

**Patterns of summer stream temperature maxima
in north Hood Canal and west Admiralty Inlet, Washington
1992-2003**

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Ted Labbe, Port Gamble S'Klallam Tribe¹
Peter Bahls, Port Gamble S'Klallam Tribe²
Carol Bernthal, Point No Point Treaty Council³

¹ Natural Resources Department, 31912 Little Boston Rd, Kingston, WA 98346; tlabbe@pgst.nsn.us

² Present address: Northwest Watershed Institute, 3407 Eddy St., Port Townsend, WA 98368

³ Present address: NOAA, Olympic Coast National Marine Sanctuary, 138 W 1st Street, Port Angeles, WA 98368

Introduction and Background

The land and waters of north Hood Canal and western Admiralty Inlet constitute the primary management area of the Port Gamble S'Klallam Tribe as set forth under the Point No Point Treaty Council revised Fisheries Management Compact (1999). The health of area rivers and streams is of primary interest to the Tribe, due to their role as nursery habitat for salmon, and as contributing waters to commercially and culturally significant shellfish tidelands. As a primary driver of aquatic ecosystems, water temperature has direct and indirect effects on the health and productivity of native biota, influencing species distribution, migration timing, food resources, growth, competition, predator-prey interactions, disease vulnerability, and other important biological processes.

The decline of regional fish populations has been linked to elevated water temperatures resulting from surface and groundwater extraction, channel simplification, and the clearing of native riparian vegetation (Beschta et al. 1986, Lichatowich 1993, Bahls and Rubin 1996, Gregory and Bisson 1997, Bahls 1998). Lying in the rain shadow of the Olympic mountains, streams of east Jefferson and northwest Kitsap counties are naturally flow limited (Amerman and Osborn 1987), rendering them highly vulnerable to impacts from water withdrawal and poor land use practices (Lichatowich 1993). Ambient stream temperature data is important to the identification and restoration of water quality-limited streams, while long-term records provide information on trends and the frequency/severity of extreme events such as droughts. Simple charts of stream temperature through time can provide resource managers with a valuable understanding of physical factors important to aquatic biota during the summer drought period; when combined with other data – such as stream flow – more complex analyses are supported.

Bahls (1993) summarized one year of maximum temperature monitoring in north Hood Canal and western Admiralty Inlet area streams, and Bahls (1998) summarized these data for 1992-1994. Bahls and Rubin (1996) reported on continuous stream temperature monitoring at 22 stations in Chimacum Creek in 1995 and related this data to other habitat and fish population information. Since that time, the Port Gamble S'Klallam

Tribe and others have continued to monitor water temperatures at select stations, but these data have not been reported or readily available. The purpose of this report is to:

1. provide a concise summary of summer stream temperature data collected over the period 1992-2003,
2. consider this information in relation to current and new proposed state water quality standards, and
3. make recommendations for further temperature monitoring and analysis.

Maximum stream temperatures were monitored at 1-2 week intervals during summers 1992-94 to provided a coarse characterization of temperature regimes across a network of sites. During summer 1996 and 2001-03 continuous temperature data loggers were deployed across an expanded monitoring site network. In this report, compiled maximum temperature data is evaluated against current and new proposed Washington State water quality standards.

In the State of Washington, the Department of Ecology (WDOE) prescribes water quality criteria that are used for the identification and targeted cleanup of water quality limited water bodies; if a stream, lake, or other water body violates a particular standard (e.g. temperature, fecal coliform, arsenic) it is listed on the federal Clean Water Act's 303-(d) list of impaired water bodies and prioritized for remedial cleanup/restoration actions. Under current water quality standards, the maximum allowable temperature in a stream or lake depends on the water quality classification specific to that waterbody. Most streams in north Hood Canal/west Admiralty Inlet are classified as AA with an annual maximum temperature standard of 16° C; however, Gamble Bay tributaries are classed as A with a standard of 18° C (Chapter 173-201A WAC). These standards represent the annual instantaneous maximum temperature (AIMT) allowable; that is, if water temperature exceeds the appropriate temperature threshold one or more times during a year, the stream is in violation of water quality standards.

