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Coast Salish and U.S. Geological Survey Tribal Journey Water Quality Project

December 2009

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USGS
science for a changing world

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Trade names are for descriptive purposes only and do not imply endorsement by the U.S. Federal government.

Coast Salish and U.S. Geological Survey: Tribal Journey Water Quality Project

Introduction

In July 2009, the Coast Salish People and U.S. Geological Survey conducted a second water quality study of the Salish Sea to investigate the Coast Salish ancestral waters and the response of its coastal environments to climate change and land use impacts. The ancestral waters of the Coast Salish People, the Salish Sea, comprise a large inland sea contained within the United States (Puget Sound) and British Columbia, Canada (Georgia Straits). The Salish Sea is home to more than 220 species of fish, 29 species of marine mammals, more than 40 species of commercial and recreationally harvested invertebrates, and numerous resident and migratory bird species (Washington Sea Grant Program, 2000). Unfortunately, at least 60 of these marine based species are listed as threatened, endangered or of concern (Fraser and others, 2006), many of which sustained Coast Salish for millennia and are of essential cultural importance. Forecasts of climate change and urban population increase across the Pacific Northwest suggest that the Salish Sea will experience significant change in ways we do not fully understand nor able to predict.

Figure 1. The North Shore canoe in Vancouver BC

The cumulative impacts of human activities and climate change are deteriorating coastal ecosystems and accelerating the loss of ecologically and culturally important marine resources (Figure 1). Watershed modifications, coastal development and industrial activities are altering river and tidal flow, sediment transport, and nutrient delivery all across the region, leading to the break down of ecosystem functions and decreasing biodiversity, thus changing the face of the Salish Sea. A cooperative trans-boundary partnership between the U.S. Environmental Protection Agency (USEPA) and the Government of Canada has identified Salish Sea indicators of health. Several of these indicators are noted to be worsening, including urbanization and forest change, river, stream, and lake quality, marine species at risk, toxics in harbor seals, and marine water quality conditions (USEPA, 2008). The functioning of the Salish Sea ecosystem is increasingly threatened by ever more frequent observations of expanding anoxic zones, invasive species that commonly exploit degraded ecosystem conditions, and changes in climate (e.g. precipitation, lower river base flows, . The complexities of monitoring, protecting, and restoring such a large and diverse geographical area are exacerbated by a political border.

The Coast Salish Peoples and U.S. Geological Survey (USGS) have commenced on a partnership to examine water quality throughout the Georgia Straits and Puget Sound, blending tradition and science, in response to the deterioration of coastal environments and the need for quantitative information on the spatial and temporal variability in water quality conditions and physical processes contributing to water quality. The Project aims to measure

the pulse of summer conditions across the Salish Sea when environmental stress is high in response to peak annual air temperatures, low river flow and high productivity. The Project also synthesizes Coast Salish ecological knowledge with state-of-the-art scientific monitoring to better understand and predict the response of essential coastal habitats and marine resources of cultural and ecological importance throughout the ancestral waters of the Salish Sea. Through large-scale spatial measurements each summer, the project helps to identify patterns in summer water quality, areas of water quality impairment, and trends occurring through time. In 2009, additional science activities were implemented including (1) depth profiling of major water quality parameters to examine vertical variability, (2) discrete sampling of surface waters for analyses of dissolved nutrients and phytoplankton community composition, and (3) mooring deployments to measure variability of water quality parameters through time as a result of diurnal changes and tidal mixing. This report describes the activities and results from the canoe track studies conducted as part of the 2009 Tribal Journey Water Quality Study.

Coast Salish Partnership with U.S. Geological Survey

We Are Coast Salish

"We, the indigenous peoples of the Salish Sea, our autonomous status as sovereign Tribes and First Nations and our inherent responsibility as protectors of our Mother Earth, will continue to speak with One Voice for the preservation, restoration, and protection of the Salish Sea Eco Region for the sustainability of our sacred inherent family rights and values that have been passed on to us by our ancestors"

- Coast Salish Gathering Mission Statement.

The Salish Sea is the homeland of the Coast Salish peoples and is rich in a diverse array of marine and upland resources unique to this area that sustain Coast Salish cultures and traditions. Salmon are the icon of this essential and yet endangered connection of Coast Salish people to their land and waters. Coast Salish homelands and resources are under significant pressure from population growth, industrial expansion and economic demands.

In February 2008, the idea of mapping the surface water quality of the Salish Sea behind canoes during the Annual Tribal Journey, *the Tribal Journey Water Quality Project (TJWQP)*, was presented to Coast Salish Leaders at the third annual Coast Salish Gathering in Tulalip, WA. With unanimous approval, The TJWQP was formally adopted by the Gathering leadership. It is the first scientific effort to come out of the Coast Salish Gathering.

The objectives of the TJWQP are two fold. The first goal is to strengthen the valuable partnership between Coast Salish and the USGS. The second is to integrate the scientific expertise provided by USGS with traditional means to gather and synthesize information on impacts to water quality, nearshore habitats, and Salish Sea resources in a way that will promote capacity building for the Coast Salish. An additional objective is to share and integrate traditional ecological knowledge to protect the Salish Sea. The information collected during the annual Tribal Journeys will advise Coast Salish Leadership in making policy decisions regarding Salish Sea resources.

No other environmental monitoring agency sponsored by the states, provinces, or federal governments of the United States or Canada have been able to sample a trans-boundary waterway as thoroughly as the TJWQP proposed. The commitment of the participating Canoe Families made this bold effort possible.

In 2009 the Tribal Journey Water Quality Project was awarded the Partners in Conservation award by the U.S. Department of the Interior for the partnerships developed between Coast Salish, the U.S. Geological Survey, and Environment Canada (Figure 2).

Figure 2. Representatives of Coast Salish leaders, Canoe Family and Skippers, Department of Interior, U.S. Geological Survey and Environmental Protection Agency.

Tribal Journey Water Quality Project

The TJWQP is a blending of state-of-the-art science with the traditional annual Tribal Canoe Journey to measure surface water quality across the vast area of the Salish Sea (Figures X). Using water quality sondes, Global Positioning Systems (GPS) and traditional canoes traveling five principal ancestral waterways, Coast Salish canoe families simultaneously measured sea surface temperature, salinity, pH, turbidity, and dissolved oxygen with GPS coordinates every 10-seconds while paddling canoes along various water bodies spanning hundreds of kilometers of Puget Sound and Georgia Basin.

The Tribal Journey occurs every summer from July through the first week of August and each year a different final landing destination is chosen. In 2009 the final destination for the canoes was Suquamish, WA. During the 2008 and 2009 journeys, the TJWQP demonstrated that the water quality science could be conducted. These data provide a baseline dataset of water quality across the Salish Sea from which "hot spots" of water quality concern were identified. With the success of the 2008 and 2009 journeys, planning is underway for 2010 with the intention of continuing to build water quality monitoring capacity for the Coast Salish communities.

Figure 3. Canoe family working together to accomplish a large task.

Figure 4. The Salish Sea with 2008 (lt. blue) and 2009 (yellow) monitoring routes with basin outlines and landing sites.

The Salish Sea

The Salish Sea has a surface area of 16,925 square kilometers with 4,740 kilometers of coast line. At its deepest point the depths reach 270 meters (SeaDoc, 2008). The Salish Sea watershed is outlined by the Olympic Mountains, Vancouver Island Ranges, and the Cascade Mountains and roughly encompasses 135,000 square kilometers (Fraser and others, 2006).

The Fraser River drainage accounts for one-quarter of British Columbia's freshwater input to the Georgia Strait and supports runs of all five species of Pacific Salmon (Environment Canada, 2000). The Fraser River is the largest fresh water source into the Salish Sea.

Methods

Geographic Scope and Routes

The routes and participating Canoe Families for the TJWQP were chosen according to two main criteria: (1) canoe families traveling the greatest extent of Salish Sea and (2) the Canoe Families willingness to participate in the Project. In most cases planning for the annual Tribal Journey takes place over the course of an entire year, and in many cases the official routes are not finalized until a few weeks before the Journey is set to begin. The planning process takes place both within the individual Canoe Families and as a group at Canoe Family Planning Meetings which are hosted by various Tribes and First Nations around the region and held monthly. The Canoe Families carefully create the yearly routes, which follow the traditional pathways of their ancestors through the Salish Sea. The TJWQP in no way intends to interfere with this planning process. The TJWQP is an added component to the Tribal Journey.

The Canoe Families that participated in the 2008 TJWQP were Squaxin Island (Shelton, WA), Swinomish Tribe (LaConner, WA), the Stolo People (Chillawack, BC), Homalco Nation (Campbell River, BC), and the Skokomish Tribe (Skokomish, WA). With permission of the Skokomish Tribe, Eric Grossman (USGS) paddled a kayak through Hood Canal, WA on the Tribes behalf. In 2009, five tribal canoes participated in the water quality monitoring traveling from their home territories towards the final destination at Suquamish, Washington. The survey began July 22, 2009 and was completed August 3, 2009. Table 1 summarizes the landing sites for each of the 2008 and 2009 monitoring routes. The Squaxin Island and Swinomish tribes participated in the project for a second year and were joined by Squamish Nation (Vancouver, BC), Quinault Nation (Taholah, WA), Songees Nation (Victoria, BC) and the Blue Heron canoe.

Table 1. Landing starting locations, number of days traveled, start and end travel dates, number of kilometers traveled and the YSI model number used by the Canoe families during the 2009 Tribal Journey to Suquamish, WA.

	Canoe Family				
	Squaxin Island	**Squamish**	**Swinomish**	**Quinault**	**Blue Heron**
Starting Location	Nisqually	Howe Sound	Birch Bay	LaPush	Deception Pass
Travel Days	5	9	5	2	5
Start Date	July 27, 2009	July 22, 2009	July 28, 2009	July 26, 2009	July 21, 2009
End Date	August 3, 2009	July 31, 2009	August 4, 2009	July 29, 2009	July 26, 2009
Distance (km)	298	574	205	135	154
YSI Model #	6600 V2	6600 V2	6920 V2	6920 V2	6920 V2

Canoe skippers typically plan the timing of the daily trips to follow the tide from one location to another. Travel departure times and trip durations depended on the distance between landing sites, weather conditions, currents, and pulling ability of the Canoes' crew. During this time period the tide regime was characterized by early morning and late afternoon high tides, therefore a large proportion of the samples collected reflect environmental conditions during falling tides.

Equipment

Canoe platform

The platform for deploying the Sonde was a Coast Salish canoe. A canoe is the ideal platform for conducting water quality testing because they are, by nature; slow moving vessels that use no form of motorized propulsion that either contaminate the water or create turbulence, affecting water quality readings.

Water quality measurements collected behind the traditional Coast Salish canoes were carried out using YSI Environmental 6600 or 6920 V2-2 sondes. Both the YSI 6600 and 6920 have temperature, conductivity, specific conductance, salinity, resistivity, total dissolved solids, pH, and oxidation reduction potential parameter capabilities. The YSI sondes have two optical ports, one for YSI 6136 turbidity probes, and the 6920 sondes have a ROX optical dissolved oxygen sensor, and the 6600 sondes have a YSI 6025 chlorophyll sensor. The YSI 6600 also has a rapid pulse dissolved oxygen probe (See Appendix I for specifications). The main water quality parameters of interest for this report are surface water temperature, dissolved oxygen (concentration and percent saturation), salinity, pH, turbidity, and chlorophyll.

Data collected by the YSI sondes were logged onto high memory YSI 650 display units. The display units were connected to the Sonde using a field cable. Garmin GPS units, boosted by Garmin GA 25MCX antenna, were connected to the YSI 650 display using a YSI 6115 GPS cable to integrate position information directly into the YSI data files. The display and GPS units were housed in a water tight Pelican case using water tight cable clams.

Figure 5. YSI sonde and cables with the Pelican water tight housing.

YSI sondes were calibrated and audited to ensure data accuracy and to correct for any instrument drift. The calibration and audit procedures were performed according to manufacturer recommendations and outlined in the Tribal Journey Operations Manual. Quality control procedures for acceptance or rejection of the data can be found in the USGS National Field Manual for the Collection of Water-Quality Data (Wilde, 2005). The calibration and audit table can be found in Appendix XVI. Dates and times for the Sonde, display, and GPS unit were synchronized prior to deployment to ensure uniformity in the data between the different tracks.

The sonde and Pelican cases containing logging equipment were fixed to the aft of the canoe using shock cord. The sondes were kept inside the canoe until after the launching ceremony and deployed into the surface waters when the canoe began the days' journey. The sondes were towed within the top half meter of the water column, as the objective was to monitor the surface waters of the Salish Sea.

Data Acquisition and Quality

To assist the project participants with regular maintenance and quality assurance and control procedures each canoe family welcomed a water quality technician on the journey. Technicians were selected for either (1) their experience with water quality testing equipment or (2) their experiences working for and/or with Tribes and First Nations. It was very important that the Canoe Families accept the technician as a part of their Family and for the technicians to not let the TJWQP interfere with the cultural and healing aspects of the Tribal Journey. The Technicians also had to be physically able and comfortable with being on the open water for six or more hours at a time.

Figure 6. Eric Grossman demonstrating the YSI to a Coast Salish elder.

Data processing procedures were modified for the 2009 field effort and 2008 data was re-processed to conform to the new procedures. Raw YSI data files were downloaded each day and processed according to the following steps.

Table 2. Data flags used during data processing.

Flag	Criteria
-1111	delete out of water (zero salinity)
-2222	delete zero value latitude/longitude
-3333	correct positive value longitude
-4444	zero negative turbidity values
-5555	zero negative chlorophyll values
-6666	salinity sensor error
-7777	outlier turbidity (>200) change to 200
-9999	failed parameter audit or probe error

1) Raw track data files were merged with the 10-second interval corresponding GPS file latitude, longitude, and speed. 2) Errors in the merged data files were flagged with a numerical code (Table, 2). 3) Flagged data errors were corrected and the files were finalized for the analysis steps.

Following this processing, data were mapped in Google Maps and posted on the Web at the US Geological Survey's Washington Water Science Center (http://www.usgs.gov/coastsalish).

Water Quality Assessment

Basin Classification

The Salish Sea is made of three main bodies of water; Puget Sound, Strait of Georgia, and the Strait of Juan de Fuca. The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) has broken the Puget Sound into seven Basins as defined by Shipman, 2008. These basins take into account the diversity in bathymetric and circulation features across the region (Shipman, 2008). The basin classification system only incorporates the portion of the

Salish Sea within Washington State. To unify the Strait of Georgia with the PSNERP basin classifications, six watershed groups (referred to as basins) were used from the BC Watershed Atlas (British Columbia, 2007) for Lower Fraser River, Squamish, Comox, Parker, Cowichan, and Victoria basins. The borders of the watershed groups were extended seaward to include the marine waters offshore of the watersheds (Figure 4). Basin names are used to break up and describe conditions of the marine water bodies within the Salish Sea (Table 3). Fresh water bodies monitored during the Tribal Journey will be referred to using the name of the water body.

Table 3. Basin codes created by the Puget Sound Nearshore Ecosystem Restoration group and the British Columbia Watershed Atlas group.

Basin Code	Basin Name
COMX	Comox
PARK	Parksville
COWN	Cowichan
SQUM	Squamish
LFRA	Lower Fraser
VICT	Victoria
SJ	San Juan
JF	Juan de Fuca
WB	Whidbey
NC	North Central Puget Sound
SC	South Central Puget Sound
HC	Hood Canal
SP	South Puget Sound
PC	Pacific Coast
Fraser	Fraser River
Skagit	Skagit River

Using GIS TJWQP data were queried for data points within each of the 16 designated basins. This procedure was done for both 2008 and 2009 TJWQP data.

Water Quality Criteria

To evaluate the variation in the water quality across the study area we evaluated the data against an established set of regulatory standards. Washington State has developed a set of water quality standards to protect the marine and fresh surface waters of the state and specific levels of protection are designated by aquatic life uses for marine surface waters. For marine surface waters, aquatic life use designations are classified as being of *extraordinary* quality, *excellent* quality, good quality, and *fair* quality. The marine surface water results from the TJWQP were compared to Washington State water quality standards and results are reported in this document for temperature, dissolved oxygen, and pH. Turbidity results are not evaluated against water quality standards at this time due to lack of data to support background level measurements. There are no criteria set for salinity. (WAC-173-201A-200 fresh waters and WAC-173-201A-210 marine waters).

Results

In total 54,522 data points were collected in 2009, capturing surface water temperature in degrees Celsius (°C), dissolved oxygen in milligrams per liter (mg/L) and percent saturation (% sat), pH in standard units, salinity, and turbidity in Formazin Nephelometric Units (FNU) information, during the Tribal Journey to Suquamish. The five canoes pulling during the TJWQP covered 1366 km of Coast Salish territory over a two week period between July 21 and August 4, 2008. The data results presented in this report are intended to summarize the data snap shot of the Salish Sea. A summary of results from the 2008 TJWQP can be found

in Akin et al, 2009. The 2008 data results tables designated by basin can be provided upon request.

Weather conditions for the Salish Sea region during the 2008 Tribal Journey were typical for the Pacific Northwest Eco Region during the month of July. The Fraser River valley experienced warm air temperatures between 23°C and 27°C (73 degrees Fahrenheit (°F) to 80°F) with calm winds. The southern Salish Sea region experienced cooler temperatures in the mornings, 12°C to 14°C (53°F to 57°F), warming into the afternoon to 20°C (68°F). The skies were sunny to partly cloudy over the two week period with light to breezy wind conditions on the water.

In contrast to conditions in year one, the last two weeks of July 2009 the Pacific Northwest experienced some of the warmest temperatures on record. A maximum temperature of 40°C (average 19.3°C) in the Olympia area and in Seattle a maximum of 39.4°C (average 20.8°C) was recorded during July 2009 (NOAA, 2009). Temperatures in the northern Salish Sea ranged from 30.0°C in Blaine to 34.4°C in Vancouver (Environment Canada, 2009). No precipitation was recorded by the traveling canoes from July 21 to August 4, 2009. Skies were mostly sunny with light wind conditions on the water.

Results by Basin

Each of the Canoe Families chosen to participate in the TJWQP came from territories at the furthest extents of the Salish Sea from the landing in Suquamish. As each of the families travel from landing to landing, the geographic areas covered will be referred to as basins, and represent the individual water bodies that make up the Salish Sea. Below is a summary, by basin within four quadrants (north, central, south, and Pacific regions) of the surface water quality conditions for parameters temperature (°C), salinity, pH, turbidity (FNU), and dissolved oxygen (mg/L) of the Salish Sea during the 2009 Tribal Journey, July 21, 2009 to August 3, 2009.

North Salish Sea

Within the north region of the Salish Sea basins Squamish (SQUM), Lower Fraser (LFRA), and the Fraser River (Fraser) will be examined. The canoes traveled Squamish basin July 22 and 23, 2009, Lower Fraser the afternoon of July 23 and 24, 2009, and in the Fraser River July 24, 2009. Important fresh water inputs from the Squamish and Fraser Rivers contribute to the regional variation in water quality parameters measured in the North Salish Sea. Figures for temperature, salinity, pH, dissolved oxygen, and turbidity results for the north Salish Sea are in figures 9 to 13. Tables of results for Squamish and Lower Fraser basins and Fraser River can be found in appendices II to IV.

The Fraser River is the largest fresh water source to the Salish Sea. The discharge of the Fraser River was decreasing from a peak of 7500 m3/s occurring in mid June to 4000 m3/s at Hope, BC in late July when the canoes were monitoring the marine waters off shore the Fraser delta. At the Environment Canada Hope monitoring station (Environment Canada, 2009), located about 150 km from the delta, water temperatures were around 17.9°C during the monitoring period and peaked a week later near 20°C (Figure 7). The results of the 2009 monitoring in the lower reach of the Fraser River show an average temperature of 19.25°C (n=914), with a maximum of 26.44°C and a minimum of 18.3°C. These results show at most

an 8.5°C increase in water temperature from the Hope station to the delta. Surface waters of the Fraser River on July 24, 2009 were of *fair* water quality for all the samples collected.

