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Long-term water quality monitoring trends and drivers of change in marine and fresh waters of the Swinomish Reservation, WA

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Background

- Analyses focused on surface water quality (SWQ) data collected on the Swinomish Indian Tribal Community Reservation (Fig. 1).
- Swinomish Reservation is surrounded on all sides by marine waterbodies that are fed by small creeks and the North fork of the Skagit River on the southeast side.
- Fish and fish habitat are crucial to the cultural, spiritual, subsistence, and commercial activities of the Swinomish Tribe.
- SWQ monitoring started in 1997 at several sites and additional sites have been added over time. Currently monitored sites include (Fig. 2):
  - Five freshwater creeks draining into the Swinomish Channel, Kiket Bay, and Skagit Bay.
  - North Fork of the Skagit River as it drains into Skagit Bay.
  - Marine water sites in the Swinomish Channel, Padilla Bay, Turner's Bay, Similk Bay, Kiket Bay, and Skagit Bay.
  - Network of sites in the sloughs of the agricultural lands in the northeast portion of the Reservation.

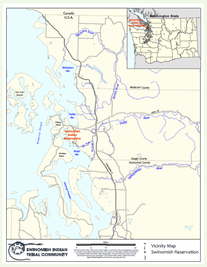

Figure 1. Swinomish Indian Tribal Community Reservation location.

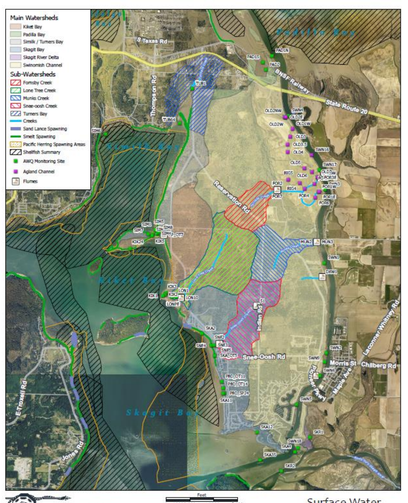

Figure 2. Current SWQ monitoring sites.

Nonparametric Statistics

- All analyses were run on pH, dissolved oxygen (DO), temperature (temp), salinity, turbidity (turb), and fecal coliform (fecal) bacteria data.
- Seasonal Mann-Kendall for long-term trend analysis and Kruskal-Wallis test with post-hoc Conover-Iman test for comparisons between sites (data through 2016).
- Correlation analyses were used to test multi-collinearity and determine highly correlated variables to exclude from regression models (data through 2018).
- Regression analyses (data through 2018): Generalized additive models (GAM) for single response variables and up to 20 explanatory variables to help identify contributors to changes over time, including variables to highlight possible weather and climate influences on SWQ response variables.

Results Summary

- Increasing DO at all creek sites (Fig. 4) and decreasing in Kiket Bay (Fig. 6). DO commonly influenced by temp, bacteria, wind direction, and season in these waterbodies. Increases in bacteria correlated with decreasing DO at many sites (Table 1).
- Bacteria and turb increases at intermittent Lone Tree Creek (Fig. 4), Kiket, Similk, and Turner's Bays (Fig. 6). Between the three perennial creeks, Munks had the lowest nutrients and turb (Fig. 4). Turb commonly influenced by pH, discharge, nutrients, and wind direction in freshwater, and temp in all waterbodies (Table 2).
- Bacteria commonly influenced by temp on the West side of the Reservation, nutrients in the creeks, and turb, precip, wind direction, and season in all waterbodies (Table 3).
- Swinomish Channel salinity was higher in the north than in the south and turbidity was higher in the south than in the north (Fig. 5). Similk and Turner's Bays had increasing temp (Fig. 6).

Trend & Site Comparison Results

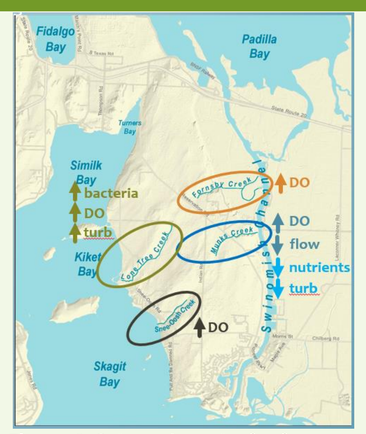

Figure 4. Selected results for four creek sites. Significant trends (dark blue) and site comparisons (light blue) at Munks.

