Temperature and Discharge Conditions Associated with Migration of Adult Sockeye Salmon Entering the Docee River and Long Lake Watershed, B.C. from 1968-2012

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V9T 6N7

2015

Canadian Manuscript Report of Fisheries and Aquatic Sciences 3052

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Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3052

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TEMPERATURE AND DISCHARGE CONDITIONS ASSOCIATED WITH MIGRATION OF ADULT SOCKEYE SALMON ENTERING THE DOCEE RIVER AND LONG LAKE WATERSHED, B.C. FROM 1968-2012

by

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Cat. No. Fs97-4/3052E ISSN 1488-5387

Correct citation for this publication:

Stiff, H.W., Hyatt, K.D., Stockwell, M.M., Cox-Rogers, S., and Levesque, W. 2015. Temperature and discharge conditions associated with migration of adult Sockeye salmon entering the Docee River and Long Lake watershed, B.C. from 1968-2012. Can. Manuscr. Rep. Fish. Aquat. Sci. 3052: vii + 159 p.

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ABSTRACT

Stiff, H.W., K.D. Hyatt, M.M. Stockwell, S. Cox-Rogers, and W. Levesque. 2015. Temperature and discharge conditions associated with migration of adult Sockeye salmon entering the Docee River and Long Lake watershed, B.C. from 1968-2012. Can. Manuscr. Rep. Fish. Aquat. Sci. 3052: vii + 159 p.

Historical meteorological and hydrological data were assembled to review the potential influence of changes in these environmental factors on patterns of adult Sockeye migration in the Docee River, British Columbia. Regional air temperature data collected at Port Hardy, B.C. were statistically related to continuous water temperature time-series (2004-2008) sampled at the Docee fence to hind-cast daily water temperature in Docee River for 1944-2012. Owikeno Lake daily water levels (1961-2012) were used as a proxy estimator of historical Docee River water levels. Frequency distributions of historical migration dates (1968-2012), weighted by the daily migration rate, were used to discern possible environmental thresholds defining high versus low migration classes. Peak-over-threshold analyses were applied to reconstructed time-series to review long-term trends in temperature and flow by site.

The climatology remains cool in this central coast watershed, with estimated daily mean water temperatures of 13.9 ±1.2°C (maximum 18.1°C) during peak Sockeye migration periods (July). However, observed mmean water temperatures varied significantly between years in relation to reinforcing ocean climate indicator (PDO/ENSO) phases, averaging 16-18ºC for warm/warm years compared to 11-12ºC in cool/cool PDO/ENSO years. The average duration of “warm water” periods (>17°C) was < 5-6 days for recent decades, and the frequency is trending upward, but mostly in August after the peak migratory period for Sockeye entry into the Docee River and long Lake. Water temperatures above 17°C during July, though infrequent, may be associated with low daily migration rates (<3.4% of total escapement). While “low flow” events (water level < 10th percentile of historic time-series), which mainly occur after peak Sockeye migration, were not readily associated with low daily migration rates, “high flows” (> 90th percentile) were often associated with delayed onset of migration of up to 10 days. However, once migration commenced, high water levels were not routinely a deterrent to high migration rates. The frequency of high flow events increased since the 1980s relative to previous decades along with the mean and maximum duration of high flow periods, with a disproportionate increase in July occurrences,. A weighted frequency distribution indicated that high migration rates for Long Lake Sockeye were centered at estimated Docee water temperatures of 12°C and recorded water levels of 3 m at Owikeno Lake, corresponding to Docee River depths of ~0.75 ± .02 m. Although temperature and discharge variations appear to have exerted subtle influences on daily variations in migration rates of adult Sockeye entering the Docee River during 1968-2012, neither variable achieved extremes sufficient to induce any obvious cessation of daily migrations by adult Sockeye into Long Lake.

RÉSUMÉ

Stiff, H.W., K.D. Hyatt, M.M. Stockwell, S. Cox-Rogers, et W. Levesque. 2015. Tendances des températures et du débit en lien avec la migration des saumons rouges adultes qui pénètrent dans le bassin versant de la rivière Docee et du lac Long, en Colombie-Britannique, entre 1968 et 2012. Rapp. manus. can. sci. halieut. aquat. 3052: vii + 159 p.

On a colligé des données météorologiques et hydrologiques historiques afin d'examiner l'influence possible des changements de ces facteurs environnementaux sur les tendances de la migration du saumon rouge adulte dans la rivière Docee, en Colombie-Britannique. On a rapproché statistiquement des données régionales sur la température de l'air recueillies à Port Hardy, en Colombie-Britannique, et une série chronologique continue sur la température de l'eau (2004-2008) provenant de la barrière de dénombrement de la rivière Docee afin de prévoir *a posteriori* les températures de l'eau quotidienne dans la rivière Docee entre 1944 et 2012. On a utilisé les niveaux d'eau quotidiens du lac Owikeno (1961-2012) pour estimer approximativement les niveaux d'eau historiques de la rivière Docee. On a utilisé les distributions des fréquences des dates de migration passées (1968-2012), pondérées par le taux de migration journalier, pour cerner des seuils environnementaux possibles définissant les classes de migration forte et basse. Des analyses des dépassements des seuils ont été appliquées aux séries chronologiques reconstituées pour examiner les tendances à long terme des températures et du débit par site.

La climatologie demeure fraîche dans ce bassin hydrographique de la côte centrale de la Colombie-Britannique, avec une température de l'eau journalière moyenne estimée de 13,9 °C ± 1,2 °C (maximum de 18,1 °C) pendant les fortes périodes de migration du saumon rouge (juillet). Toutefois, les températures moyennes de l'eau observées varient grandement d'une année à l'autre selon le renforcement des phases des indicateurs climatiques océaniques (ODP/ENSO) pour une moyenne entre 16 et 18 °C lors des années chaudes consécutives par rapport à 11 ou 12 °C lors des années froides consécutives de l'ODP ou de l'ENSO. La durée moyenne des périodes « d'eau chaude » (> 17 °C) était inférieure à 5 ou 6 jours dans les dernières décennies, et leur fréquence était à la hausse, surtout en août après la forte période migratoire alors que le saumon rouge fait son entrée dans la rivière Docee et le lac Long. Des températures de l'eau supérieures à 17 °C en juillet, bien qu'elles soient peu fréquentes, peuvent être liées à de faibles taux journaliers de migration (< 3,4 % des échappées totales). Si les phénomènes de « faible débit » (niveau d’eau < 10^{e} percentile des séries chronologiques historiques), qui se produisent surtout après le pic de migration du saumon rouge, n'ont pas été facilement associés aux faibles taux journaliers de migration, les « débits forts » (> 90^{e} percentile) ont souvent été liés à un retard du début de la migration pouvant aller jusqu'à 10 jours. Toutefois, une fois la migration commencée, de hauts niveaux d'eau ont rarement eu un effet dissuasif sur des taux élevés de migration. La fréquence des débits forts a augmenté depuis les années 1980 par rapport aux

décennies précédentes, tout comme la durée moyenne et maximale des périodes de débit fort, avec une hausse disproportionnée des événements en juillet. Une répartition pondérée de la fréquence a indiqué que des taux élevés de migration pour le saumon rouge du lac Long se produisaient en moyenne lorsque la température de l'eau de la rivière Docee est de 12 °C et que le niveau d’eau consigné dans le lac Owikeno est de 3 m, ce qui représente une profondeur d'environ 0,75 m ± 0,02 m dans la rivière. Bien que les variations de la température et du débit semblent avoir eu une influence subtile sur la variation quotidienne des taux de migration du saumon rouge entrant dans la rivière Docee entre 1968 et 2012, aucune variable n'a atteint des extrêmes suffisants pour entraîner une cessation évidente des migrations quotidiennes du saumon rouge adulte dans le lac Long

INTRODUCTION

Maintaining healthy and diverse populations of salmon that will support sustainable fisheries in the present and for future generations is the key goal of the Department of Fisheries and Oceans' Wild Salmon Policy (DFO 2005). This goal is advanced by safeguarding the genetic diversity of wild salmon populations, maintaining habitat and ecosystem integrity, and managing fisheries for sustainable benefits.

However, management methods to meet sustainable fisheries and biodiversity objectives are likely to be affected by climate change impacts on the distribution, abundance, and productivity of wild salmon populations (Finney et al. 2002). Therefore, conservation, restoration, and harvest management of many wild salmon populations will require improvements in knowledge of the extent to which human disturbance versus natural disturbance events control variations in salmon growth, survival, and production.

Within the general category of natural disturbance regimes or events, annual and seasonal variations in freshwater temperature and flow represent the most common factors exerting a major influence over salmon life history outcomes. Analyses of historical data indicate that significant changes in regional meteorological factors (such as air temperature and precipitation) that directly affect freshwater quantity and quality have already occurred in response to climate change in Canada's Pacific region (e.g., Whitfield and Cannon 2000; Whitfield 2001; Whitfield, Bodtker, and Cannon 2002), and regional climate model projections point to increased changes in these factors through the 21^{st} century (Abdul-Aziz, Mantua, and Myers 2011; Littell et al. 2011).

Recent investigations in the Pacific Northwest and British Columbia have demonstrated regional temperature shifts of about 0.8°C over the past century, with projected temperature increases of 1.5-3.2°C in near-future decades (Mote et al. 2003). Seasonal precipitation has also changed markedly in the recent past (Walker and Sydneysmith 2008), and future projections point to wetter winters and drier summers, with a high likelihood that extreme events involving regional temperature and precipitation will become more frequent (Mantua, Tohver, and Hamlet 2010; IPCC 2007). These analyses also indicate that the magnitude and direction of historical and projected climate variability exhibit sub-regional specificity due to the large and topographically complex areas involved (Walker and Sydneysmith 2008).

Temperature effects on migrating adult Sockeye (*Oncorhynchus nerka*) have been documented for various river systems in the Pacific Northwest (Nelitz et al. 2007; Salinger and Anderson 2006). Lethal temperatures for adult Sockeye are reported in the range 21-24°C, and water temperatures in excess of 18°C may affect migration speed, cause timing delays, and alter spatial distribution of Sockeye salmon. Increased water temperature also may result in secondary effects such as increased disease, resulting in pre-spawn mortality (Cooke et al. 2004; Hinch and Martins 2011). Thermal stress has also been found to reduce salmon gamete viability, fertilization rates and decrease egg to fry survival rates (Jensen et al. 2004). Since

Sockeye populations may also differ in their thermal tolerances, reflecting local adaptation to conditions over their historic evolution (Farrell 2009; Martins et al. 2012), stock-specific responses to climate variation and change impacts are also possible (Martins et al. 2010).

Stream discharge levels may also be associated with variations in migration timing, causing delays, affecting swimming speed, and inducing biological stress during upstream migration of adult salmonids (Hinch and Bratty 2000). The quantitative effects may differ between waterbodies due to unique physical stream attributes (rapids and falls, canyons, etc., but also man-made fishways and weirs) which influence water velocity in key locations along the migratory route. In some cases, low flows may result in physical limits to fish passage; in other cases, high flows may generate velocity barriers that reduce or prohibit upstream migration.

This report is one of a series intended to consolidate and document historic observations on key life history events and associated environmental variables for relatively data-rich Sockeye and Chinook salmon populations distributed throughout their range in Canada's Pacific region (Hyatt et al. 2015; Stiff et al. 2013, 2015a, 2015b; Damborg et al. 2015). Although there are many potential uses for these data, the focus of our current work is to develop lifestage-specific models that identify potential associations between salmon production variations and climate variation effects in freshwater and marine ecosystems throughout the eastern rim of the north Pacific.

Specifically, this report documents the data assembled for derivation of historic water temperature and flow of the Docee River and spawning tributaries in the Long Lake watershed, once a major source of Sockeye production in central British Columbia. Total annual returns ranged from 111,000-950,000 fish between 1980 and 1993, with an average harvest rate of 50%[1] (English, Glova and Blakley 2008). Average stock size declined precipitously to less than 50,000 fish in the years since, for reasons related to changing ocean conditions resulting in chronically depressed marine survival (McKinnell et al. 2001; Borstad et al. 2011) for the relatively small-sized smolts of this region (Hyatt, Rankin and Hanslit 2000; Rutherford and Wood 2000).

STUDY AREA

Long Lake is a clear, cold 21 km^2 waterbody draining 40,800 hectares in the relatively undisturbed OWIKENO watershed group in the Central Coast district of British Columbia (Management Area 10) (Hyatt and Stockner 1985). The watershed is located in the productive coniferous forests of the COASTAL WESTERN AND MOUNTAIN HEMLOCK biogeoclimatic zones, at an elevation of only 15 meters.[2] The climate is characterized primarily by cool, wet summers and mild, wet winters as it is strongly influenced by air masses flowing east from the Pacific Ocean (Hyatt et al, 2006), in conjunction with high altitudes of the PACIFIC RANGE eco-province (Figure 3). Average temperatures coastward of the lake range from 4-14ºC (at EGG ISLAND

[1] Harvest rates peaked to 75-80% in 1991 and 1992 (English et al. 2008).
[2] Long Lake (51.25ºN x 127.15ºW watershed code 910-025600) has a mean depth of 80 m and a maximum depth 170 m (Rutherford,et al. 1986).

meteorological station, 1971-2000)[3] with total annual precipitation of 2,564 mm (including 48 cm of snow). Much of the drainage basin is further inland at higher elevations. As opposed to typical coastal lakes where discharge is dominated by winter rain events, Long Lake basin hydrology is seasonally-driven by nival and glacial melt, with peak flows usually between May-July. This results in a highly variable seasonal hydrograph, as demonstrated at gauged streams in the region (e.g., Owikeno Lake: Figure 5)[4], with average minimum flows generally occurring in late winter and average maximum flows in mid-summer (Shortreed and Morton 2003). Natural productivity in the nursery lake is limited by nutrient availability (ibid).[5]

Migrating adult Sockeye normally appear at Quashalla Narrows towards the end of June (Figure 3, Figure 4), with migration into Wyclees Lagoon often taking place during high tides through August. From Wyclees Lagoon, Sockeye move up the Docee River (<1 km in length) into Long Lake where they hold until early September. The stock spawns in two streams: Smokehouse Creek, which accommodates approximately 70-75% of the spawning stock, and Canoe Creek at the distal end of the lake.[6] Spawning usually peaks in October and is finished by early to mid-November (Wood 1970; in Chambers et al. 2001).

