An Analysis of Salinity Stratification in San Juan Channel

Jesse Kruttschnitt[1]

Pelagic Ecosystem Function (PEF) Research Apprenticeship

Fall 2014

[1]Friday Harbor Laboratories, University of Washington, Friday Harbor, WA 98250

Contact information:

Jesse Kruttschnitt Jessekruttschnitt@mail.com

Abstract

The Salish Sea in an estuarine circulation system comprising of the Fraser River in Canada and the Pacific Ocean. Stratification in the San Juan Channel is variable by two very distinctly different means in the north and in the south of the channel. This study examined the variability of tidal forcing on the San Juan Channel. NANOOS archived data, 2004-2013 for the north channel and 2008-2013 for the south channel along with 2014 PEF data, was used to analyze salinity data values. A subsample was taken from the salinity data depending on the resulting standard deviations. Every subsample was then classified by being either flood-spring, flood-neap, ebb-spring, ebb-neap using a dyadic relationship. In the southern channel, there was a large saline intrusion at depth due to a Pacific Ocean exchange from tidal forcing during a flood cycle. The salinity in the northern part of the channel had variability that could not be explained through tidal height. When the standard deviations were very small, all four classifications were found to have very strong mixing throughout the water column in both the north and south of the San Juan Channel.

Introduction

The Salish Sea in an estuarine circulation system with its three major bodies of water comprising of the Strait of Georgia, The Strait of Juan De Fuca, and the Puget Sound. The San Juan Channel is one of three passageways, the Haro Strait and the Rosario Strait being the other two, which connects the Strait of Juan de Fuca and the Strait of Georgia (Fig 1). The Strait of Juan de Fuca is directly connected with the Pacific Ocean. Oceanic input found in the Strait of Georgia mainly comes the Strait of Juan De Fuca even though the Strait of Georgia has smaller inputs to the north (Masson 2002). A large fresh water input from the Fraser River into the Strait of Georgia completes the estuarine circulation. This connection defines the San Juan Channel as part of a greater estuarine circulation system.

Tidal forcing is defined by a semidiurnal tide cycle intrinsic of the region (Thomson 1994). Hydrostatic pressure draws less saline water into the San Juan Channel by pulling in sea surface traces from the Fraser River along with entrained seawater via the Strait of Georgia (Thomson 1994). Highly saline water flows into the system at depth from the Pacific Ocean to the Strait of Juan De Fuca. Tidal forcing drives this water into the San Juan Channel by the semidiurnal tide cycle.

The halocline is a change in salinity at depth, measured in psu (practical salinity units). Fresh water input from a surface source creates a less saline layer at the sea surface since fresh water is less dense than salt water. A well-mixed water column would make the halocline homogenous and not be very stratified. A large input of ocean water at depth would bring highly saline water to the bottom of the water column. The halocline can be measured in terms of standard deviation, dispersion from the average, as it relates to how much stratification the halocline shows. A well-mixed water column would have a halocline with very little stratification and have a small standard deviation. A small standard deviation looks like a vertically straight line graphically in this case. A water column with a high input of fresh water at the surface layer or a large input of highly saline water at depth would have a highly stratified halocline and have a very large standard deviation. A large standard deviation with fresh water input at the sea surface would be stretched from more saline water at depth to less saline water at the sea surface. A large standard deviation with highly saline water at depth would be stretched from less saline water at mid depth to more saline water at near bottom depth.

The underlying oceanographic process that is relevant to my study is tides. Tidal phases are defined by two factors in magnitude when relating to tidal height, spring/neap tidal phases and flood/ebb tidal cycles. Spring/neap tidal phases are related to the phases of the moon because the moon's gravitational pull affects the height of the water in the ocean basins. Spring tides have large exchanges that are due to a combined gravitational effort from the moon and the sun by being in line with each other and the Earth. Neap tides have smaller exchanges that are due to the moon not being in line with the sun and the earth which creates a lesser gravitational force on the ocean basins. Flood/ebb tidal cycles are the relationship of tidal height in respect to the mean sea surface height. When the tidal height is receding, it is ebb. When the tidal height is proceeding, it is flood.

This study examined the variability of tidal forcing on the San Juan Channel. Stratification in the San Juan Channel does appear to be variable by two very distinctly different means in the north and in the south of the channel. It is hypothesized that a large Fraser River exchange at the sea surface with tidal forcing going in a progressive direction is needed for the north to have a large stratification of salinity at the sea surface. A large exchange being a spring tidal phase and a tidal forcing direction being an ebb tidal cycle that would draw the fresh water south into the channel. It is hypothesized that a large Pacific Ocean exchange at depth with tidal forcing going in a northerly direction is needed for the south to have a large stratification of salinity at depth. A large exchange being a spring tidal phase and a tidal forcing direction being a flood tidal cycle that would push the more saline water north into the channel. Because this stratification does appear to be variable, this study also postulates when the stratification appears to be very small. It is hypothesized that a smaller exchange with tidal forcing going in a regressive direction in both the north and the south would equate to having very little stratification. A smaller exchange being a neap tidal phase and a regressive direction being a flood tidal cycle in the north and an ebb tidal cycle in the south.

This study used archived data from the Pelagic Ecosystems Function Research Apprenticeship program (PEF) at Friday Harbor Labs. The program has collected data from the San Juan Channel since 2004 and builds upon the work of its prior internships and other adjacent studies. In 2011, Katie Thomas, a PEF apprentice, looked at the seasonal and tidal effects on water density gradients in the San Juan Channel and in 2013, Jessica M. Thompson, also a PEF apprentice, looked at the annual and inter-annual patterns of physical oceanography properties in the San Juan Channel: effects of external drivers (Thomas 2011, Thompson 2013). These two studies were referenced in terms of their defining the external drivers of the study area. The constraints of this study is that all data herein is bounded by the availability of the vessel used by PEF to collect data and the complexity of the inputs and drivers that affect the San Juan Channel as a whole. To resolve some of these difficulties, this study only used data points of salinity and tidal height during the fall season, September-November, not adjoining local weather, wind, or greater inputs of fresh water patterns that may have occurred during the data point's years.

