman et al. 2014), and persistent exposure to pH < 7.5 for several months causes vast metabolic changes (Lannig et al. 2010).

For Ω_{Ca}, the thresholds chosen correspond to both biological and thermodynamic conditions. When $\Omega_{Ca} > 1$, calcification is thermodynamically favorable, resulting in less energy spent by oysters in producing their shell. However, oysters can still produce a shell under non-favorable conditions albeit at a considerable energetic cost. We have identified a possible acute threshold at $\Omega_{Ca} < 0.4$ when the energetic cost of calcifying is no-longer sustainable and calcification is net zero based on published work on adult Pacific oysters (Gazeau et al. 2007) and on juvenile Eastern oysters (Waldbusser et al. 2011).

While these laboratory studies are suggestive, many factors play a role in determining the ultimate effect of environmental stressors on growth, survival, or reproductive success. These factors include the duration of the exposure to stressful environmental conditions, the magnitude of the exposure (or how detrimental the environmental conditions are), the number of repeat stressful events, and the occurrence of multiple environmental or biological stressors simultaneously.

Given the confounding effects of such factors, the thresholds displayed within CIOOS Pacific are considerations that stakeholders may consider, but are not definitive of biological response. These thresholds will be updated as new observational and experimental results become available.

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