METHODS

SOCKEYE MIGRATION DATA

Daily Long Lake Sockeye escapement estimates at the Docee River site were provided by Fisheries and Oceans Canada (DFO) as online data[7] or published reports for the years 1963, 1968, 1970-2012.

Over the years, Sockeye enumeration methods have varied, affecting the reliability of the daily and annual total counts. Prior to 1963, sockeye enumerations were mostly conducted from visual surveys of Smokehouse and Canoe Creeks, with spawner estimates based on standardized stream index counts (Rutherford & Wood 2000). In 1963, daily counts of Sockeye entering Long Lake were conducted from a tower on the Docee River as an experimental program to provide improved estimates in a period useful for in-season management. After a lapse of 4 years, the tower count was re-established for 1968, 1970 and 1971, enabling more reliable daily estimates (Chambers et al. 2001). The results from these programs demonstrated that Docee River counts provided more effective management of the Smith Inlet sockeye fishery and more accurate monitoring of escapement estimates (Thomson and Goruk 1988; Bachen, Rutherford and Goruk 1997).

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[3] Egg Island Station 1062646 data: http://climate.weather.gc.ca.
[4] WSC Station 08FA002 (51º40N x 127º10W; Environment Canada Water Survey of Canada).
[5] Long Lake was artificially fertilized in 1977-1979, and 1982-1997 (Hyatt and Stockner 1985; Hyatt et al. 2004; Rutherford and Wood 2000, Stockner et al. 2001).
[6] Shore spawning may occur in Long Lake between Canoe and Smokehouse Creeks, and on the south side of the lake near the Docee River outlet.
[7] Docee River daily Sockeye counts published online by DFO North Coast Stock Assessment Division: http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/docee-eng.htm (downloaded 23Oct 2012).

The Docee Fence permanent counting facility was constructed[8] for the 1972 season and has since provided consistent estimates of sockeye salmon escapement to Long Lake (Bachen, Thomson and Goruk 1988a, 1988b; Thomson and Goruk 1988; Winther, Bachen and Goruk 1989 1990, 1991, 1992a, 1992b; Bachen, Rutherford and Goruk 1997; Rutherford & Wood 2000)[9]. From 1972-1997, the Docee Fence was operational from the end of June through to the second week of August. A two-man crew counted fish at the fence over one-hour shifts, as they passed through a gate over a section of white expanded metal on the counting panels from 5 a.m. – 10 p.m. (Thomson and Goruk 1988). After dark, the fence was closed, preventing migration through the structure.

Bachen et al. (1997) attempted to account for bypass on an annual basis for the years 1982-1996 by reporting an *estimated final escapement* value which included a subjective correction for bypass. However, daily estimates of fish bypassing the count station were not available for any year. Thus, it is assumed here that bypass was negligible and insensitive to changing hydrological conditions and/or the structural integrity of the fence.

Species composition was determined from dip net catches made on the downstream side of the fence, and from carcasses or moribund sockeye salmon that drifted back onto the fence panels. Dip-netted salmon were sampled for length and scales before being live-released on the downstream side of the fence (Bachen et al. 1997).

In 1998, fence operation was extended to the end of September to enumerate Coho and Chinook salmon (Chambers et al. 2001). Final fence count was reported along with an estimated final escapement. The final estimated escapement was usually higher than the actual fence count due to the inclusion of a subjective correction for sockeye bypass (Bachen et al. 1997).

Since 2006, the Gwa’sala-Nakwaxda’xw First Nation fisheries program has been responsible for all enumeration activities at the Docee Fence, during which time an underwater camera has been implemented for species identification purposes (DFO 2007).

Review of the online daily Sockeye counts in conjunction with published reports indicated a number of data issues, mostly minor, which were handled in this analysis as follows:

- 1963, 1968, 1970, 1971 – Adjusted daily count data collected from the Docee River tower were excluded from certain multi-year analyses due to differences in field methods and associated sources of error relative to subsequent years when consistent fence counts were available. For example, tower counts

[8] Docee fence structure and flashboard observation are described in Chambers et al. (2001).

[9] In addition to providing post season sockeye escapement estimates, the Docee Fence is an important tool for in-season assessment of both statistical Area 9 and 10 sockeye salmon: stock status determinations for Smith Inlet sockeye are based on abundance and age structure data collected at the fence, and fisheries managers use daily fence counts in combination with harvest data (if any) for in-season management of fisheries. However, due to persistent low returns of Long Lake sockeye salmon since the early 1990s, the Area 10 commercial gillnet salmon fishery has been closed since 1997 (Chambers et al. 2001), with the exception of 2011.

were sensitive to weather conditions, water levels, turbidity, and light levels (uncounted overnight migrants were estimated to make up 12% of the escapement), not to mention peak migration events when large numbers of fish passed by in short periods of time across the river span (Wood 1970). Though not directly comparable with fence count data, tower count data may still be useful for examination of relative changes in migration rates in-season when standardized as a daily percentage of the annual total, and therefore were used cautiously in analyses with environmental data.

- 1972-2000 – Apparent transcription errors, mostly minor, and omissions at front and tail ends of run were evident in the online data[10] (as of October 2013) versus published reports (Thomson and Goruk 1988; Chambers et al. 2001).
    - Transcription errors (July 11, 18, 21, 23, 1973; July 11, 1974; August 6, 1984; July 31, 1997; July 4, 1999) were replaced with published data.
    - Missing data in the online table (July 9 and August 1-12, 1973; August 9, 1982; August 9, 1985; August 6, 1989; August 1-9, 1996; August 1-5, 1997; August 8 – September 5, 1998; August 11 – September 5, 1999; August 11 – September 5, 2000) were updated with published data.
    - Known cumulative estimates used as initial counts in the online table (which commences on July 3rd each year) were partitioned to July 1-3 based on actual reported daily counts where available (e.g., 1985-1988, 1991-1995, 1998-2000). However, any counts in late June were accumulated in the July 1st count – these were infrequent and not large.
    - Other high initial counts (15,666 on July 12, 1972; 41,173 on July 10, 1973; 1,311 on July 8, 1976; 7,400 on July 4, 1978), which appear unlikely, may be related to commercial fishery removals and/or cumulative estimates of early migrants prior to fence operations artificially obscuring natural run timing. These data were not revised.
- 1997 – Online data were displaced one week later relative to the original data report (Chambers et al. 2001), with non-zero counts commencing on July 9th instead of July 2nd. All count dates in 1997 were shifted back 7 days in this study.
- 2001-2007: Docee fence counts compiled in the POST-SEASON REVIEWS (or RECORD OF MANAGEMENT STRATEGY (RMS) reports; DFO 2005; 2006; 2007; 2008) are insignificantly different from archived online data[11], likely due to round-off errors incurred in species composition estimates for these years.

[10] DFO North Coast: Docee River Counting Fence http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/docee-eng.html

[11] DFO North Coast Fisheries Archived Data http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/archives-eng.html

    - One exception occurred for July 24th, which was set at 1,218 in the 2006 time-series on DFO website, but 1,467 in the RMS report (DFO 2007), and also 1,467 in cumulative multi-year table online. The latter number was retained for this study.
- 2008-2012 – no meta-data yet retrieved to qualify the online daily counts.

Prior to closure of the commercial fishery in 1997, Docee Fence counts were reconstructed in data reports (Bachen et al. 1997; Chambers et al. 2001) to provide daily estimates at the fence as if a commercial fishery not occurred[12]. However, unadjusted fence counts were used for this study, which is focused specifically on environmental factors affecting daily migration "behaviour" in Docee River. Nevertheless, since the only available indicator of Long Lake Sockeye migratory "behaviour" is adult migrant counts, which may be impacted by harvest removals (ranging as high as 70-96% of total run prior to 1992)[13], it is still necessary to interpret migratory stop/start events and low migration rates cautiously, or exclude data altogether, when fishery openings occurred that accounted for more than 50% of the weekly total run.

To standardize the annual adult migration time-series for inter-year and inter-stock comparisons, daily percentages of total Sockeye migrants were calculated relative to the total annual stock escapement through the Docee fence. Annual plots of daily migration rate (% relative to the annual total escapement) were overlaid with historical mean and maximum daily migration rate by Julian day-of-year, for inter-annual migration pattern comparisons.

Univariate statistical analyses were used to characterize the historical stock migration data (number of observations, central tendency e.g. mean, median, mode, etc., scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis) for the years of consistent fence count data (1972-2012). Median (50th percentile) and 75th quartile values of the historical datasets were calculated to establish low (0-75th percentile), medium (75-90th percentile) and high (90-100th percentile) categories for daily migration rate classification. Quartiles of the Julian dates of migration in the historical data were used to categorize daily migrant data into early (0-25th percentile), middle (25-50th percentile), and late (75-100th percentile) observations. Daily migration rate (%) data were transformed using the arcsin function to normalize the percentage data where appropriate for parametric analyses (Sokal and Rohlf 1969).

ENVIRONMENTAL DATA

Meteorological, hydrological, and water temperature data necessary for derivation of long-term (30+ years) time-series of water temperature and flow conditions were assembled from online databases, published documents, unpublished reports, and personal records from government agencies (e.g., B.C. MINISTRY of ENVIRONMENT,

[12] First Nation food-social-ceremonial fisheries generally remained open, however these fisheries represented less than 1% of the total stock (Rutherford and Wood 2000) and the impacts on migration timing were considered negligible.

[13] Episodic escapements through the fence were generally considered to be attributable to the Area 10 commercial sockeye fisheries held during the previous week in Smith Inlet (Bachen et al. 1988).

ENVIRONMENT CANADA, WATER SURVEY OF CANADA (WSC), and FISHERIES AND OCEANS CANADA (DFO).

Basic statistical analyses were used to document and describe the available data, establish relationships between regional air and site-specific water temperature datasets, and define inter-site relations for both water temperature and discharge to infill missing observations. STATISTICAL ANALYSIS SOFTWARE (SAS® Version 9.3) was used to assemble data from MICROSOFT EXCEL® spreadsheets and analyze the data. The resulting datasets were stored in a relational MICROSOFT ACCESS® FRESHWATER ENVIRONMENTAL VARIABLES DATABASE and are available from DFO upon request.[14]

HYDROLOGY

Docee River

Water levels (and general weather conditions) at the Docee Fence site were recorded twice daily between 8:00 and 18:00 during the migration season (late June - September) for the years 1986-2012. The staff gauge used to monitor water level was located 1 meter downstream of the Docee fence. A staff gauge reading of zero was considered equal to a water depth of 1 meter at the fish counting panel (Chambers et al. 2001).

Unusual flow conditions at the Docee fence were noted in various reports:

- 1963-1971 – counting tower not operational due to flooding in 1964; tower operations discontinued 1965-1968; accurate Sockeye migrant counts hampered due to high water 1970-1971 (Thomson and Goruk 1988; Wood 1970).
- 1972-1987 – no water level issues noted (Thomson and Goruk 1988); flows below normal in July and August 1986 (DFO 1986).
- 1988-1991 – no water level issues noted (Winther et al. 1989, 1990, 1991, 1992a).
- 1992 – low water levels late July and early August (Winther et al. 1992b).
- 1993-1996 – no water level issues noted (Bachen et al. 1997); however: the data, which were recorded in feet, appear to be rounded off to the nearest foot, resulting in a time-series that is less suitable for statistical analyses.
- 1997 – water levels near 5 feet on July 9-10 (Chambers et al. 2001).
- 1998 – no issues noted (Chambers et al. 2001)
- 1999 – low water late July, early August (recorded minimum: -1.0 m); no fence count from August 25-28 due to high water (over panels), fish passage estimated to be 90 Coho and zero sockeye (Chambers et al. 2001).
- 2000 – water levels near 5 feet July 28-30 (Chambers et al. 2001).
- 2001-2004 – no water level issues specified (unpub. Records of Management Strategy (RMS) reports: DFO 2002, 2003, 2004, 2005).

[14] Contact Howard.Stiff@dfo-mpo.gc.ca or Kim.Hyatt@dfo-mpo.gc.ca.

- 2005 – water levels were “unseasonably high” in early July, with extreme lows for extended periods in late July and mid-to-late August (unpub. RMS report: DFO 2006).
- 2006 – water levels at Docee were “unseasonably low” in early August until the end of the field program (unpub. RMS report: DFO 2007).
- 2007 – water levels at the Docee Fence were “very high” during mid-July to early August, with “water overtopping the fence panels and flowing around the fence structure for several days. Senior Technician Steve Bachen reported that he had not observed water levels that high during the sockeye migration in 30+ years.” (unpub. RMS report: DFO 2008).
- 2008-2009 – no information.
- 2010 – water levels were < 0.10 m but not below 0 meters from August 10-30 (supplemental field notes, W. Levesque, North Coast biologist).
- 2011 – water levels were “too high to check” (> 1 m) during heavy rains: August 22-24 (pers. comm., W. Levesque, North Coast biologist; supplemental field notes).
- 2012 – water levels were “over meter stick” during heavy rains: July 1-3, 13-14, 19-23 (pers. comm., W. Levesque, North Coast biologist; supplemental field notes).

Evident typographic errors in the raw data were corrected or set to missing. Single missing morning or afternoon water levels were linearly interpolated between previous and next readings. Morning and afternoon observations were averaged by date to provide an indicator of daily mean water level. Missing mean daily water levels were interpolated between dates not greater than 3 days apart. Water levels recorded in feet were converted to meters (1986, 1992-2000).

Reference Hydrometric Stations

WSC hydrometric data were not available for the Long Lake watershed. Potential predictors of flow conditions in the Long Lake system were obtained from the web archives of the WATER SURVEY OF CANADA (WSC).[15] The nearest active hydrometric stations from the ENVIRONMENT CANADA web site included (Figure 3):

- *Owikeno Lake* Station 08FA007 (51°41’26” N x 127°9'43" W) is an active lake station in the Owikeno watershed. Historical water level data obtained via seasonal (1964-1965, 1969) and continuous (1961-1963, 1966-1968, 1970-present) recording devices were retrieved from online archives for the years 1961-2010. Quality-assured data for 2011 were not available online but preliminary data were provided from WSC upon request (pers. comm., Lynn Campo, WSC). Real-time (hourly) data for 2012 were also retrieved from the WSC site, summarized by date and appended to the time-series. Partial hydrometric coverage during the Sockeye migration season occurred only in

[15] ENVIRONMENT CANADA – WATER SURVEY OF CANADA: http://www.wsc.ec.gc.ca/applications/H2O/HydromatD-eng.cfm.