Methods

The Pelagic Ecosystems Function Research Apprenticeship program (PEF) at Friday Harbor Labs collected data from the San Juan Channel on the University of Washington's *R/V Centennial*. The program took fall seasonal data from September to November on a weekly basis, weather permitting. A five station transect, North, A, B, C, South, has been used in the program to take consistent, spatial weekly data (Fig 2). At each station, a Seacat Model SBE-19 CTD mounted on a rosette was cast by a data cord assemblage to take readings every 0.5 meters depth. The resulting water column that was measured at each station was the sea surface to about ten meters above the sea floor. The raw CTD data was stored using SBEDataProcessing software. The raw data was saved in hex file format and had to be changed to a CNV file format which Excel could then be used as an analysis platform per Jan Newton's S.O.P. Once the raw CTD data was extracted into Excel, Salinity and depth could be extracted for analysis. For every 0.5 meters depth, a corresponding Salinity reading was measured. Having the entire water column profiled this way, a standard deviation was applied to the halocline.

NANOOS, the Pacific Northwest regional ocean observing system at www.nanoos.org which stored archived data from the years of 2004-2013 for the North Station and 2008-2013 for the C Station, was used to extract salinity data values. Other programs were included in the archive, but were taken out of the final analysis as their sampling time was not during the fall season. Salinity and depth were analyzed for all years included in the archive for North and C stations. All the Salinity depth profiles were ascribed a standard deviation, variation from the average, over the whole halocline profile.

A subsample was taken from the salinity depth profiles depending on the resulting standard deviations. If the C Stations standard deviation was over 0.1 psu, it was large. If the North Stations standard deviation was over 0.3 psu, it was large. If the C stations standard deviation was less than 0.05, it was small. If the North Stations standard deviation was less than 0.05 psu, it was small.

The cast times of the CTD data was analyzed in two ways. By referencing the tidal height website, http://tbone.biol.sc.edu/tide/index.html, the cast time was able to be differentiated in the flood and ebb tidal cycle. If the cast time fell on blue, it was a flood. If the cast time fell on green, it was an ebb (Fig 3). The day of the cast was modeled in two week increments. The tidal phase could then be easily seen. If the phase had a large exchange during the cast, it was a spring tide. If the phase had a small exchange, it was a neap tide. If the cast was in-between, whichever phase drew nearest, was the phase it was ascribed (Fig 4). Every subsample was then classified by being either flood-spring, flood-neap, ebb-spring, ebb-neap using a dyadic relationship (Fig 5).

Results

Of the 80 C station casts from 2008-2014, 19 of them had standard deviations of greater than 0.1 psu (Fig 6) and 18 of them had standard deviations of less than 0.05 psu (Fig 7). The 19 casts of the C station with large standard deviations had (n=11) that were classified as Ebb-spring, (n=0) ebb-neap, (n=4) flood-spring, and (n=4) flood-neap (Fig 8). The 18 casts of the C Station with small standard deviations had (n=4) that were classified as ebb-spring, (n=6) ebb-neap, (n=4) flood-spring, and (n=4) flood-neap (Fig 9).

Because my methodology had a very binary approach, some results were skewed. Two data points, the casts of 10/11/09 and 10/18/11 had larger than average standard deviations. The average was around 0.15 standard deviations psu. 10/11/19 had a standard deviation of about 0.4 psu and 10/18/11 had a standard deviation of about 0.5 psu. By analyzing the cast times in relation to tide heights, these two casts were very close to a strong flooding cycle. Taken out of the data set, the graphs became more similar when these two dates were excluded (Fig 10).

Of the 120 North Station casts from 2004-2014, 27 of them had standard deviations of more than 0.3 psu (Fig 11) and 22 of them had less than 0.05 psu (Fig 12). The 27 casts of the North Station with large standard deviations had (n=5) that were classified as ebb-spring, (n=5) ebb-neap, (n=6) flood-spring, and (n=11) flood-neap (Fig 13). The 22 casts of the North Station with small standard deviations had (n=4) that were classified as ebb-spring, (n=6) ebb-neap, (n=4) flood-spring, and (n=4) flood-neap (Fig 14).

Discussion

The salinity depth profiles at C station that had a large standard deviation did not disprove the hypothesis that in order to have a large saline intrusion at depth from a large Pacific Ocean exchange, there needed to be tidal forcing going in a progressive direction, which in this case was a flood cycle. The strength of the exchange, whether spring or neap, would appear to not make any significant difference. The ebb-spring classification salinity depth profiles appeared to be standardized too by taking out two dates, 10/11/09 and 10/18/11 (Fig 10). These two dates had cast times that fell in the ebb cycle only slightly after a large flooding cycle. If the method of choosing was able to classify intermediate times in the spring/neap phase or the flood/ebb cycle, then certain cast time dates could probably be compared more closely than having some dates thrown out to standardize the graph. There were no ebb-neap large standard deviations in any of C Stations 80 casts from 2008-2014. This could be explained that in order to see any salt water intrusion at depth, there has to either be some kind of flood cycle, so the tidal forcing would be in a progressive direction, or a spring phase, where there was a large exchange at depth with some dispersion around the mean salinity could just be a residual effect from such a large exchange.

The salinity depth profiles at North Station that had a large standard deviation did not support the hypothesis. A large exchange in a progressive direction, in this case being an ebb tide, did not have the greatest standard deviations. The five salinity depth profiles that were classified with ebb-spring were similar to the graphs of the eleven that fell into the flood-neap category which would have supported the hypothesis. The five ebb-neap would support the hypothesis in only the respect that the tidal forcing would be in the progressive direction. The six flood-spring salinity profiles that were classified as flood-neap rejected the hypothesis. Flooding is in the regressive direction and a large exchange would infer that the entire water column would be more saline and not have a large stratification of less saline water at the sea surface. More than tidal forcing would have to be brought to bear on the explanation of this. Wind forcing or a larger than normal Fraser River input could explain why this categorization rejects the hypothesis.

The smallest standard deviation at North and C Station both rejected the hypothesis. Not seeing any stratification at the C station was hypothesized to have a very small Pacific Ocean Exchange, neap, with tidal forcing going in a regressive direction, ebb and not seeing any stratification at the North station was hypothesized to have a very small Fraser River exchange, neap, at the sea surface with tidal forcing going in the regressive direction, ebb, did not support the hypothesis. All four categories were found to have very strong mixing throughout the water column. There was no significant difference between flood-spring, flood-neap, ebb-spring, or ebb-neap.

In conclusion, this study was useful in the ability to explain stratification by way of tidal height. As prior studies in PEF and others colleagues who studied the region have pointed out, there are many physical drivers that manipulate the San Juan Channel water basin; tidal height is just one of them. By looking at all the data points, non-Fall casts, it could be hypothesized that there is no temporal factor in relation to inter-annual variability of the halocline in the north and south San Juan Channel. Other factors could attribute the supporting of the original hypotheses like using a broader approach to say whether the CTD was cast in a flood or ebb tide, referencing tidal speed, or the further study on the semidiurnal effects on the water column.

