Ecosystem thresholds in surface waters of the Salish Sea using continuous measurements from ferry sensors

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INTRODUCTION

Surface waters are the nexus where organisms, humans, and pollution interact. Yet, surface waters are variable and quickly respond to land, climate, and human impacts. To better understand and predict water quality and ecological processes throughout Puget Sound, the Washington State Department of Ecology has sought creative approaches to collecting cost-effective and representative near-surface water quality data. In 2009, we partnered with Clipper Navigation to understand spatial gradients, variability, and seasonal dynamics of impacted surface water quality.

Ferry Monitoring a collaboration with Clipper Navigation, Inc.

- Collaboration started in May 2010 on MV *Victoria Clipper IV*
- Travels between Seattle and Victoria, BC
- Cost-effective data collection
- 100-m spatial resolution (5 sec)
  - 4-hr temporal resolution
- Regular schedules, reliable
  - 80-mile long transect at 35 mph
  - 1-2 times daily year-round
- Daily NetCDF data files available on Digital Ocean via telemetry

MV *Victoria Clipper IV*

Parameters	Sensor	Start Date
Fluorescence (chlorophyll *a*)	Turner Designs C3	May-2010
Temperature	Turner Designs C3	May-2010
Salinity	Citadel TSNH	Apr-2012
Colored dissolved organic matter (CDOM)	Turner Designs C3	May-2010
Turbidity	Turner Designs C3	May-2010

Table 1. Variables measured by the Victoria Clipper.

VICTORIA CLIPPER FERRY MONITORING

Since May 2010, we've collected continuous, high-frequency water surface measurements along a transect crossing the Salish Sea from 47.5° to 48.5 °N. Measurements are made using oceanographic sensors aboard the *Victoria Clipper IV* passenger ferry during twice daily runs between Seattle, WA. and Victoria, BC, Canada. The sensors measure geo-referenced chlorophyll *a*, turbidity, colored dissolved organic matter, salinity, and temperature. These observations record key surface indicators that delineate spatially and temporally varying features such as water masses, river plumes, and algal blooms (Fig. 1).

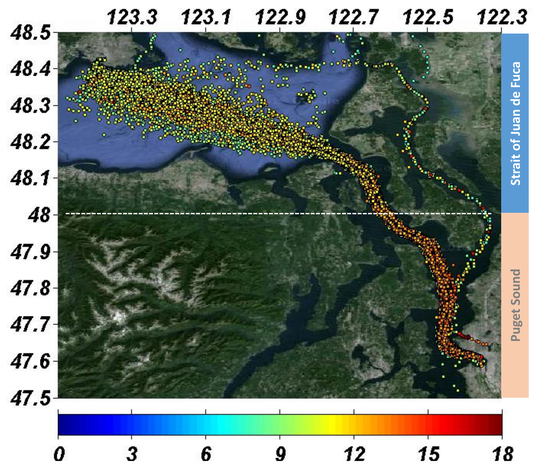

Fig. 1.
Temperature measurements collected via transect.
(1% of all observations collected May, 2010 – Oct., 2015 shown.)

TIMING OF KEY TEMPERATURE CHARACTERISTICS

Temperature is an important structuring factor of ecological processes in temperate coastal seas. The timing and transition of temperature thresholds or isothermal conditions are markers for seasonal cycles for many species and processes that are relevant to ecosystem functioning. Specific surface isotherms along the ferry transect can provide context for species and their vulnerability to undesirable conditions. Isothermic surface water (8-9° C) during the winter months (Fig. 2) give way to temperature gradients across Admiralty Reach (dotted line) in spring around April and initial warming in Puget Sound south of 48° N. Timing of this transition varies from year to year, depending on large-scale climate conditions.