1962 and 1965, representing < 1% of dates.

- *Wannock River* Station 08FA002 (51°40'45" N x 127°10'45" W) is a long-term active flow station (1927-2011) at the outlet of Owikeno Lake (drainage area 3,900 km^2). Quality-assured daily mean flow data obtained from manual (1927-1934), seasonal (1964-1965) and continuous (1961-1963, 1966-2011) recording devices were retrieved from online archives. No missing data existed for the Sockeye migration months for the period 1961-2011. However, 2012 flows were not available at the time of this study, limiting the use of Wannock flows as the primary predictor of Docee water levels.

As correlation of the time-series between the highly proximal WSC stations was high ($r = 0.99$), enabling confident reconstruction of Owikeno water levels back to 1927, and correlation between either WSC station with Docee water levels was approximately equivalent for any given year, *Owikeno Lake* water levels were selected as the predictor variate for reconstructing Docee water levels.

Simple least-squares regression models (linear: $Y = a + bX$; logarithmic: $Y = aX^b$; quadratic: $Y = a + bX + cX^2$; and cubic: $Y = a + bX + cX^2 + dX^3$) were derived[16] for estimating missing and pre-1961 daily *Owikeno Lake* water levels as a function of the more extensive discharge time-series for *Wannock River*. Model selection was based on: lowest Akaike Information Criterion (AIC), maximum adjusted correlation (r^2), the significance of the lack-of-fit component of the regression error term, and lowest root mean square error (RMSE) (SAS 1987).

Equivalent analyses (linear, logarithmic, quadratic, and cubic regression relations) were used to identify the best model for reconstructing Docee River water levels from observed Owikeno water levels. However, due to incongruities in the observed Docee River water level data in some years, annual correlation analyses were first used to identify a high-quality multi-year subset of Docee fence data for statistical analyses. Data suitable for inter-site statistical analyses were selected based on a minimum annual correlation between log-transformed Docee and Owikeno water levels ($r^2 > 50\%$, $P < 0.01$), after omitting data exhibiting systematic observation bias in correlation plots. Model selection for reconstruction of Docee water levels as a function of *Owikeno Lake* water levels was based on: lowest Akaike Information Criterion (AIC), maximum adjusted correlation (r^2), the significance of the lack-of-fit component of the regression error term, and lowest root mean square error (RMSE).

Univariate statistical analyses were used to characterize the subset of observed Docee River daily water levels and WSC station data (number of observations, central tendency e.g. mean, median, mode, etc…, scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis). Plots of the historic mean and variance of daily water level were used to characterize the flow patterns during the adult migration period (July-August). Deciles and quartiles were derived for the peak migration months to identify low (< 10^{th} percentile), moderate ($10\text{-}90^{th}$ percentile) and high ($90\text{-}100^{th}$ percentile) flow categories.

[16] Omitting partial days (flagged as “A” in WSC data) and one outlier: 19-Sep-1968.

WATER TEMPERATURE

Water temperature data for the Long Lake watershed were collected via data loggers installed and maintained by DFO personnel between 2003 and 2008.

Docee River daily mean water temperatures for the period November 2003 – August 2008 were assembled from multiple data loggers located at the fence. Raw hourly data were obtained from Hobo® Data Logger # 687423 from 29-Nov-03 – 17-Oct-05. This device was replaced with two probes (# 201900 and #765907) on 17-Oct-05 but with no temporal overlap with #687423 for reliable calibration. Of the two new probes, #201900 recorded water temperatures up to 10% lower than #765907 (approximately 0.5 degrees), and was discontinued in February 2007. Though independent calibration data were not available to validate either time-series, for consistency, further analyses were restricted to the hourly data from probes #687423 (up to 17-Oct-2005) and #765907 (from 18-Oct-05), averaged by date.

Continuous mean daily water temperatures, summarized from hourly readings, were provided for the spawning tributaries (Canoe Creek (probe 575271) and Smokehouse Creek (probe 575272)) for the period 30-Oct-2003 to 12-Apr-2006.[17]

Univariate statistical analyses were used to characterize the daily mean water temperature (MWT) time-series for the period of record (i.e., number of observations, central tendency e.g. mean, median, mode, etc…, scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis).

Water temperature data cleanup consisted of examining descriptive statistics and graphic output to identify anomalous data and outliers, in conjunction with a review of field notes regarding data logger installation and removal dates and times. Anomalous data, if any, were corrected, or retained in the database but flagged for omission (i.e., OMIT field = YES) from data analyses.

The relatively brief time-span of the Long Lake MWT time-series render them inadequate for accurately assessing baseline conditions for climatological studies in themselves. Reconstruction of a long-term freshwater temperature dataset suitable for climate analyses is contingent on a set of daily mean air temperature records spanning 2-3 decades, or more for historic trend analyses. Studies have demonstrated that variations in regional air temperature are generally sufficient to explain as much as 80% of the variation in local daily mean water temperature (Mohseni and Stefan 1999; Hyatt and Stockwell 2003; Pilgrim, Fang and Stefan 1998; Stefan and Preud'homme 1993; Webb and Nobilis 1997); long-term air temperature datasets provided by federal or state climate monitoring networks spanning much of the 20th century may therefore be used in predictive regression models to extend or infill site-specific water temperature time-series. Linear and nonlinear regression models are known to be accurate at moderate air temperatures typical of adult Sockeye migration periods (i.e. 10-20°C), while water temperature "extremes" (<5°C or >20°C) are more appropriately modeled nonlinearly (Mohseni, Stefan, and Erickson 1998). The resulting time-series spanning the period of record

[17] Hourly data for Canoe and Smokehouse Creeks are available from Shannon.Anderson@dfo-mpo.gc.ca (Fisheries & Oceans Canada, Campbell River 250-287-9564).

of meteorological observations can be used as a consistent index of local water temperature conditions at the daily time-scale, and summarized to examine trends and shifts in water temperature regimes at longer time-scales (e.g., decadal).

AIR TEMPERATURE

ENVIRONMENT CANADA'S METEOROLOGICAL SERVICES group maintains an archive of climate data collected at both active and inactive stations distributed throughout British Columbia and the Yukon.[18] For the majority of Canadian climate stations, air temperature measurements are taken from self-registering, maximum and minimum thermometers that record the extremes of each parameter within a 24-hour period. Daily mean temperature, where provided, is defined as the average of the maximum and the minimum temperatures attained during the 24-hour period. These datasets undergo detailed quality-control analysis before posting to the web site.

The EC web site was accessed to identify potential sites of air temperature data within the area of interest for statistical relationships with water temperature data (Figure 3). As there were no climatological records available specifically for the Long Lake watershed, EC climate station *Port Hardy* 1026270 (50.7°N x 127.4°W; 22 m elevation) was selected for climate data retrieval on the basis of: (i) the quantity and quality of data available (1944-2012); (ii) proximity to Long Lake watershed (<80 km) (Figure 3); and (iii) the potential to routinely update data from an "active" climate station. In addition, ENVIRONMENT CANADA has refined the air temperature and precipitation time-series for this station, as part of the ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD)[19] group of climatological stations across Canada. These data incorporate a number of adjustments applied to the original station data to address non-climatological shifts related to changes in instruments and observation conditions or procedures, thus optimizing their use for climate research (Vincent et al. 2012).[20]

Port Hardy Multi-day Mean Air Temperature Index

The best predictive air-to-water relationships exist for associations between daily mean water and multi-day mean air temperature (Hyatt and Stockwell 2003; Webb and Nobilis 1997). Centered moving averages (i.e., mean temperatures from *Date – (n-1)/2* to *Date + (n-1)/2*, where *n* is the number of days) center the multi-day means such that peaks and troughs more accurately align with the flux in the original daily MAT time-series. Hyatt et al. (2015) found that a seven-day centered moving average air temperature (7D-CMAT) index[21] provided the best trade-off between

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[18] ENVIRONMENT CANADA Climate Data: http://climate.weatheroffice.gc.ca/climateData/canada_e.html

[19] ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD surface air temperature data are not currently freely distributable or available online but may be obtained by request to AHCCD@ec.gc.ca. See http://www.ec.gc.ca/dccha-ahccd/default.asp?lang=En&n=B1F8423A-1 for monthly AHCCD data.

[20] AHCCD Licence Agreement: *This work contains data licenced "as is" under the Government of Canada Open Data Licence Agreement. Such licencing does not constitute an endorsement by the Government of Canada of this product*.

[21] Like other multi-day moving average temperature indices, this indicator tends to bias extreme air temperatures towards the mean, thus under-estimating the amplitude and frequency of peak thermal events that may affect fish behaviour. Therefore, this index, and, by extension, any water

maximizing air/water time-series correlations and minimizing the effects of multi-day averaging on predictive power at longer period lengths. Thus, the *Port Hardy* 7d-CMAT was used for subsequent air/water temperature analyses.

Selection of data for the calibration dataset was based on subjective and statistical examinations of the annual air and water temperature time-series plots and annual regression relationships. Years with consistent and apparently unbiased data logger readings associated with a maximum range of temperature values for both warming and cooling periods[22] were preferred for characterizing the all-year air/water temperature relationship. The remaining data (if any) were used for validation of statistical relations.

AIR/WATER TEMPERATURE RELATIONSHIPS

Stiff et al. (2013) describe the basic methodology used to estimate missing or historical daily MWTs based on statistical relations with the regional 7-day MAT index. The authors calibrated linear (Equation 1) and logistic (Equation 2) air-to-water temperature relations using a subset of the site daily MWTs as a function of the regional multi-day air temperature index. A minimum of 5 years of representative data including sufficient observations at the upper end of the temperature range for both warming and cooling seasons were found to be sufficient to calibrate the models. The remaining water temperature data were used as a validation dataset to test the goodness of fit for the following air-to-water temperature models:

Equation 1: $T_w = \alpha + \beta * T_a$; where

T_w is the *estimated mean water temperature in the waterbody*;

T_a is the *PORT HARDY 7-day mean air temperature index*; and

α is the y-intercept and β is the regression coefficient.

Equation 2 : $T_w = \mu + (\alpha - \mu) / (1 + e^{\gamma(\beta - T_a)})$; where

T_w is the estimated mean water temperature in the waterbody;

T_a is the PORT HARDY 7-day mean air temperature index;

α is the estimated maximum water temperature;

μ is the estimated minimum water temperature;

γ is a measure of the steepest slope of the function; and

β represents the air temperature at the inflection point.

The existence of hysteresis[23] in a water body, and the resulting need to use

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temperatures estimated as a function of this index, should be treated as a conservative indicator of extreme events.

[22] Derivation of the seasonal flux point between warming and cooling "seasons" is described below.

[23] Hysteresis: the heat storage properties of water. Hysteresis is a measure of the seasonal effect of the differential rates of heat exchange between air and water as the spring-to-summer period warms up and the fall-to-winter period cools down (Wetzel 1975). The observed pattern of hysteresis is related to the complex physics of air-water heat exchange processes. These involve evaporative cooling of the lake in the late summer-to-fall, thermal de-stratification in the fall-to-winter; rapid, wind-

separate warming and cooling season regression models to describe air/water temperature relations at a particular site, was evaluated for both linear and logistic models. In the linear model, an additional categorical "season" effect was tested for significance (signifying different seasonal model intercepts), and as an interaction effect with air temperature, signifying differences in seasonal model slopes (i.e., $P < 0.05$ for the Type III model sum of squares (SAS 1987), either of which would suggest a hysteresis effect. For the logistic analysis, hysteresis was assessed by comparison of the *Nash-Sutcliffe Coefficient* (NSC) value for the all-season model versus the averaged NSC values for the separate warming and cooling season models (Mohseni et al. 1998):

Equation 3*:* $Hysteresis = [(NSC_w + NSC_c) / 2 - NSC_{all}] \geq 0.01$; where

NSC_w = NSC for warming season;

NSC_c = NSC for cooling season;

NSC_{all} = NSC for all seasons combined.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

Model Calibration

Logistic regression relations described above were developed using site-specific daily mean water temperatures (MWTs) for the Docee River (migration route) and spawning locations (Canoe and Smokehouse Creeks) as a function of the regional air temperature index (7-day centered *Port Hardy* MAT variate).

Calibration data were selected based on examination of annual air and water temperature time-series and correlation plots. As the time-series were limited to less than five years, source MWT datasets were partitioned as follows:

Waterbody	Calibration Years	Validation Years
Canoe Creek	2003 – 2006	None
Smokehouse Creek	2003 – 2006	None
Docee River	2004 – 2008 2004 – 2005 (warm-phase PDO years) 2007 – 2008 (cool-phase PDO years)	None 2006 – 2008 2004 – 2006

To determine whether seasonally-distinct regression relations were required, the air/water temperature data for each water body were checked for hysteresis. To detect hysteresis, separate functions were fitted to the air and water temperature data in each of the warming and cooling seasons.

The warming and cooling seasons were first distinguished from each other by determining the seasonal temperature "turn-around point" (the timing of the winter

induced, mixing of surface and deep waters through the winter, and initiation of thermal stratification and evaporative cooling once again in the spring-to-summer season.

season turn-around point was not required for the purpose of this analysis).[24] The seasonal transition dates were obtained by plotting weekly mean daily water temperatures as a function of weekly mean daily air temperatures, and connecting the points chronologically. The week associated with the maximum mean air temperature, indicating the ending of the warming season (and the starting point of the cooling season) was converted to day-of-year to pinpoint the seasonal turn-around date.

Site-specific hysteresis effects were then assessed as described above using the calibration data. If hysteresis was detected, then regression coefficients obtained from logistic models fitted to the multi-year data for each of the warming and cooling seasons separately were retained for water temperature estimation. To minimize any abrupt inter-seasonal step-effect in the predicted time-series, daily water temperature estimates for five days on each side of the turn-around-point were generated using an intermediate model parameterized with the means of the coefficients for the warming and cooling seasons.

Model Validation

Site-specific linear and nonlinear air/water regression parameter estimates were tested for statistical significance, and applied to the *Port Hardy* air temperature index to estimate reference site daily MWT for the period of record of air temperature data. Modeled MWTs for the validation dataset were correlated with observed reference site water temperature data graphically and statistically as a measure of goodness-of-fit. The all-year Pearson and Spearman correlations for the validation years were compared between model types to determine whether linear or logistic outputs best simulated observed MWTs in the waterbody.