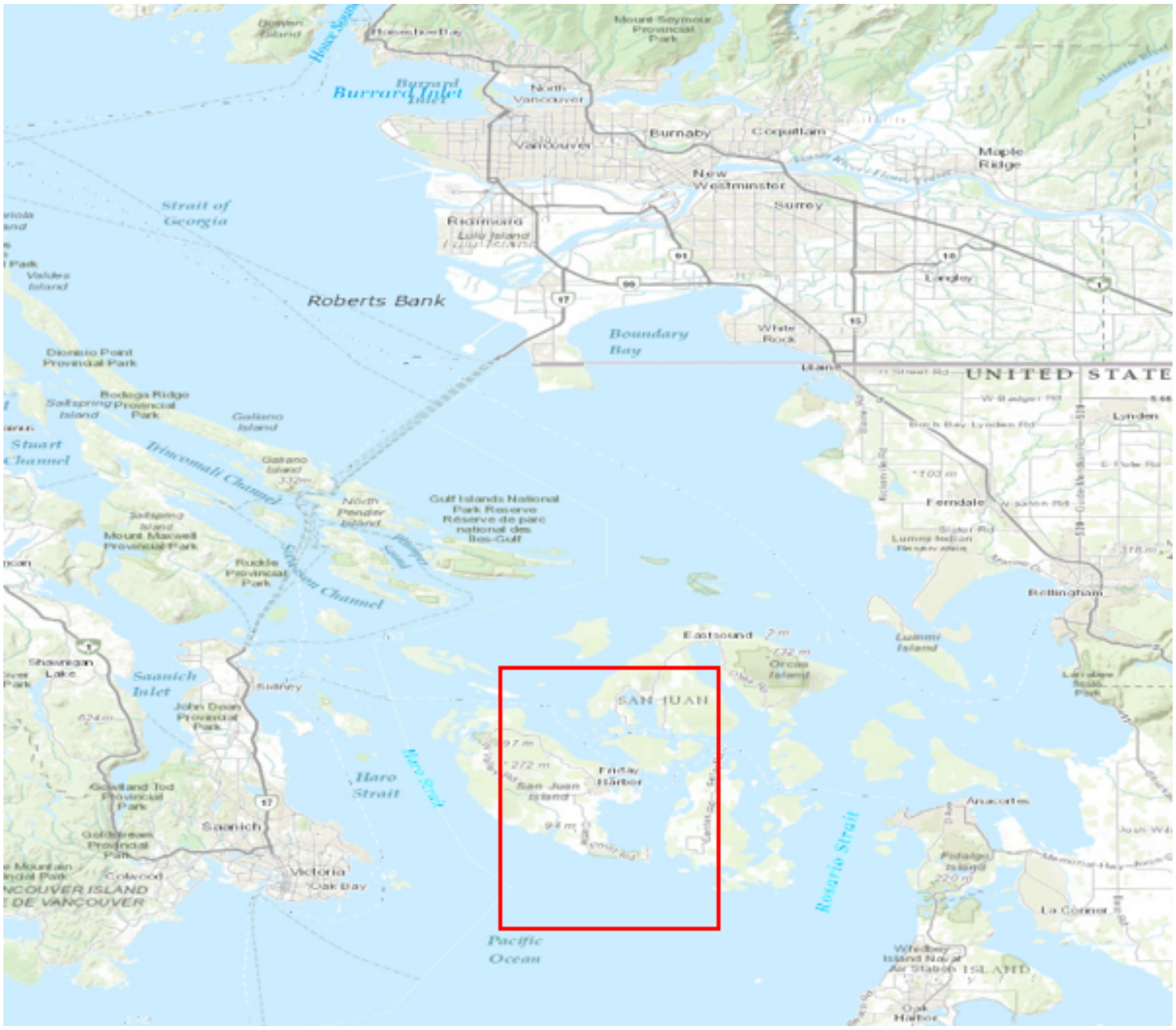


Fig 1. San Juan Channel study area

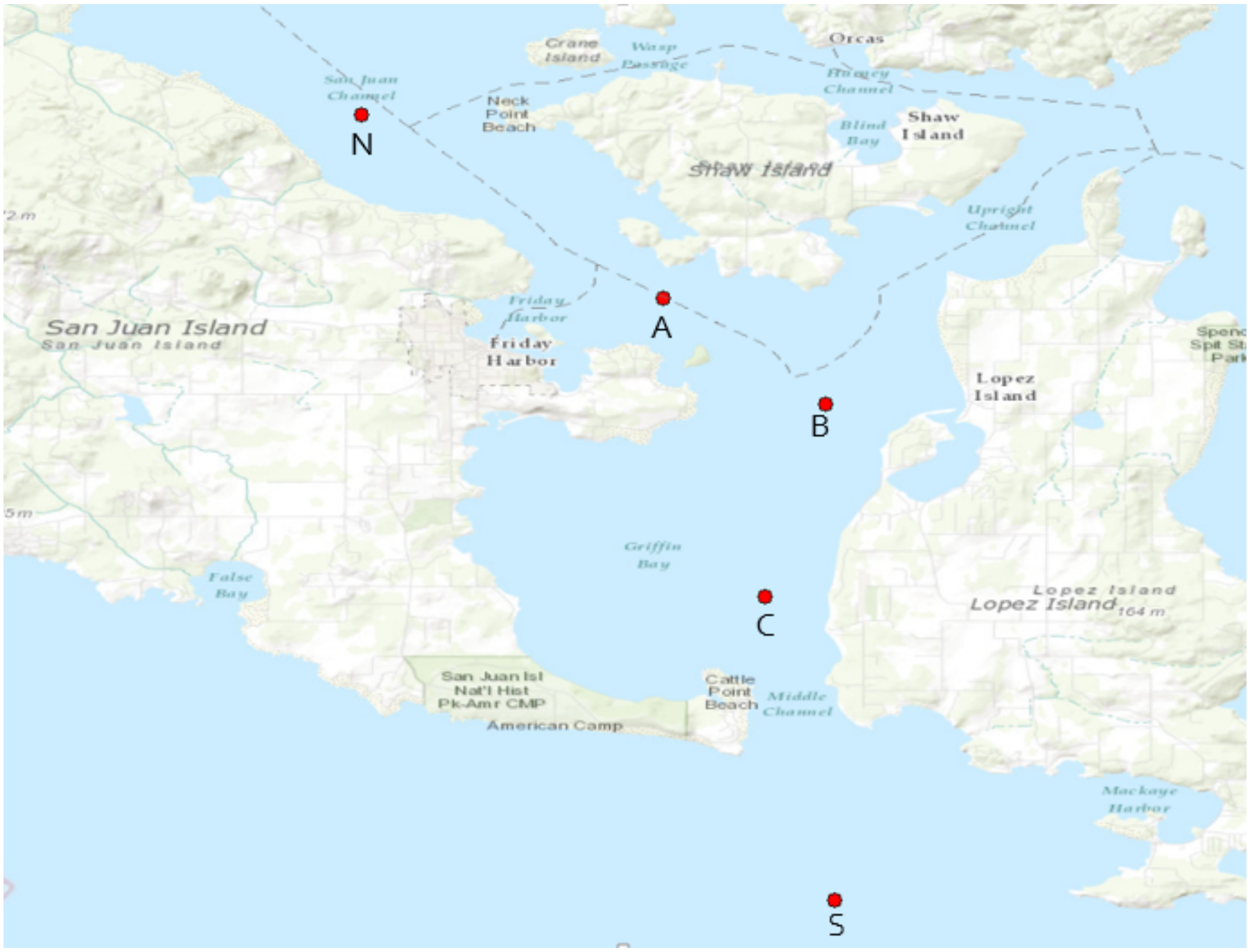


Fig 2. The five station transect of PEF