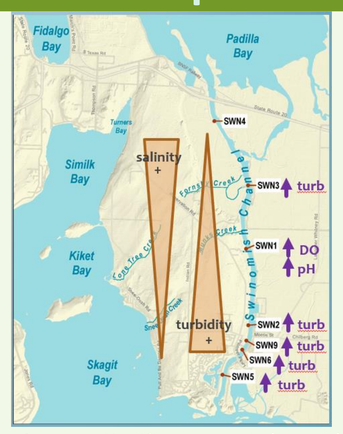

Figure 5. Significant trends (purple) and site comparisons (gold) for the Swinomish Channel.

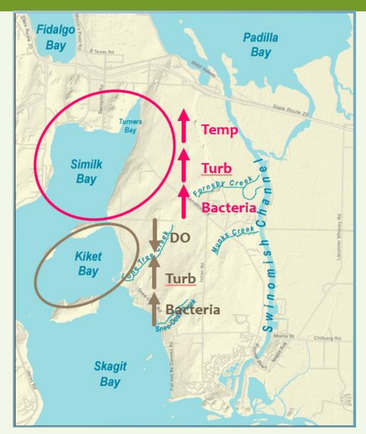

Figure 6. Significant trend results for Kiket, Similk, and Turner's Bay.

Regression & Correlation Results

Table 1. Dissolved oxygen (DO) response variable with significant explanatory variables that influence DO levels. Focus area in Kiket Bay, Lone Tree Lagoon (LT Lagoon), Lone Tree Pocket Estuary (LONPE) and the freshwater creeks.

	Dissolved Oxygen Response, Explanatory Variables (full model for creeks)												*Nutrient models (additional variables)*			
Location	**ph**	**temp**	**salinity**	**turb**	**fecal**	**discharge**	**precip**	**wind speed**	**wind direction**	**ozone**	**solar rad**	**season**	**Ortho-phosphate**	**TKN**	**Ammonia**	**Nitrate**
North KIK	Positive	Positive	Negative					Positive	Negative (WSW high)		Positive	Negative (Q4 low)				
South KIK	Positive	Negative	Negative	Positive					Negative (N/SSE high)							
LT Lagoon	Positive	Negative			Negative	Positive		Positive	Negative (WSW high)			Negative (Q4 low)				
LONPE		Negative	Negative	Positive	Positive	Positive		Positive	Positive (WSW high)	Positive	Positive	Negative (Q3/4 low)				
LON1	Negative	Negative	Negative		Negative		Negative	Positive				Negative (Q3 low)				
LON10					Negative											
SNE2	Negative	Negative		Positive	Negative			Positive	Negative (N/SSE high)		Negative	Negative (Q3 low)	Negative		Positive	
MUN2		Negative	Negative		Negative	Positive			Negative (SSE high)		Negative	Negative (Q3 low)	Negative*		Negative	
FOR2		Negative				Positive	Positive		Negative (SSE high)	Positive	Negative	Negative (Q3 low)	Negative*			

Table 2. Turbidity response variable with significant explanatory variables that influence turbidity levels in all areas of focus.

	Turbidity Response, Explanatory Variables (full model for creeks)												Nutrient models (additional variables)			
Location	**ph**	**DO**	**temp**	**salinity**	**fecal**	**discharge**	**precip**	**wind speed**	**wind direction**	**ozone**	**solar rad**	**season**	**Ortho-phosphate**	**TKN**	**Ammonia**	**Nitrate**
North SWN	Negative		Negative				Positive		Negative (SSE high)		Negative	Positive (Q2 low)				
Village SWN		Positive	Negative		Positive		Positive			Positive						
South SWN			Negative	Negative			Positive			Positive		Positive (Q3 high)				
Similk	Positive	Positive														
Turner's					Positive			Positive				Negative (Q3 high)				
North KIK			Positive	Negative	Positive					Positive						
South KIK		Positive						Positive								
LT Lagoon		Positive	Positive		Positive				Negative (SSE/WSW high)			Negative (Q3 high)				
LONPE	Negative	Positive	Negative	Negative		Positive	Positive	Positive	Negative (SSE/WSW high)	Positive						
LON1	Negative		Negative	Negative	Negative	Positive	Positive	Negative	Negative (SSE high)	Positive		Negative (Q3 low)				
LON10	Negative				Negative	Positive			Negative (N/SSE high)				Positive		Negative	
SNE2	Negative		Negative	Negative		Positive							Negative		Positive	Positive
MUN2	Negative	Positive	Negative	Negative	Positive	Positive	Positive	Positive	Negative (SSE high)		Negative	Negative (Q3 low)	Negative*		Positive	
FOR2	Negative		Negative		Negative	Positive	Positive	Positive	Negative (SSE high)		Negative	Negative (Q3 low)	Negative*		Positive	

Table 3. Fecal coliform (bacteria) response variable with significant explanatory variables that influence fecal levels in all areas of focus. (M2) indicates two models were run for this station and the results from the second model are reported.