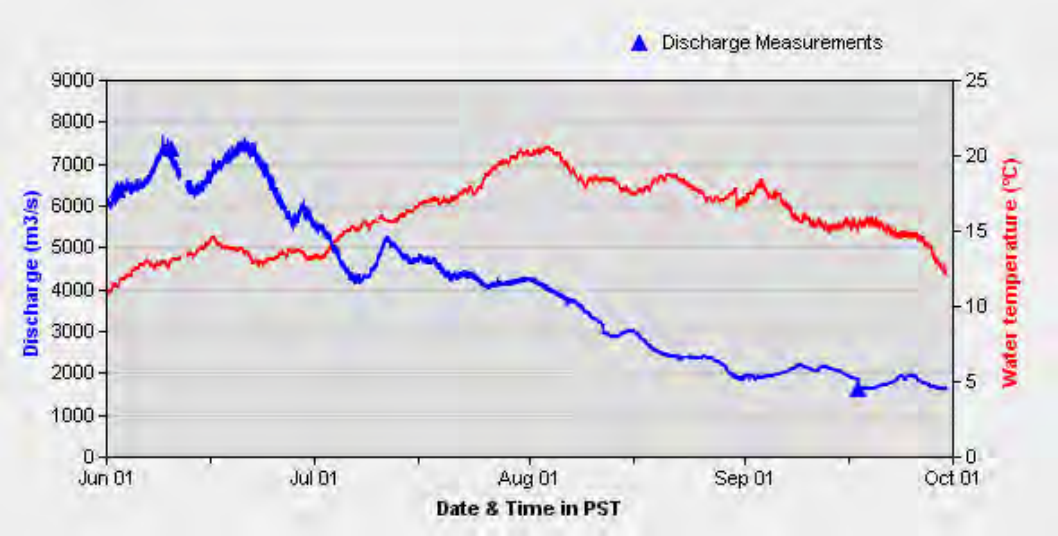


Figure 7. Discharge measurements in cubic meters per second for the Fraser River at Hope, BC from June 1, 2009 to October 1, 2009. Data collected by Environment Canada.

Fraser River salinity levels ranged from 0.09 to 5.77 near the delta, with an average of 1.04. The median pH was 7.79 with a range of 7.66 to 8.4 units. Dissolved oxygen levels were within a range of 8.58 mg/L to 9.98 mg/L with an average of 9.06 mg/L. Dissolved oxygen percent saturation ranged from 96.3 % to 124.5%. Turbidity levels were visually elevated in the Fraser River and averaged 28.47 FNU with a minimum of 3.9 FNU and a maximum of 88.5 FNU.

Surface water temperatures in the Squamish basin were cooler in northern Howe Sound and warmed as the canoes traveled toward Horseshoe Bay. Squamish basin was sampled over a two day period. The average temperature for Squamish basin was 18.39°C (n=4946) over the two day period, with an average of 18.61°C the first day and 17.39°C the second day. The surface plume of freshwater in Squamish basin depressed the salinity levels, resulting in an average of 10.65 (n=4057), with a maximum of 26.77 and a minimum of 0.5. The pH results widely ranged from 6.77 units at the northern extent of Howe Sound to 9.11 units (median of 8.29, n=4946) in the southern portion of the basin. Nearly 24% of pH samples were above 8.5 units resulting in *fair* water quality conditions. Dissolved oxygen averaged 10.8 mg/L (n=4946) with a maximum of 16.89 mg/L and a minimum of 7.86 mg/L. The average dissolved oxygen saturation level for Squamish basin was 124.2% with a minimum of 93.6% and a maximum of 208.3%. The elevated dissolved

Figure 8. Red algae bloom observed in Squamish basin north of Horseshoe Bay.

oxygen levels were observed by project staff while traveling through a deep red algae bloom which extended roughly 11 km (Figure 8). Dissolved oxygen levels observed in Squamish basin all qualified for *extraordinary* water quality during the daylight monitoring. Turbidity measurements averaged 17.1 FNU (n=4946), with a maximum of 200.0 FNU and a minimum of 0.0 FNU.

Lower Fraser basin surface water temperatures between July 23 and July 25, 2009 (n=1986) ranged between 12.24°C and 23.47°C, with an average temperature of 17.49°C. Lower Fraser basin observed a cooling in surface water temperature moving south from the city of Vancouver, BC across the Fraser Delta front and into the deeper waters offshore of the delta. Due to equipment errors salinity was only measured in Lower Fraser basin one afternoon following an offshore transect from the river mouth toward the delta front. The average salinity was 3.89 (n=207) with a maximum of 22.91 and a minimum of 0.01. The pH in Lower Fraser basin ranged from 7.46 to 8.46 (median of 8.05, n=1968). Dissolved oxygen levels averaged 8.47 mg/L (n=1827) with a maximum of 13.82 mg/L and a minimum of 6.31 mg/L. Dissolved oxygen saturation levels reached a maximum of 181.6% in the Lower Fraser basin indicating high productivity levels in the calm warm weather conditions. Turbidity measurements averaged to 13.4 FNU, with a maximum of 200.0 FNU and a minimum of 0.0 FNU for the Lower Fraser basin.

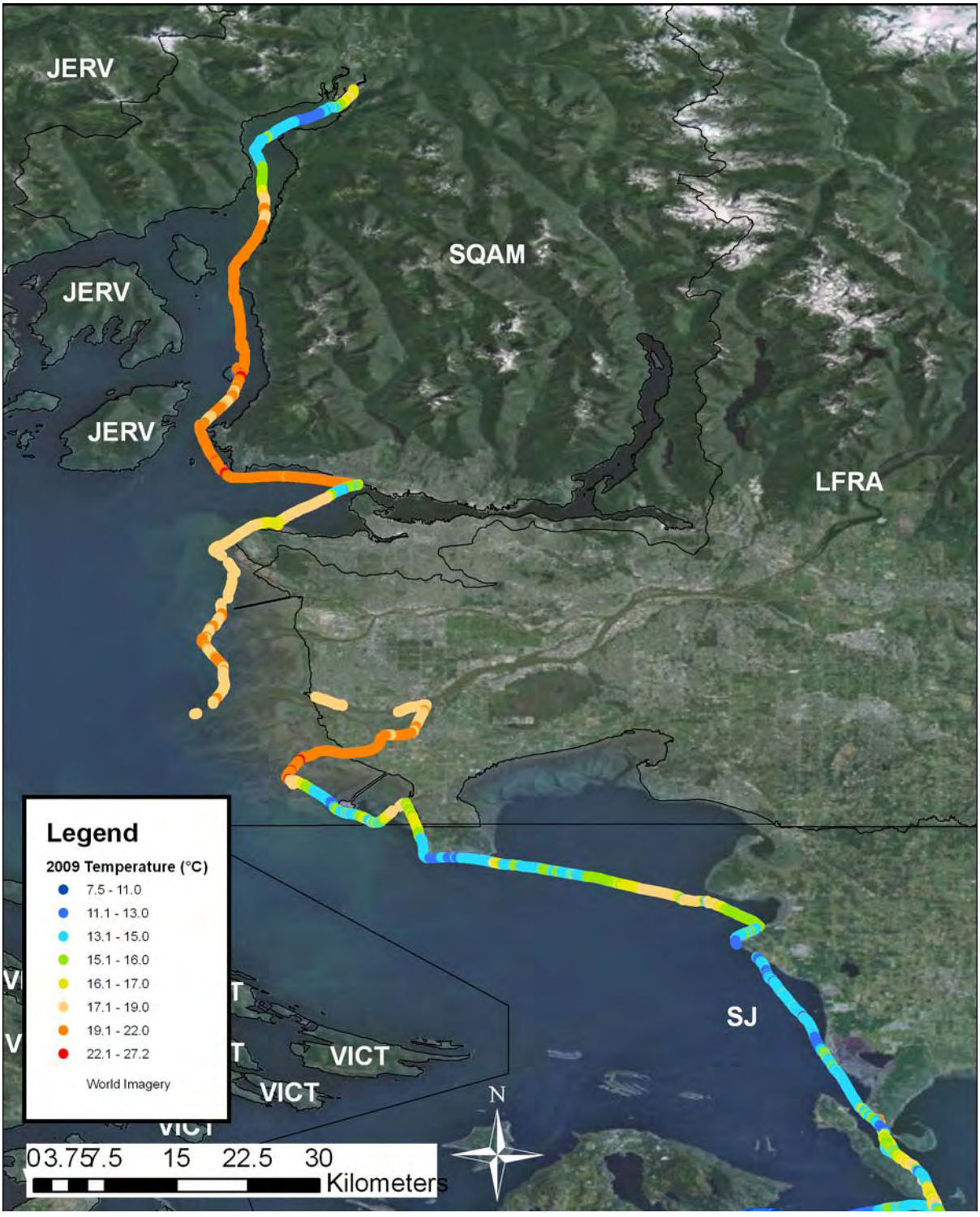


Figure 9. Temperature recorded in degrees Celsius along the northern portion of the Salish Sea from July 22 to 24, 2009. This region includes data within the Squamish and Lower Fraser basins, and the Fraser River.

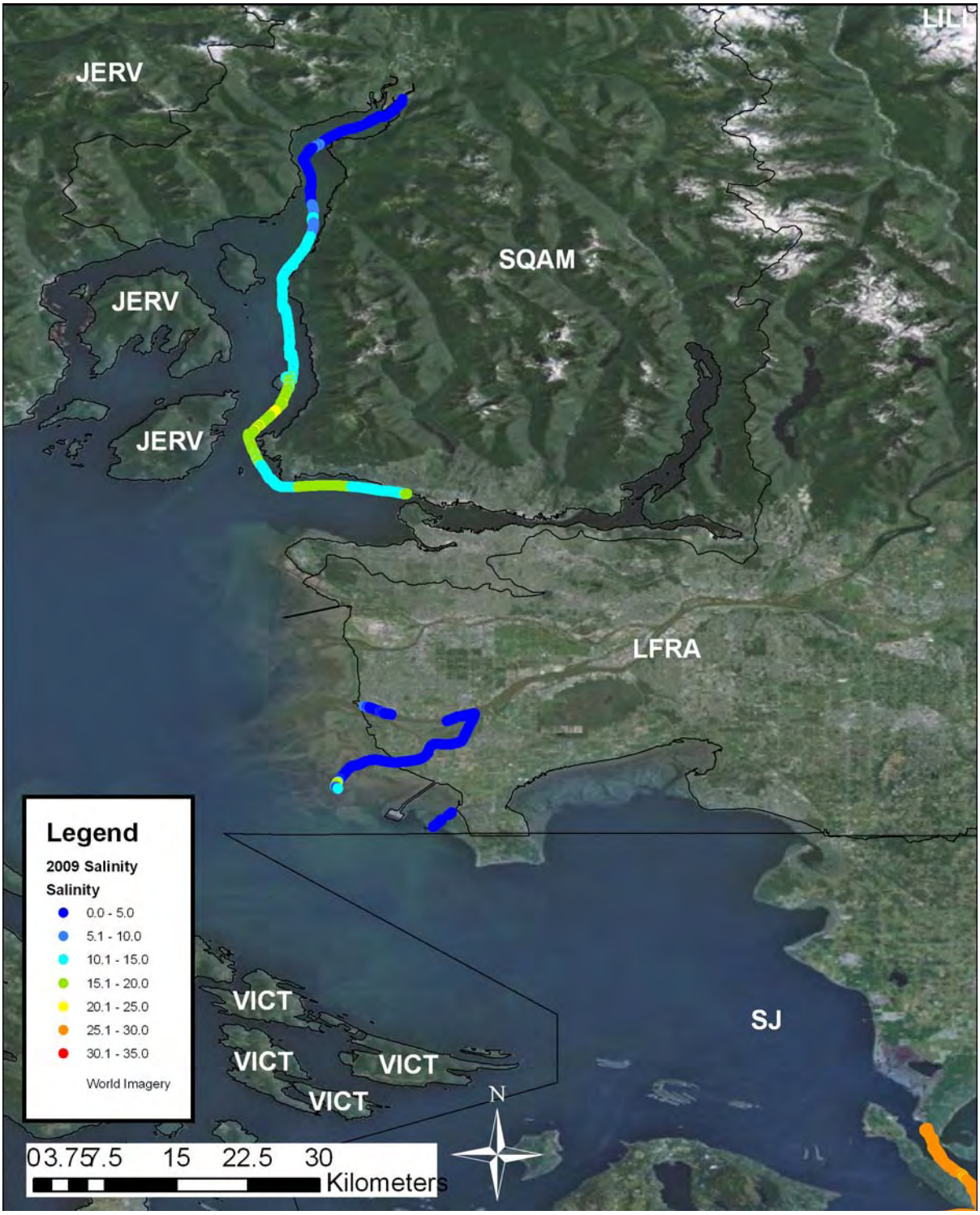


Figure 10. Salinity results along the northern portion of the Salish Sea from July 22 to 24, 2009. This region includes data within the Squamish and Lower Fraser basins, and the Fraser River.

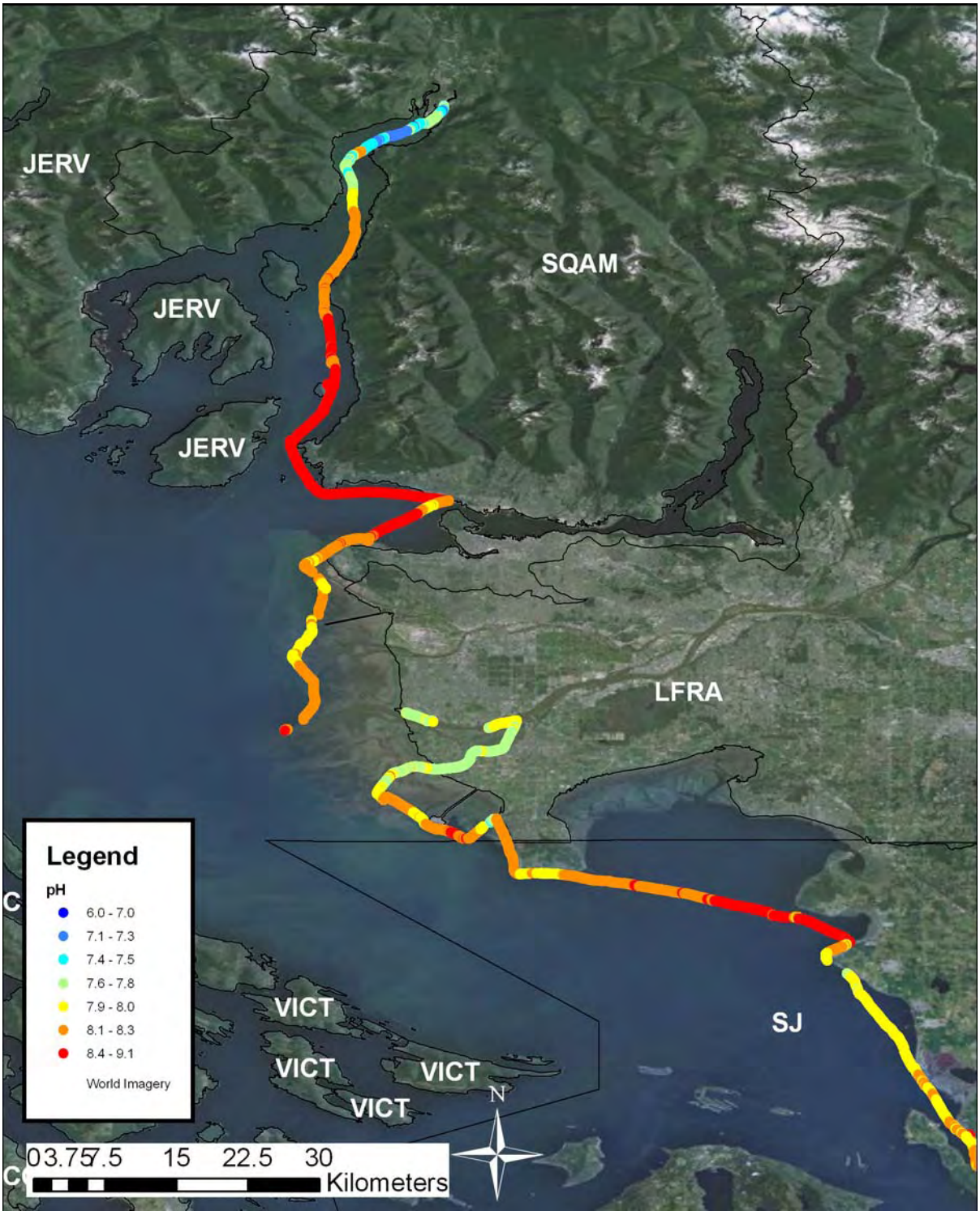


Figure 11. pH recorded in standard units along the northern portion of the Salish Sea from July 22 to 24, 2009. This region includes data within the Squamish and Lower Fraser basins, and the Fraser River.

Figure 12. Dissolved oxygen recorded in milligrams per liter along the northern portion of the Salish Sea from July 22 to 24, 2009. This region includes data within the Squamish and Lower Fraser basins, and the Fraser River.

Figure 13.Turbidity recorded in Formazin Nephelometric Units along the northern Salish Sea from July 22 to 24, 2009. This region includes data within the Squamish and Lower Fraser basins, and the Fraser River.

Central Salish Sea

In examining the central region of the Salish Sea the San Juan (SJ), Whidbey (WB), and North Central Puget Sound, from here on referred to as North Central (NC), basins will be considered. San Juan and North Central basins are mixing zones where water quality parameters are influenced by water from the Pacific as well as the waters circulating through the Georgia Strait and Puget Sound-Hood Canal respectively. In 2009 San Juan basin was monitored for seven days from July 22 to July 29, Whidbey basin was monitored six days from July 21 to August 4, North Central basin was monitored August 3, and the Skagit River was monitored August 1 and August 2. Air temperatures recorded in Blaine, WA for the month of July show an average air temperature of 18°C with a high of 30°C (NOAA, 2009). The Blaine monitoring station recorded the lowest maximum temperature for July in the Salish Sea region. Tables of results of temperature, salinity, pH, dissolved oxygen concentration and percent saturation, and turbidity for San Juan, Whidbey, and North Central basins and the Skagit River can be found in appendices V to VII.

The average surface water temperature for the San Juan basin was 13.63°C (n=18,212), with a maximum of 22.46°C and a minimum of 10.66°C (Figure 15). The warmer portions were along the eastern shoreline of the basin, particularly Samish Bay and the Swinomish Channel, Bellingham Bay off of Lummi Island, and offshore of Blaine, WA. The average salinity was 29.42 (n=12,260) with a maximum of 31.51 and a minimum of 2.52 (Figure 16). Median pH reading for San Juan basin was 7.94 (n=18,212), with a maximum of 8.86 and a minimum of 5.99 (Figure 17). Dissolved oxygen concentrations ranged from 16.3 mg/L to 4.2 mg/L with an average of 7.87 mg/L (n=10,235) (Figure 18). The dissolved oxygen saturation ranged from 57.0% to 204%. The average turbidity was 1.78 FNU (n=18,212) with a maximum of 200 FNU and a minimum of 0.0 FNU (Figure 19).

North Central surface water temperatures averaged 13.94°C (n=1,104), with a maximum reading of 15.47°C and a minimum of 12.34°C (Figure 15). The salinity ranged from 30.25 to 20.57, with an average of 29.16 (Figure 16). The median pH reading was 8.12, and ranged from 8.26 to 7.88 (Figure 17). Dissolved oxygen readings averaged 7.08 mg/L with a maximum reading of 9.36 mg/L and a minimum of 5.89 mg/L (Figure 18). Dissolved oxygen percent saturation readings ranged from 107.9% to 69.7%. Turbidity measurements were not made in North Central basin due to instrument errors.

The surface water temperatures for Whidbey basin averaged 16.82°C (n=7,962), and ranged from 21.82°C to 11.15°C (Figure 15). The coolest surface water temperatures in Whidbey basin were recorded from Deception Pass across to Hope Island and the warmest region was in south Whidbey basin near the outlet of East Basin. The average salinity was 25.49 (n=5,915), and ranged from 16.02 to 30.22 with the Swinomish Channel and off shore of the Tulalip Reservation experiencing depressed salinity levels (Figure 16). The median pH reading was 8.16 (n=7,962) and ranged from 7.46 to 8.39 (Figure 17). The average dissolved oxygen was 8.41 mg/L (n=5,465), with a maximum of 12.56 mg/L and a minimum of 4.02 mg/L (Figure 18). Dissolved oxygen saturation ranged from 48.1% to 146.7% in Whidbey basin. The average turbidity was 3.38 FNU (n=7,962), with a minimum of 0.0 FNU and a maximum of 200 FNU (Figure 19).