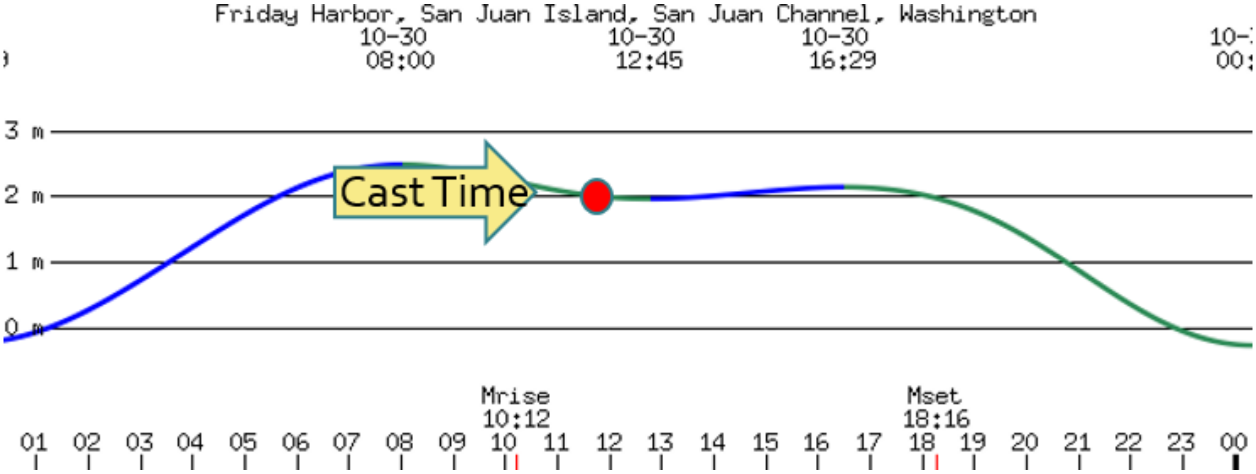


Fig 3. Example of cast time referenced by flood/ebb tidal cycle

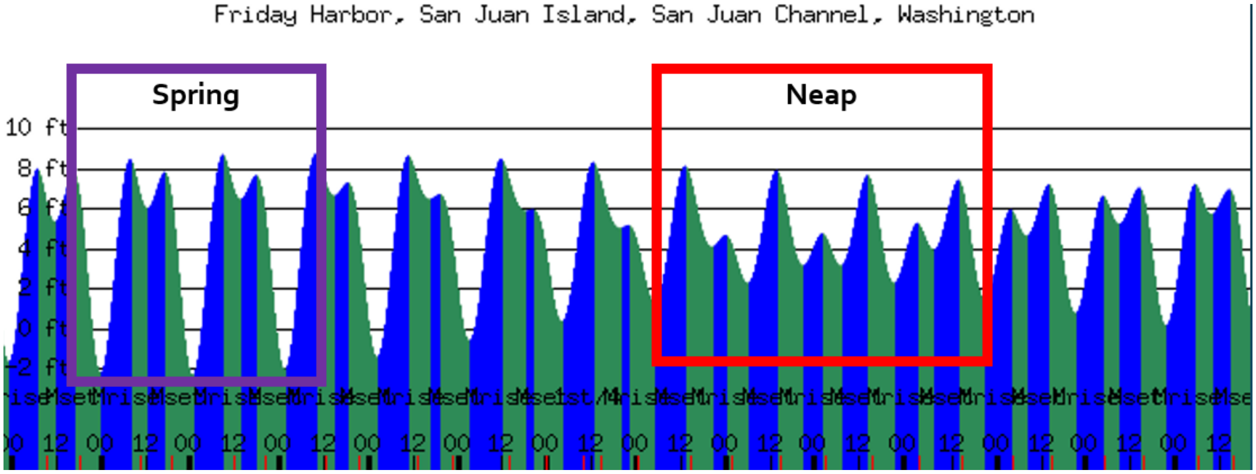
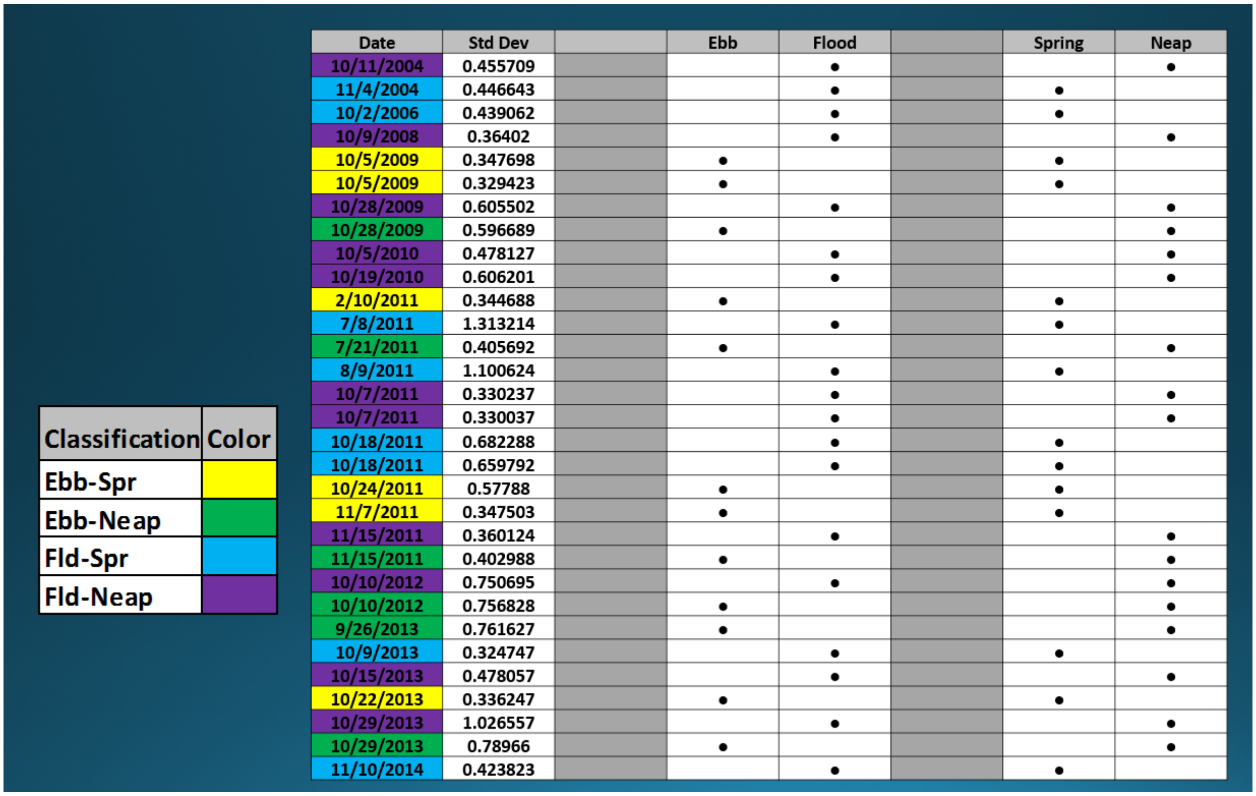