Recently, the U.S. Environmental Protection Agency (USEPA) and WDOE have proposed new water temperature standards based on the seven-day average of the daily

maximum temperature (7DADMT) to replace current AIMT standards (Hicks 2001, USEPA 2003). The 7DADMT standard better describes maximum stream temperatures over longer periods, reducing the influence of single-day extreme events. Although state and federal agencies have not yet agreed on common standards, the USEPA has provided guidance on appropriate 7DADMT standards (USEPA 2003). For salmon and trout “core” rearing streams USEPA recommends a summertime 7DADMT standard of 16° C, and for spawning/egg incubation/fry emergence USEPA recommends a 7DADMT standard of 13° C. The latter 13° C standard generally applies during the fall-winter-spring time period, but may also apply during early or late summer when and where sensitive stocks spawn – such as spring/summer chinook or summer chum salmon.

Methods

During the late summer-early fall low flow periods of 1992-94, Taylor maximum-minimum thermometers (Taylor Precision Products, La Cruces, NM) were deployed at 29 sites located in 18 discrete stream systems of north Hood Canal and western Admiralty Inlet (Table 1 & Figure 1). Maximum stream temperatures were monitored over the following periods: August 4-October 2, 1992; July 12-September 28, 1993; and June 30-September 29, 1994. Before and after thermometer deployment, accuracy was verified by probe immersion in constant temperature water baths and readings compared to a laboratory reference thermometer. Thermometers were placed at the bottom of a pool, attached to a rock or stick using rubber strapping, and checked at intervals of 7-14 days. Though duration of the monitoring periods varied by year, their timing generally coincided with the period of maximum stream temperatures observed regionally. Monitoring stations were located in principal salmon streams of north Hood Canal/west Admiralty Inlet near road crossings to facilitate ease of access.

During 1996 and 2001-03, continuous temperature data loggers (Hobo Temps and StowAway TidBit Temps, Onset Corporation, Pocasset, MA) were deployed at multiple stream stations over varying time periods (Table 1). At various sites, summer stream temperatures were monitored during 13 July-7 September 1996, 1 July-30 September 2001, and 1 June-30 September 2002 & 2003. At three sites in Chimacum Creek (Lower,

Main, and EF Chimacum) the 2001 monitoring period ran 1 June-30 September, and in the Dosewallips and Duckabush rivers snowmelt runoff delayed thermograph deployment until July 13 in 2002.

Temperature probes were placed at the bottom of large, well-mixed pools, and attached to rebar stakes or embedded tree roots using plastic lock-ties. Where available, well-shaded locations were selected to avoid probe exposure to direct sunlight. Prior to each summer monitoring period, temperature data loggers were calibrated following procedures outlined in Schuett-Hames et al. (1999). Minimum calibration procedures included immersion of temperature probes in a constant temperature bath and comparison of probe temperature measurements against a laboratory reference thermometer (Model 1003BLS, Ever Ready Thermometer Co., West Paterson, NJ). Calibration checks generally confirmed that temperature data logger measurements were within the required range of $\pm 0.2^{\circ}\text{C}$ as compared to laboratory reference thermometers.

Our monitoring network included 43 primary and 16 secondary stations (Figure 1). Primary stations had ≥ 2 years of continuous temperature data, whereas secondary stations had one year of continuous temperature data and/or three years of maximum temperatures. In larger streams and rivers, multiple monitoring locations provided information on the spatial variation of temperature regimes and helped characterize longitudinal thermal patterns. Jefferson County Conservation District graciously provided temperature data for three stations along Chimacum Creek for the period 2001-03 (Lower, Main, and EF Chimacum).

Stations were located in core salmon spawning and rearing reaches of the north Hood Canal/west Admiralty Inlet region, with additional stations in problem watersheds to pinpoint areas of temperature degradation. In a few instances, monitoring stations were relocated in later years as a result of habitat changes or land owner access issues. However, comparable new sites were generally within 100m of former sites to support characterization of thermal patterns across years (see Table 1 for site location details).

Temperature data loggers were downloaded to Onset BoxCar Pro 4.0 and then exported to MS Excel spreadsheets for computation of summary statistics. In MS Excel, we calculated annual instantaneous maximum temperature (AIMT) and seven-day average daily maximum temperature (7DADMT) metrics.