The Skagit River is the largest freshwater input into the Salish Sea south of the Fraser River. The average discharge of the Skagit River as the canoes traveled through the region

was 322 cubic m/s (Figure 14) at Mt. Vernon, and approaching base flow levels (USGS, 2009). The average temperature of the Skagit River was 16.78°C (n=2,367), with a maximum of 23.82°C at the delta and a minimum of 15.45°C (Figure 15). Salinity ranged from 0.02 to 5.96, with an average of 0.11 (Figure 16). The median pH of the Skagit River was 7.36, with a minimum of 6.63 and a maximum of 8.84 (Figure 17). Dissolved oxygen readings averaged to 9.72 mg/L (n=2,367), and ranged from 7.47 mg/L to 18.71 mg/L (Figure 18). Dissolved oxygen saturation ranged from 77.9% to 187.3%. Turbidity measurements averaged 22.29 FNU (n=587), and ranged from 10.3 FNU to 28.6 FNU (Figure 19).

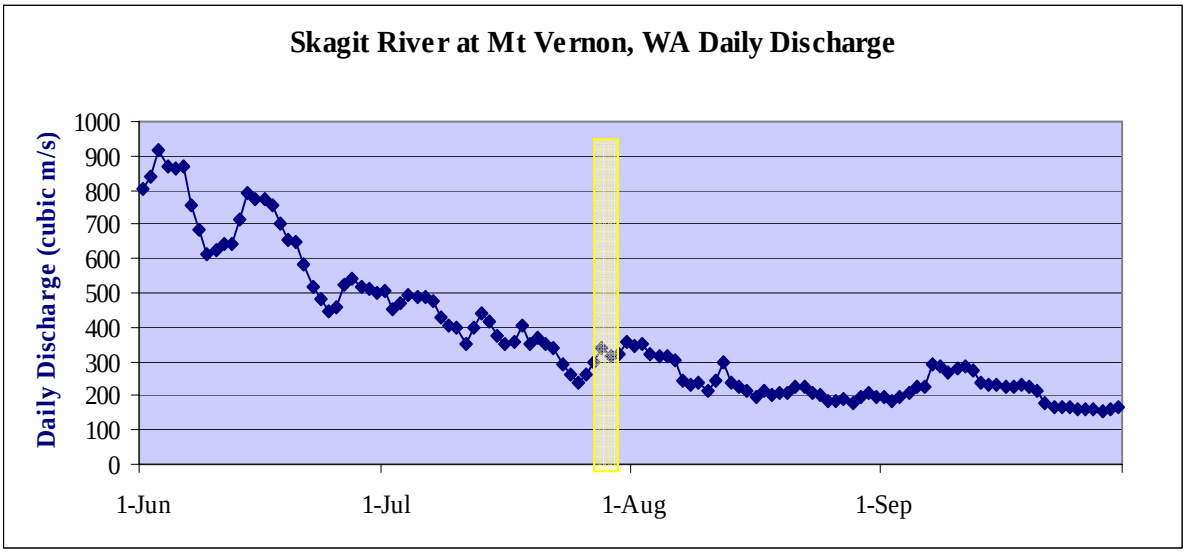


Figure 14. Daily Discharge in cubic meters per second for the Skagit River at Mt. Vernon, WA. The yellow box indicates the time period that the canoes pulled past the Skagit delta.

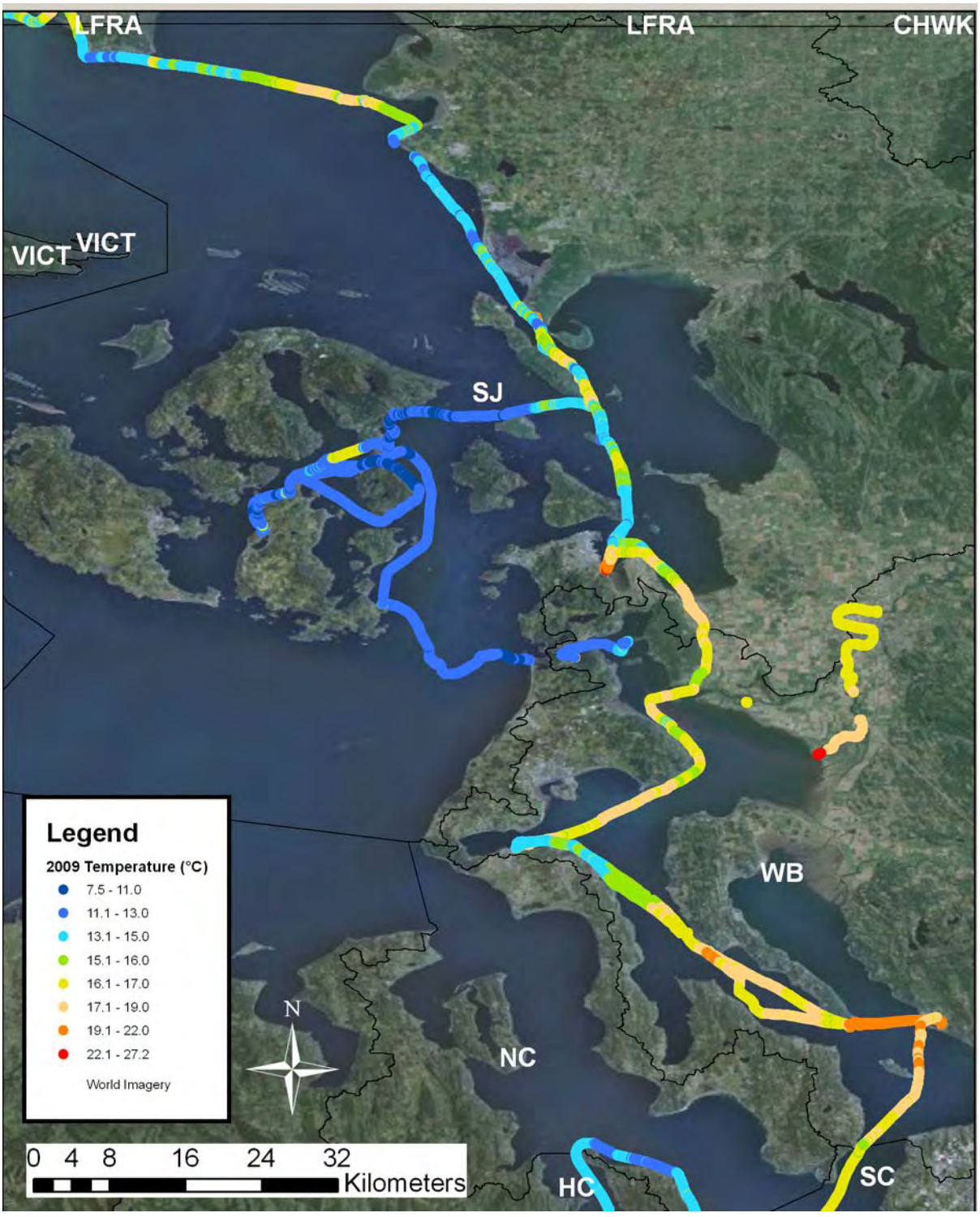


Figure 15. Temperature recorded in degrees Celsius along the central Salish Sea from July 21 to August 3, 2009. This region highlights results from San Juan, Whidbey, North Central Puget Sound and the Skagit River.

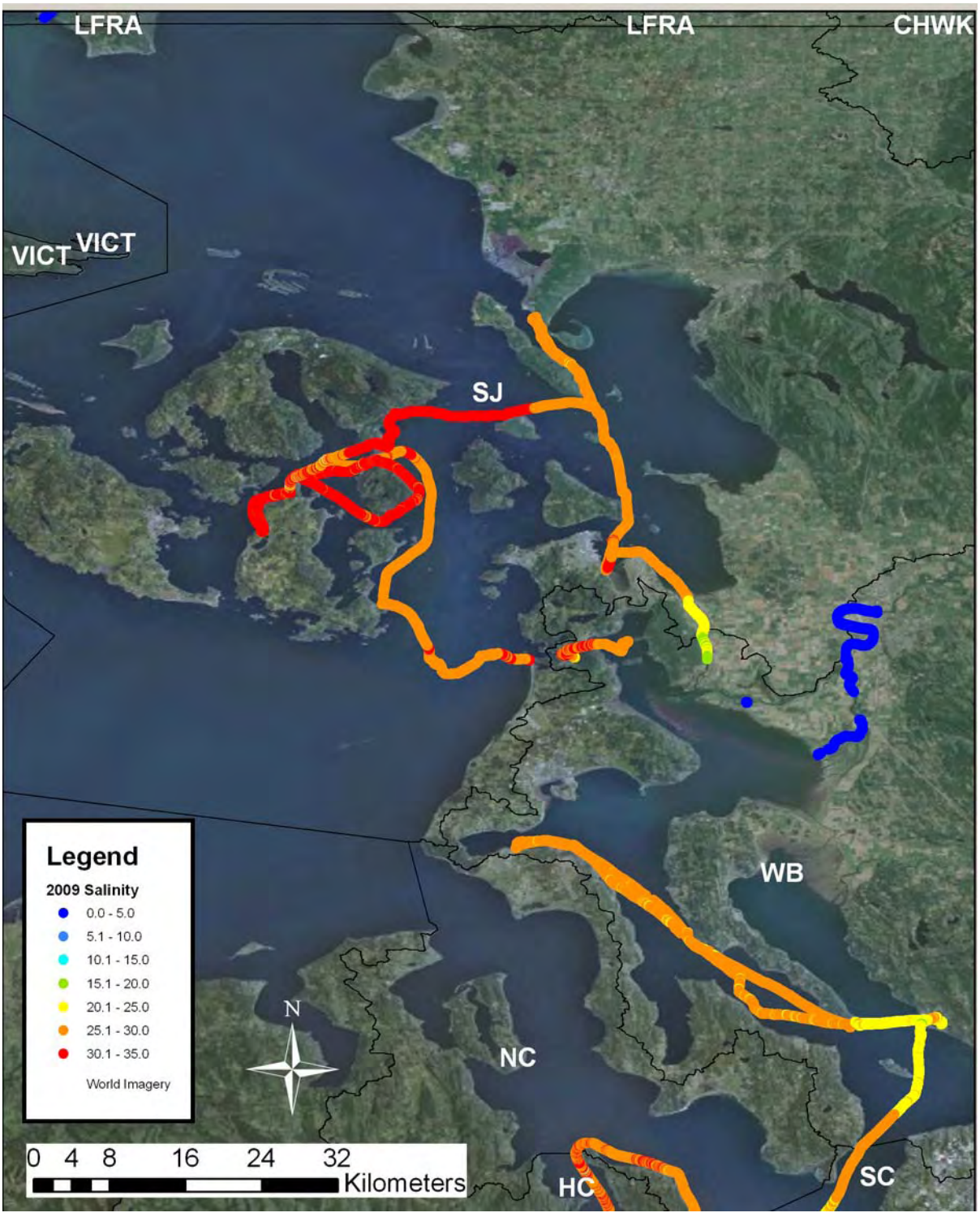


Figure 16. Salinity recorded along the central Salish Sea from July 21 to August 3, 2009. This region highlights results from San Juan, Whidbey, North Central Puget Sound and the Skagit River.

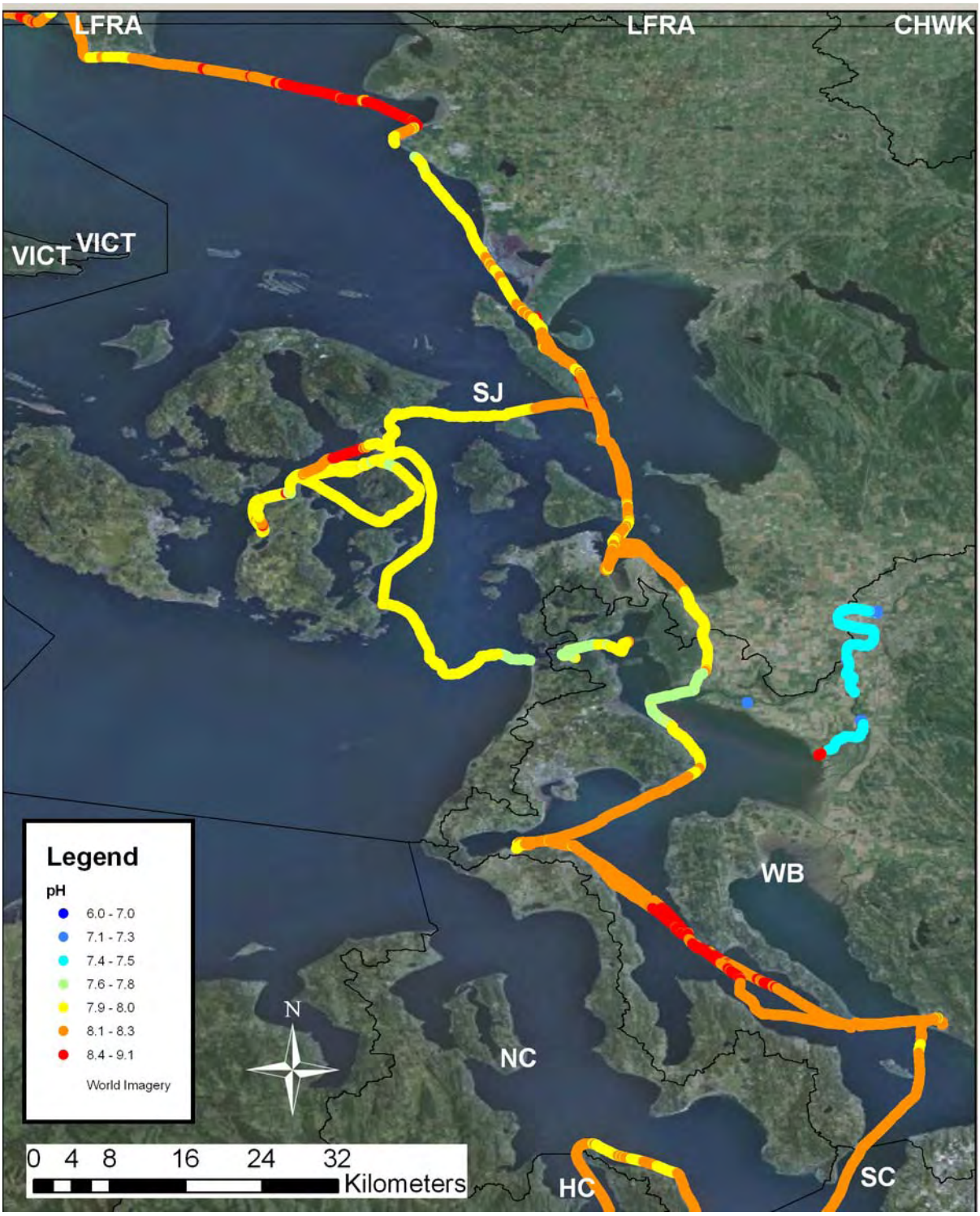


Figure 17. pH recorded along the central Salish Sea from July 21 to August 3, 2009. This region highlights results from San Juan, Whidbey, North Central Puget Sound and the Skagit River.

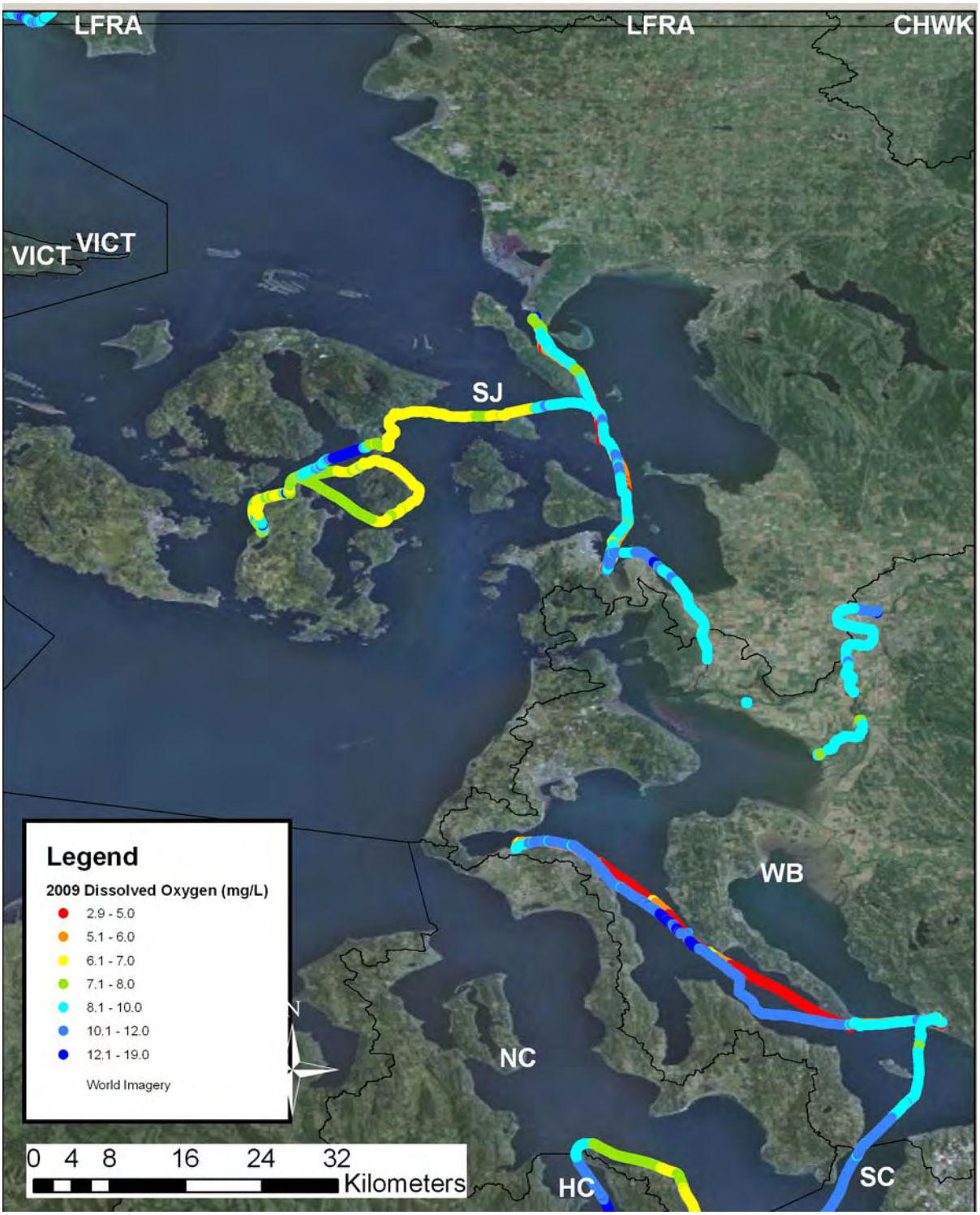


Figure 18. Dissolved oxygen recorded in milligrams per liter along the central Salish Sea from July 21 to August 3, 2009. This region highlights results from San Juan, Whidbey, North Central Puget Sound and the Skagit River.

Figure 19. Turbidity recorded in Formazin Nephelometric Units along the central Salish Sea from July 21 to August 3, 2009. This region highlights results from San Juan, Whidbey, North Central Puget Sound and the Skagit River.

South Salish Sea Region

South Salish Sea region consists of three basins; Hood Canal (HC), South Central Puget Sound (SC) from here forward referred to as South Central, and South Puget Sound (SP). Hood Canal in 2009 was monitored four days from July 28 to August 3. South Central was monitored two days August 3 and 4, 2009. South Puget Sound was monitored one day July 27, 2009. Air temperatures in the south Salish Sea ranged from 4.4°C at night in Quilcene, WA to a day time high of 40.0°C in Olympia, WA. The average air temperatures ranged from 19.3°C to 20.8°C for the month of July (NOAA, 2009). Tables of results for temperature, salinity, pH, dissolved oxygen, and turbidity for Hood Canal, South Central, and South Puget Sound are located in appendices IX to XI.