Fig 4. Spring/Neap tidal phases



Date	Std Dev		Ebb	Flood		Spring	Neap
10/11/2004	0.455709			•			•
11/4/2004	0.446643			•		•	
10/2/2006	0.439062			•		•	
10/9/2008	0.36402			•			•
10/5/2009	0.347698		•			•	
10/5/2009	0.329423		•			•	
10/28/2009	0.605502			•			•
10/28/2009	0.596689		•				•
10/5/2010	0.478127			•			•
10/19/2010	0.606201			•			•
2/10/2011	0.344688		•			•	
7/8/2011	1.313214			•		•	
7/21/2011	0.405692		•				•
8/9/2011	1.100624			•		•	
10/7/2011	0.330237			•			•
10/7/2011	0.330037			•			•
10/18/2011	0.682288			•		•	
10/18/2011	0.659792			•		•	
10/24/2011	0.57788		•			•	
11/7/2011	0.347503		•			•	
11/15/2011	0.360124			•			•
11/15/2011	0.402988		•				•
10/10/2012	0.750695			•			•
10/10/2012	0.756828		•				•
9/26/2013	0.761627		•				•
10/9/2013	0.324747			•		•	
10/15/2013	0.478057			•			•
10/22/2013	0.336247		•			•	
10/29/2013	1.026557			•			•
10/29/2013	0.78966		•				•
11/10/2014	0.423823			•		•	