The 13° C isotherm is a recognized threshold which depicts significant changes in ecosystem functioning and depicts upper temperature limits for marine waters designated as extraordinary quality, protective of fish and shellfish migration, rearing, and spawning (Sullivan et al., 2000, WAC 173-201A). It also is a reported threshold for toxicity in shellfish as well as accelerated growth and toxicity of developing harmful algal blooms species (Moore et al., 2015). Typically the 13 °C isotherm appears in mid-May (purple – Fig. 2), but during a strong La Niña event in 2011, the transition occurred later in June.

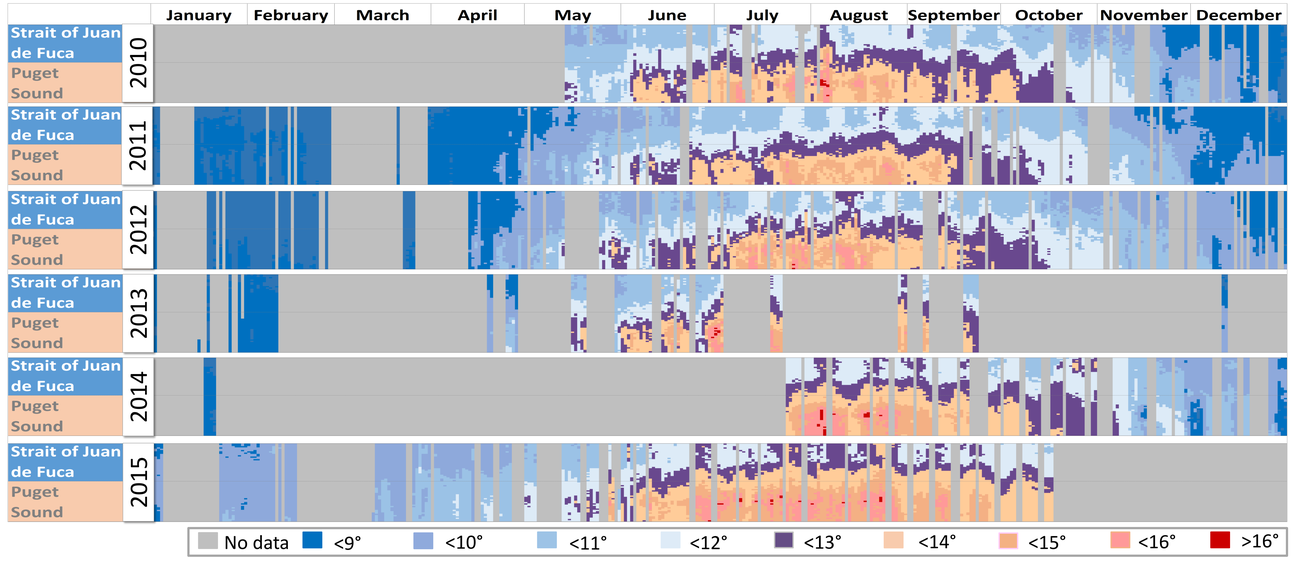

Fig. 2. Isotherms along the north to south ferry transect for 2010 - 2015. In the winter, surface conditions are isothermic, typically around 8-9 °C. The timing of the transition to warmer surface conditions varies from year to year, depending on climate conditions. The 13° C isotherm (purple) appears in the spring, typically in May. During summer, strongest temperature gradients persist from south to north across Admiralty Reach and, at times, extend into the Strait of Juan de Fuca.

SPATIAL EXTENT OF KEY TEMPERATURE CHARACTERISTICS

In 2014-2015, the eastern Pacific sea surface temperature anomaly (the "Blob") entered the Salish Sea on a massive scale, affecting the spatial and temporal temperature structure of the Salish Sea. In the winter of 2014-2015, surface water did not cool to 8-9 °C, and temperature gradients persisted between Puget Sound and the Strait. In summer of a normal year, the 13 °C isotherm (purple) remains within Puget Sound, extending just past the entrance at 48° N. In the summer of 2015, waters at the entrance reached 14 °C, with the 13 °C isotherm warm anomaly extending across the entire Strait of Juan de Fuca and persisting for most of the year (Fig. 2).

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