To explore limitations in the model fit in the Docee system, air/water temperature relations were re-evaluated based on calibration data limited to PDO-warm-phase (2004-2005) and cool-phase years (2007-2008).

PRECIPITATION

Precipitation data may be correlated with discharge levels and water temperature. They may also be useful for downscaling projected changes in regional precipitation from global or regional climate models to specific sites at the local level.

As there were no meteorological records available for the Long Lake watershed, daily precipitation data from *Port Hardy* AHCCD station 1026270 were obtained from ENVIRONMENT CANADA.[25] The AHCCD precipitation data (1944-2011) were supplemented with unadjusted daily total precipitation data for 2012. Due to the highly localized and non-normal distribution of precipitation data, missing values

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[24] For linear models, an additional “winter” season was defined (November 25th to March 10th), encompassing the cold-weather months when changes in air temperature are not reflected in changes in water temperature due to hysteresis effects at low temperature extremes. These data were omitted from this analysis.

[25] ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD precipitation data are not currently freely distributable or available online but may be obtained by request to AHCCD@ec.gc.ca. See the ENVIRONMENT CANADA website for monthly AHCCD values.

were not interpolated, nor were time-series extendible based on parametric statistical relations with other stations.[26]

TREND AND EXCEEDANCE ANALYSES

Air Temperature

Historic mean daily air temperature data (based on PORT HARDY daily MAT, 1944-2012) were summarized by year to obtain the mean value during the summer months (July-September), and plotted to review the long-term time trend in regional air temperature during the migratory period.

Monthly mean air temperatures of 20°C are considered an upper threshold for salmonid life history stages (Mote et al. 2003). Historic mean daily air temperature data at PORT HARDY were analyzed for the frequency of dates in each year and month (July-September) for which mean daily air temperature exceeded this threshold value, and summarized by decade as a trend indicator. In addition, the frequency of annual periods in which water temperature continuously exceeded this value, and the mean duration (days) of these periods, was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful temperature conditions.

Water Temperature

Reconstructed daily mean temperature data were summarized by site and year to determine mean values during the summer months (July-September), and plotted to review the long-term time trend in site-specific water temperature conditions during the migratory period.

A threshold exceedance analysis, tallying the decadal mean monthly frequency of dates for which the reconstructed MWT temperature index exceeded 18°C ($POT_{18°C}$; i.e., peak-over-threshold > 18°C), was used to examine site-specific trends in water temperature conditions during the adult migration period (July-September).

In addition, the frequency of annual periods in which water temperature continuously exceeded this value, and the mean duration (days) of these periods, was derived for each year. These data were summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful water temperature conditions.

River Level / Discharge

For discharge, exceedance analyses for both “low flow” and “high flow” dates are of potential interest, since, conceivably, either flow extreme may influence upstream migration. The frequency of dates for which estimated water levels for Owikeno Lake (as a proxy for Docee River conditions) were either less than the lower 10th percentile, or greater than the upper 90th percentile of summer readings, was calculated by year and month (July-September), and summarized by decade. From these data, the frequency of annual periods in which flow levels continuously

[26] An alternative approach, not attempted here, may be to obtain daily precipitation data for multiple regional meteorological stations to derive an appropriate area average. Regional meteorological stations within 100 km of the Meziadin watershed can be found in Figure 2. Source: NATIONAL CLIMATE DATA AND INFORMATION ARCHIVE (March 2013).

remained below/above the lower/upper thresholds, and the mean duration (days) of these periods was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potential flow barriers to upstream migration.

Migration, Temperature and Discharge

Estimated Docee River daily mean water temperature and Owikeno Lake water level time-series were merged un-lagged with daily Sockeye migration rate data for co-variation analyses.

To characterize the temperature and discharge conditions during historical stock migration, frequency distributions of observed active migration dates (i.e., filtered for non-zero migration rates) at varying levels of temperature, water level, and both temperature and level, were generated. By simply tallying the number of dates in the historical dataset at which some migratory activity occurred, these plots indicate the general distribution of temperature and water level conditions that were available during the migratory period.

A similar frequency distribution of active migration dates, weighted by the daily migration rate, were plotted to indicate how much migration occurred at a given temperature, water level, or temperature x level combination. In contrast to the simple distribution of dates of migration, these plots indicate which water temperature and level conditions are associated with highest migration rates (i.e., presumably most favourable to salmon migration), and, by extension, the thermal and hydrological limits (if any) that differentiate high versus low rates of migration.

The 50th percentile migration rate (1972-2012) was used to define whether a daily migration rate value is positive or negative in relation to the zero-line, and the 75th percentile of migration rates was used to define whether a positive migration rate was “high” or “low”. Thus, the anomaly threshold (“zero-line”) for migration data was set to the 50th percentile of the historical daily migration rate. The migration threshold value was subtracted from the historical daily migration rates to derive the anomaly for daily migration.

Environmental “limits” derived subjectively from the weighted frequency analyses were used to set threshold values for calculation of daily deviations in the modeled water temperature and water level time-series, and combined with deviations in daily Sockeye migration rate on annual anomaly plots to examine the patterns of daily variation in each time-series in relation to each other.

Stressful conditions for Sockeye can occur at and above 18°C (Nelitz et al. 2007; Salinger and Anderson 2006). In the Docee River, this corresponds approximately to the 99th percentile of *estimated* daily water temperatures, yielding insufficient data for MWT exceedance analyses, thus a threshold of 17°C was used instead.

Utilizing *Owikeno Lake* daily water levels as an indicator of Docee River depths, depth values of 3.0 m was used as the zero-line threshold to review patterns of migration in relation to low and high flow periods. The difference between these thresholds and the daily mean values were plotted on a common axis (water levels were multiplied by a factor of 10 to display readably on the y-axis).

RESULTS

SOCKEYE MIGRATION

An annual average of ~104,000 Sockeye were counted at the Docee River fence over the past 41 years (1972-2012), ranging from a high of 259,000 in 1991 to a low of 1,430 in 2000 (Table 1). Long Lake Sockeye freshwater migration typically commences in late June or early July and terminates by mid-to-late August, with time-to-50% (TT50%) occurring approximately July 18th (Figure 6)[27]. Non-zero migrant counts averaged approximately 2,661 fish per day since 1972 (median fish passage: 565 fish per day); maximum daily counts surpassed 69,000 fish in 1982 (Table 1). The corresponding all-year mean daily migration rate is 2.55% of total annual escapement. The median daily migration rate of 1.0% (50th percentile) was defined as the threshold for "negligible" versus "significant" migration, and the 75th percentile of 3.4% was defined as the threshold for low versus high migration (Table 1).

Annual peak daily rates are typically in the range of 20-30% of the run (e.g., over 40% of the annual escapement occurred on one day in 1974); Table 1). Combined with a TT90% of ~August 1st, these high daily rates suggest a stock characterized by narrow run-timing. Summarized across all years, a skewed uni-modal pattern emerges, with the primary migration mode centered in the middle of July (Figure 6).

Annual time-series of Long Lake Sockeye daily migration rates (%) are plotted in Appendix A, along with mean and maximum daily migration rates from 1972-2012, displaying, in many years, late onset of migration (e.g., 1975, 1999, 2005) and/or multi-modal migration pulses separated by periods of relatively low migration (e.g., 1972, 1976, 1979, 1987, 1995, 2005, 2006, 2007), which might be evidence of environmental factors influencing migration patterns.

On the other hand, gaps or reductions in migration activity may in some cases be a function of harvest removals, at least in the years with commercial fishery openings (1960-1996, 2011).[28] Commercial fishery exploitation rates averaged 56% prior to 1997, and ranged up to 96% of the total stock in some years (Figure 8). Years in which annual total commercial harvest rates exceeded 50% in Area 10 and potentially impacted daily Sockeye migration rates at the Docee fence include: 1963, 1968-1971, 1973, 1974, 1976, 1978, 1982, 1985-1988, 1991-1993.

Specific weekly fishery openings[29] which likely impacted the following week's migration rate at the Docee fence include (plotted in Appendix B): 1971 (073, 074); 1973 (073, 074); 1974 (072-074); 1976 (072-074); 1978 (071-072); 1981 (074-075); 1982 (073-074); 1985 (073-074); 1986 (072-073); 1987 (073); 1988 (073-074); 1991

[27] TT50% was also day 199 (~July 18th) when data were limited to "low" harvest rate years (<30% of annual returns – 1977, 1980, 1984, 1997-2012 – Figure 7) or "zero" harvest rate years (1997-2010, 2012 – not shown). These years were characterized by returns of <100,000 fish on average.

[28] First Nation harvests represent less than 1% of the total stock (Rutherford and Wood 2000) and the impacts on migration timing may be considered negligible.

[29] Commercial fishery harvests are summarized by month (mm) and week (w): e.g., fishery period 073 refers to harvest operations in the 3rd week in the seventh month (July).

(073-075); 1992 (073-075); 1993 (074-082); 2011 (074). Apparent effects on daily migration rate due to water temperature or discharge levels were interpreted with caution for these periods (e.g., 1976, 1986, 1987, 1990 multi-modal migration timing at the fence was likely due to fisheries, with annual commercial harvest rates >60%).

HYDROLOGY

Docee River

Annual statistics of observed water level at the Docee River fence for all available years (June-September, 1986-2000, 2010-2012) were assembled in Table 2. Review of annual hydrographs indicated likely systematic recording errors for some or all Docee water level data in 1993-1996[30], and 1999[31] (Figure 9; Appendix A). These years were excluded from statistical analyses, including univariate statistics used to define all-year means and percentile thresholds (Table 5).

Daily water levels observed at the Docee fence ranged from -0.15 – 1.9 m during the July-August Sockeye migration period, with a mean of 0.66 ± 0.41 m (Table 5). The mean water level corresponds closely with the median (0.63 m), reflecting a relatively normal distribution of observations (Figure 10). Though highly variable, the annual time-series (Appendix A) typically display a steady drop in mean water level from a seasonal high during the peak Sockeye migration period in early-to-mid-July, to late-August lows approaching zero meters at the gauge (Figure 11) (corresponding to ~1 m of depth at the fence). This seasonal hydrological pattern is largely reflected in the Owikeno system (Figure 12). Since more than 95% of the Sockeye have moved upstream by mid-August (Figure 6), typical conditions appear to be highly compatible for Sockeye migration.

A review of apparent low-water years revealed little visual evidence of migratory impacts (Appendix A):

- 1986 - Water levels of ~0.5 m in late July and early August 1986, considered “low” by DFO personnel at the time, exhibited significant, above-average daily migration rates (>3-6%). Total escapement: 197,851 fish.
- 1992 - Observed water levels gradually approached zero near the end of July, 1992, and remained there until August 5th, but this interval was marked by a sustained and significant migration event from July 24-28 (daily migration rate >3-6%). Total escapement: 217,106 fish.
- 1999 - Peak migration rates occurred during low water periods in 1999, when staff gauge readings were ostensibly below 0 meters (though it should be noted that the daily numbers of fish were low (total returns: 5,875 fish)).
- 2005 - Extended lows (observations not available, but estimated at ~0.5 m) in late July were associated with average but significant daily migration rates (2-5%) for that time of year; interestingly, heavy rain at the end of the month briefly elevated water levels to ~1.5 m; this was accompanied by a migration

[30] 1993-1996 data appear to be rounded off to the 1’ level.
[31] 1999 data appear to be consistently 1 meter below average relative to the long-term average despite normal precipitation and discharge conditions at regional stations.

event peaking at >11% (total returns: 14,070 fish).

- 2006 - “Unseasonably low” water levels (estimated at <0.5 m) that persisted from early August 2006 were associated with falling migration rates, though this may have also been the end of the small run (total return: 26,740 fish).
- 2010 - when water levels were <0.2 m from August 10-30th, daily migration rates were average during this period (escapement: 38,634 fish).

A review of years with high water events, as identified in published and unpublished reports, indicated mixed effects on migration rates (Appendix A):

- 1997 – July 7-10 - Heavy rain and spiking water levels (up to 1.6 m) apparently did not completely halt migration activity, though it may have reduced highly significant migration rates (8-9%) occurring a few days earlier (July 5-6) to low migration rates (2-3%) until water levels settled back to ~1 m by July 12th, after which migration rates were high (>4%) and sustained for a week of water levels of 0.7-1.1 m. Peak water level (1.6 m, July 9th) was associated with the nadir of migration for this period (1.6%, i.e., still “significant” but low). Total migrants: 30,997 fish. *This all suggests a high flow impact, with thresholds: 0.9 m (rising), 1.1m (falling)…*
- 1999 – River flows “topped the panels” in late August (estimated at ~1.8 m); however, Sockeye migrants were unaffected as the small run (5,875 fish) was 100% complete by mid-August.
- 2000 – Rapidly rising water levels, from 0.9 m on July 27 to 1.5 m the next day were associated with a drop in migration from low (but significant: 1.4%) to trace amounts. However, this may simply have been the end of the weakest return on record (1,430 fish).
- 2005 – Two high water events occurred:
    - The first in early July before migrants were present in significant numbers (though it should be noted that the first significant migration dates (>1%) occurred when estimated water levels dropped back to ~1 meter ~July 14th).
    - Heavy rain at the end of July briefly elevated water levels to ~1.5 m (estimated); this was accompanied by a highly significant migration event (>3.4%) July 30 – August 2, peaking at >11%. This positive migration response to floodwaters may be related to the effect of a prior, prolonged low water period associated with low-to-moderate migration rates July 24-29.
- 2007 – Unprecedented high waters characterized the interval from mid-July to early August, with (estimated) levels exceeding the 75th percentile of Docee fence observations (~1 m) for the entire Sockeye migratory period, and exceeding the 95th percentile (~1.3 m) during peak migration from July 12-25. High migration rates on July 7th and 8th (6-7%) were reduced to low levels (<3%) while waters rose above 1.1 m, but surged again to high average rates of 7-8% between July 13-21, with a peak of 20% on July 18th, despite

estimated water levels in excess of 1.4 m. The last day of high migration rates on July 21 coincided with a further rise in water levels to 1.6 m by July 23. Total returns: 19,102.