Classification	Color
Ebb-Spr	🟨
Ebb-Neap	🟩
Fld-Spr	🟦
Fld-Neap	🟪

Fig 5. Example of classification process

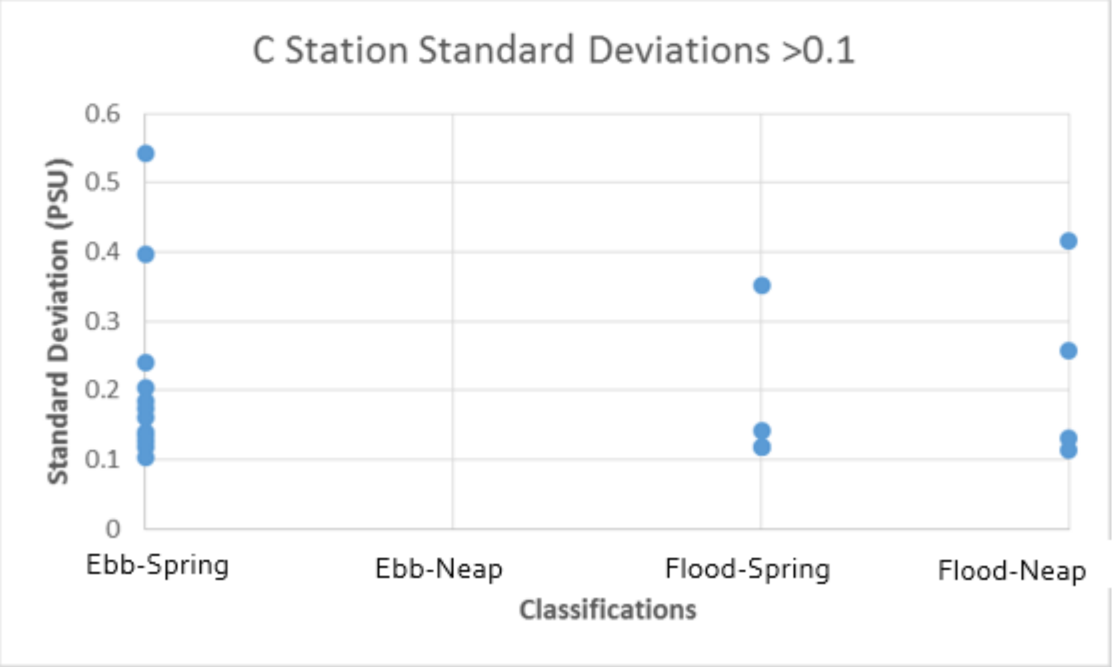


Fig 6. C station standard deviations >0.1 per classification

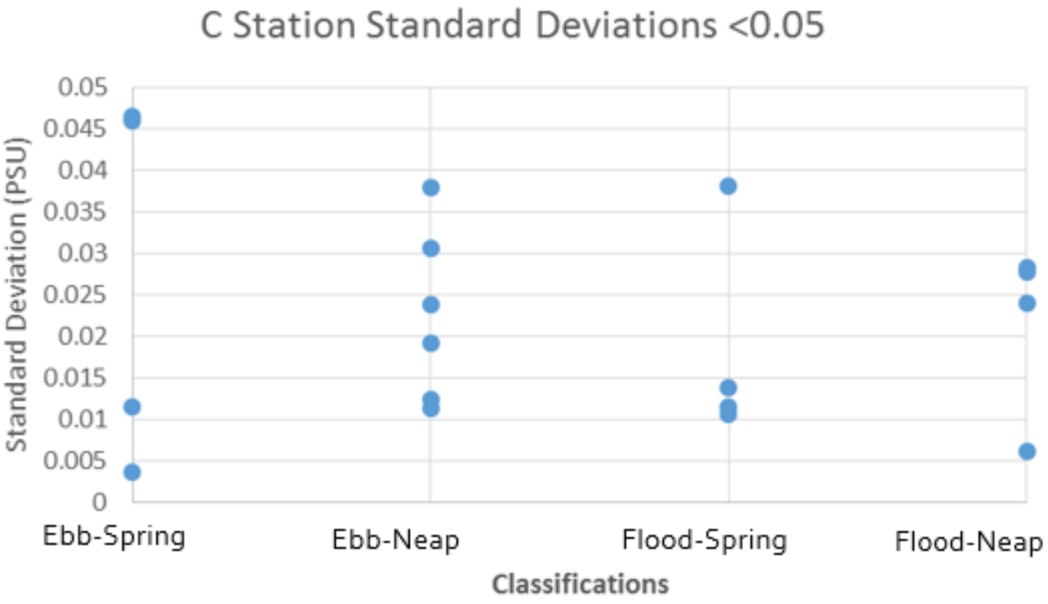


Fig 7. C Station standard deviations <0.05 per classification

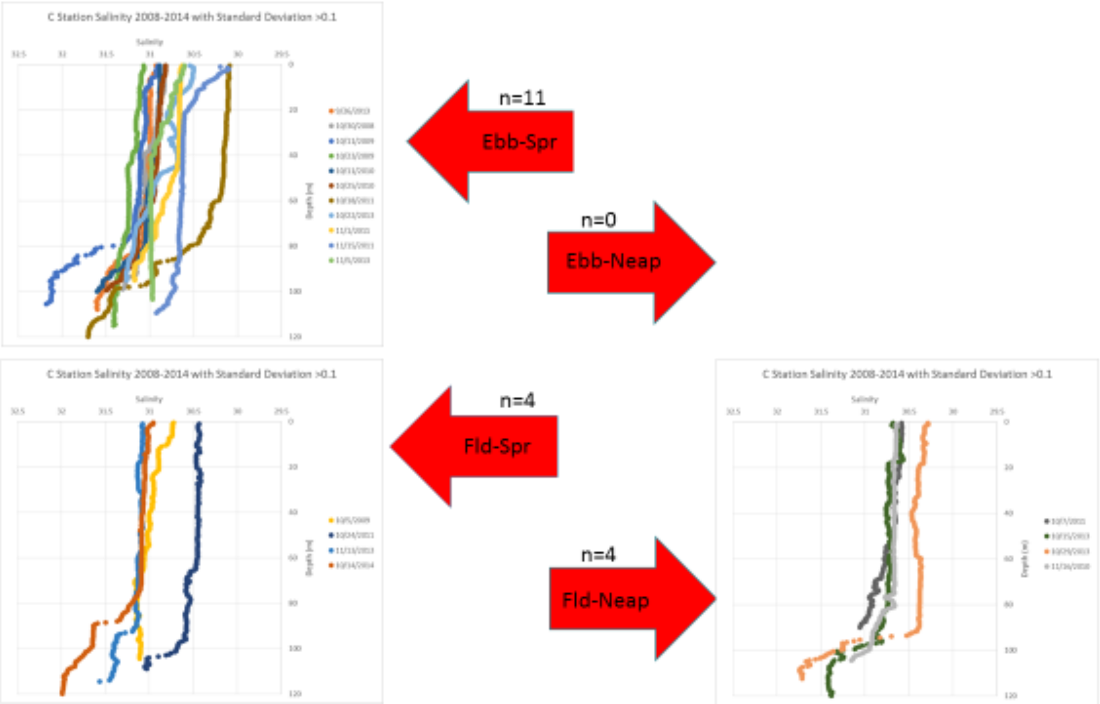


Fig 8. Halocline profiles of C Station with standard deviations >0.1 per classification

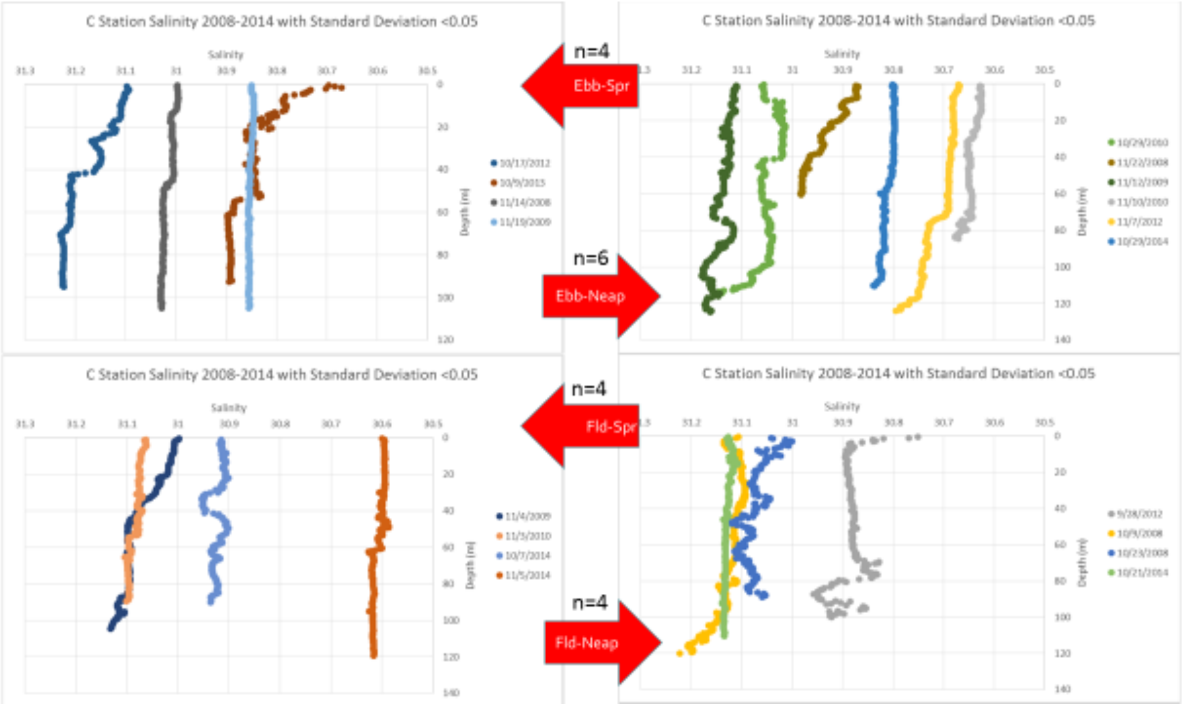


Fig 9. Halocline profiles of C Station with standard deviations <0.05 per classification