Hood Canal temperatures averaged 19.90°C (n=6,312), and ranged from 13.4°C to 27.15°C. The surface water temperature daily averages decreased as the canoes traveled from south Hood Canal to northern Hood Canal where there is a greater exchange of cool water from the Pacific (Figure 21). The average salinity was 27.27, with a minimum of 0.67 at the mouth of the Skokomish River and a maximum reading of 31.36 (Figure 22). The median pH reading was 8.11, and Hood Canal pH ranged from 6.96 to 8.35 (Figure 23). Dissolved oxygen readings were not analyzed until the third day of travel in Hood Canal because of audit errors. The northern portion of Hood Canal had an average dissolved oxygen of 6.37 mg/L (n=2,791) and ranged from 3.96 mg/L to 13.35 mg/L (Figure 24). Dissolved oxygen saturation levels ranged from 52.2% to 152.6%. The average turbidity was 10.32 FNU (n=6,047), and ranged from 0.0 FNU to 200.0 FNU (Figure 25).

In 2009 the canoes only traveled though the northern portion of South Central basin. The average surface water temperature for South Central basin was 15.68°C (n=1,739) with a minimum temperature of 13.23°C and a maximum of 20.51°C (Figure 21). Salinity measurements ranged from 17.7 to 29.8 with an average of 27.8 (Figure 22). The median pH reading was 8.23 over the two day period and ranged between 7.96 and 8.46 (Figure 23). Dissolved oxygen measurements averaged to 8.31 mg/L, with a minimum concentration of 5.28 mg/L and a maximum of 12.67 mg/L (Figure 24). Dissolved oxygen saturation averaged 99.0% with a minimum of 60.9% and a maximum of 146.5%. The average turbidity for South Central basin was 81.73 FNU (n=786) with a maximum reading of 200.0 FNU and a minimum of 0.3 FNU (Figure 25). Diatom film on the waters surface and quarter sized clumps of diatoms were observed in South Central basin during the Tribal Journey (Figure 20).

Figure 20. Diatom growth observed in South Central basin, August 2009. Photo by E. Grossman.

Surface water temperatures in South Puget Sound basin averaged 18.60°C (n=1453) with a minimum of 15.97°C and a maximum of 23.35°C (Figure 21). Salinity measurements ranged from 27.83 to 29.77, with an average of 29.27 (Figure 22). The pH ranged from 8.05 to 8.49, and the median reading was 8.14 (Figure 23). Dissolved oxygen results were not analyzed due to an audit error. The average turbidity for South Puget Sound basin was 10.45, and

ranged from 0.0 FNU to 200.0 FNU (Figure 25). The canoes and support boat crew observed several large lion's mane jellyfish and a persistent high density of 'quarter' sized diatom clusters throughout the basin.

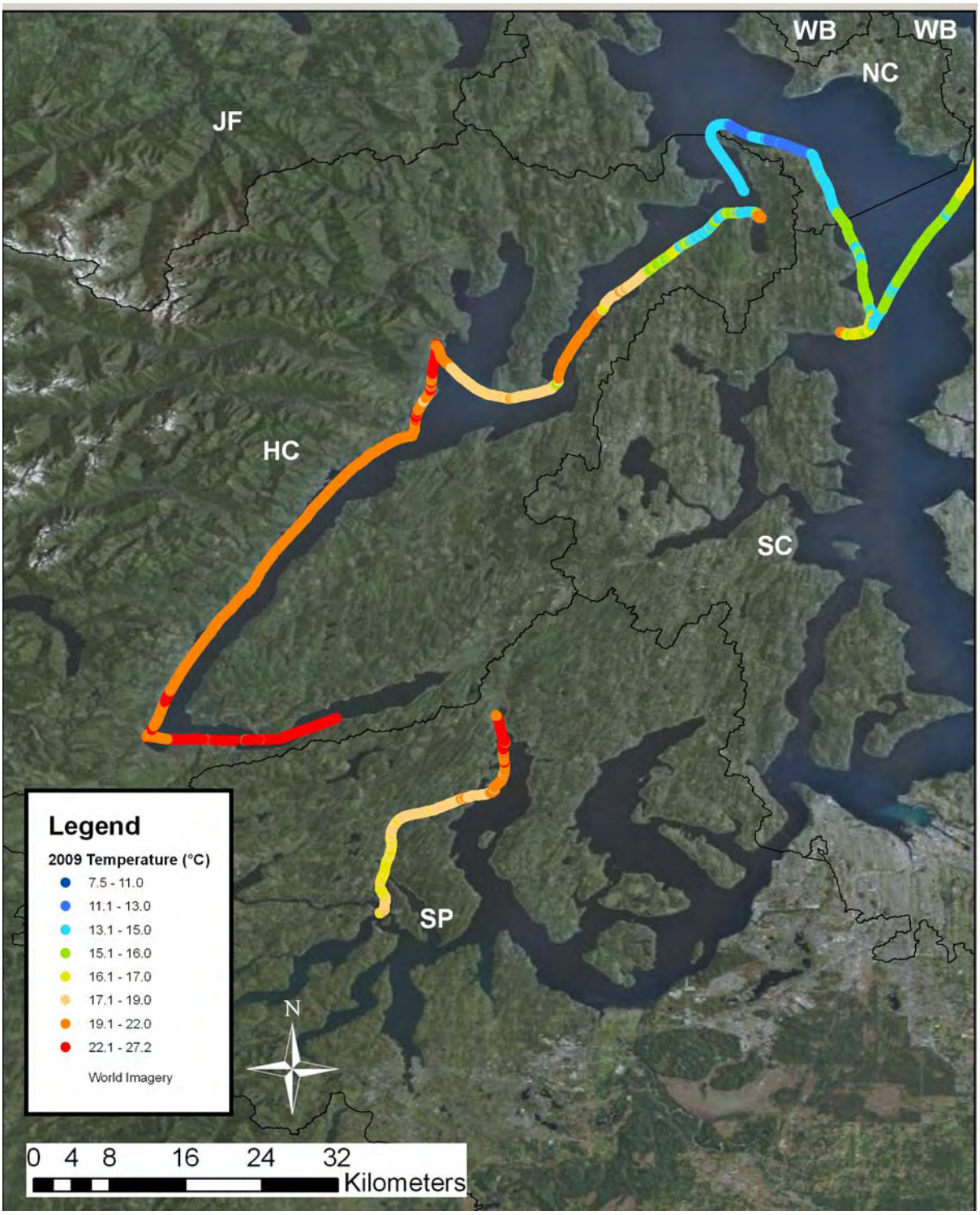


Figure 21. Temperature recorded in degrees Celsius along the southern Salish Sea region from July 21 to August 3, 2009. This region highlights results from Hood Canal, South Central Puget Sound, and South Puget Sound.

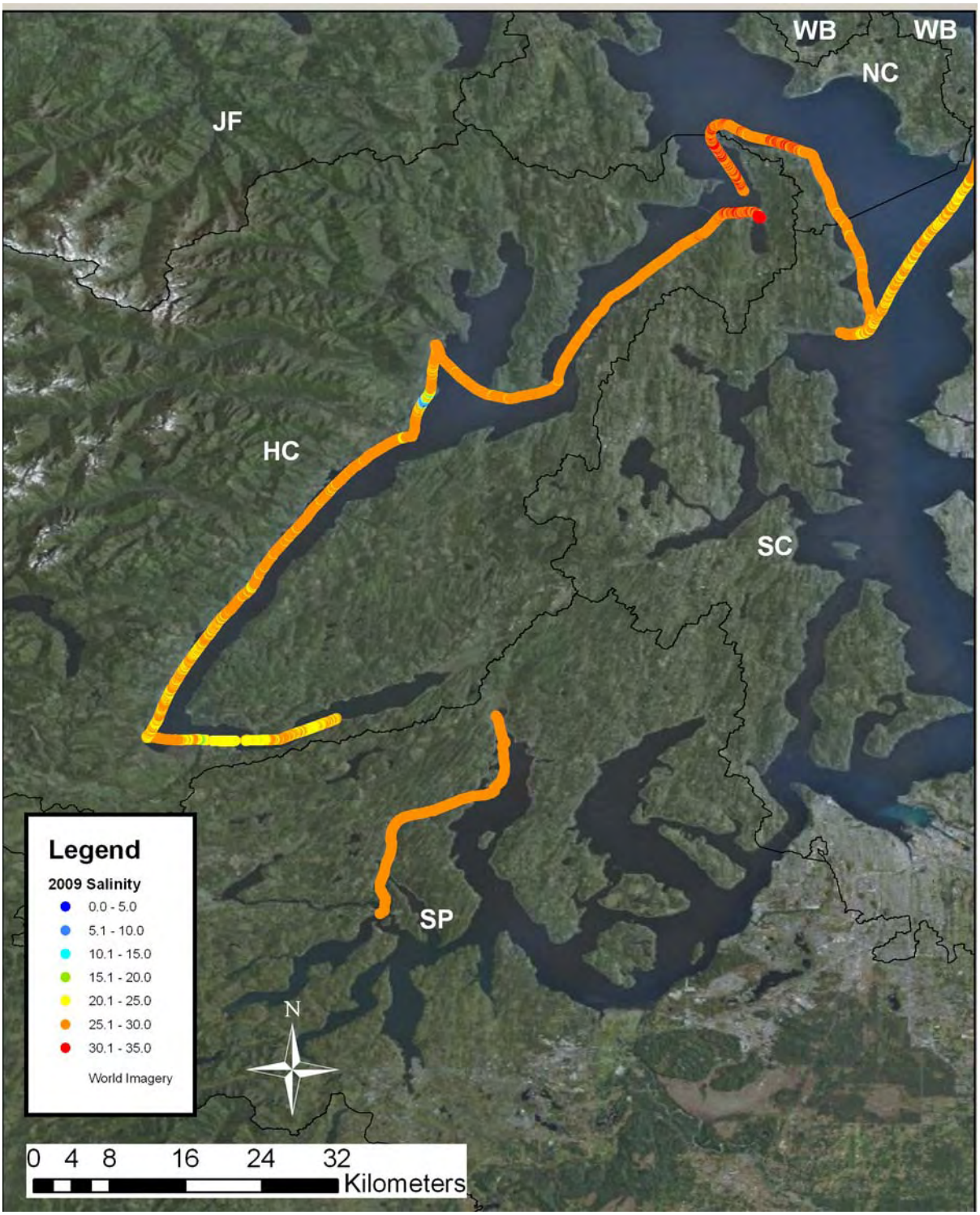


Figure 22. Salinity recorded along the southern Salish Sea region from July 21 to August 3, 2009. This region highlights results from Hood Canal, South Central Puget Sound, and South Puget Sound.

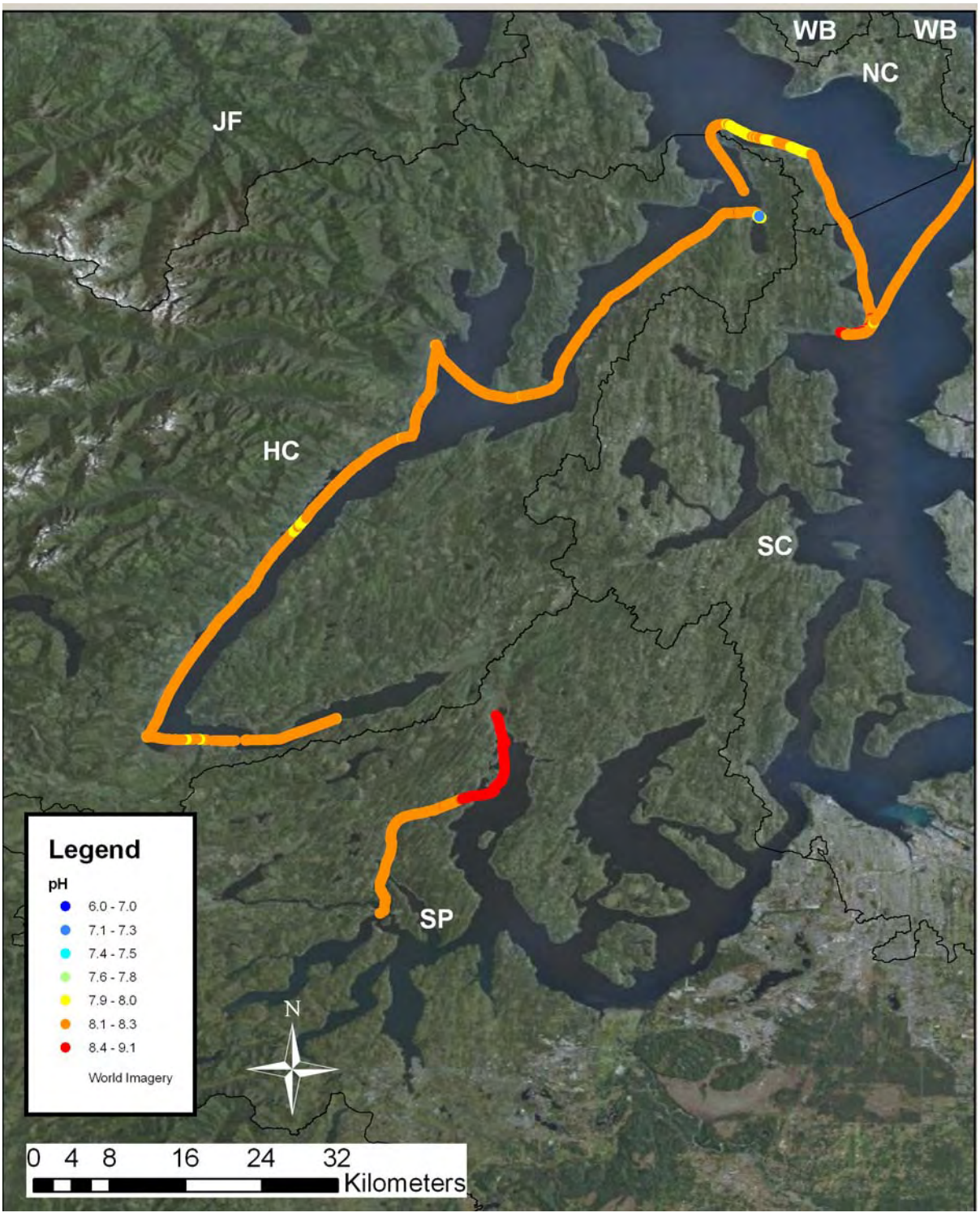


Figure 23. pH recorded along the southern Salish Sea region from July 21 to August 3, 2009. This region highlights results from Hood Canal, South Central Puget Sound, and South Puget Sound.

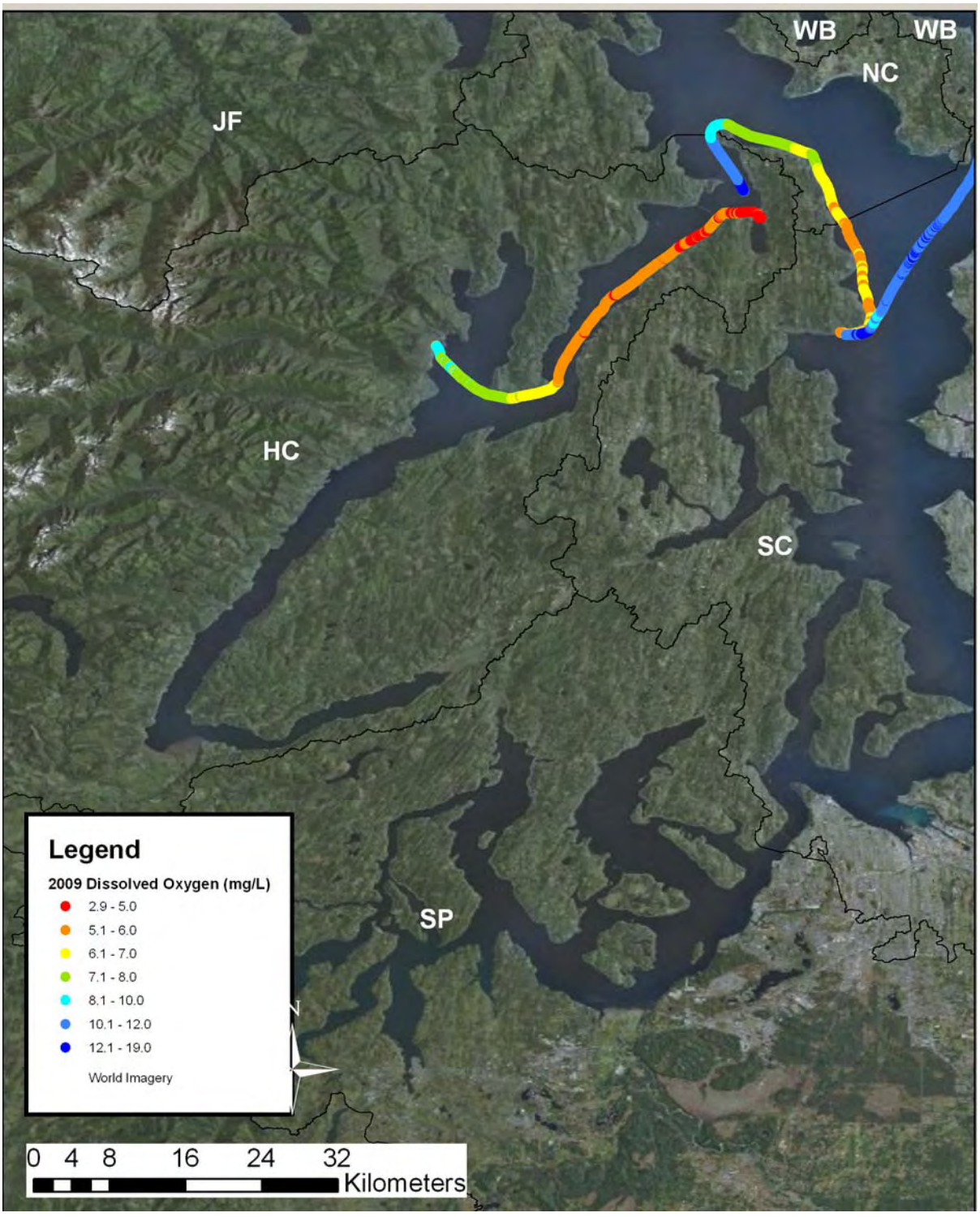


Figure 24. Dissolved Oxygen recorded in milligrams per liter along the southern Salish Sea region from July 21 to August 3, 2009. This region highlights results from Hood Canal, South Central Puget Sound, and South Puget Sound.

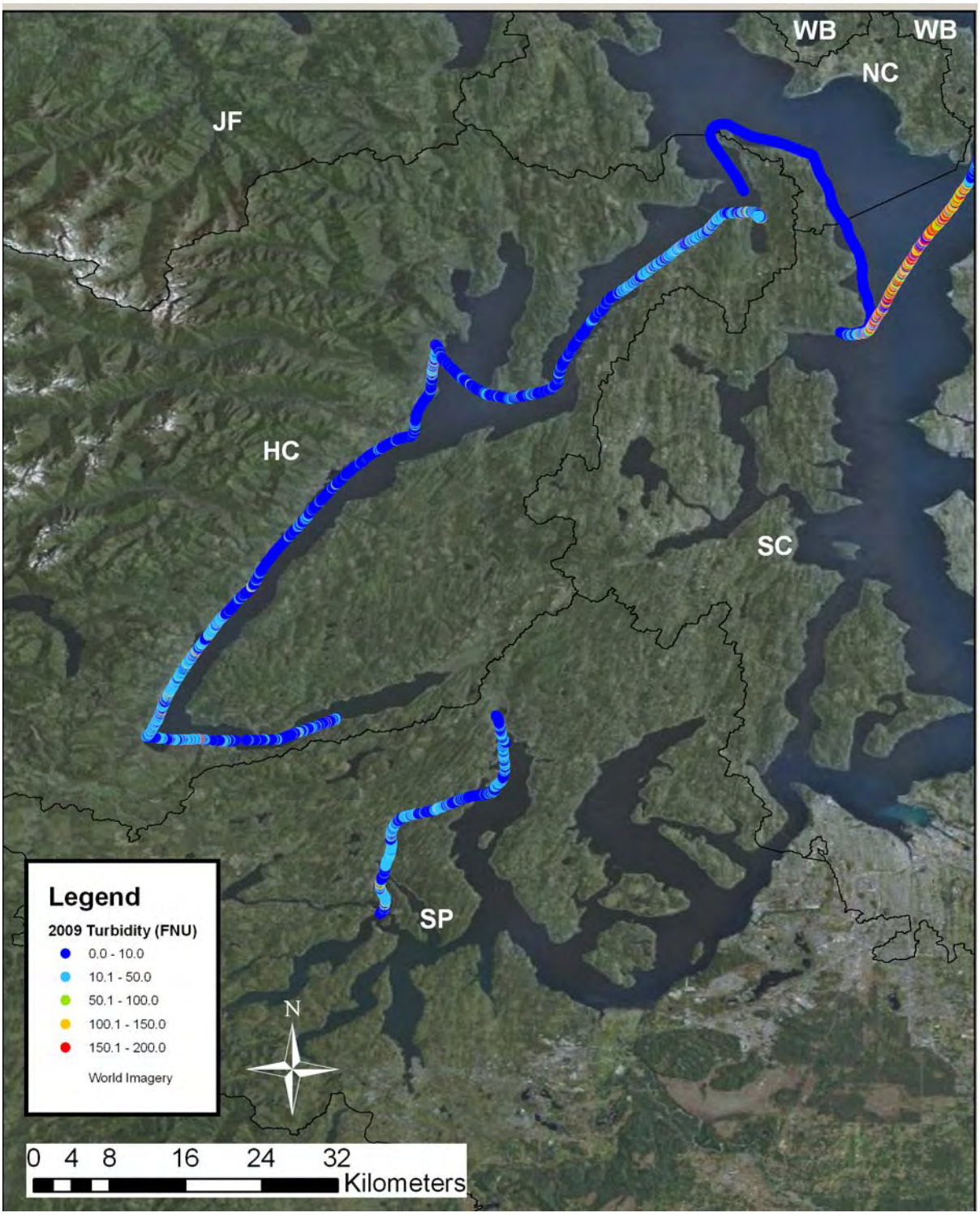


Figure 25. Turbidity recorded in Formazin Nephelometric Units along the southern Salish Sea region from July 21 to August 3, 2009. This region highlights results from Hood Canal, South Central Puget Sound, and South Puget Sound.