- 2011 – River flow apparently exceeded the (1 meter) staff gauge from August 22-24 (estimated maximum: ~1.6 m); however, Sockeye migrants were unaffected as the sizable run (139,504 migrants) was 100% complete by early August.
- 2012 – Water levels again exceeded the staff gauge maximum of 1 meter, on July 1-4 and 13-23. As in 2007, maximum water levels (estimated at 1.3-1.7 m), exceeding the 95^{th} percentile of Docee water level observations, coincided with peak migration activity (ranging from 6-16% per day), indicating little apparent impacts on migratory behaviour. In this case, total returns were low (15,664 fish), and daily totals did not exceed 2,500 fish.

<u>Reference Stations</u>

Annual statistics for water level data from the *Owikeno Lake* WSC station indicated historic daily mean flows (1961-2012) of 2.80 ± 0.46 m (Table 6; Figure 5, Figure 12). Recent high water years observed at the Docee fence (2007, 2011) were also marked by above average water levels at Owikeno Lake, where mean summer levels approximated the all-year 75^{th} percentile. While the time-series indicated a weak negative trend in average summer water levels since 1961, recent years have displayed an apparent increase in variability (Figure 12).

Regression analysis of *Owikeno Lake* water level as a function of *Wannock River* discharge (Table 6) indicated that the log model ($Owikeno = a \bullet Wannock^{b}$) provided the best fit based on lowest AIC, highest correlation ($r^2 = 0.99$; $P < .0001$; $n = 6,133$) and lowest RMSE (Figure 13; Table 7). This relationship was used to infill 37 missing *Owikeno Lake* observations in 1962 and 1965 (of a total 3,224 July-August observations from 1961-2012), and extend the *Owikeno Lake* daily time-series back to 1927.

Daily water levels from the *Owikeno Lake* station were then used to extend the Docee River water level time-series via a statistical function, based on a subset of high quality Docee data. The subset was derived primarily from annual correlation analyses between observed Docee River water levels and observed Owikeno Lake levels (Table 3, left), which indicated the years where Owikeno data explained at least 50% of variation (i.e., $r^2 > 50\%$; $r > 0.71$) in Docee water levels, i.e., 1986, 1987, 1991, 1992, 1997, 1999, 2000, 2011, 2012. Review of a correlation plot based on these data (Figure 14, top) indicated the anomalous distribution of Docee depths in 1999, which appear to be consistently biased low by ~1 meter. After omission of 1999 data, explained variance estimates were approximately equivalent across all models (i.e., RSQ ~ 0.30), but lowest AIC and RMSE were associated with the log-log model (Table 9; Table 8; Figure 14).[32]

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[32] Omitting 1992 data (which appeared to exhibit some negative bias similar to 1993-1996 and 1999), further improved the fit ($r^2 = 0.43$; $r = 0.62$; $n = 393$), but exclusion of 1992 data could not be rationalized from the plots or meta-data, so the data were retained in the final relationship.

The model goodness-of-fit was not easily quantifiable due to the lack of high quality validation data. Overall correlation between observed and estimated Docee water levels (r = 0.33, P < .0001, n = 991) was not particularly meaningful due to the inclusion of unresponsive observations from 1993-1996 and unlikely values from 1999. Excluding anomalous data showed an improved coefficient of variation (r = 0.54, P < .0001, n = 413), but this unsurprising outcome must be considered circular.

Annual plots (Appendix A) for years where observed data exist suggest that estimated Docee River water levels provide a relatively weak indicator of the flux in water levels in-season and between years, likely overestimating low water years (e.g., 1992, 1998), and underestimating peak flow events (e.g., 1986, 1997).

Hence, for multi-variate statistical analyses, the more consistently responsive Owikeno Lake water level time-series was utilized as a proxy for Docee water levels. This allowed better parameterization of water level threshold values in relation to variation in Long Lake Sockeye migration. Derived threshold values were then converted to Docee River levels using the log-log transfer function and error term to characterize conditions in the Docee waterbody. An Owikeno-to-Docee water level conversion table can be found in Table 10.

AIR TEMPERATURE

PORT HARDY AHCCD data provided a continuous time-series of air temperatures since 1944, with less than 0.1% missing observations during the Sockeye migratory period, and requiring no infilling from other stations.

Average summer (July-September) air temperatures have trended upward in the region at approximately 0.14ºC per decade (Figure 15), but indicated a negative trend (-0.3ºC per year) for the period of observed water temperatures (2004-2008; Figure 16). Trends and conditions at PORT HARDY were highly correlated (r = 0.97) with the more limited air temperature record at the EGG ISLAND lighthouse near Smith Inlet (Figure 17).

Regional air temperature conditions for 2004-2008 (and the associated 7-day air temperature index,) appeared to reflect shifts in ocean conditions, specifically, shifts in PDO/ENSO phase (CIG 2013):

- warm/warm in 2004 and 2005 (mean summer temps ~ 14-15ºC);
- cool/neutral in 2006 (mean temp 13.8ºC);
- cool/warm in 2007 (mean temp 14.1ºC);and
- cool/cool in 2008 (mean temperature 13.2ºC) (Table 11; Figure 18).

Analysis of means indicated significant main and interaction effects due to PDO and ENSO phases (P = 0.01), with reinforcing PDO/ENSO phases (i.e., cool/cool and warm/warm years) presenting significantly different mean summer air temperatures during the migratory period during this time frame (Figure 19)[33]. These effects have

[33] To examine whether the apparent PDO/ENSO effects on mean air temperature were not an artifact of an abbreviated time-series (2004-2008), the analysis of means was extended to the complete record of PORT HARDY AHCCD air temperatures for the summer months (July-September; Figure 20)

relevance for the development of suitable air/water temperature relationships, discussed below.

WATER TEMPERATURE

Docee River

The annual time-series of observed water temperature data obtained at the Docee River fence (October 2003 – August 2008) are displayed in Appendix A, condensed in Figure 22, and summarized for the months of peak migration (July-August) by year in Table 12. Average water temperature during the migration period (Jul-Sep 2004-2008) was 15.2°C, with <5% of dates surpassing 19°C (Figure 22, Figure 23). However, mean summer temperatures varied significantly between years in the observed data, averaging 16-18ºC for 2004-2006, but only 11-14ºC in 2007-2008 (Table 12).

The declining trend in average water temperatures for the observational period mirrored declines in air temperature at the reference station in Port Hardy and, more locally, at Egg Island (Figure 17), thereby ruling out systematic inaccuracies in the water temperature time-series (i.e., due to faulty data logger calibration, etc.).

The short-term time trend in Docee water temperatures and regional air temperatures from 2004-2008 may instead reflect a shift in ocean conditions associated with PDO and ENSO phase shifts, described above (Figure 24). Mean water temperatures appear to be strongly influenced by warm PDO and cool ENSO phases (main effects $P < 0.0001$), with maximum differences in means occurring under reinforced PDO/ENSO interactions (warm/warm and cool/cool) (Figure 25). However, the five years of available water temperature data were insufficient to identify any significance level for these interaction effects.

Spawning Creeks

Complete years of continuous data logger records from Canoe Creek (Figure 26 - Figure 28) and Smokehouse Creek (Figure 29 - Figure 31) were available for 2004-2005, and indicated average July-September temperatures of 11-12ºC, and maximum temperatures not exceeding 15ºC (Table 13). Given that these data were recorded during warm/warm PDO/ENSO years, it is likely they represent near-maximum stream temperatures for these waterbodies in recent decades.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

Seasonal Turn-Around Point

The mid-year seasonal turn-around point for all sites was in week 33 – day 231, or approximately August 18th – based on maximum mean weekly air and water temperatures (Canoe: Figure 32; Smokehouse: Figure 36; Docee: Figure 40). The "warming season" therefore extended from April 1st to August 18th, followed by the

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and for all seasons (Figure 21).Though the overall pattern is the same as for 2004-2009 (i.e., reinforcing PDO/ENSO phases (cool/cool and warm/warm) presenting significantly different mean air temperatures relative to the overall mean, warm summer air temperature conditions in 1963, 1967, 1979, 1981, 1990, 1994, and 1997; Figure 21, top) appear to be driving the anomalous mean temperature estimate during "cool/neutral" PDO/ENSO years (Figure 21, bottom).

“cooling season” from day 232-329, i.e., August 19th - November 24th.

Model Calibration and Validation

Since only five summers of water temperature data were available at Docee, and just two summers of data were available for the spawning ground sites, linear and logistic air/water temperature models were initially calibrated for each site using all of the available water temperature observations, leaving no data for testing goodness-of-fit for model validation (Canoe: Table 14; Smokehouse: Table 17; Docee: Table 20).

Hysteresis was detected at all sites, indicating that air/water temperature relationships were best modeled using separate seasonal models (Canoe: Figure 33, Figure 34; Smokehouse: Figure 38; Docee: Figure 41, Figure 42). Due to data limitations, the logistic intercept (μ parameter) was constrained to 0°C or more, and the α parameter was constrained to 30°C or less, to enable logistic model convergence. Minor differences in the seasonal models’ predicted temperature at the upper end of the thermal range, resulting in a “step-effect” in the estimated daily MWT time-series in mid-August, were mitigated by using a transitional model parameterized with the mean of the seasonal coefficients to re-estimate daily MWT for the five days before and after the mid-year turn-around-point. Logistic model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed for Canoe: Table 15; Smokehouse: Table 18; and Docee: Table 21.

Correlations indicate that linear and logistic model types were essentially equivalent in their skill at predicting Long Lake system water temperatures (Canoe: Table 16; Smokehouse: Table 19; Docee: Table 22), likely due to observations being largely limited to the linear range of air/water temperatures. The seasonal logistic model parameters were selected as the preferred estimators of daily mean water temperature at each site, and were used to reconstruct historical daily water temperature estimates for the period of available air temperature data.

For the spawning ground waterbodies, correlations between observed and estimated MWTs were unsurprisingly high ($r_S = 0.97$) for both creeks (Canoe: Figure 35; Smokehouse: Figure 39), given that the “validation” plots were based on the same years as the calibration data.

“Validation” plots of Docee River observed and modeled MWT output ($r_S = 0.87$), indicated that the modeled estimates tend to underestimate water temperatures in warm (PDO +ve) years (e.g., 2004-2005; Figure 43), and overestimate water temperatures in cool (PDO –ve) years (2007-2008; Figure 44).

Logistic models calibrated only on the PDO +ve years yielded better fits to observed data in the warm years ($r_S > 0.93$, 2004-2006; Figure 45) but further overestimated the cool years (2007-2008). Similarly, logistic models based on 2007 and 2008 data unsurprisingly fit the cool PDO years reasonably well ($r_S > 0.90$), but further underestimated the warm/warm PDO/ENSO years (Figure 46). These results indicate that separate models corresponding to PDO phase, or combined PDO/ENSO phases, might be most appropriate for reconstructing historic water temperatures in the Long Lake region. However, for the purposes of this study, and comparability with similar studies for other coastal Sockeye stocks (Hyatt et al. 2015, Stiff et al. 2013, 2015a, 2015b), a single all-year model approach was utilized, knowing that this would err in both directions approximately equally, while providing a conservative estimate of warm water events.

TEMPERATURE, FLOW, AND MIGRATION

Trends in Environmental Variables

Since a weak long-term warming trend in the regional air temperature index for the summer months (July-September) was evident over the period of record (1944-2012) (Figure 18), the analogous estimated Docee River mean water temperature indicated a corresponding warming trend of ~0.02 degrees per year (or 0.2ºC per decade) ($r^2 = 0.20$, $P < .0001$, Figure 47). Median summer water temperature has remained below 15ºC, however.

While there was insufficient data at the Docee fence to detect any trends in water level observations since 1986 (Figure 48), a significant positive trend in water levels at Owikeno Lake was evident during that period (Figure 49).This recent trend is masked in the long-term trend at Owikeno Lake (1961-2012) since water levels, which were largely above the long-term mean during the 1960s and early 1970s, depressed below the long-term mean from 1977-1998, before rebounding in recent decades (Figure 50). This pattern is basically coincident with the PDO phase shifts in the Pacific during this period.

Migration in Relation to Temperature and Discharge

An un-weighted tally of non-zero migration dates indicated that approximately 67% of the historic migration dates (1972-2012) occur when water levels at *Owikeno Lake* WSC station are ~2.75 – 3.0 m (Figure 51), corresponding to ~0.60 – 0.70 m of depth at the Docee staff gauge (Table 10). Weighting the frequency distribution by the daily migration rate indicated that the highest daily migration rates (>3.4% per day) at the Docee fence occur when *Owikeno Lake* water levels are ~3.0 – 3.5 m (Figure 52). Though migration rates were reduced at 3.75 m levels, a low frequency (< 5% of all dates) of high daily migration rates (up to 19.9%) at 4.0 – 4.5 m indicated a high tolerance for peak water levels, at least in 2007 and 2012 when the bulk of these estimated water levels occurred. Though water level observations were not available for 2007, unprecedented high water conditions at the Docee fence were noted (DFO 2008), coinciding with a multi-day precipitation event following a spring-time warm spell (recorded at Port Hardy) and subsequent snow-melt (as evidenced by falling stream temperatures as air temperatures rose; Appendix A). In 2012, field notes indicated water levels over-topped the meter-stick staff gauge, indicating significant migration occurred at Docee water levels up to 1.3 – 1.5 m.

Dates of migration activity are characterized by (estimated) Docee water temperatures normally-distributed around 14°±2°C, with 80% of migration dates occurring at 13-15°C (Figure 53). Low, but significant daily migration (1% – 3.4%) occurred across the full range of available temperatures (10-18°C), but high average migration rates (>3.4%) occurred at 12°C (Figure 54).

A weighted two-way frequency distribution based on combined flow and temperature ranges showed that high migration rates for Long Lake Sockeye were centered at estimated Docee water temperatures of 12°C and recorded water levels of 3 m at

Owikeno Lake WSC station (Figure 55), corresponding to Docee River depths of ~0.75 ± .02 m. Another high migration node, associated with the high water level events in 2007 and 2012, were characterized by water temperatures of 14-16°C. As noted above, these represented less than 5% of all migratory observations.