Results

Annual instantaneous maximum temperatures (AIMT) were monitored at 29 sites in 18 independent watersheds across the north Hood Canal/western Admiralty Inlet region during summers 1992-94 (Table 1 & Figure 2). Seventeen sites violated the current state water temperature standard of 16° C (or 18° C for Gamble Bay tributaries) in ≥ 1 years. Seven sites (Miller Lake, Gamble-Lower, Big Beef-Below Lake, Donovan, Tarboo, Chimacum-Lower, Chimacum-Main, and Chimacum-Upper) had severe water quality violations exceeding their respective standards in two or three years by $>2^{\circ}$ C.

Annual temperature maxima monitored in 1996 and 2001-03 generally matched patterns observed in 1992-94, and were remarkably stable across years (Table 1). The expansion of our monitoring network and use of continuous data loggers supported more refined analyses of the severity, duration, and extent of stream temperature exceedences (Figures 2 & 3). Sites at Miller Lake, Big Beef-Lower, Rocky Brook, Big Quilcene-Lower, Big Quilcene-Middle, Little Quilcene-Lower, Tarboo, EF Tarboo, and Chimacum-Lower violated the proposed 16° C AIMT standard by 0.1-2.0 degrees. Sites in lower Gamble, middle Big Beef, Fulton, Marple, Little Quilcene tributary (Leland, Ripley, Howe), Donovan, Golf Course, and three upper Chimacum sites violated the new AIMT standard by $\geq 2^{\circ}$ C.

Four sites (Big Beef-2000' Below Lake, Big Beef-Below Lake, Howe, and Chimacum-Main) had stream temperature maxima exceeding 20° C, in the range considered lethal to salmon (Bjornn and Reiser 1991). Two sites showed significantly reduced AIMT metrics in 2001-2003 vs. 1992-94, Miller Lake and Tarboo, likely owing to along-channel shifts in monitoring site locations. Miller Lake also showed AIMT differences between years

during 2001-2003, as a result of upstream beaver dam manipulation by Kitsap County Public Works.

The seven-day average daily maximum temperature (7DADMT) metrics highlighted many of these same problem streams. Gamble, Big Beef, Fulton, Rocky Brook, Marple, Leland, Ripley, Howe, Donovan, Golf Course, Chimacum, EF Chimacum, and Big Quilcene all had sites that failed to meet the 7DADMT standard of 16° C during summers 1996 and/or 2001-2003.

For select sites with summer chum salmon, we evaluated compliance with the 7DADMT standard of 13° C for the period following August 25, the approximate average date of first spawning. Of these seven sites, only one (Big Anderson) met the 13° C standard, four (Big Beef-Lower, Duckabush, Dosewallips-Lower, Big Quilcene-Middle, Little Quilcene-Lower) were <2° C in exceedence of the standard, and two (Big Quilcene-Lower and Chimacum-Lower) violated the standard by $\geq 2^{\circ}$ C.

We evaluated the effect of changing water quality standards by comparing current AIMT vs. new proposed 7DADMT metrics for 56 sites with continuous temperature data for summers 1996 and 2001-2003. For 50 sites management status (in compliance/violation) remained the same under both current and new proposed temperature standards. Five sites (9%) with temperature maxima at/near water quality standards shifted management status, all showing violations under the current 16/18° C AIMT and compliance using the proposed 16° C 7DADMT metrics: Foxhole, Big Quilcene-Middle, Little Quilcene-Lower, Tarboo, and EF Tarboo.

Discussion

Summer water temperatures are a significant limiting factor across the southernmost ranges of Pacific salmon, especially in areas with low rainfall and extensive human land use impacts (Gregory and Bisson 1997). Stream temperature monitoring conducted by various groups often lacks sufficient spatial resolution or temporal continuity to be directly useful for management decision-making. In north Hood Canal/west Admiralty

Inlet, WDOE maintains just seven water quality monitoring stations at which spot (not continuous) measurements are made. With the advent of low-cost digital thermographs, continuous temperature data is now readily available and easily analyzed; we encourage others to implement such monitoring networks.

We monitored water temperatures at 59 stations in 33 north Hood Canal/west Admiralty Inlet tributary streams, encompassing an area with marked gradients of rainfall, topographic relief, and human land use impacts. Temperatures were monitored at the bottom of large, well-mixed pools; thus, reported temperature metrics likely offer a conservative representation of the summer thermal extremes experienced by salmonids in these stream reaches. Twenty-five (42%) of the sites violated current (AIMT) water temperature standards in one or more years, and 15 (25%) of the sites had serious violations where annual temperature maxima exceeded current standards by $>2^{\circ}\text{C}$.