Without 10/11/09 & 10/18/11

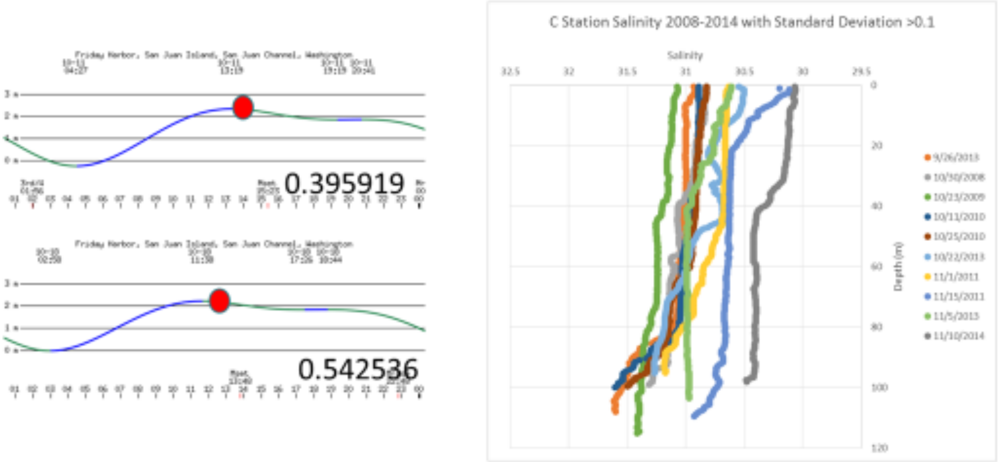


Fig 10. Halocline profiles of C Station with standard deviations >0.1 per ebb-spring classification excluding outliers