Anomaly plots of migration, water temperature and discharge deviations based on these environmental thresholds were inconclusive regarding the exact temperature level constituting a critical threshold between low and high migration rates for Long Lake Sockeye (Appendix B). Only in a few years did water temperatures approach the threshold of 17°C[34] during peak Sockeye migration (1981, 1993, 2004, 2005, 2006)[35], though in each case, these temperatures were associated with lower migration rates. In 2006, for example, daily migration rates of 3-6% in mid-July were reduced to low migration rates of 2% as water temperatures warmed above 17°C, and then rebounded as temperatures fell back below this threshold again (Figure 56). Only in late July 2004, could an actual migration stoppage be associated with increasing water temperatures (Appendix B).

A subjective review of the anomaly plots (Appendix B) suggested that water levels > 3.4 m at Owikeno may be associated with a delay (e.g., 1972; 1975; 1976; 1982; 1984; 1986; 1987; 1992; July 2005; 2008)[36] or reduction in migration (e.g., 1986; late July 1995; early August 1996; 1997; mid-July 1998; 2009). Typical delays in the onset of migration of a week to 10 days were evident in some years (Figure 57 and Appendix B). On the other hand, high flows were not always a deterrent to high migration, once migration commenced (1991; 1994; 1999; 2002; early August, 2005; 2007; 2012).

Extended low water level periods (<25th percentile: 2.5 m) may have contributed to migration delays of a week or more (e.g., 1989; 1993; 2009)[37], and were sometimes associated with falling migration rates (2005; 2006), although the latter may be equally explained as the natural decline of the small run (Appendix B).

Temperature Exceedance Analyses

Peak-over-threshold analysis of regional air temperatures indicated only one date where daily mean air temperature exceeded 20°C ($POT_{>20°C}$) since 1944. To examine trends, the $POT_{>15°C}$ (not shown) and $POT_{>17°C}$ (Table 29) exceedance analyses were reviewed. At these threshold temperatures, a general trend from low but relatively constant frequencies of annual POT events (< 2 per year) through the 1950s – 1980s doubled during the 1990s and 2000s (Figure 58), with peak events spreading into September. While the average duration of continuous $POT_{>17°C}$

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[34] While a threshold of 18°C was consistently used in similar reports for northern watersheds such as the Tahltan, Meziadin and Babine (Stiff et al. 2013; 2015a; 2015b), corresponding to the 75th percentile of *observed* Docee River temperatures, that threshold corresponds to the 99th percentile of *estimated* Docee daily water temperatures due to limitations in the air/water temperature model, yielding too few estimates exceeding 18°C for meaningful trend analysis in “extremes”. Thus a threshold of 17°C was used instead.

[35] Of these years, 1981 and 1993 had confounding fishery openings that may affect the daily migration rates.

[36] Apparent delays in migration may have been influenced by early fisheries in 1976 and 1986.

[37] Although 1989 and 1993 had confounding early fisheries.

periods was still less than two days on average in all decades, the frequency of these periods has also doubled since the 1990s (Figure 59).

A similar frequency analysis based on estimated daily mean water temperature exceeding 17ºC in Docee River indicated that the cumulative total number of $POT_{>17^{\circ}C}$ dates per year is also low (<5-6 days), but trending upward since the 1950s (Table 30). Most of the gains were in August and September, though temperatures are estimated to have exceeded the 17ºC threshold in July for the first time in recent history in 2006 (Figure 60).

While the decadal average length of Docee River $POT_{>17^{\circ}C}$ periods was < 5-6 days for most decades[38] (Figure 61), maximum period length, however, has on occasion extended 11-25 days (Table 30). However, the majority of these $POT_{>17^{\circ}C}$ events occurred in mid-to-late August, after the end of the adult migration period (e.g., see Appendix B: 1963, 1974, 1979, 1983, 1986, 1987, 1997, 1998, 2004). The only year in which a multi-day $POT_{>17^{\circ}C}$ period directly overlapped with Sockeye migration was in July 2006 – as mentioned above, moderate daily migration rates of 3-6% during this 5-day period were reduced to low migration rates of 2% as water temperatures warmed above 17°C, and then rebounded as temperatures fell back below this threshold again (Figure 56).

Discharge Exceedance Analyses

Docee River

Insufficient data exist to document possible trends in extremes in observed Docee River water levels.[39] However, low water levels (<10^{th} percentile: ~0.20 m) during the Sockeye migration period (July-August) occurred most frequently in the 1990s (specifically 1990, 1992, and 1998)[40], characterized by 5 events averaging 11 days (maximum: 22 days) in duration (Figure 62; Table 32; Table 33). An extended low-flow period (38 days) also occurred in 2010.[41]

Although no low water events were observed between 1986-1989 at the fence, seven high water events (>1.2 m) during the Sockeye migration period occurred, averaging 4-5 days in length (maximum 10 days) (Figure 63; Table 32; Table 33). Subsequently, in the 1990s, observed high water levels occurred only during 1997, and then increased in frequency and duration again in the 2000s, specifically in 2000, 2005, 2007, 2011 and 2012.[42]

[38] With the exception of the 10-day average during the 1960s, based on 5 $POT_{>17^{\circ}C}$ events ranging from 3-19 days in length.
[39] Suitable Docee observed water level data were restricted to “high quality” data years: 1986-1992, 1997, 1998, 2000, 2010-2012, i.e., 4 years of the 1980s, 5 years of the 1990s, and 4 years in the 2000s.
[40] Does not include low water levels noted in 1999 (Chambers et al. 2001) or 2006 (DFO 2007) as water level observations for these years were either unavailable or excluded from analysis.
[41] 1992, 1998 and 2010 were El Niño years.
[42] High water levels in 2005, 2007 and 2012 were noted in reports but actual observations were not recorded, and therefore not included in Docee high-water exceedance analyses.

Owikeno Lake

A similar exceedance analysis based on 10^{th} and 90^{th} percentile thresholds (i.e., ~2.5 m and ~3.4 m) for the more extended Owikeno Lake daily water level dataset indicated that low flows have increased over the decades 1960s to present, almost entirely in August (Figure 64). While low flows have continued to average less than 1 day in July over this time period, August frequencies have at least doubled to 4-7 days since the 1980s, with mean duration of low-flow periods peaking to ~20 days in the 1990s (Figure 65, Table 34).

In contrast to low-flow events which occurred mostly in August at, or after, the tail end of the Sockeye run, the majority of the high-flow events occurred in July, before or coincident with the onset of the peak migration period. A steady increase in the annual average number of high water level dates at Owikeno Lake (>3.4 m) has occurred since the 1980s (Figure 66), accompanied by a rise in average period length from 2 days (1980s) to 7 days (2000s) (Figure 67, Table 35). Apparent “dry” conditions in the 1980s and 1990s transitioned back to “wet” conditions in the 2000s, similar to average conditions in the 1960s-1970s. However, the early 1970s (1971-1976) all experienced high flow periods of 11-17 days at least once a year; similar, extensive, high flow conditions did not recur till 2007, and again in 2012, during which at least one event persisted for 22 days (Table 35).

Owikeno Lake water level exceedance indicators generally mirrored Docee River indicators for years where suitable Docee data exist, thus any lack of correspondence between sites (e.g., 1980s, when the frequency and duration of high-water events was apparently at a maximum for Docee but a minimum for Owikeno) can be attributed to insufficiently informative data at the Docee site.

DISCUSSION

Sockeye Migration and Water Temperature Conditions

Summer air temperatures at the regional climatological station in PORT HARDY, which were highly correlated (r = 0.97) with the more limited air temperature record at the EGG ISLAND lighthouse near Smith Inlet, have trended upward at approximately 0.14ºC per decade since the 1940s (Figure 15). A low but relatively constant annual frequency of “warm days” (>17°C) during the 1940s - 1980s doubled during the 1990s and 2000s (Figure 58). While the average duration of warm periods was less than two days on average across all decades, the frequency of these periods has also doubled since the 1990s (Figure 59). These indicators reveal a shift in regional temperatures between the 1980s and 1990s.

Reinforcing PDO/ENSO phases (i.e., cool/cool versus warm/warm years) presented significantly different mean summer air temperatures during this time frame (Figure 19), with obvious implications for water temperature. While high resolution Docee River water temperatures recorded during the migration period from 2004-2008 averaged 15.2 ± 2.4°C, mean temperatures varied significantly between years, averaging 16-18ºC for 2004-2005 (warm/warm PDO/ENSO phase), compared to 11-12ºC in 2008 (cool/cool PDO/ENSO phase) (Figure 24; Table 12). This suggests a range of 5-6°C in mean summer water temperatures in this region, depending on ocean conditions, and indicates that reinforcing warm phase PDO/ENSO cycles can present stressful conditions to Sockeye migrants. Indeed, maximum recorded temperatures of 20°C occurred in 2004, and ~5% of dates surpassed 19°C in the warm/warm years.

Choice of linear or logistic model to utilize for air-to-water temperature conversion may depend on specific analytical needs. Bias analyses suggest that, relative to observed data, both linearly- and logistically-estimated time-series tends to over-estimate water temperatures in July, and to under-estimate it in August. Thus, the results of analyses regarding peak temperatures (e.g., frequency and duration thereof) using the logistic model might be considered conservative.

More significantly, perhaps, the influence of PDO/ENSO phase on temperatures has further implications for air/water temperature modelling. Validation plots of Docee River observed and modeled MWT output, indicated that the modeled estimates tend to underestimate water temperatures in warm (PDO +ve) years (e.g., 2004-2005; Figure 43), and overestimate water temperatures in cool (PDO –ve) years (2007-2008; Figure 44). Separate, air/water, temperature models, calibrated by PDO phase, yielded better fits to observed data. Thus, separate models, corresponding to PDO phase, might be most appropriate for reconstructing historic water temperatures in the Long Lake region. For the purposes of comparability with other coastal Sockeye stock studies (Hyatt et al. 2004, Stiff et al. 2013, Stiff et al. 2015a and 2015b), however, an all-year logistic model was utilized for estimating Docee water temperatures, with the realization that this would err in both directions approximately equally, while providing a conservative estimate of warm water events.

Given these qualifications, it appears that estimated mean water temperatures in the Docee River during the Sockeye migratory period are rising slowly, concurrent with air temperatures, at a rate of about 0.14°C per decade, but currently remain below 15°C. Only in a few years did water temperatures approach, let alone exceed, stressful temperatures (i.e., >17°C) during the peak migration period in July. In some years, where daily migration rates were not confounded by harvest operations (2004, 2005, 2006), migration rates may have been reduced, though not stopped, in association with this temperature threshold. These were, notably, in warm/warm PDO/ENSO years. Events such as these, though currently rare, may provide some insight into the potential impacts if regional climate conditions were to become warmer or drier in the future.

Water temperatures in the spawning creeks (Canoe and Smokehouse), which were recorded hourly for the particularly warm 2004 and 2005 years (PDO/ENSO phase: warm/warm), appear to be hospitable to spawning Sockeye for the foreseeable future. Changing climatic conditions may, however, affect the hydrology of these sites, with attendant impacts potentially influencing eggs and alevins during incubation and emergence intervals.

Sockeye Migration and Flow Conditions

Though highly variable on an annual basis, the seasonal hydrological pattern at

Docee River typically displays a steady drop in mean water level from a seasonal high during the peak Sockeye migration period in early-to-mid-July, to late-August lows approaching zero meters at the gauge, corresponding to ~1 m of depth at the fence (Figure 11). Since more than 95% of the Sockeye have moved upstream by mid-August (TT50% July 18th), typical hydrological conditions appear to be highly compatible for Sockeye migration.

This pattern is largely reflected in the Owikeno system (Figure 12). Due to apparent inter-annual biases in measurement error in the Docee water level observational record, which suggest an inadvertent vertical displacement of the staff gauge over the years, the predictive power of the multi-year relationship between the two sites was not strong: Owikeno water levels explained only 30% of Docee water level variations (Figure 14). Since within-year inter-site relationships were, however, highly linear (with r-values exceeding 0.8 for select years), it was deemed reasonable to use the Owikeno time-series as a proxy for Docee daily hydrological conditions, extending back to 1961.

A review of low-water events (<25th percentile of historical data) revealed little hard evidence of migratory impacts, since significant migration activity (>75th percentile of historical daily migration) often occurred during such periods (e.g., 1986, 1992, 1999, 2005, 2010). Commercial fishery activity likely obscures or confounds the actual cause for several cases where extended low water levels appeared to be associated with delayed or reduced migration (1989, 1993). However, the association between low water levels and migration rates in low exploitation years such as 2005, 2006, and 2009 may indicate a minimum Owikeno Lake threshold of 2.5 m (approximately equivalent to a Docee River threshold level of 0.4 - 0.5 m; Table 10), below which high migration rates, with few exceptions (e.g., 1983, mid-to-late July 2005), are not prevalent.

The frequency of dates below this threshold water level appeared to be increasing since the 1960s, though the largest increases are in August, and therefore outside the peak Sockeye migration period. The 1990s marked the most extreme decade in the past 50 years, with dry conditions averaging 20 days in length (Figure 64, Figure 65).

As for high flow impacts, water levels > 3.4 m at Owikeno were associated with delays of up to 10 days in the onset of migration. Excluding years with probable harvest impacts (e.g., 1975, 1982, 1987); this was evident in 1999, 2005, and 2008. In some years, however, such as 2007 and 2012, migration ultimately commenced despite continuous high water conditions, though it must be noted that neither of these years were characterized by large escapements (less than 20,000 fish).

Once migration has commenced, high water levels (> 3.4 m) were not always a deterrent to high migration, however. There were probably as many instances of significant migration rates during such flows (e.g., 1972, 1983, 1991, 1994, 1999, 2002, 2005) as there were displaying reduced migration rates (e.g., 1974, 1976, 1985, 1986, 1988, 1995, 1996, 1997, 1998, 2009).

Exceedance analyses based on this threshold level indicated that high flow conditions have increased in frequency and duration since the 1980s, with a disproportionate increase in July occurrences (Figure 66, Figure 67), perhaps due to earlier snow melt.[43] If the principle impact of high flows on Long Lake Sockeye is a delay in the onset of migration, as indicated above, then this trend towards larger flows in early summer may ultimately influence upstream migration timing. In combination with an evident upward trend in August low flows, the potential for a reduced migration window, with possible impacts on spawn timing.