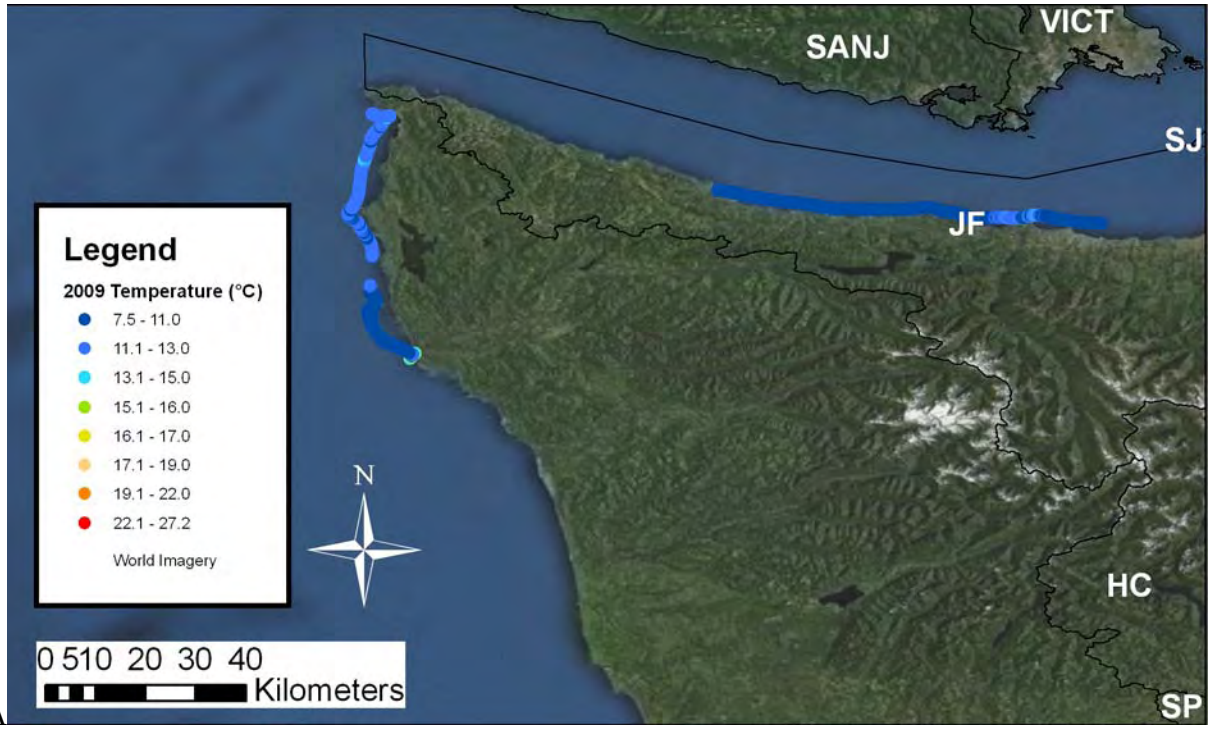
Pacific Coast and Juan de Fuca Strait

In 2009 the Tribal Journey Project expanded the monitoring area to include the Pacific coast off of Washington State. The rugged Pacific Coast route was monitored by the Quinault Nation. The Pacific Coast basin was monitored July 26, 2009 and the Juan de Fuca basin (JF) was monitored July 29, 2009. The Songees Nation pulled a YSI sonde from Vancouver Island to Port Angeles, but the data could not be validated. The maximum air temperature was 31.1°C for the Quillayute, WA area during July 2009 (NOAA, 2009). At Victoria International Airport a maximum temperature of 35.0°C was recorded in July 2009 during the time of the Tribal Journey. Tables of results for temperature, salinity, pH, dissolved oxygen concentration and percent saturation, and turbidity for the Pacific Coast and Juan de Fuca basins are located in Appendices XIII to XIV.

The average surface water temperature for the Pacific Coast basin was 11.04°C (n=4,394) with a maximum reading of 16.18°C and a minimum reading of 9.73°C (Figure 26A). Water properties salinity and pH for the Pacific Coast failed audit criteria and were not used for analysis. Dissolved oxygen concentration readings averaged 7.73 mg/L (n=4,394) and ranged from 6.87mg/L to 9.67mg/L (Figure 27B). Dissolved oxygen saturation levels ranged from 75.5% to 103.9%, with an average of 86.5%. The average turbidity for the Pacific Coast was 8.11 FNU (n=4394), with a minimum of 0.0 FNU and a maximum reading of 200.0 FNU (Figure 28).

The Juan de Fuca basin surface water temperatures averaged 10.23°C (n=3,153), the minimum reading was 7.48°C and the maximum reading was 13.72°C (Figure 26A). Juan de Fuca basin had the coolest surface water temperature of all the basins monitored in 2009. Salinity readings ranged from 3.66 to 33.83, with an average of 32.24 (n=3,151) (Figure 26B). The median pH reading was 7.68 and values ranged from 7.51 to 7.89 (Figure 27A). The average dissolved oxygen concentration was 5.65 mg/L, and the minimum value was 2.88 mg/L and the maximum value 8.20 mg/L (Figure 27B). Dissolved oxygen saturation remained below 100% with an average of 61.9% and a range of 29.9% to 90.1%. The average turbidity was 6.25 FNU and ranged between 0.0 FNU and 200.0 FNU (Figure 28).

A



B

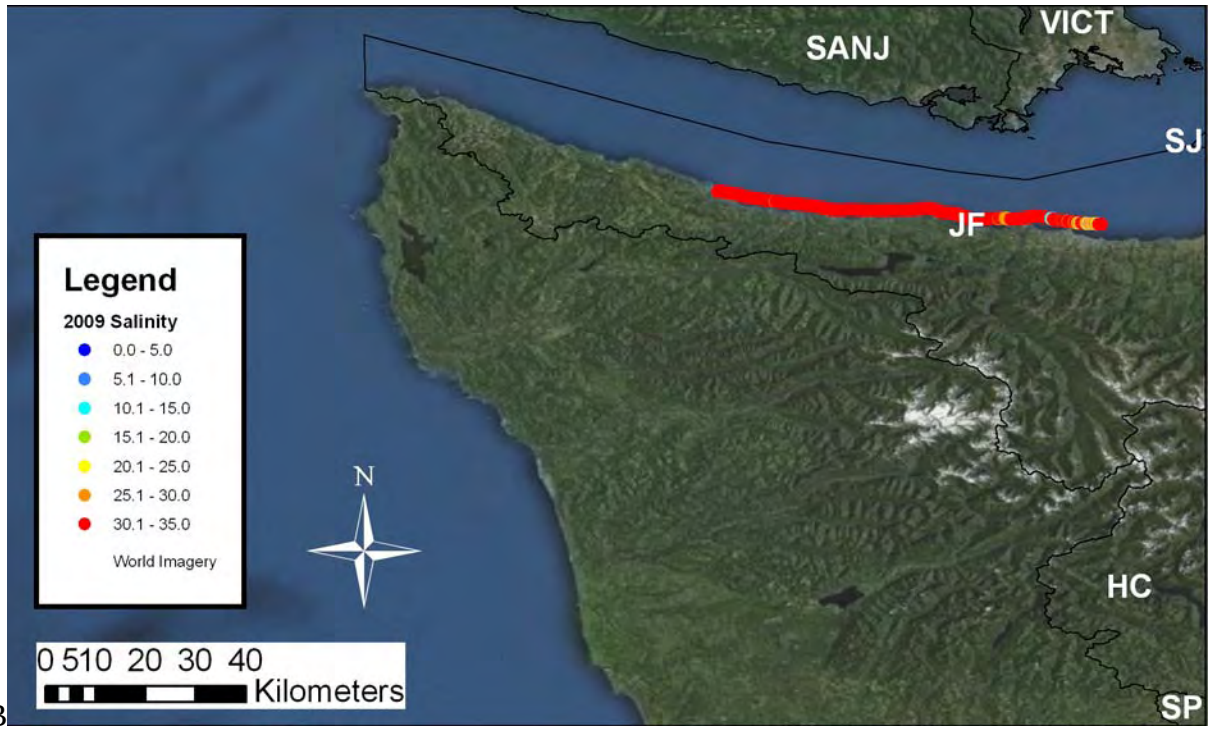
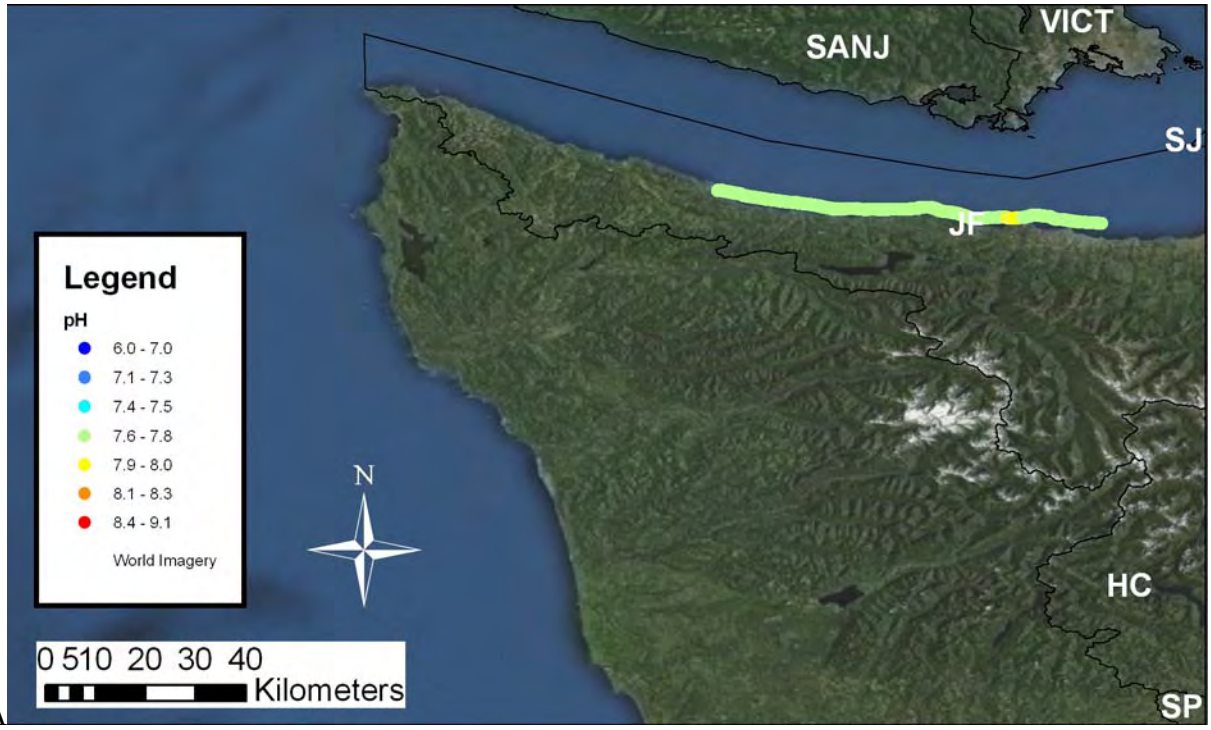


Figure 26. Temperature (A) recorded in degrees Celsius and salinity (B) along the west Salish Sea from July 26 to 29, 2009. This region highlights results from Pacific Coast and Juan de Fuca basins.

A



B

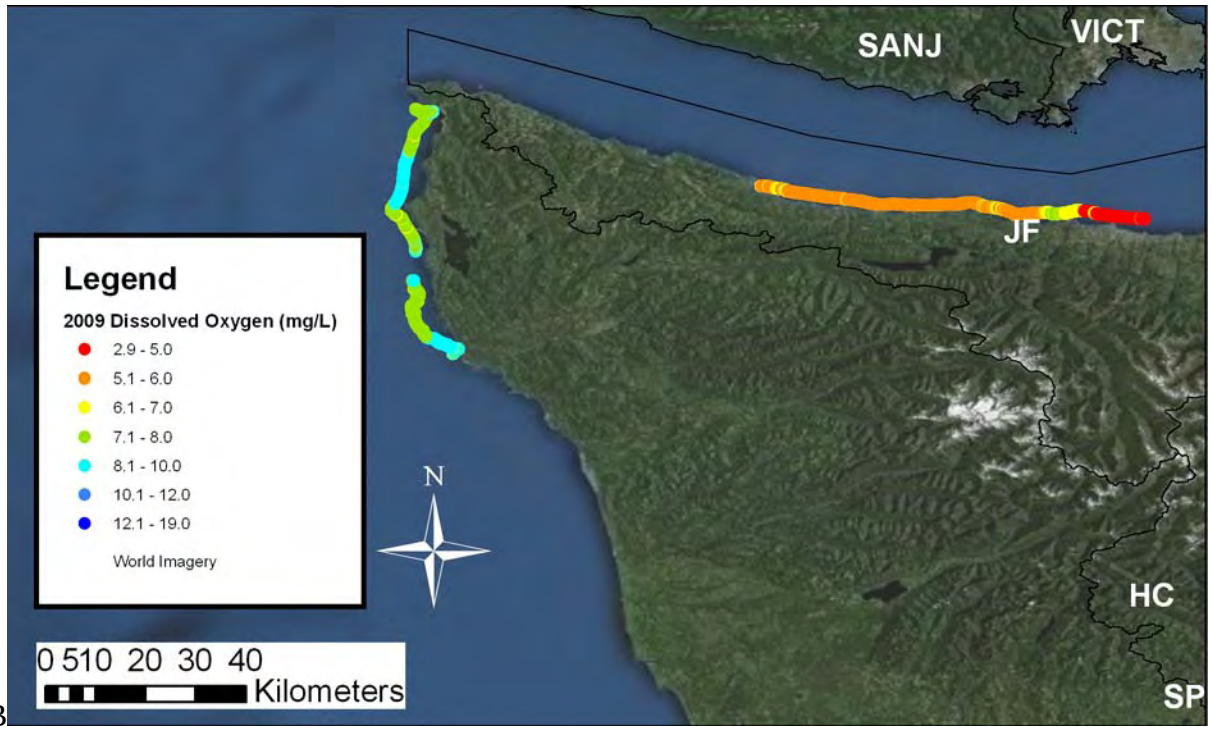


Figure 27. pH (A) recorded pH units and dissolved oxygen (B) recorded in milligrams per liter along the west Salish Sea from July 26 to 29, 2009. This region highlights results from Pacific Coast and Juan de Fuca basins.

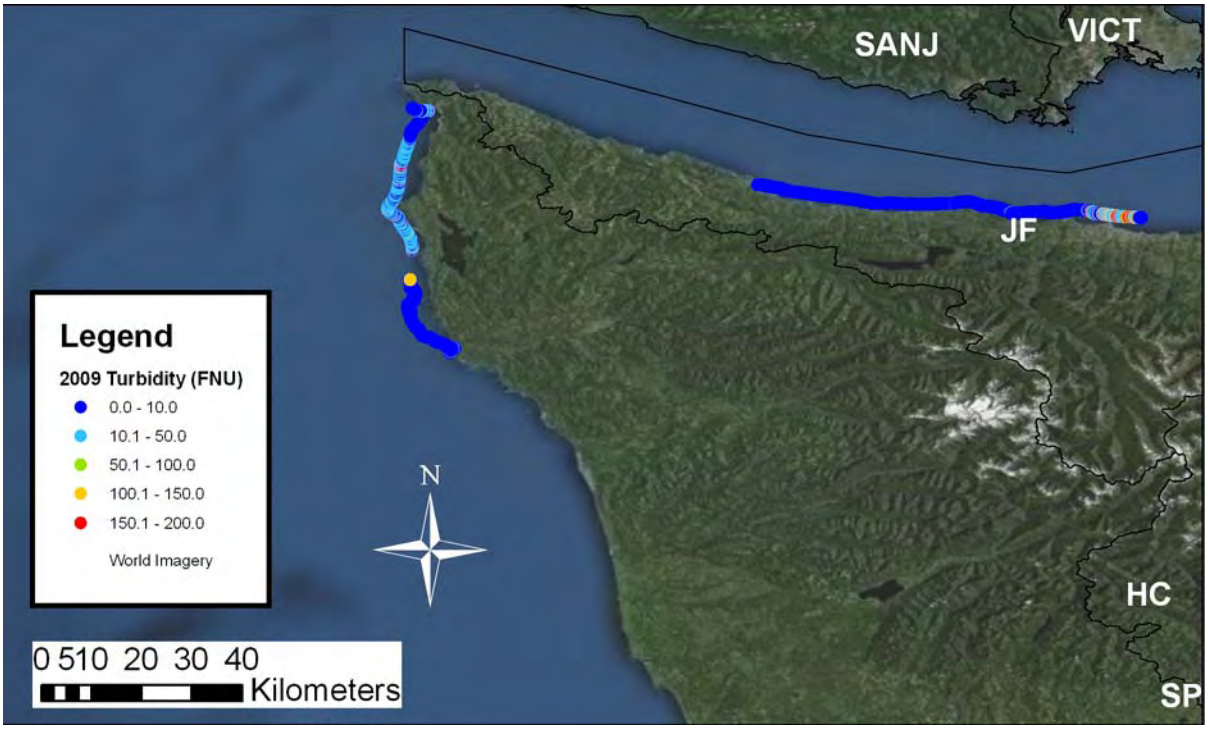


Figure 28. Turbidity measured in Formazin Nephelometric Units along the west Salish Sea from July 26 to 29, 2009. This region highlights results from Pacific Coast and Juan de Fuca basins.

Discussion and Conclusions

The Tribal Journey study provides detailed quantitative information on water quality properties across a vast region during the stressful conditions of middle to late summer when surface water temperatures are highest, fresh water runoff from streams is past peak and biological growth and decay are high. The 2008 TJWQP survey demonstrated that intensive water quality monitoring across the Puget Sound and Georgia Strait could be accomplished and that large landscape scale and site-specific patterns in water body characteristics could be identified. In 2009, with the strong commitment of Coast Salish canoe families, Tribal and First Nation natural resource managers, educators, the U.S. Geological Survey, and many other contributors the Project continued and mapped conditions during a very warm period, including record high air temperatures exceeding 40 °C.

In 2009, surface waters from the Pacific were lower coming into the Juan de Fuca Strait. As the oceanic water mixed with the inland waters of Puget Sound and Georgia Strait in the North Central Puget Sound and San Juan basins, and continuing to the north and the south, surface waters increased. The highest temperatures were recorded in Hood Canal, South Puget Sound, and Squamish Basins. Pacific coast and Juan de Fuca were the only two basins with *extraordinary* average surface water temperatures. San Juan, North and South Central Puget Sound had *excellent* water temperature levels. South Puget Sound, Whidbey, Lower Fraser, and Squamish basins had *good* surface water average temperature. Hood Canal basin was the only basin with *fair* quality average temperature (Table, 4). Comparisons between 2008 and 2009 results show that all basins experienced an increase in surface water

temperature except for Juan de Fuca basin which experienced a decrease in temperature. South Puget Sound basin had the greatest increase in surface water temperature followed by Whidbey and Hood Canal basins (Figure 29).