Twenty of 56 sites (36%) with continuous temperature data violated the new proposed summertime 7DADMT standard of 16°C . Of seven sites with summer chum salmon spawning, one met and six failed the new proposed 7DADMT 13°C standard for the Aug 26-Sep 30 spawning period. Table 2 summarizes patterns of compliance and violations under both current and new proposed temperature standards.

Table 2. Comparison of temperature standard violations for 56 stations in north Hood Canal/west Admiralty Inlet streams with continuous summer temperature data under current and new proposed water quality criteria.

Management Status	Current Standard AIMT $>16/18^{\circ}\text{C}$	New Standard summer 7DADMT $>16^{\circ}\text{C}$	New Standard Aug 26-Sep 30 7DADMT $>13^{\circ}\text{C}$
Sites in Compliance	32	37	1
Sites in Violation	24	18	7
In violation $0.1-2^{\circ}\text{C}$	11	9	5
In violation by $>2^{\circ}\text{C}$	13	9	2
Total	56	56	8

The most severe, long-duration temperature standard violations occurred in Big Beef and Chimacum creeks. Less severe or frequent temperature standard exceedences were observed in Gamble, Fulton, Rocky Brook, Marple, Leland, Ripley, Howe, Donovan, Golf Course, and EF Chimacum creeks, as well as lower Big Quilcene River. Notably, temperatures in these streams violated both current and proposed water quality standards. Another class of streams violated either current or proposed temperature standards: Miller Lake, Little Quilcene, Tarboo, and EF Tarboo creeks.

While temperature regimes at fixed stations do not show a spatially-continuous thermal conditions map for salmon and other coldwater-dependent biota, such data do serve as helpful indicators of stream network-wide habitat conditions. Information on riparian forest conditions and water use can be linked with spatially- and temporally-continuous thermal data to document factors contributing to elevated summer stream temperatures. Hatten and Conrad (1995) linked data on elevated stream temperatures with loss of late-seral stage forest in streams of the western Olympic Peninsula, and determined that stream temperature maxima in managed basins violated the AIMT standard of 16° C ten times more often, on average, than comparable unmanaged basins. Bahls (1993, 1998) showed a relationship between AIMT and percent canopy cover and adjacent land use, implicating agricultural and residential development practices as water quality degradation factors in this region.

Stream-specific riparian forest data from watershed assessments provide some perspective on a key factor contributing to elevated summer water temperatures. Based on aerial photo analyses, riparian forest conditions were considered good in Harding, Spencer, and Penny creeks; but degraded in Big Anderson, Stavis, Seabeck, Big Beef, Little Anderson, and Marple creeks, as well as Big Quilcene River (USFS & WADNR 1994, WA DNR 1995). Field data on canopy closure indicates that riparian forest conditions were generally good in Thorndyke, Shine, and Ripley; but degraded in Howe and Chimacum creeks (USFWS 1993, Bahls and Rubin 1996, Bernthal and Rot 2001).

Recommendations

Temperature monitoring should continue at our extensive site network to provide long-term trend data and to inform management decision-making. To ensure that the full period of stream temperature extremes is documented, the monitoring period should run June 1-Sep 30. Where feasible, longitudinal thermal profiles should be conducted to better delineate temperature-limited reaches, similar to the intensive work performed by P. Bahls in Chimacum Creek during summer 1995 (Bahls and Rubin 1996). This could be accomplished by synchronous temperature measurements across a stream network by teams of trained volunteers (Booth 2002) or by use of airborne forward-looking infrared radiometry (FLIR, Torgerson et al. 1999). Target streams for such work should include: Big Beef, Chimacum, and Gamble creeks, as well as Big and Little Quilcene rivers and their principal tributaries.

Once new stream temperature standards are formally adopted by WDOE, available temperature data should be reviewed to assess their Clean Water Act 303(d) listing status. Ultimately, WDOE is required to develop Total Maximum Daily Load estimates to determine acceptable temperature loadings for all contributing land uses in temperature-impaired streams. However, in the near-term this monitoring information should be used to guide restoration, and to condition land and water use in documented temperature-impaired streams to ensure that summer thermal conditions are not further degraded.

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Figure 1. Primary and secondary temperature monitoring site locations and names in north Hood Canal/west Admiralty Inlet, Washington. Not all secondary sites are labeled.