Recommendations

The Long Lake system was one of the most important Sockeye watersheds in British Columbia, and occupies a key location climatologically, as it is situated between the Alaskan downwelling and Californian current upwelling marine domains. Though the stock status of Long Lake Sockeye has been depressed for decades, and the net effect of environmental conditions on productive capacity is largely unknown, conditions conducive to stock rebuilding may be returning. Monitoring of the physical environment, however, appears to be under-resourced. High resolution water temperature data at the fence site, collected 24 hours a day by automated data loggers, would improve the confidence in the site air/water temperature relationships. An automated data logger maintained at the lake outlet or the fence site would serve to improve water temperature observations going forward as well as retrospective analyses looking backwards. The current inability to reliably hind-cast or forecast Docee River hydrology may also limit climate analyses that depend on suitable baseline reference data for downscaling of climate model outputs to local conditions. Enhanced monitoring of environmental variables in this watershed via automated data logger installations, combined with advances in the analysis of how these factors co-vary with salmonid behaviour and migration patterns, might be considered a wise investment in the recovery of the Long Lake Sockeye population.

ACKNOWLEDGEMENTS

The material data for this report was made available from a variety of organizations, through the generous provision of time and effort of a number of individuals. This study would not be possible without the dedicated efforts of FISHERIES AND OCEANS CANADA field crew and personnel in the northern and central DFO STOCK ASSESSMENT GROUPS (S. Bachen, K. Chambers, R. Goruk, D. Rutherford, B. Spilsted, B. Thompson, I. Winther) as well as the following contributors:

- Gwa'sala-Nakwaxda'xw First Nation fisheries program
- Shannon Anderson collated Smokehouse and Canoe Creek water temperature data.
- Lucie Vincent (CLIMATE RESEARCH DIVISION), Eva Merkis and Giselle Bramwell (CLIENT SERVICES METEOROLOGICAL SERVICES) of ENVIRONMENT CANADA provided AHCCD daily meteorological datasets.

Funding for this report was provided by FISHERIES AND OCEANS CANADA through the

[43] However, it should be noted that similar high flow conditions were not uncommon in the 1960s and 1970s, when Sockeye returns were strong.

AQUATIC CLIMATE CHANGE ADAPTATION SERVICES PROGRAM.

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	Long Lake										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
1963	21	12JUL	01AUG	3,271	8,629	68,686	3.24	9.24	10.40	4.76	12.56
1968	16	08JUL	23JUL	12,371	28,030	197,930	5.41	10.91	14.16	6.25	14.16
1970	15	09JUL	23JUL	4,671	11,366	70,065	7.26	10.87	16.22	6.67	16.22
1971	15	14JUL	29JUL	9,005	30,772	135,068	6.13	9.95	22.78	6.67	22.78
1972	20	12JUL	31JUL	3,812	23,501	76,248	1.32	5.94	25.68	5.00	30.82
1973	35	09JUL	12AUG	4,857	41,180	170,002	0.15	3.13	22.59	2.86	24.22
1974	25	08JUL	01AUG	3,642	37,265	91,043	0.41	1.42	22.86	4.00	40.93
1975	26	07JUL	01AUG	2,422	14,321	62,967	0.91	7.12	15.18	3.85	22.74
1976	22	08JUL	31JUL	2,768	21,652	60,904	0.24	5.20	25.50	4.55	35.55
1977	25	09JUL	02AUG	5,144	21,133	128,601	2.55	5.20	15.27	4.00	16.43
1978	33	04JUL	05AUG	2,546	11,502	84,015	1.85	4.24	10.55	3.03	13.69
1979	30	10JUL	08AUG	675	4,689	20,257	1.51	2.61	12.75	3.33	23.15
1980	29	08JUL	05AUG	4,429	18,424	128,435	2.82	5.02	9.92	3.45	14.34
1981	28	12JUL	08AUG	7,655	38,158	214,345	1.17	5.52	13.08	3.57	17.80
1982	38	03JUL	09AUG	5,623	69,654	213,674	0.82	3.50	7.59	2.63	32.60
1983	36	02JUL	06AUG	5,477	28,885	197,161	0.42	4.71	13.33	2.78	14.65
1984	37	01JUL	06AUG	2,406	21,588	89,011	0.73	3.10	11.45	2.70	24.25
1985	40	01JUL	09AUG	6,186	24,109	247,437	1.42	4.21	7.54	2.50	9.74
1986	39	01JUL	08AUG	5,073	18,794	197,851	2.08	3.40	9.24	2.56	9.50
1987	39	01JUL	08AUG	4,969	47,933	193,781	0.09	2.24	15.26	2.56	24.74
1988	43	01JUL	12AUG	4,697	43,742	201,963	0.62	3.16	6.69	2.33	21.66
1989	34	04JUL	06AUG	4,818	14,732	163,804	2.69	4.06	8.47	2.94	8.99
1990	41	03JUL	12AUG	3,561	13,358	146,016	1.48	3.67	6.48	2.44	9.15
1991	38	01JUL	07AUG	6,824	30,149	259,316	1.72	3.50	8.34	2.63	11.63
1992	40	01JUL	09AUG	5,428	25,516	217,106	1.27	3.76	9.91	2.50	11.75
1993	39	01JUL	10AUG	5,575	20,270	217,422	1.26	4.44	9.07	2.56	9.32
1994	40	01JUL	09AUG	2,357	6,793	94,295	1.95	4.11	6.70	2.50	7.20
1995	43	01JUL	12AUG	1,308	5,414	56,244	1.08	3.62	8.17	2.33	9.63
1996	40	01JUL	09AUG	1,332	6,042	53,272	1.08	3.24	9.18	2.50	11.34
1997	35	02JUL	05AUG	886	3,006	30,997	2.18	4.21	8.31	2.86	9.70
1998	48	01JUL	22AUG	1,583	6,081	75,988	1.43	3.62	5.70	2.08	8.00
1999	43	01JUL	16AUG	137	1,695	5,875	0.19	1.12	17.20	2.33	28.85

Table 1. Annual statistics for daily tallies of Long Lake Sockeye migrants at the Docee River fence, 1963, 1968, 1970-1999 (filtered for non-zero observations), including annual migration period and length (days), mean and maximum daily migrant count, total annual escapement, and mean, maximum, and 50th, 75th, 95th percentiles of daily migration rate (%) (Source: DFO North Coast Stock Assessment Division). Note: tower count data (1963-1971) and fence count data (1972-2012).

	Long Lake										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
2000	31	01JUL	13AUG	46	309	1,430	1.19	4.41	13.22	3.23	21.61
2001	32	03JUL	10AUG	264	1,764	8,450	1.78	4.40	10.07	3.13	20.88
2002	46	01JUL	25AUG	1,999	13,110	91,942	0.85	2.43	7.82	2.17	14.26
2003	57	01JUL	01SEP	3,148	14,001	179,462	0.79	2.78	6.17	1.75	7.80
2004	39	03JUL	16AUG	201	758	7,823	1.43	4.60	8.95	2.56	9.69
2005	52	01JUL	29AUG	271	1,662	14,070	0.73	2.98	6.50	1.92	11.81
2006	54	01JUL	30AUG	495	2,569	26,740	0.34	3.37	6.57	1.85	9.61
2007	41	01JUL	10AUG	466	3,808	19,102	0.90	2.99	8.08	2.44	19.94
2008	49	02JUL	21AUG	334	1,585	16,389	0.67	4.79	6.16	2.04	9.67
2009	66	01JUL	06SEP	279	1,173	18,446	0.81	2.74	4.15	1.52	6.36
2010	57	01JUL	26AUG	678	3,515	38,634	1.03	2.63	5.80	1.75	9.10
2011	60	03JUL	04SEP	2,325	18,687	139,504	0.25	1.87	9.71	1.67	13.40
2012	37	06JUL	11AUG	423	2,577	15,664	1.07	2.64	12.01	2.70	16.45
1963-2012	1,674	01JUL	06SEP	2,836	69,654	4,747,436	1.06	3.65	9.67	2.69	40.93
1972-2012	1,607	01JUL	06SEP	2,661	69,654	4,275,687	1.00	3.44	9.12	2.55	40.93

Table 1, cont'd. Annual statistics for Long Lake Sockeye migrants, 2000-2012 (filtered for non-zero observations), including annual migration period and length (days), mean and maximum daily migrant count, total annual escapement, and mean, maximum, and 50th, 75th, 95th percentiles of daily migration rate (%). Summary statistics (bottom two rows) were derived from all data (1963-2012) and statistically-comparable data from fence counts (1972-2012) (Source: DFO North Coast Stock Assessment Division).

	Water Level (m)						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1986	47	0.54	1.14	1.94	0.38	0.12	0.80	1.15	1.46	1.84
1987	45	0.64	0.99	1.43	0.25	0.47	0.81	0.90	1.20	1.39
1988	58	0.86	1.19	1.47	0.14	-0.33	1.13	1.20	1.26	1.44
1989	34	0.67	0.89	1.09	0.13	-0.22	0.75	0.90	1.00	1.07
1990	37	0.18	0.31	0.60	0.14	0.92	0.20	0.25	0.43	0.58
1991	41	0.31	0.69	1.11	0.21	-0.05	0.59	0.67	0.85	1.01
1992	48	-0.15	0.23	0.59	0.24	-0.13	0.04	0.24	0.47	0.56
1993	43	0.00	0.20	0.63	0.23	0.79	0.01	0.03	0.34	0.62
1994	54	0.02	0.29	0.92	0.21	0.83	0.17	0.32	0.33	0.78
1995	49	0.31	0.58	0.93	0.16	-0.09	0.47	0.62	0.62	0.92
1996	47	0.03	0.41	0.64	0.16	0.04	0.32	0.33	0.61	0.63
1997	35	0.38	0.84	1.65	0.31	0.67	0.61	0.79	1.05	1.49
1998	96	0.00	0.36	0.94	0.22	0.31	0.18	0.38	0.53	0.77
1999	91	-1.09	-0.27	1.35	0.46	0.73	-0.53	-0.30	-0.08	0.40
2000	87	0.18	0.67	1.46	0.27	0.60	0.49	0.67	0.82	1.16
2010	69	0.00	0.22	0.80	0.21	0.81	0.04	0.17	0.42	0.60
2011	68	0.16	0.84	1.35	0.35	-0.40	0.48	0.90	1.17	1.25
2012	42	0.28	0.64	1.00	0.23	-0.17	0.42	0.67	0.85	0.93
All	991	-1.09	0.52	1.94	0.47	-0.25	0.23	0.53	0.85	1.28

Table 2. Annual statistics for observed water level at the Docee River fence, June-September: all available years (1986-2000, 2010-2012); see Table 5 for "high quality" years.

	Statistic			
	CORR	MEAN	N	STD
Year				
1986	0.89	1.14	47.00	0.38
1987	0.83	0.99	45.00	0.25
1988	-0.14	1.20	60.00	0.15
1989	-0.12	0.89	34.00	0.13
1990	-0.32	0.31	37.00	0.14
1991	0.75	0.69	41.00	0.21
1992	0.80	0.23	48.00	0.24
1993	0.51	0.20	43.00	0.23
1994	0.27	0.29	54.00	0.21
1995	0.50	0.58	49.00	0.16
1996	0.05	0.41	47.00	0.16
1997	0.97	0.84	35.00	0.31
1998	0.65	0.36	96.00	0.22
1999	0.87	-0.27	91.00	0.46
2000	0.81	0.67	87.00	0.27
2010	0.24	0.22	69.00	0.21
2011	0.73	0.84	68.00	0.35
2012	0.87	0.64	42.00	0.23

	LOG Statistic			
	CORR	MEAN	N	STD
Year				
1986	0.89	0.74	47.00	0.18
1987	0.83	0.68	45.00	0.12
1988	-0.16	0.79	60.00	0.07
1989	-0.14	0.63	34.00	0.07
1990	-0.32	0.26	37.00	0.10
1991	0.77	0.51	41.00	0.13
1992	0.77	0.19	48.00	0.21
1993	0.51	0.17	43.00	0.18
1994	0.25	0.24	54.00	0.16
1995	0.50	0.46	49.00	0.10
1996	0.08	0.34	47.00	0.12
1997	0.96	0.60	35.00	0.17
1998	0.67	0.30	96.00	0.16
1999	0.80	-0.52	87.00	0.93
2000	0.80	0.50	87.00	0.16
2010	0.23	0.19	69.00	0.17
2011	0.79	0.59	68.00	0.21
2012	0.87	0.48	42.00	0.14

Table 3. Correlation statistics for observed daily mean water level at the Docee River fence versus daily mean water level at Owikeno Lake, by year, for all available data (1986-2000, 2010-2012) (left), and corresponding statistics for log-transformed data (right). CORR = Pearson's correlation coefficient (R); MEAN = mean Docee water level (m); N = number of observations; STD = mean Docee water level (m). Data for years associated with R > 0.707 (i.e., >50% of variance explained by Owikeno water levels) were assessed for inclusion in the Owikeno-to-Docee predictive function.

		Intercept	Coeff A	Coeff B	Coeff C	Power	AIC	RSQ	RMSE
Variable	Model								
Docee	MODEL1	-1.071	0.612				-945.2	0.296	0.318
	MODEL2	-2.404	1.509	-0.149			-946.2	0.301	0.317
	MODEL3	6.685	-7.686	2.907	-0.334		-949.2	0.310	0.315
LogDocee	MODEL4	-0.620				1.066	-1367	0.289	0.191

Table 4. Regression model statistics for Docee River levels (m) as a function of Owikeno Lake levels (m), July-September 1961-2012. Models tested: 1 – linear; 2 – quadratic; 3 – cubic; 4 – logarithmic. Lowest AIC and RMSE are associated with the linear order functions (i.e., linear, quadratic, cubic), with preference for the simplest model: *Docee* = -0.933 + 0.572 * *Owikeno*; P < .0001; n = 402.

	Water Level (m)						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1986	47	0.54	1.14	1.94	0.38	0.12	0.80	1.15	1.46	1.84
1987	45	0.64	0.99	1.43	0.25	0.47	0.81	0.90	1.20	1.39
1988	58	0.86	1.19	1.47	0.14	-0.33	1.13	1.20	1.26	1.44
1989	34	0.67	0.89	1.09	0.13	-0.22	0.75	0.90	1.00	1.07
1990	37	0.18	0.31	0.60	0.14	0.92	0.20	0.25	0.43	0.58
1991	41	0.31	0.69	1.11	0.21	-0.05	0.59	0.67	0.85	1.01
1992	48	-0.15	0.23	0.59	0.24	-0.13	0.04	0.24	0.47	0.56
1997	35	0.38	0.84	1.65	0.31	0.67	0.61	0.79	1.05	1.49
1998	96	0.00	0.36	0.94	0.22	0.31	0.18	0.38	0.53	0.77
2000	87	0.18	0.67	1.46	0.27	0.60	0.49	0.67	0.82	1.16
2010	69	0.00	0.22	0.80	0.21	0.81	0.04	0.17	0.42	0.60
2011	68	0.16	0.84	1.35	0.35	-0.40	0.48	0.90	1.17	1.25
2012	42	0.28	0.64	1.00	0.23	-0.17	0.42	0.67	0.85	0.93
All	707	-0.15	0.66	1.94	0.41	0.24	0.35	0.63	0.94	1.34

Table 5. Annual statistics for “high quality” years of observed water level at the Docee River fence, June-September: 1986-1992, 1997, 1998, 2000, 2010-2012.