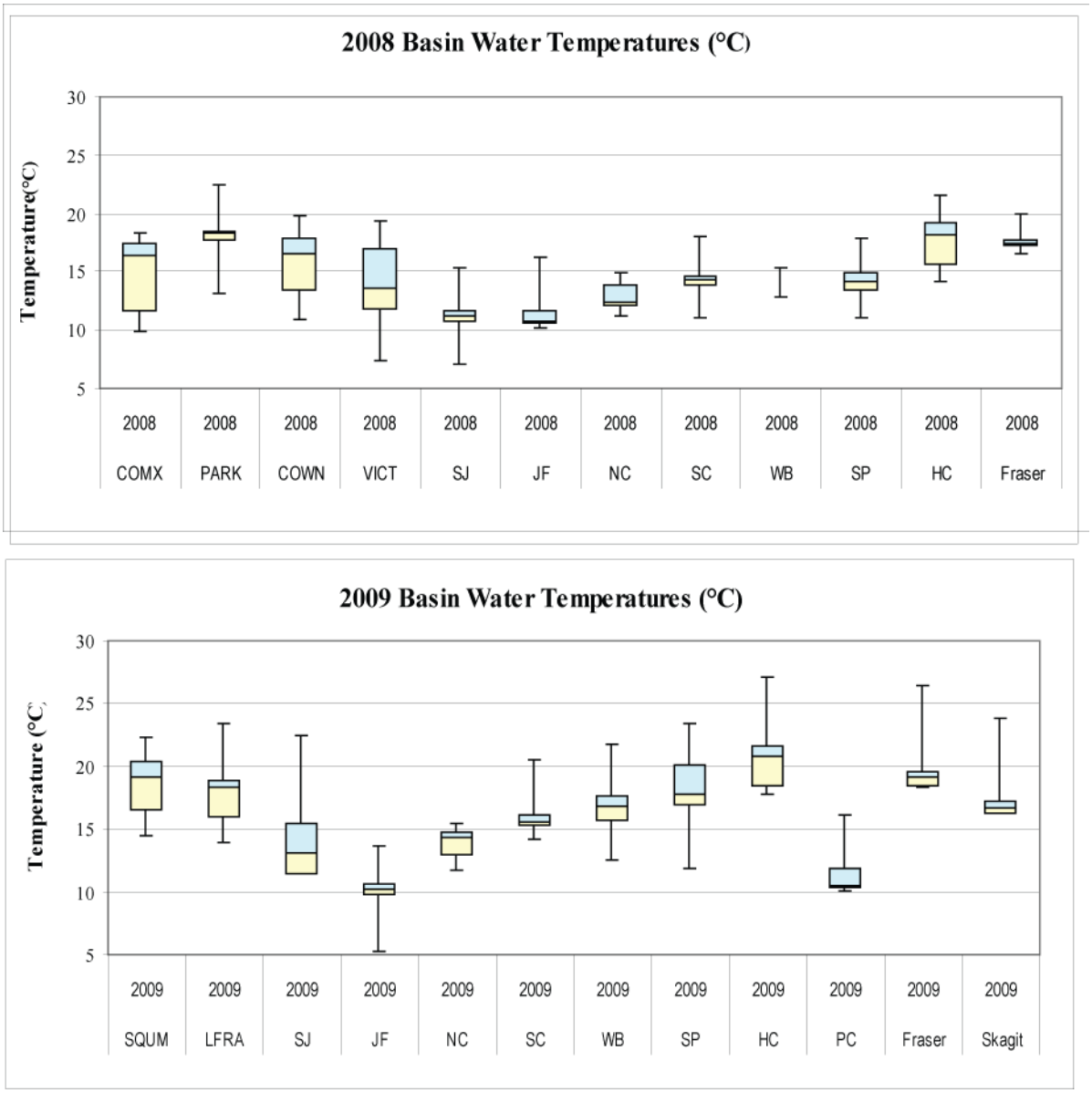


Figure 29. 2008 and 2009 box and whisker plot of surface water temperature (°C) by basin for marine water bodies Comox, Parkville, Cowichan, Victoria, Squamish, Lower Fraser River, San Juan, Juan de Fuca, North Central Puget Sound, South Central Puget Sound, Whidbey Basin, South Puget Sound, Hood Canal, and Pacific Coast and fresh water inputs into the Salish Sea the Fraser and Skagit Rivers. Basins arranged from furthest north (left) to furthest south (right), followed by oceanic and fresh water inputs to the Salish Sea.

Dissolved oxygen concentrations in the surface waters reached levels that are recognized by the USEPA and Environment Canada as threatening in several locations across the Salish

Sea. With the elevated air temperatures experienced throughout the region in the summer of 2009 it was expected that dissolved oxygen would be lower throughout the region. This was the case for the Juan de Fuca, North Central, South Central, and Hood Canal basins, and the Fraser River. Hood Canal average dissolved oxygen results qualified the basin for *excellent* criteria. The San Juan and Squamish basins had dissolved oxygen concentrations above 16.0 mg/L and corresponding percent saturation levels above 200%. In areas of dissolved oxygen super saturation there were observations of a noticeable increase in suspended algal blooms. The most striking algal bloom occurred in Squamish basin and spanned a distance of over 11 km. Additional information derived from the depth profiling showed temperature, salinity, and dissolved oxygen stratification in these water bodies reaching 8 m thick (Grossman, in Prep.). The lowest levels of dissolved oxygen were observed in the Juan de Fuca basin. Juan de Fuca basin qualified for good water quality criteria status during the tribal journey. All other basins were *extraordinary* for dissolved oxygen during the 2009 survey (Table, 4). Further investigations into the dissolved oxygen levels on a diurnal cycle could have revealed sharp declines in oxygen concentrations during the night, and might be elucidated by the mooring results (to be presented in a subsequent report). San Juan and Whidbey basins had higher average dissolved oxygen in 2009 than in 2008 (Figure 30).

Salinities were greatest in the Juan de Fuca basin. Squamish, Lower Fraser, and Whidbey basins showed depressed salinity results because of the significant freshwater inputs from the Squamish, Fraser, and Skagit rivers. The 2009 results for pH showed a higher instance of basic waters above the water quality criteria standards. The San Juan basin had the highest spread of pH readings. Instances of pH levels above 9.0 units were generally associated with a super saturation of dissolved oxygen. Generally, Salish Sea surface waters were clear with low turbidity across all of the basins. The exception was South Central Puget Sound basin where turbidity levels were significantly elevated due to a high level of biological productivity in the basin.

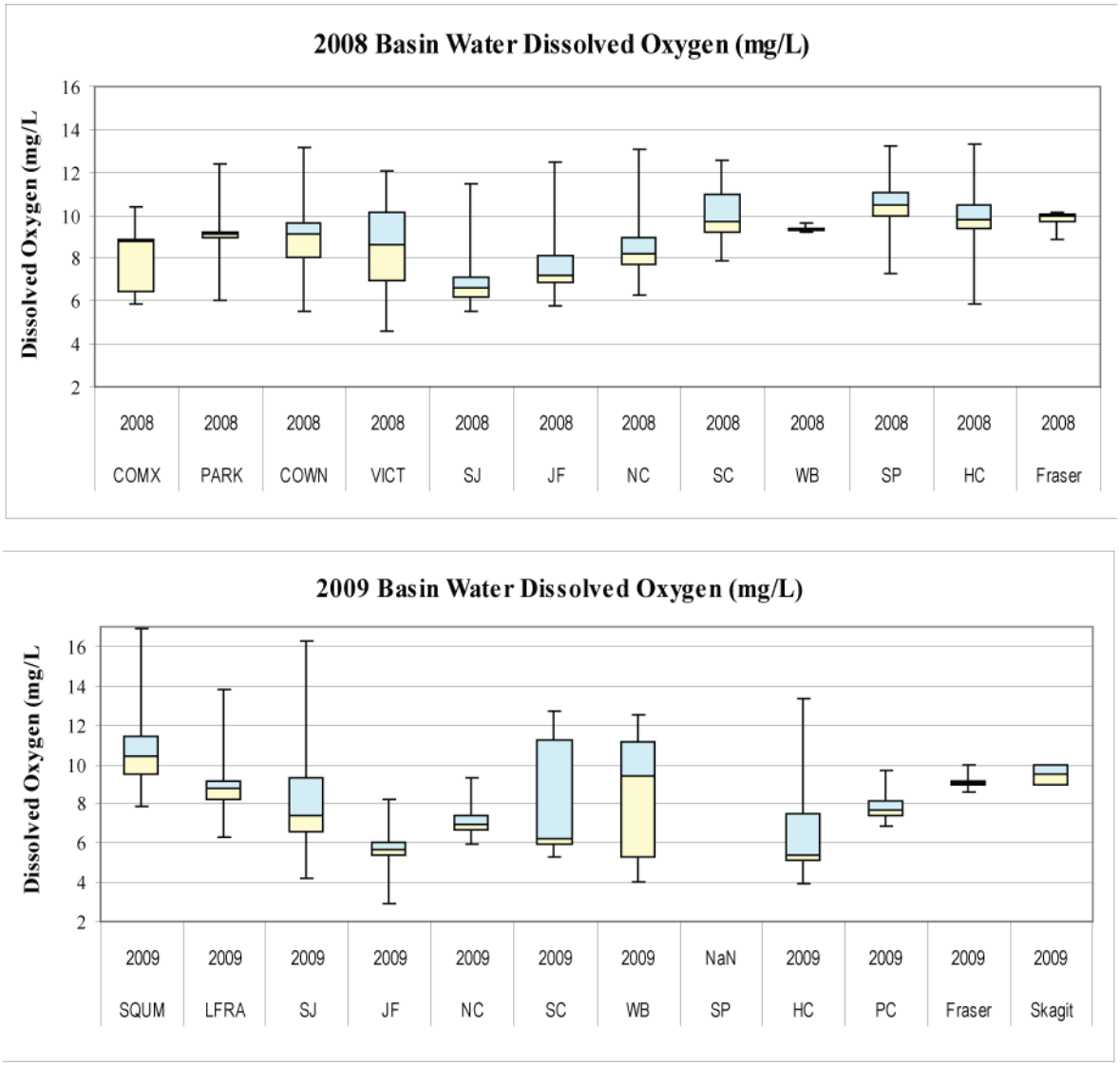


Figure 30. 2008 and 2009 box and whisker plot of dissolved oxygen (mg/L) by basin for marine water bodies Comox, Parkville, Cowichan, Victoria, Squamish, Lower Fraser River, San Juan, Juan de Fuca, North Central Puget Sound, South Central Puget Sound, Whidbey Basin, South Puget Sound, Hood Canal, and Pacific Coast and fresh water inputs into the Salish Sea the Fraser and Skagit Rivers. Basins arranged from furthest north (left) to furthest south (right), followed by oceanic and fresh water inputs to the Salish Sea. NaN indicates no data.

Table 4. Squamish, Lower Fraser, San Juan, North Central Puget Sound, South Central Puget Sound, Whidbey, Hood Canal, South Puget Sound, Pacific Coast, and Juan de Fuca basin average temperature and dissolved oxygen results for 2008 and 2009 classified by Washington State water quality criteria extraordinary, excellent, good, and fair.

Squamish	2008	2009
Temperature		Good
Dissolved Oxygen		Extraordinary

Lower Fraser	2008	2009
Temperature		Good
Dissolved Oxygen		Extraordinary

San Juan	2008	2009
Temperature	Extraordinary	Excellent
Dissolved Oxygen	Excellent	Extraordinary

North Central Puget Sound	2008	2009
Temperature	Extraordinary	Excellent
Dissolved Oxygen	Extraordinary	Extraordinary

Whidbey	2008	2009
Temperature	Excellent	Good
Dissolved Oxygen	Extraordinary	Extraordinary

South Central Puget Sound	2008	2009
Temperature	Excellent	Excellent
Dissolved Oxygen	Extraordinary	Extraordinary

Hood Canal	2008	2009
Temperature	Good	Fair
Dissolved Oxygen	Extraordinary	Excellent

South Puget Sound	2008	2009
Temperature	Excellent	Good
Dissolved Oxygen	Extraordinary	

Pacific Coast	2008	2009
Temperature		Extraordinary
Dissolved Oxygen		Extraordinary

Juan de Fuca	2008	2009
Temperature	Extraordinary	Extraordinary
Dissolved Oxygen	Extraordinary	Good

The 2009 results for surface water temperature could be showing the water property effects that an increase in air temperature will have on tide flats and shallow embayments throughout the Salish Sea. During day-time low tide cycles the sun heats up the exposed mud and sand. As the tide begins to rise over the warm substrate the heat is transferred into

the water. In a low circulation shallow embayment a critical water volume of water may not be attained to cool the protective habitat for juvenile fishes and invertebrates. In Samish Bay, Port Susan, Port Gamble, Lynch Cove in Hood Canal and South Puget Sound north of Squaxin Island, surface water temperatures were much higher in the shallow waters (Figure 31, A, B, C, D, E). Also of interest, The Fraser River delta, with a constant flow of fresh water, warmed two degrees Celsius as the river water mixed in the estuary (Figure 31 C).

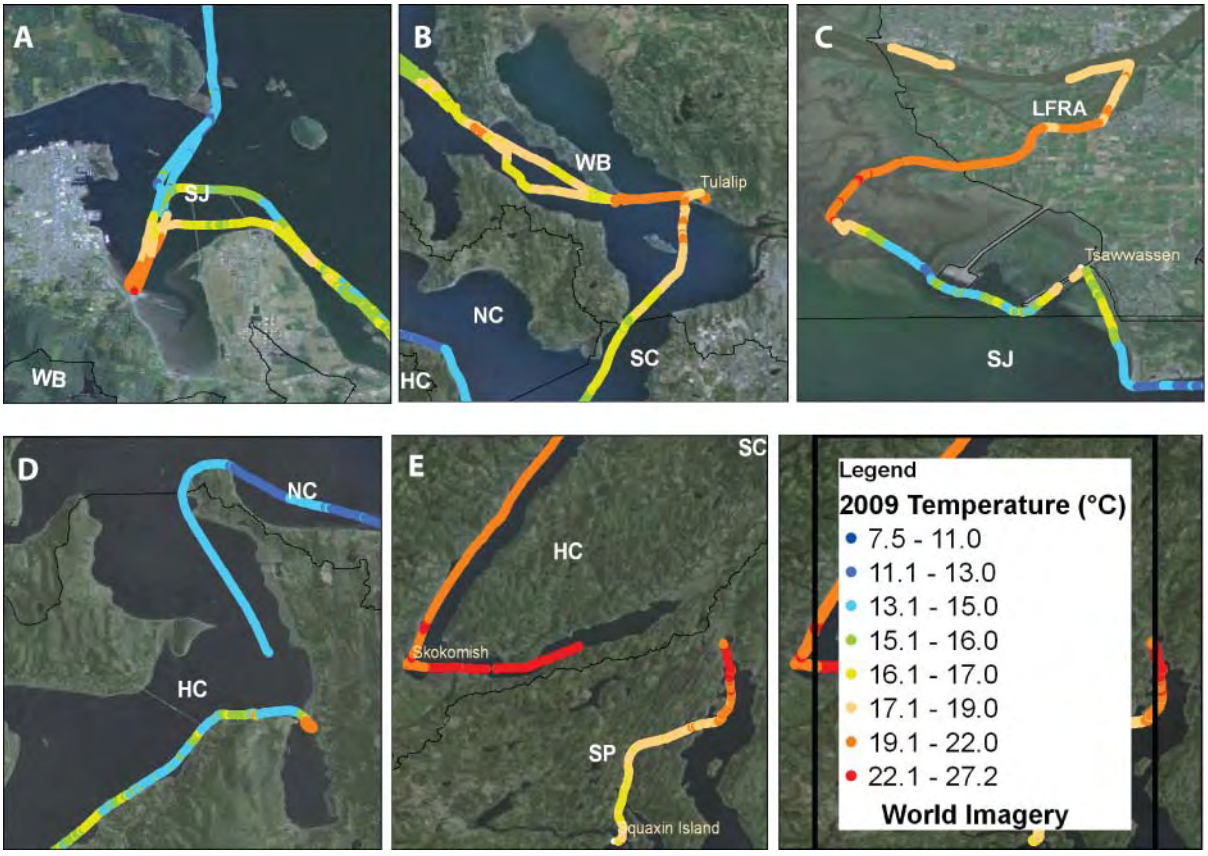


Figure 31. Elevated temperature readings in degrees Celsius may be associated with shallow embayments. A. Samish Bay B. Port Susan C. Fraser River delta D. Port Gamble, WA E. South Puget Sound and Hood Canal.

With regard to temperature, pH, and dissolved oxygen, an interesting phenomenon was observed near East Sound at the south end of Orcas Island in the San Juan Islands. At the mouth of East Sound an abrupt increase in surface water temperature was observed to be associated with an anonymously high pH, and an increase in the dissolved oxygen concentration (Figure 32). While the canoes were traveling past East Bay the tide was falling from a low-high tide (NOAA, 2009B) that likely was transporting the water from East Sound out into the channel.

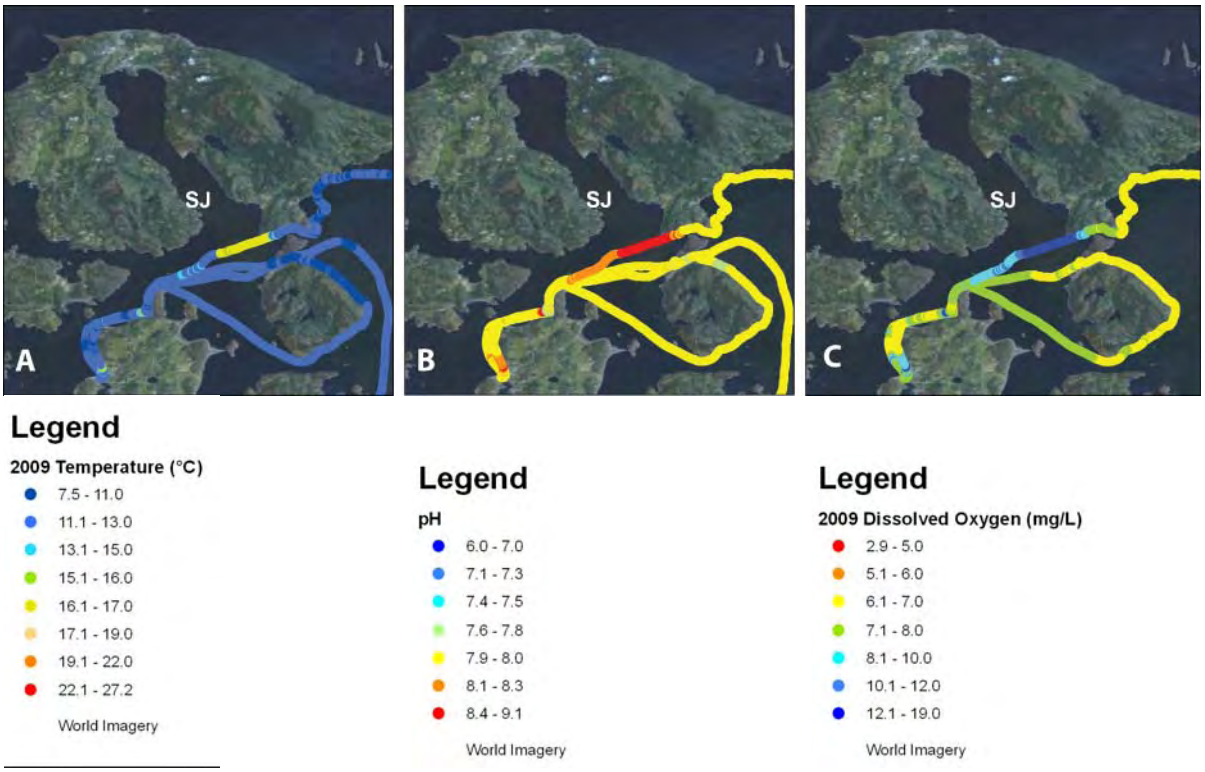


Figure 32. Water properties temperature in degrees Celsius (A), pH in pH units (B), and dissolved oxygen in milligrams per liter (C) offshore of East Bay south of Orcas Island in the San Juan Islands.