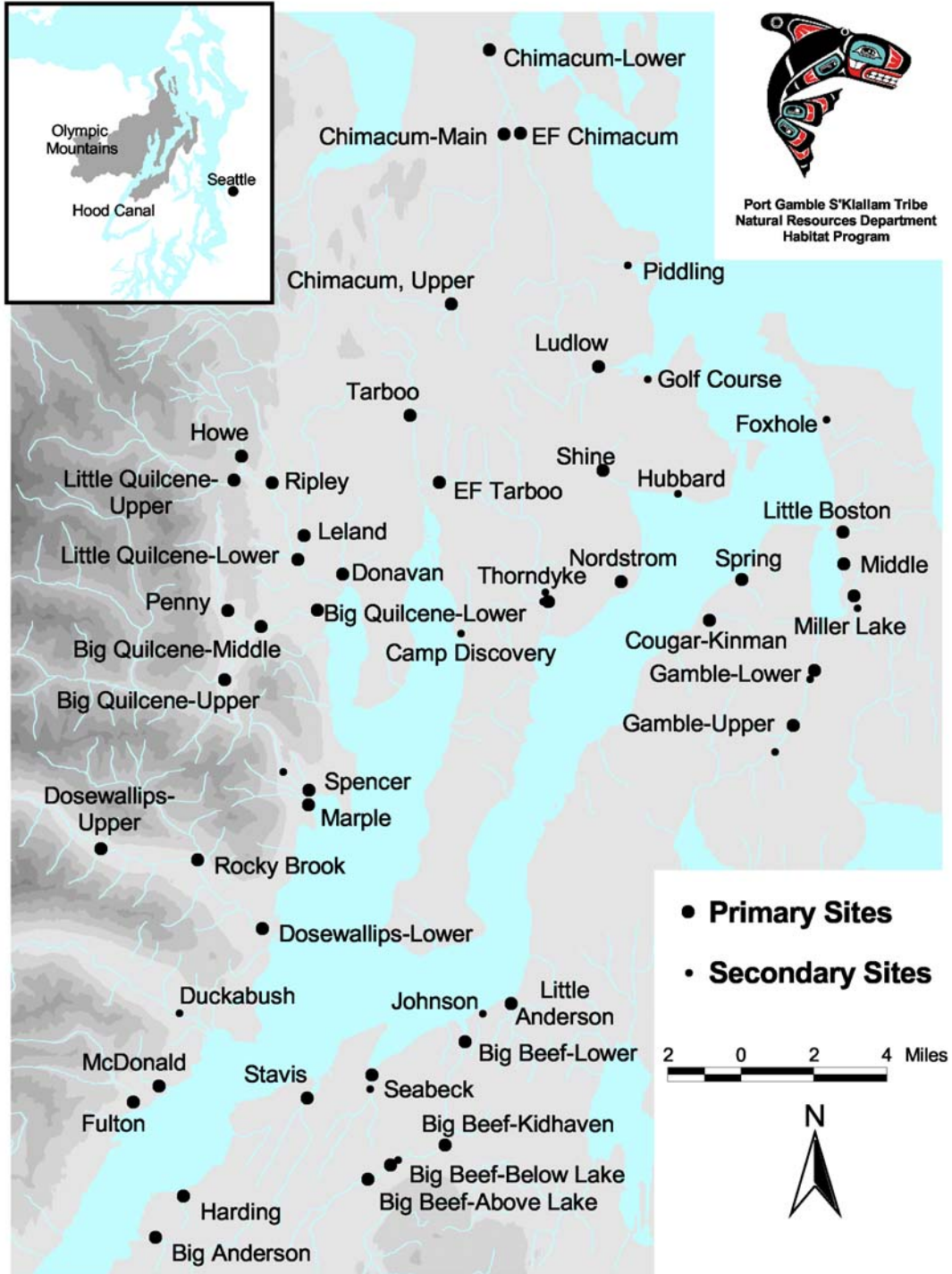


Figure 2. Summertime annual instantaneous maximum temperatures (AIMT) for all 59 stream sites. Large and small diamonds represent primary (with ≥ 2 yrs of continuous data) and secondary (with ≤ 1 yr of continuous data), respectively. Split diamonds show average AIMT for 1992-94 (left half) and 1996/2001-03 (right half) time periods. Unsplit diamonds show average AIMT for 1996/2001-03. Unsplit diamonds show average AIMT for 1996/2001-03.