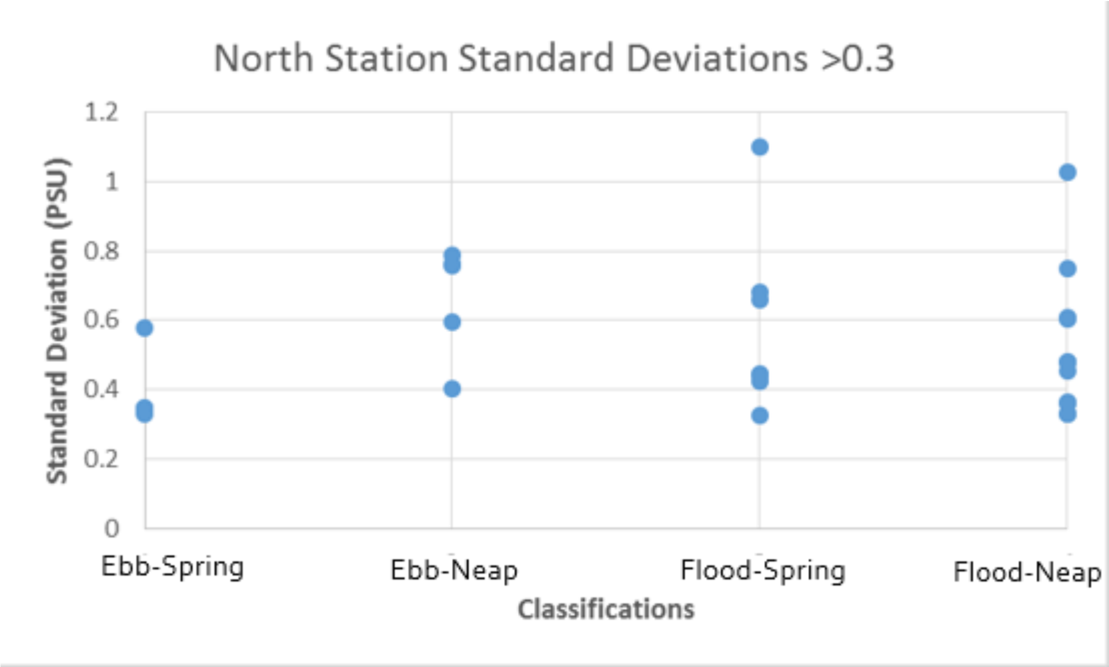


Fig 11. North Station standard deviations >0.3 per classification

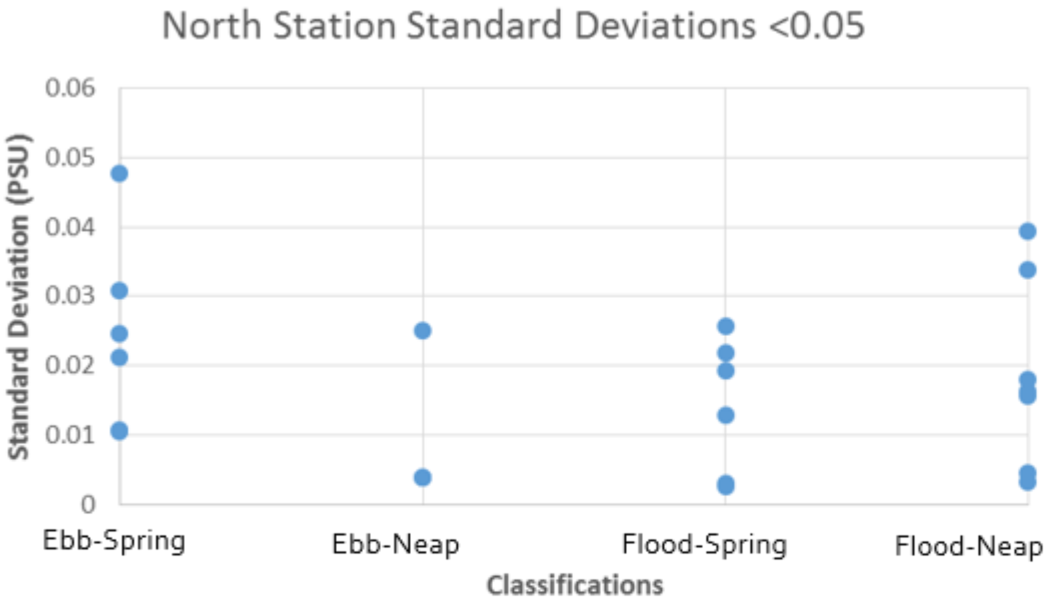


Fig 12. North Station standard deviations <0.05 per classification

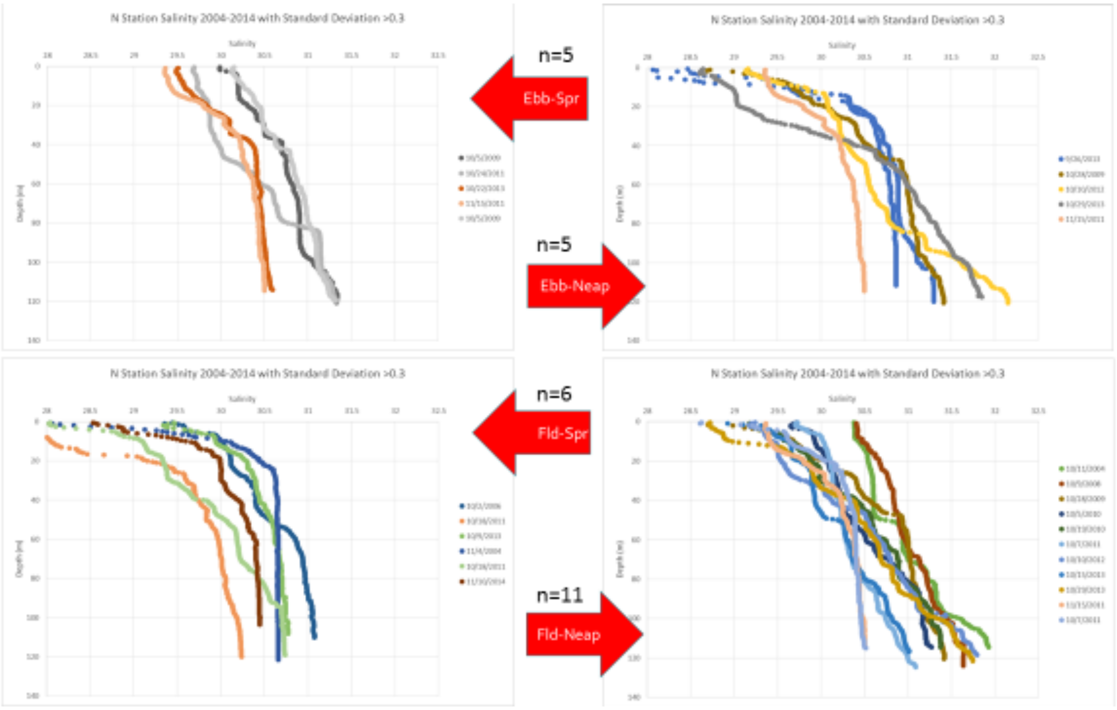


Fig 13. Halocline profiles of North Station with standard deviations >3.0 per classification

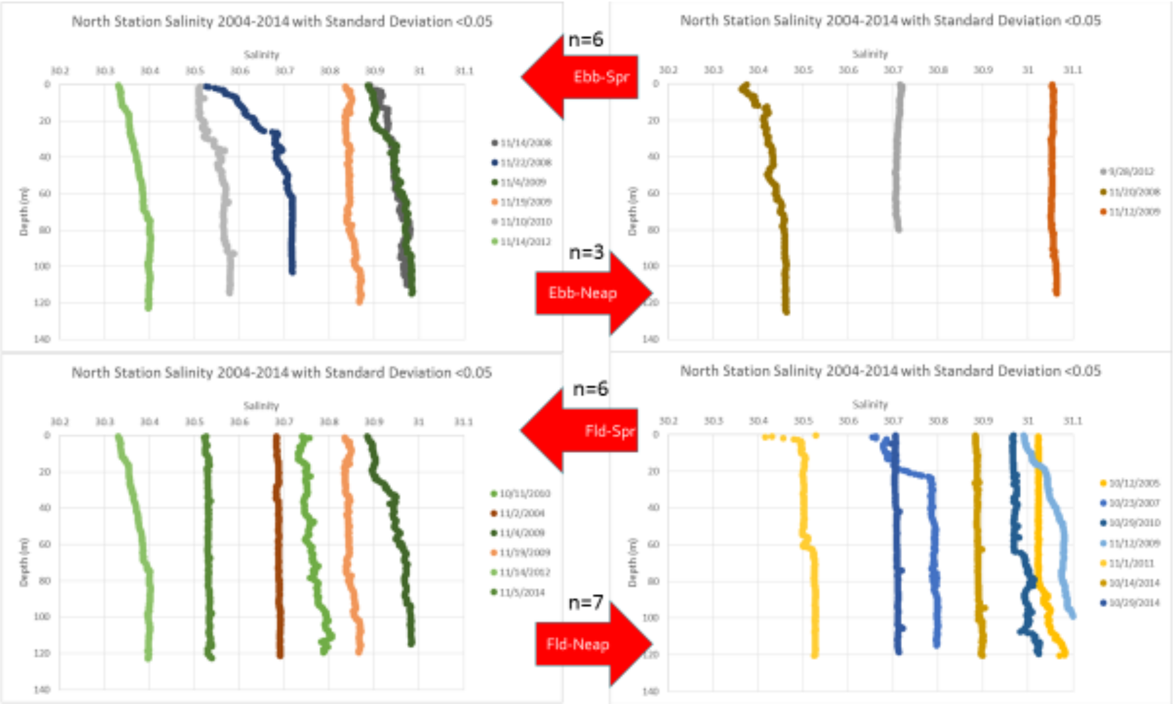


Fig 14. Halocline profiles of North Station with standard deviations <0.05 per classification

Works Referenced

Masson D. 2002. Deep water renewal in the Strait of Georgia. Estuarine, Coastal, and Shelf Science 54:115-126

Thomas K. 2011. Seasonal and tidal effects on the water density gradients in the San Juan Channel. PEF 2011.

Thompson J. 2013. Annual and inter-annual patterns of the physical oceanographic properties in the San Juan Channel: effects of external drivers. PEF 2013.

Thomson RE. 1994. Physical oceanography of the Strait of Georgia-Puget Sound-Juan de Fuca Straight System. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1948