Blending Science and Tradition

Along the Tribal Journey stories were shared between the Elders, the Youth, the Skippers and the Pullers. For some people the Tribal Journey is a time of healing, for others it is a way to reconnect with long lost relatives, for all it is a way to maintain tradition. With the introduction of the TJWQP, there is an added dialogue: the status of the environment. The Project has created an *excellent* opportunity for a concerned group of people, who are not necessarily scientists, to play a key role in a research effort as well as re-affirm the Coast Salish people's role as stewards of the environment.

With the success of the TJWQP the Coast Salish People have made a significant contribution towards monitoring the waters of the Salish Sea. The outcomes of the Project will support the Coast Salish Nation's effort to address the environmental impacts. As the aboriginal inhabitants of the Salish Sea Ecosystem, Coast Salish are responsible for the well being and health of their ecosystem and communities and to share their understanding and vision for the Salish Sea. Coast Salish has an important and leading role in helping to manage their communities today and into the future. The project acknowledges this role and encourages all Coast Salish people to actively participate and learn more about their traditional territory, the Salish Sea.

Degradation of water quality has caused hardship in the fishing and shellfish activities of the Coast Salish people. Culturally and economically, these are the core resources that define

Coast Salish Communities. These environmental issues are central to the families and relatives on both sides of the border. We now have such an opportunity as this project provides a Coast Salish Science tool and the derived information that can be shared with the world. We know these environmental issues cannot be addressed individually or be resolved with only local policy and actions, but rather this is an ecosystem that needs to be addressed at a larger scale. The TJWQP is building strength by solidifying the scientific foundation to gather data and provide information for a structured policy dialogue process. Data and findings will be disseminated through the Coast Salish Gathering, to share the information with federal agencies and other interested parties. An open dialogue between the Coast Salish Gathering leadership and federal representatives will strengthen the local effort to provide a safe and healthy home for Coast Salish people for today and tomorrow. This is the common goal on a local and regional basis for the Coast Salish Nation.

Recommendations and Future Directions

The strength of the water quality study lies in gathering information over extensive areas and over multiple years/decades to identify trends and persistent impacts owing to human activities and expected climate change. Planning is underway to secure funding and support to repeat the surveys during the 2010 Tribal Journey to Makah and into the future. As the project has grown scientifically from year one to year two, so have the relationships developed between the Coast Salish canoe families and TJWQP staff. In 2010, planning is underway to develop an internship program through the Northwest Indian College and other local colleges and universities. The hope of this internship will be to broaden the impact of the TJWQP by providing additional environmental education to the Coast Salish communities and to provide opportunities for the Coast Salish community members to participate in the environmental monitoring from their own communities. These community based internships would be a way to provide water quality technician training to interested individuals and to broaden the duration of the study outside the time frame of the annual tribal journeys.

In addition to the monitoring conducted from the canoes, in 2009 support boats were utilized to take CTD casts from the surface to a maximum depth of 40 meters, and to sample phytoplankton and dissolved nutrient. We believe that the extra support boat monitoring will provide information about food web dynamics throughout the Salish Sea. Analysis of the 2009 support boat monitoring will be completed in 2010. Also in 2009, four buoys with YSI sondes, temperature sensors and water level loggers were deployed at Nisqually, Suquamish, Samish, and Nanaimo and recorded water quality parameters and water levels at 10 minute intervals continuously for a three month period. We hope to continue to utilize the buoys in future monitoring. The results of these activities are being synthesized into a subsequent report.

This information is essential for the Coast Salish Nations to develop policy and implement resource management the Salish Sea Ecosystem. It is the ultimate goal of the TJWQP coordinators that the TJWQP becomes a sustainable Coast Salish project and that Coast Salish build the capacity to administer and expand the project to suit their needs. Ideally members of Canoe Families from around the Salish Sea will take the Project forward for the greater need of the Coast Salish Peoples.

Acknowledgements

The 2009 Tribal Journey Water Quality Project was funded by the Northwest Straits Commission, the Swinomish Tribe, Environment Canada, and the U.S. Geological Survey and supported by Coast Salish Chiefs, Chairmen, Elders, and Canoe Skippers, the U.S. EPA, Environment Canada, and Parks Canada. We are grateful to the Squaxin Island Tribe, Homalco Nation, Stolo People, Squamish Nation, Songees Nation, Blue Heron Canoe Club, and the Swinomish Canoe Families and are especially thankful for the dedicated efforts of the water quality technicians who supported them. Thank you to the Northwest Straits Commission for the use of the GPS units. Thank you to Jude Apple for all of your advice and late night efforts. We would also like to thank Elissa Fjellman and Eric Haskins of the Swinomish GIS team for all of their help. We thank Ray Julich and Andrew Stevens of USGS for technical assistance in data visualization. Paul Dorn of Suquamish Tribe was of great assistance for monitoring at the final landing at Suquamish. Last but not least we would like to thank Jennifer LaVista and Susan Marcus for all of their communications assistance.

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Appendices

Appendix I: YSI 6920 V2-2 Sensor specifications including units, range, resolution, and accuracy. Units include milligrams per liter (mg/L), percent (%), Formazin Nephelometric Units (FNU)[1], millisemans per centimeter (mS/cm), parts per thousand (ppt), degrees Celsius (°C), pH standard units, millivolts (mV), and meters (m).

YSI Sensor	Units	Range	Resolution	Accuracy
ROX Optical Dissolved Oxygen	mg/L	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ± 0.1 mg/L or 1% of reading
	% Saturation	0 to 500%	0.10%	0 to 200 %: ± 1 % or 1% of air saturation
Dissolved Oxygen 6562 Rapid Pulse	mg/L	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ± 0.2 mg/L or 2% of reading
	% Saturation	0 to 500 %	0.10%	0 to 200 %: ± 2 % or 1% of air saturation
Turbidity 6136 Sensor	FNU	0 to 1,000 FNU	0.1 FNU	±2% of reading or 0.3 FNU, whichever is greater
Conductivity 6560 Sensor	mS/cm	0 to 100 mS/cm	0.001 to 0.1 mS/cm	±0.5% of reading + 0.001 mS/cm
Salinity	ppt	0 to 70 ppt	0.01 ppt	±1% of reading or 0.1 ppt, whichever is greater
Temperature 6560 Sensor	°C	-5 to +50°C	0.01°C	±0.15°C
pH 6561 Sensor	pH units	0 to 14 units	0.01 units	±0.2 units
ORP	mV	-999 to +999 mV	0.1 mV	±20 mV
Chlorophyll 6025	µg/L	~0 to 400 µg/L	~0.1	0.1 µg/L Chl
Depth - Shallow	m	0 to 9.1 m	0.001m	±0.02 m

1. The United States Geological Survey methods for reporting turbidity data collected with near-infrared turbidimeters following ISO 7027 protocols is reported as Formazin Nephelometric Units (FNU). More information can be found in the USGS National Field Manual (http://water.usgs.gov/owq/FieldManual/Chapter6/6.8.pdf)

Appendix II: Water Quality Statistics from Squamish basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between July 22, 2009 and July 23, 2009.

Squamish			
n	4057	889	4946

Temperature	7/22/2009	7/23/2009	Grand Total
Average (°C)	18.61	17.39	18.39
Maximum (°C)	22.36	18.85	22.36
Minimum (°C)	11.97	12.62	11.97
StdDev (°C)	2.78	1.27	2.62

Salinity	7/22/2009	7/23/2009	Grand Total
Average	10.65	NaN	10.65
Maximum	26.77	NaN	26.77
Minimum	0.5	NaN	0.5
StdDev	5.55	NaN	5.55

pH	7/22/2009	7/23/2009	Grand Total
Maximum	9.11	8.48	9.11
Minimum	6.77	7.85	6.77
Median	8.30	8.18	8.29

Dissolved Oxygen	7/22/2009	7/23/2009	Grand Total
Average (mg/L)	10.99	9.92	10.80
Maximum (mg/L)	16.89	11.62	16.89
Minimum (mg/L)	8.62	7.86	7.86
StdDev (mg/L)	1.87	1.13	1.80

Dissolved Oxygen	7/22/2009	7/23/2009	Grand Total
Average (% sat)	125.97	116.17	124.21
Maximum (% sat)	208.3	138.7	208.3
Minimum (% sat)	95.7	93.6	93.6
StdDev (% sat)	27.23	14.49	25.69

Turbidity	7/22/2009	7/23/2009	Grand Total
Average (FNU)	20.41	2.17	17.13
Maximum (FNU)	200	103.9	200
Minimum (FNU)	0	0	0
StdDev (FNU)	32.41	6.37	30.30

Appendix III: Water Quality Statistics from Lower Fraser basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between July 23, 2009 and July 25, 2009.

Lower Fraser				
n	981	846	141	1968

Temperature	7/23/2009	7/24/2009	7/25/2009	Grand Total
Average (°C)	18.71	16.33	15.93	17.49
Maximum (°C)	19.69	23.47	16.55	23.47
Minimum (°C)	17.16	12.24	15.42	12.24
StdDev (°C)	0.43	2.39	0.30	2.01

Salinity	7/23/2009	7/24/2009	7/25/2009	Grand Total
Average	NaN	3.89	NaN	3.89
Maximum	NaN	22.91	NaN	22.91
Minimum	NaN	0.01	NaN	0.01
StdDev	NaN	6.24	NaN	6.24

pH	7/23/2009	7/24/2009	7/25/2009	Grand Total
Maximum	8.32	8.46	8.29	8.46
Minimum	7.87	7.46	8.1	7.46
Median	8.05	8.04	8.23	8.05

Dissolved Oxygen	7/23/2009	7/24/2009	7/25/2009	Grand Total
Average (mg/L)	8.67	8.82	NaN	8.74
Maximum (mg/L)	9.87	13.82	NaN	13.82
Minimum (mg/L)	7.83	6.31	NaN	6.31
StdDev (mg/L)	0.41	1.20	NaN	0.88

Dissolved Oxygen	7/23/2009	7/24/2009	7/25/2009	Grand Total
Average (% sat)	102.36	116.07	NaN	108.71
Maximum (% sat)	112.8	181.6	NaN	181.6
Minimum (% sat)	92.8	85.2	NaN	85.2
StdDev (% sat)	5.17	20.07	NaN	15.74

Turbidity	7/23/2009	7/24/2009	7/25/2009	Grand Total
Average (FNU)	17.40	10.94	0.29	13.40
Maximum (FNU)	200	200	10.7	200
Minimum (FNU)	0	0	0	0
StdDev (FNU)	36.25	27.96	1.26	31.84

Appendix IV: Water Quality Statistics from the Fraser River. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured July 24, 2009.

Fraser River		
n	914	914

Temperature	7/24/2009	Grand Total
Average (°C)	19.25	19.25
Maximum (°C)	26.44	26.44
Minimum (°C)	18.3	18.3
StdDev (°C)	0.97	0.97

Salinity	7/24/2009	Grand Total
Average	1.04	1.04
Maximum	5.77	5.77
Minimum	0.09	0.09
StdDev	1.56	1.56

pH	7/24/2009	Grand Total
Maximum	8.4	8.4
Minimum	7.66	7.66
Variation	7.79	7.79

Dissolved Oxygen	7/24/2009	Grand Total
Average (mg/L)	9.06	9.06
Maximum (mg/L)	9.98	9.98
Minimum (mg/L)	8.58	8.58
StdDev (mg/L)	0.14	0.14

Dissolved Oxygen	7/24/2009	Grand Total
Average (% sat)	98.69	98.69
Maximum (% sat)	124.5	124.5
Minimum (% sat)	96.3	96.3
StdDev (% sat)	1.91	1.91

Turbidity	7/24/2009	Grand Total
Average (FNU)	28.47	28.47
Maximum (FNU)	88.5	88.5
Minimum (FNU)	3.9	3.9
StdDev (FNU)	14.02	14.02

Appendix V: Water Quality Statistics from San Juan basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between July 22, 2009 and July 29, 2009.

San Juan								
n	3702	1082	1933	2141	3992	3604	1758	18212

Temperature	7/22/09	7/23/09	7/24/09	7/25/09	7/26/09	7/28/09	7/29/09	Grand Total
Average (°C)	11.65	11.65	11.38	15.01	13.59	15.08	16.95	13.63
Maximum (°C)	14.33	18.01	13.39	18.79	20.04	22.46	20.49	22.46
Minimum (°C)	10.74	10.81	10.66	11.84	10.72	11.84	13.8	10.66
StdDev (°C)	0.44	1.16	0.47	1.52	2.24	1.96	1.13	2.38

Salinity	7/22/09	7/23/09	7/24/09	7/25/09	7/26/09	7/28/09	7/29/09	Grand Total
Average	29.69	30.41	30.23	NaN	29.27	28.96	26.51	29.42
Maximum	31.51	30.86	30.74	NaN	30.74	30.55	31.18	31.51
Minimum	12.22	27.33	20.87	NaN	2.52	19.68	20.01	2.52
StdDev	0.50	0.32	0.39	NaN	1.98	1.07	3.44	1.66

pH	7/22/09	7/23/09	7/24/09	7/25/09	7/26/09	7/28/09	7/29/09	Grand Total
Maximum	8.24	8.69	8.14	8.86	8.69	8.33	8.3	8.86
Minimum	5.99	7.79	7.78	7.8	7.59	7.78	7.81	5.99
Median	7.86	7.86	7.86	8.24	7.93	8.13	8.06	7.94

Dissolved Oxygen	7/22/09	7/23/09	7/24/09	7/25/09	7/26/09	7/28/09	7/29/09	Grand Total
Average (mg/L)	NaN	7.95	7.02	NaN	8.56	7.37	9.64	7.87
Maximum (mg/L)	NaN	15.82	9.58	NaN	16.3	12.52	12.94	16.3
Minimum (mg/L)	NaN	6.5	6.12	NaN	6.24	4.18	7.8	4.18
StdDev (mg/L)	NaN	1.63	0.54	NaN	2.04	2.01	0.79	1.88

Dissolved Oxygen	7/22/09	7/23/09	7/24/09	7/25/09	7/26/09	7/28/09	7/29/09	Grand Total
Average (% sat)	NaN	88.98	77.76	NaN	99.50	93.66	117.50	93.63
Maximum (% sat)	NaN	194.2	109	NaN	204.7	162.7	159.4	204.7
Minimum (% sat)	NaN	71.2	66.8	NaN	68.9	57	95.4	57
StdDev (% sat)	NaN	20.68	6.71	NaN	27.95	20.54	10.74	23.02

Turbidity	7/22/09	7/23/09	7/24/09	7/25/09	7/26/09	7/28/09	7/29/09	Grand Total
Average (FNU)	2.32	4.71	2.56	0.15	1.15	0.92	3.16	1.78
Maximum (FNU)	200	200	200	36.8	200	200	200	200
Minimum (FNU)	0	0	0	0	0	0	0	0
StdDev (FNU)	8.73	15.01	8.30	1.06	6.28	5.85	9.90	7.91

Appendix VI: Water Quality Statistics from North Central Puget Sound basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured August 3, 2009.

North Cental		
n	1104	1104

Temperature	8/3/2009	Grand Total
Average (°C)	13.94	13.94
Maximum (°C)	15.47	15.47
Minimum (°C)	12.34	12.34
StdDev (°C)	0.92	0.92

Salinity	8/3/2009	Grand Total
Average	29.16	29.16
Maximum	30.25	30.25
Minimum	20.57	20.57
StdDev	0.89	0.89

pH	8/3/2009	Grand Total
Maximum	8.26	8.26
Minimum	7.88	7.88
Median	8.12	8.12

Dissolved Oxygen	8/3/2009	Grand Total
Average (mg/L)	7.08	7.08
Maximum (mg/L)	9.36	9.36
Minimum (mg/L)	5.89	5.89
StdDev (mg/L)	0.72	0.72

Dissolved Oxygen	8/3/2009	Grand Total
Average (% sat)	82.07	82.07
Maximum (% sat)	107.9	107.9
Minimum (% sat)	69.7	69.7
StdDev (% sat)	7.65	7.65

Turbidity	8/3/2009	Grand Total
Average (FNU)	NaN	NaN
Maximum (FNU)	NaN	NaN
Minimum (FNU)	NaN	NaN
StdDev (FNU)	NaN	NaN

Appendix VII: Water Quality Statistics from Whidbey basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between July 21, 2009 and August 4, 2009.

Whidbey Basin							
n	450	444	1805	4300	949	14	7962

Temperature	7/21/2009	7/29/2009	7/30/2009	7/31/2009	8/2/2009	8/4/2009	Grand Total
Average (°C)	11.95	16.91	16.82	17.11	17.74	15.97	16.82
Maximum (°C)	18.35	19.32	19.3	21.82	19.87	16.1	21.82
Minimum (°C)	11.15	15.78	12.4	11.73	14.3	15.4	11.15
StdDev (°C)	1.19	0.50	0.83	2.21	1.18	0.17	2.13

Salinity	7/21/2009	7/29/2009	7/30/2009	7/31/2009	8/2/2009	8/4/2009	Grand Total
Average	29.20	20.20	NaN	25.62	24.25	27.58	25.49
Maximum	30.22	21.18	NaN	28.24	28	28.03	30.22
Minimum	21.42	19.2	NaN	17.08	16.02	26.63	16.02
StdDev	1.26	0.42	NaN	1.34	2.39	0.37	2.15

pH	7/21/2009	7/29/2009	7/30/2009	7/31/2009	8/2/2009	8/4/2009	Grand Total
Maximum	8.24	8.01	8.27	8.39	8.28	8.18	8.39
Minimum	7.75	7.83	7.46	7.78	7.86	8.17	7.46
Median	7.81	7.91	8.05	8.24	8.16	8.17	8.16

Dissolved Oxygen	7/21/2009	7/29/2009	7/30/2009	7/31/2009	8/2/2009	8/4/2009	Grand Total
Average (mg/L)	NaN	9.38	NaN	8.16	9.31	10.41	8.41
Maximum (mg/L)	NaN	9.72	NaN	12.56	10.51	10.47	12.56
Minimum (mg/L)	NaN	7.93	NaN	4.02	7.73	10.35	4.02
StdDev (mg/L)	NaN	0.18	NaN	3.12	0.80	0.04	2.83

Dissolved Oxygen	7/21/2009	7/29/2009	7/30/2009	7/31/2009	8/2/2009	8/4/2009	Grand Total
Average (% sat)	NaN	109.11	NaN	98.76	113.09	124.67	101.70
Maximum (% sat)	NaN	117.7	NaN	146.7	127.7	125.3	146.7
Minimum (% sat)	NaN	94	NaN	48.1	96.3	123.9	48.1
StdDev (% sat)	NaN	2.26	NaN	37.63	8.91	0.45	34.07

Turbidity	7/21/2009	7/29/2009	7/30/2009	7/31/2009	8/2/2009	8/4/2009	Grand Total
Average (FNU)	9.32	4.74	2.98	3.11	1.95	4.51	3.38
Maximum (FNU)	200	42	81.8	200	200	9.4	200
Minimum (FNU)	0	0.6	0	0	0	0.6	0
StdDev (FNU)	25.90	3.25	5.51	10.13	13.15	2.70	11.12

Appendix VIII: Water Quality Statistics from the Skagit River. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between August 1, 2009 and August 2, 2009.

Skagit River			
n	578	1789	2367

Temperature	8/1/2009	8/2/2009	Grand Total
Average (°C)	17.12	16.67	16.78
Maximum (°C)	23.38	23.82	23.82
Minimum (°C)	16.78	15.45	15.45
StdDev (°C)	0.43	1.52	1.35

Salinity	8/1/2009	8/2/2009	Grand Total
Average	0.02	0.14	0.11
Maximum	0.02	5.96	5.96
Minimum	0.02	0.02	0.02
StdDev	0.00	0.61	0.53

pH	8/1/2009	8/2/2009	Grand Total
Maximum	7.9	8.84	8.84
Minimum	7.25	6.63	6.63
Median	7.27	7.37	7.36

Dissolved Oxygen	8/1/2009	8/2/2009	Grand Total
Average (mg/L)	8.95	9.97	9.72
Maximum (mg/L)	16.19	18.71	18.71
Minimum (mg/L)	7.47	7.77	7.47
StdDev (mg/L)	1.37	1.25	1.36

Dissolved Oxygen	8/1/2009	8/2/2009	Grand Total
Average (% sat)	92.81	102.40	100.06
Maximum (% sat)	166.9	187.3	187.3
Minimum (% sat)	77.9	89.3	77.9
StdDev (% sat)	13.92	11.69	12.94

Turbidity	8/1/2009	8/2/2009	Grand Total
Average (FNU)	22.29	NaN	22.29
Maximum (FNU)	28.6	NaN	28.6
Minimum (FNU)	10.3	NaN	10.3
StdDev (FNU)	1.64	NaN	1.64

Appendix IX: Water Quality Statistics from Hood Canal basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between July 28, 2009 and August 3, 2009.