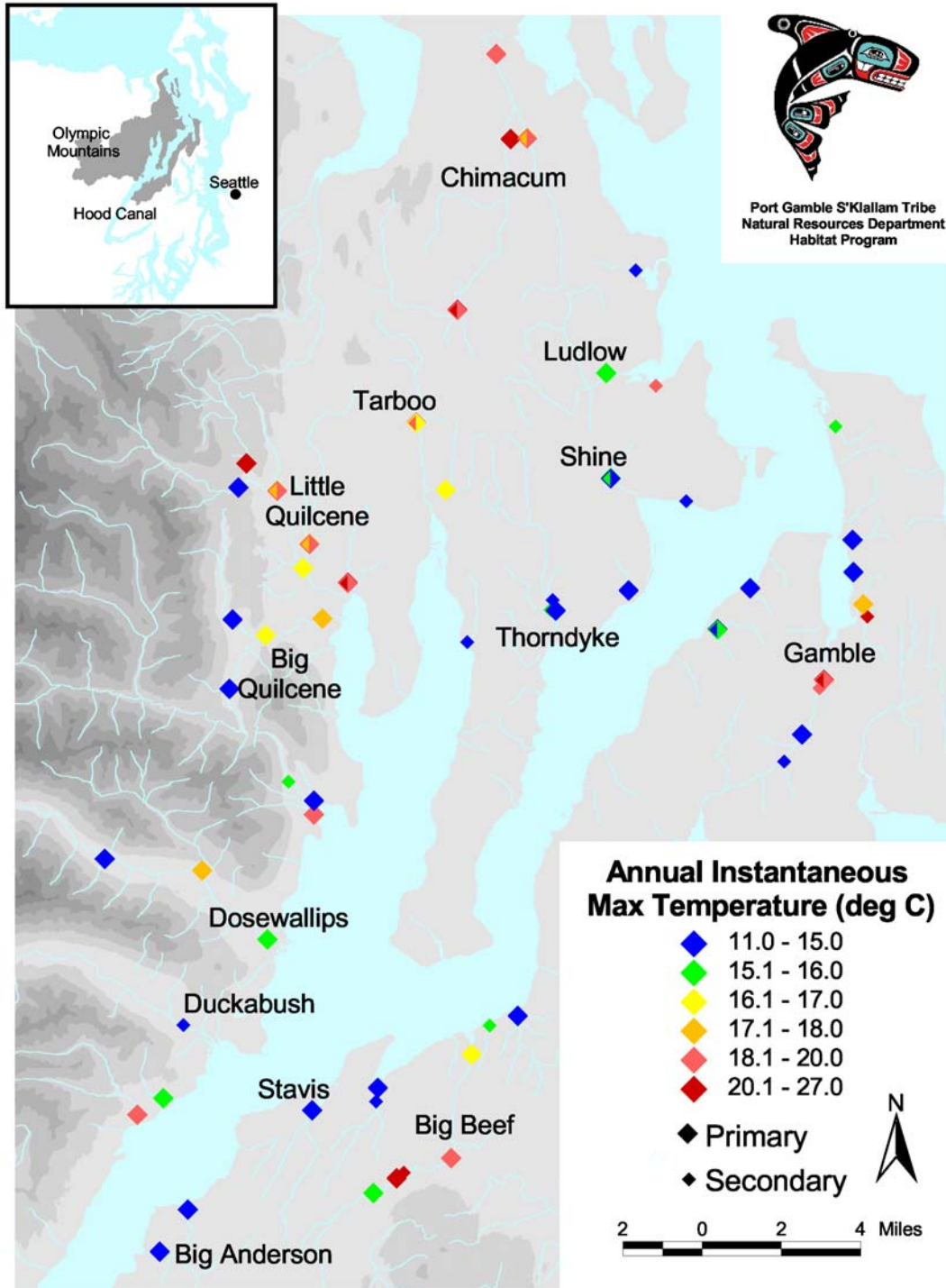


Figure 3. Seven-day average daily maximum temperatures (7DADMT) for 56 stream sites with continuous data over summers 1996/2001-03. Temperature maxima for the period Aug 26-Sep 30 for seven sites with summer chum spawning are shown as crowns around markers and coded with reference to the 13° C 7DADMT standard.