	Fecal coliform Response, Explanatory Variables (full model for creeks)												Nutrient models (additional variables)			
Location	**ph**	**DO**	**temp**	**salinity**	**turb**	**discharge**	**precip**	**wind speed**	**wind direction**	**ozone**	**solar rad**	**season**	**Ortho-phosphate**	**TKN**	**Ammonia**	**Nitrate**
North SWN	Negative	Negative			Positive		Positive				Negative					
Village SWN		Negative	Positive	Negative	Positive		Positive	Positive		Positive	Positive	Positive (Q3 high)				
South SWN							Positive	Positive	Negative (SSE high)	Negative						
Similk							Positive		Negative (SSE/WSW high)							
Turner's		Negative									Positive					
North KIK			Positive		Positive		Positive				Negative	Positive (Q4 high)				
South KIK			Positive		Positive		Positive		Positive (SSW high)			Positive (Q3/4 high)				
LT Lagoon		Negative	Negative		Positive	Positive	Positive		Negative (SSE/WSW high)			Positive (Q3 high)				
LONPE	Positive		Positive	Positive	Positive			Positive		Positive	Positive	Positive (Q2 high)				
LON1	Positive		Positive	Positive	Negative	Negative	Positive	Negative	Positive (SSE/WSW high)	Negative		Positive (Q3 high)				
LON10 (M2)			Positive				Positive		Negative (SSE/WSW high)				Negative	Negative	Negative	
SNE2	Positive		Positive	Positive	Negative	Negative	Negative	Negative	Positive (SSE/S/SSW high)	Negative	Positive		Positive		Negative	Positive
MUN2	Negative			Neutral	Positive		Negative	Negative	Positive (SSE/WSW high)	Negative	Positive	Positive (Q3 high)	Positive*		Negative	
FOR2					Negative	Negative	Positive						Positive*			

Marine water
Freshwater
Significant in final GAM. Positive correlation: Response variable increases as explanatory variable increases.
Significant in final GAM. Negative correlation: Response variable decreases as explanatory variable increases.
Significant in final GAM. Neutral correlation: Correlation value of 0, flat line.
Not included in starting GAM model.
*Single regression, not in GAM model

Discussion

Wind:

- High SSE and WSW winds were often correlated with WQ changes.
  - SSE winds may indicate Skagit River influence and occur more frequently in winter/fall.
  - WSW winds may indicate greater marine climate influence and occur more frequently in the spring/summer.
- Creeks, LONPE, and Kiket Bay: *DO* influenced by wind direction at all sites except Lone Tree Creek (Table 2). DO also increased with increasing wind speed at many sites, suggesting mixing. SSE winds had higher *turb* values in freshwater, whereas WSW winds had higher turb values in marine waters, which could indicate unique seasonal influences on turb (runoff in fresh, algal in marine).
- *Bacteria* influenced by wind direction at many sites (Table 3). SSE and WSW winds had high bacteria values, indicating both precip and temperature influences on bacteria levels.

Precip/Discharge:

- Common influence of precip and discharge on *turb and bacteria* levels at many sites, indicating heavy influence of runoff on fresh and marine waterbodies.
- Freshwater creeks and LONPE *turb* increased with increasing *discharge* (Table 2).
- *Bacteria* was influenced by *precip* in most waterbodies (Table 3). *Temp* also influenced bacteria levels, especially at Lone Tree and Kiket Bay sites.
- *Turb* was positively correlated with *precip* in the Swinomish Channel (Table 2). Channel turb increased over the years at most sites, but significant increasing trends were more common in the south (Fig. 5). Differences between north and south may be related to Skagit River influence or elevated turb inputs from commercial activity runoff in the south.

Nutrients:

- Only collected in creeks, and difficult to include in all models due to high collinearity, but indications of influence on *turb* and *bacteria* in freshwater (Tables 2 and 3).
- Positive relationship between nutrients and turb may indicate algal sources of turb. Positive relationship between nutrients and bacteria indicate potential wastewater influence.
- Lone Tree Creek turb and fecal responses were often the opposite of the other creeks, which could indicate unique wastewater, stormwater, or fertilizer influences in this creek.

Next Steps:

- Results from these analyses and others are being used to update a Unified Watershed Assessment for the Swinomish Reservation to help guide long-term monitoring strategies, management, and future restoration projects.
- Ongoing analyses to inform the influence of weather and climate on WQ.

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