Hood Canal					
n	1242	2279	2526	265	6312

Temperature	7/28/2009	7/30/2009	7/31/2009	8/3/2009	Grand Total
Average (°C)	22.11	21.46	18.00	14.20	19.90
Maximum (°C)	27.15	23.79	21.57	15.02	27.15
Minimum (°C)	19.92	17.8	14.1	13.4	13.4
StdDev (°C)	1.52	0.73	2.06	0.32	2.65

Salinity	7/28/2009	7/30/2009	7/31/2009	8/3/2009	Grand Total
Average	25.46	26.43	28.70	29.44	27.27
Maximum	27.21	28.5	31.36	30.31	31.36
Minimum	14.53	2.83	0.67	11.44	0.67
StdDev	1.62	2.71	1.49	1.48	2.46

pH	7/28/2009	7/30/2009	7/31/2009	8/3/2009	Grand Total
Maximum	8.26	8.35	8.33	8.16	8.35
Minimum	7.88	7.72	6.96	8.02	6.96
Median	8.13	8.11	8.08	8.10	8.11

Dissolved Oxygen	7/28/2009	7/30/2009	7/31/2009	8/3/2009	Grand Total
Average (mg/L)	NaN	NaN	5.86	11.32	6.37
Maximum (mg/L)	NaN	NaN	8.8	13.35	13.35
Minimum (mg/L)	NaN	NaN	3.96	9.4	3.96
StdDev (mg/L)	NaN	NaN	1.15	0.88	1.96

Dissolved Oxygen	7/28/2009	7/30/2009	7/31/2009	8/3/2009	Grand Total
Average (% sat)	NaN	NaN	73.60	132.26	79.17
Maximum (% sat)	NaN	NaN	116.1	152.6	152.6
Minimum (% sat)	NaN	NaN	52.2	108.5	52.2
StdDev (% sat)	NaN	NaN	15.53	10.29	22.90

Turbidity	7/28/2009	7/30/2009	7/31/2009	8/3/2009	Grand Total
Average (FNU)	5.82	11.67	11.31	NaN	10.32
Maximum (FNU)	200	200	200	NaN	200
Minimum (FNU)	0	0	0	NaN	0
StdDev (FNU)	18.20	25.00	22.86	NaN	22.96

Appendix XI: Water Quality Statistics from South Central basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured between August 3, 2009 and August 4, 2009.

South Central			
n	953	786	1739

Temperature	8/3/2009	8/4/2009	Grand Total
Average (°C)	15.62	15.76	15.68
Maximum (°C)	20.51	16.7	20.51
Minimum (°C)	13.52	13.23	13.23
StdDev (°C)	0.91	0.66	0.81

Salinity	8/3/2009	8/4/2009	Grand Total
Average	28.78	26.65	27.82
Maximum	29.76	29.82	29.82
Minimum	17.7	20.1	17.7
StdDev	0.92	2.25	1.97

pH	8/3/2009	8/4/2009	Grand Total
Maximum	8.46	8.3	8.46
Minimum	8.07	7.96	7.96
Median	8.24	8.22	8.23

Dissolved Oxygen	8/3/2009	8/4/2009	Grand Total
Average (mg/L)	5.93	11.21	8.31
Maximum (mg/L)	7.19	12.67	12.67
Minimum (mg/L)	5.28	8.94	5.28
StdDev (mg/L)	0.22	0.72	2.68

Dissolved Oxygen	8/3/2009	8/4/2009	Grand Total
Average (% sat)	71.05	132.85	98.98
Maximum (% sat)	86.7	146.5	146.5
Minimum (% sat)	60.9	102.9	60.9
StdDev (% sat)	3.29	8.54	31.39

Turbidity	8/3/2009	8/4/2009	Grand Total
Average (FNU)	NaN	81.73	81.73
Maximum (FNU)	NaN	200	200
Minimum (FNU)	NaN	0.3	0.3
StdDev (FNU)	NaN	75.13	75.13

Appendix XII: Water Quality Statistics from South Puget Sound basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured July 27, 2009.

South Sound		
n	1453	1453

Temperature	7/27/2009	Grand Total
Average (°C)	18.60	18.60
Maximum (°C)	23.35	23.35
Minimum (°C)	15.97	15.97
StdDev (°C)	2.13	2.13

Salinity	7/27/2009	Grand Total
Average	29.27	29.27
Maximum	29.77	29.77
Minimum	27.83	27.83
StdDev	0.22	0.22

pH	7/27/2009	Grand Total
Maximum	8.49	8.49
Minimum	8.05	8.05
Median	8.14	8.14

Dissolved Oxygen	7/27/2009	Grand Total
Average (mg/L)	NaN	NaN
Maximum (mg/L)	NaN	NaN
Minimum (mg/L)	NaN	NaN
StdDev (mg/L)	NaN	NaN

Dissolved Oxygen	7/27/2009	Grand Total
Average (% sat)	NaN	NaN
Maximum (% sat)	NaN	NaN
Minimum (% sat)	NaN	NaN
StdDev (% sat)	NaN	NaN

Turbidity	7/27/2009	Grand Total
Average (FNU)	10.45	10.45
Maximum (FNU)	200	200
Minimum (FNU)	0	0
StdDev (FNU)	18.16	18.16

Appendix XIII: Water Quality Statistics from Pacific Coast basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured July 26, 2009.

Pacific Coast		
n	4394	4394

Temperature	7/26/2009	Grand Total
Average (°C)	11.04	11.04
Maximum (°C)	16.18	16.18
Minimum (°C)	9.73	9.73
StdDev (°C)	0.99	0.99

Salinity	7/26/2009	Grand Total
Average	NaN	NaN
Maximum	NaN	NaN
Minimum	NaN	NaN
StdDev	NaN	NaN

pH	7/26/2009	Grand Total
Maximum	NaN	NaN
Minimum	NaN	NaN
Variation	NaN	NaN

Dissolved Oxygen	7/26/2009	Grand Total
Average (mg/L)	7.73	7.73
Maximum (mg/L)	9.67	9.67
Minimum (mg/L)	6.87	6.87
StdDev (mg/L)	0.47	0.47

Dissolved Oxygen	7/26/2009	Grand Total
Average (% sat)	86.47	86.47
Maximum (% sat)	103.9	103.9
Minimum (% sat)	75.5	75.5
StdDev (% sat)	5.91	5.91

Turbidity	7/26/2009	Grand Total
Average (FNU)	8.11	8.11
Maximum (FNU)	200	200
Minimum (FNU)	0	0
StdDev (FNU)	22.52	22.52

Appendix XIV: Water Quality Statistics from Juan de Fuca Strait basin. Average, median, maximum, minimum, standard deviations (StdDev), and number of observations (n) for temperature in degrees Celsius (°C), salinity, pH in standard pH units, turbidity in Formazin Nephelometric Units (FNU), and dissolved oxygen in milligrams per liter (mg/L) and percent saturation (%sat). The data error code NaN was used for parameters which did not meet data quality standards. Data was measured July 29, 2009.

Juan de Fuca		
n	3151	3151

Temperature	7/29/2009	Grand Total
Average (°C)	10.23	10.23
Maximum (°C)	13.72	13.72
Minimum (°C)	7.48	7.48
StdDev (°C)	0.95	0.95

Salinity	7/29/2009	Grand Total
Average	32.24	32.24
Maximum	33.83	33.83
Minimum	3.66	3.66
StdDev	2.54	2.54

pH	7/29/2009	Grand Total
Maximum	7.89	7.89
Minimum	7.51	7.51
Median	7.68	7.68

Dissolved Oxygen	7/29/2009	Grand Total
Average (mg/L)	5.65	5.65
Maximum (mg/L)	8.2	8.2
Minimum (mg/L)	2.88	2.88
StdDev (mg/L)	0.86	0.86

Dissolved Oxygen	7/29/2009	Grand Total
Average (% sat)	61.94	61.94
Maximum (% sat)	90.1	90.1
Minimum (% sat)	29.9	29.9
StdDev (% sat)	10.22	10.22

Turbidity	7/29/2009	Grand Total
Average (FNU)	6.25	6.25
Maximum (FNU)	200	200
Minimum (FNU)	0	0
StdDev (FNU)	30.03	30.03

Appendix XV: Calibration and Audit Log recording the accuracy of conductivity in millisiemans per centimeter (mS/cm), pH in standard units, Turbidity in Formazin Nephelometric Units (FNU), and Dissolved Oxygen in milligrams per liter (mg/L). Failed audits are highlighted in red.

	Tribal Journey Water Quality Monitoring - YSI Sonde Calibration and Audit Log															
				Conductivity (<0.3 mS/cm)		pH (<0.2 units)			Turbidity (<5%)			D.O. (mg/l)(<3%)				
Canoe Family	Date	Aud	Temp C	Cond. (10.00) mS/cm	Drift	pH 7	pH span	Drift	0 FNU	123 FNU	Drift	Barometric Pressure*	Air DO % saturation	Air DO mg/l	Theroetical DO mg/L	Drift (mg/L)
Quinault	7/24/2009	cal	22.65	10.01		7.02	10.02	0.22	0.00	123.000	1.30	761.7	100.2	8.6	8.6	0.0
Quinault	7/26/2009	audit	18.34	10.04	0.03	7.24	8.97	1.05	1.30	BLANK		BLANK	109.3	8.4	9.4	1.0
Quinault	7/26/2009	cal	18.77	10.00		7.01	10.01	0.84	0.00	BLANK		BLANK	101.1	7.7	9.4	1.7
Quinault	7/28/2009	audit	22.39	2.85	7.15	7.85	9.98	0.03	0.20	BLANK		758.4	BLANK	BLANK	8.7	
Quinault	7/28/2009	cal	22.13	9.99		7.00	10.00	0.04	0.00	BLANK		758.0	100.6	8.8	8.7	0.1
Quinault	7/29/2009	audit	29.07	10.03	0.04	7.04	9.97	0.03	-1.10	124.100	1.10	757.6	93.5	7.5	7.6	0.1
Quinault	7/29/2009	cal	29.07	10.00		6.99	9.95		0.00	123.000	1.10	757.6	99.7	8.0	7.6	0.4
Songees	7/17/2009	cal	27.66	10.00		7.00	10.00		0.00	122.800		765.9	100.9	8.0	7.9	1.9
Blue Heron	7/20/2009	cal		10.00		7.02	10.05	0.01	0.00	123.000		Blank	Blank	Blank	Blank	
Blue Heron	7/23/2009	audit	15.7	9.97	0.03	7.01	10.11	0.06	BLANK	BLANK		762.0	97.0	9.2	10.0	0.8
Blue Heron	7/23/2009	cal	15.85	10.00		7.04	10.11	0.01	BLANK	BLANK	0.70	762.0	100.4	9.5	10.0	0.5
Blue Heron	7/27/2009	audit	27.69	10.01	0.01	7.03	10.00	0.11	0.70	121.000	2.00	759.8	103.3	7.9	7.9	0.1

Appendix XVI continued: Calibration and Audit Log recording the accuracy of conductivity in millisiemans per centimeter (mS/cm), pH in standard units, Turbidity in Formazin Nephelometric Units (FNU), and Dissolved Oxygen in milligrams per liter (mg/L). Failed audits are highlighted in red.

	Tribal Journey Water Quality Monitoring - YSI Sonde Calibration and Audit Log															
				Conductivity (<0.3 mS/cm)		pH (<0.2 units)			Turbidity (<5%)			D.O. (mg/l)(<3%)				
Canoe Family	Date	Aud	Temp C	Cond. (10.00) mS/cm	Drift	pH 7	pH span	Drift	0 FNU	123 FNU	Drift	Barometric Pressure*	Air DO % saturation	Air DO mg/l	Theroetical DO mg/L	Drift (mg/L)
Swinomish	7/27/2009	cal	27.69	10.00		7.00	10.00	0.03	0.00	123.000	0.10	759.3	100.0	7.6	7.9	0.3
Swinomish	7/29/2009	audit	21.11	9.92	0.08	7.03	10.04	0.04	-0.10	BLANK		760.5	99.6	8.4	8.5	0.1
Swinomish	7/29/2009	cal	21.11	10.00		7.00	10.00	0.00	0.00	BLANK	0.40	760.0	100.0	8.4	8.5	0.1
Swinomish	7/29/2009	audit	25.31	9.97	0.03	7.00	9.98	0.02	-0.40	BLANK		756.1	101.8	8.4	8.2	0.2
Swinomish	7/29/2009	cal	25.31	10.00		7.00	10.00	0.02	0.00	BLANK	0.20	756.2	99.4	8.2	8.2	0.0
Swinomish	7/31/2009	audit	24.76	10.04	0.04	6.98	10.02	0.02	0.20	BLANK		759.5	101.4	8.8	8.3	0.5
Swinomish	7/31/2009	cal	24.76	10.00		7.00	10.00	0.04	0.00	BLANK	0.80	759.5	99.9	8.7	8.3	0.4
Swinomish	8/2/2009	audit	23.73	10.07	0.07	7.04	10.02	0.02	-0.80	123.300	0.30	761.5	99.5	8.4	8.5	0.1
Swinomish	8/2/2009	cal	23.7	10.00		7.01	10.03	0.06	0.00	123.000	0.40	761.5	100.4	8.4	8.5	0.1
Swinomish	8/4/2009	audit	18.84	9.98	0.03	6.95	10.08	0.05	0.40	123.600	0.60	762.1	100.7	9.2	9.3	0.1
Swinomish	8/4/2009	cal	18.84	10.00		7.03	10.08		0.00	123.000		762.1	100.2	9.2	9.3	0.1

Appendix XVI continued: Calibration and Audit Log recording the accuracy of conductivity in millisiemans per centimeter (mS/cm), pH in standard units, Turbidity in Formazin Nephelometric Units (FNU), and Dissolved Oxygen in milligrams per liter (mg/L). Failed audits are highlighted in red.

Tribal Journey Water Quality Monitoring - YSI Sonde Calibration and Audit Log																
				Conductivity (<0.3 mS/cm)		pH (<0.2 units)			Turbidity (<5%)			D.O. (mg/l)(<3%)				
Cance Family	Date	Aud	Temp C	Cond. (10.00) mS/cm	Drift	pH 7	pH span	Drift	0 FNU	123 FNU	Drift	Barometric Pressure*	Air DO % saturation	Air DO mg/l	Theoretical DO mg/L	Drift (mg/L)
Squamish	7/21/2009	cal	27	10.00		7.00	9.98	0.15	0.00	123.000	3.10	762.3	100.3	8.2	7.9	0.3
Squamish	7/22/2009	audit	21.95	10.09	0.09	7.15	9.98	0.00	3.10	BLANK		761.1	100.7	9.1	8.7	0.4
Squamish	7/22/2009	cal	21.95	10.00		7.00	10.00	0.00	0.40	BLANK	0.10	761.1	100.2	9.1	9.1	0.0
Squamish	7/23/2009	audit	18.7	5.35	4.65	7.00	10.04	0.04	0.50	BLANK		762.8	103.4	9.7	9.4	0.3
Squamish	7/23/2009	cal	18.7	10.00		7.00	10.00	0.04	0.00	BLANK	0.00	762.8	100.3	9.5	9.4	0.1
Squamish	7/24/2009	audit	19.87	9.73	0.27	6.98	9.99	0.01	0.00	BLANK		761.7	98.0	9.1	9.2	0.1
Squamish	7/24/2009	cal	19.88	10.00		7.00	10.00	0.00	0.00	BLANK	0.50	761.7	100.2	9.3	9.2	0.1
Squamish	7/25/2009	audit	21.06	10.32	0.32	7.00	10.02	0.02	0.50	BLANK		762.2	90.6	8.0	8.9	0.9
Squamish	7/25/2009	cal	21.07	10.00		7.00	10.00	0.06	0.00	BLANK	1.99	762.3	100.2	8.9	8.9	0.1
Squamish	7/27/2009	audit	27.7	11.50	1.50	6.94	9.96	0.04	-1.99	119.400	3.60	759.3	81.0	6.5	8.1	1.6
Squamish	7/27/2009	cal	27.7	BLANK		7.00	10.00	0.14	0.00	123.000	0.50	759.3	99.8	8.0	8.1	0.1
Squamish	7/29/2009	audit	25.31	9.71	0.29	7.14	9.96	0.04	0.50	BLANK		755.9	106.5	8.7	8.3	0.5
Squamish	7/29/2009	cal	25.3	9.99		7.00	10.00	0.10	0.00	BLANK	0.20	755.9	99.4	8.2	8.3	0.1
Squamish	7/30/2009	audit	21.62	9.87	0.12	6.90	10.08	0.08	-0.20	BLANK		757.6	113.1	9.7	8.7	1.0
Squamish	7/30/2009	cal	21.62	10.00		7.00	10.05	0.07	0.00	BLANK	0.70	757.6	99.5	8.5	8.7	0.2
Squamish	7/31/2009	audit	23.02	9.96	0.04	6.93	10.06	0.01	0.70	BLANK		761.4	81.6	7.0	8.6	1.6
Squamish	7/31/2009	cal	23.02	10.01		7.00	10.00		0.00	BLANK		761.2	100.0	8.5	8.6	0.1

Appendix XVI continued: Calibration and Audit Log recording the accuracy of conductivity in millisiemans per centimeter (mS/cm), pH in standard units, Turbidity in Formazin Nephelometric Units (FNU), and Dissolved Oxygen in milligrams per liter (mg/L). Failed audits are highlighted in red.

	Tribal Journey Water Quality Monitoring - YSI Sonde Calibration and Audit Log															
				Conductivity (<0.3 mS/cm)		pH (<0.2 units)			Turbidity (<5%)			D.O. (mg/l)(<3%)				
Canoe Family	Date	Aud	Temp C	Cond. (10.00) mS/cm	Drift	pH 7	pH span	Drift	0 FNU	123 FNU	Drift	Barometric Pressure*	Air DO % saturation	Air DO mg/l	Theroetical DO mg/L	Drift (mg/L)
Squaxin Island	7/26/2009	cal	31.06	10.00		6.99	9.95	0.07	0.00	123.000	0.40	769.5	100.6	7.6	7.4	0.2
Squaxin Island	7/27/2009	audit	30.37	10.12	0.12	7.06	9.96	0.01	0.40	BLANK		762.7	91.3	6.9	7.6	0.7
Squaxin Island	7/27/2009	cal	30.37	10.00		6.99	9.95	0.00	0.00	BLANK	0.50	762.7	100.3	7.6	7.6	0.0
Squaxin Island	7/28/2009	audit	30.22	9.99	0.01	6.99	10.01	0.06	-0.50	BLANK		759.4	86.2	5.4	6.4	1.0
Squaxin Island	7/28/2009	cal	30.22	10.01		6.99	9.96	0.05	0.00	BLANK	0.20	759.4	98.2	6.4	6.4	0.0
Squaxin Island	7/31/2009	audit	20.14	9.95	0.06	7.04	10.06	0.10	-0.20	120.000	3.00	760.3	105.0	8.5	9.1	0.6
Squaxin Island	7/31/2009	cal	20.14	10.00		7.02	10.05	0.11	0.00	123.000	0.20	760.3	99.6	8.5	9.1	0.6
Squaxin Island	8/1/2009	audit	23.48	9.94	0.06	6.91	9.99	0.06	-0.20	120.000	3.00	748.6	103.2	8.6	8.5	0.1
Squaxin Island		cal	Blank	Blank		Blank	Blank		Blank	Blank		Blank	Blank	Blank	Blank	
Squaxin Island	8/4/2009	audit	18.15	10.09	0.09	7.06	10.09	0.04	122.10	BLANK	122.10	761.7	103.0	9.4	9.5	0.1
Squaxin Island	8/4/2009	cal	18.15	10.08		7.03	10.08	0.03	0.00	BLANK		761.7	100.0	9.2	9.5	0.3