	Water Level (m)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1961	92	2.01	2.85	4.19	0.45	0.26	2.16	2.21	2.65	2.81	3.07	3.52
1962	89	1.92	2.81	4.31	0.54	0.10	1.97	2.00	2.36	2.91	3.21	3.47
1963	92	2.34	2.86	3.58	0.25	0.33	2.50	2.55	2.68	2.84	3.03	3.30
1964	92	1.95	2.98	4.03	0.47	0.07	2.10	2.39	2.80	2.96	3.19	3.90
1965	58	1.96	2.47	3.05	0.41	0.17	2.00	2.01	2.07	2.29	2.89	3.03
1966	92	2.32	2.85	3.46	0.30	-0.00	2.38	2.43	2.61	2.89	3.07	3.32
1967	92	2.55	3.18	5.04	0.44	1.87	2.63	2.73	2.93	3.12	3.33	3.93
1968	92	2.34	2.85	3.86	0.37	0.59	2.36	2.41	2.56	2.83	3.08	3.52
1969	92	2.25	2.77	4.00	0.39	1.29	2.31	2.37	2.53	2.65	2.91	3.66
1970	92	1.84	2.65	3.33	0.30	-0.49	1.99	2.32	2.49	2.66	2.86	3.11
1971	92	1.82	3.06	4.22	0.58	-0.20	2.00	2.21	2.68	3.07	3.49	3.84
1972	92	1.77	2.84	3.74	0.56	-0.11	1.92	2.14	2.44	2.75	3.35	3.63
1973	92	1.99	2.74	4.58	0.51	0.93	2.04	2.06	2.28	2.79	3.01	3.45
1974	92	2.14	2.92	3.34	0.29	-0.79	2.41	2.48	2.76	3.01	3.14	3.26
1975	92	2.14	2.83	4.13	0.53	0.54	2.18	2.20	2.28	2.84	3.21	3.92
1976	92	2.58	3.22	3.91	0.35	-0.20	2.65	2.72	2.88	3.27	3.51	3.72
1977	92	1.76	2.72	3.43	0.47	-0.10	2.03	2.12	2.35	2.71	3.20	3.37
1978	92	2.19	2.85	3.57	0.37	-0.24	2.24	2.33	2.48	2.97	3.13	3.44
1979	92	2.26	2.79	3.28	0.21	-0.25	2.44	2.54	2.64	2.82	2.92	3.10
1980	92	2.32	2.77	4.24	0.35	2.39	2.40	2.47	2.58	2.70	2.87	3.45
1981	92	1.94	2.73	3.25	0.31	-0.38	2.12	2.41	2.52	2.74	2.94	3.22
1982	92	1.99	2.85	4.68	0.50	1.58	2.30	2.35	2.54	2.75	3.00	3.94
1983	92	2.01	2.60	3.38	0.30	0.16	2.07	2.25	2.37	2.61	2.81	3.09
1984	92	1.96	2.83	4.12	0.36	0.70	2.30	2.48	2.60	2.85	3.00	3.46
1985	92	1.74	2.57	3.44	0.50	0.05	1.86	1.93	2.09	2.56	3.06	3.32
1986	92	1.74	2.66	3.34	0.41	-0.78	1.85	1.96	2.49	2.76	2.96	3.19
1987	92	2.20	2.77	3.81	0.36	0.84	2.28	2.35	2.49	2.74	2.96	3.58
1988	92	1.70	2.78	4.21	0.43	-0.39	1.84	2.08	2.70	2.85	2.99	3.28
1989	92	1.90	2.49	2.91	0.29	-0.42	1.95	2.03	2.29	2.52	2.76	2.89
1990	92	2.12	2.61	3.14	0.33	-0.23	2.15	2.18	2.27	2.73	2.90	3.00
1991	92	2.14	2.87	3.56	0.39	-0.22	2.24	2.26	2.53	2.89	3.16	3.43
1992	92	1.89	2.69	3.64	0.39	0.20	2.04	2.25	2.36	2.72	2.90	3.45
1993	92	1.67	2.46	3.13	0.33	-0.96	1.73	1.86	2.39	2.53	2.66	2.83
1994	92	2.19	2.76	3.35	0.29	-0.01	2.21	2.35	2.59	2.73	2.97	3.28
1995	92	2.00	2.65	3.45	0.38	0.04	2.08	2.13	2.33	2.64	2.97	3.20
1996	92	1.92	2.76	3.47	0.34	-0.67	1.99	2.26	2.67	2.78	2.93	3.33

(Continued)

Table 6. Water level statistics for observed data from the *Owikeno Lake* WSC Station 08FA007, July-September 1961-2012.

	Water Level (m)						Percentiles					
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P95
Year												
1997	92	2.00	2.77	3.78	0.37	-0.14	2.07	2.20	2.55	2.80	2.98	3.32
1998	92	1.97	2.76	3.32	0.34	-0.44	2.11	2.32	2.50	2.82	3.02	3.27
1999	92	2.19	3.09	4.57	0.49	0.12	2.22	2.38	2.78	3.18	3.38	3.80
2000	92	2.08	2.71	3.57	0.33	0.16	2.16	2.29	2.43	2.73	2.94	3.31
2001	92	2.16	2.84	3.60	0.34	-0.29	2.19	2.22	2.67	2.84	3.05	3.35
2002	92	2.08	2.77	3.81	0.37	0.64	2.27	2.33	2.53	2.71	2.97	3.50
2003	92	2.49	2.84	3.81	0.25	1.48	2.56	2.60	2.65	2.78	2.96	3.25
2004	92	2.02	2.90	4.28	0.42	0.78	2.20	2.36	2.71	2.88	3.03	3.78
2005	92	1.90	2.74	3.87	0.45	0.36	2.03	2.14	2.46	2.70	3.03	3.65
2006	92	1.91	2.42	3.17	0.39	0.52	1.93	2.00	2.10	2.31	2.80	3.06
2007	92	2.08	2.98	4.28	0.63	0.53	2.13	2.27	2.51	2.79	3.46	4.14
2008	92	2.01	2.81	4.02	0.53	0.51	2.07	2.12	2.45	2.76	3.07	3.81
2009	92	2.17	2.82	3.84	0.34	0.73	2.41	2.45	2.55	2.83	2.97	3.49
2010	92	1.96	2.72	6.00	0.72	2.76	2.07	2.11	2.29	2.68	2.84	4.68
2011	92	2.35	3.09	6.24	0.78	2.28	2.36	2.43	2.57	2.96	3.15	5.13
2012	92	2.10	2.98	4.18	0.61	0.09	2.12	2.19	2.37	3.07	3.46	4.00
All	4747	1.67	2.80	6.24	0.46	0.82	2.09	2.22	2.51	2.79	3.05	3.54

Table 6, cont'd. Water level statistics for observed data from the Owikeno Lake WSC Station 08FA002, July-September 1961-2012. (Note: Owikeno P10 and P90 percentiles for the July-August Sockeye migration period are 2.5 m and 3.4 m, respectively.)

Owikeno Water Levels as a Function of Wannock River Discharge

		Intercept	Coeff A	Coeff B	Coeff C	Power	AIC	RSQ	RMSE
Variable	Model								
Level	MODEL1	1.6704E+00	2.2462E-03				-31537.3	0.970	0.076
	MODEL2	1.4550E+00	3.0055E-03	-5.8168E-07			-34644.8	0.982	0.059
	MODEL3	1.1759E+00	4.4079E-03	-2.5888E-06	8.0198E-10		-37606.0	0.989	0.047
LogLevel	MODEL4	-1.5625E+00				4.1917E-01	-51493.5	0.990	0.015

Table 7. Regression model statistics for *Owikeno Lake* levels (m) as a function of Wannock River discharge (cms), July-September 1961-2012. Models tested: 1 – linear; 2 – quadratic; 3 – cubic; 4 – logarithmic. Lowest AIC and RMSE are associated with the log-log model (note: Intercept value must be antilogged): *Owikeno* = $e^{-1.56}$ * *Wannock* $^{0.419}$; $P < .0001$; $n = 6{,}133$.

Number of Observations Read	976
Number of Observations Used	413
Number of Observations with Missing Values	563

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	17.47062	17.47062	173.13	<.0001
Error	411	41.47302	0.10091		
Lack of Fit	360	37.05769	0.10294	1.19	0.2278
Pure Error	51	4.41533	0.08658		
Corrected Total	412	58.94365			

Root MSE	0.31766	R-Square	0.2964
Dependent Mean	0.74722	Adj R-Sq	0.2947
Coeff Var	42.51225		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-1.07073	0.13904	-7.70	<.0001
Owikeno	Owikeno Lake Level (m)	1	0.61175	0.04649	13.16	<.0001

Number of Observations Read	976
Number of Observations Used	413
Number of Observations with Missing Values	563

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	6.07349	6.07349	167.04	<.0001
Error	411	14.94370	0.03636		
Lack of Fit	360	13.27187	0.03687	1.12	0.3111
Pure Error	51	1.67183	0.03278		
Corrected Total	412	21.01719			

Root MSE	0.19068	R-Square	0.2890
Dependent Mean	0.53351	Adj R-Sq	0.2872
Coeff Var	35.74063		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.62031	0.08977	-6.91	<.0001
LogOwikeno		1	1.06568	0.08246	12.92	<.0001

Table 8. Linear (top) and log-log (bottom) model regression statistics for Docee River levels (m) as a function of *Owikeno Lake* levels (m), July-September 1986-1992, 1997, 1998, 2000, 2010-2012. (Note: log model Intercept value must be antilogged, and 1 must be subtracted from water levels: *Docee* = $e^{-0.62}$ * *(Owikeno)* $^{1.07}$ – 1 (P < .0001; n = 413)).

		Intercept	Coeff A	Coeff B	Coeff C	Power	AIC	RSQ	RMSE
Variable	Model								
Docee	MODEL1	-1.071	0.612				-945.2	0.296	0.318
	MODEL2	-2.404	1.509	-0.149			-946.2	0.301	0.317
	MODEL3	6.685	-7.686	2.907	-0.334		-949.2	0.310	0.315
LogDocee	MODEL4	-0.620				1.066	-1367	0.289	0.191

Table 9. Regression model statistics for Docee River levels (m) as a function of *Owikeno Lake* levels (m), July-September 1986-1992, 1997, 1998, 2000, 2010-2012. Models tested: 1 – linear; 2 – quadratic; 3 – cubic; 4 – logarithmic. Lack-of-Fit statistics were all non-significant, and explained variance estimates were approximately equivalent across models (i.e., RSQ ~ 0.3), but lowest AIC and RMSE were associated with the log-log model.

Owikeno (m)	Docee Low	Docee Linear (m)	Docee High	Docee Low.	Docee Log (m)	Docee High.
0.0	-1.21	-1.07	-0.93	-1.00	-1.00	-1.00
0.5	-0.88	-0.76	-0.65	-0.70	-0.74	-0.78
1.0	-0.55	-0.46	-0.37	-0.41	-0.46	-0.51
1.5	-0.22	-0.15	-0.08	-0.12	-0.17	-0.22
2.0	**0.11**	**0.15**	**0.20**	**0.16**	**0.13**	**0.09**
2.5	0.44	0.46	0.48	0.45	0.43	0.41
3.0	**0.76**	**0.76**	**0.76**	**0.73**	**0.73**	**0.74**
3.5	1.09	1.07	1.05	1.02	1.04	1.07
4.0	**1.42**	**1.38**	**1.33**	**1.30**	**1.36**	**1.41**
4.5	1.75	1.68	1.61	1.58	1.67	1.76
5.0	**2.08**	**1.99**	**1.89**	**1.86**	**1.99**	**2.12**
5.5	2.41	2.29	2.18	2.14	2.31	2.48
6.0	2.74	2.60	2.46	2.43	2.63	2.85
6.5	3.07	2.91	2.74	2.71	2.95	3.22
7.0	3.40	3.21	3.03	2.99	3.28	3.59

Table 10. Conversion table for Owikeno-to-Docee River water levels (m) based on linear (green) and log-log (yellow) regression relations (±1 standard error) for observed data, July-September 1986-1992, 1997, 1998, 2000, 2010-2012 (see Table 8). Linear and log-log relations suggest that typical Owikeno Lake water levels of 3 m correspond to ~ 0.75 ± 0.02 m depth in Docee River.

	AHCCD Air Temp (C)							
	N	Min	P10	Med	P95	Max	Avg	Std
Year								
2004	92	8.40	11.90	15.10	17.20	18.60	14.68	2.21
2005	92	8.40	12.00	14.50	16.10	17.70	14.21	1.72
2006	92	8.50	11.60	13.50	15.70	22.10	13.77	2.04
2007	92	8.00	12.20	14.10	16.40	18.50	14.07	1.85
2008	92	7.80	11.30	13.00	15.40	17.60	13.20	1.71
Total	460	7.80	11.65	14.00	16.50	22.10	13.98	1.97

Table 11. Annual summary of AHCCD daily air temperature from PORT HARDY during Sockeye migration (July-September). AVG is average of daily mean temperatures for #DATES times per year. MIN and MAX are minimum and maximum of the daily mean temperatures (i.e., not recorded extremes).

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2003	1	18.14	18.14	18.14			18.1	18.1	18.1	18.1
2004	92	13.98	17.12	20.01	1.84	-0.07	15.6	17.2	18.8	19.8
2005	92	13.57	16.21	19.16	1.36	0.25	15.2	16.1	17.3	18.5
2006	92	13.14	16.29	18.14	1.16	-0.69	15.6	16.4	17.2	17.8
2007	92	10.86	13.48	15.79	1.34	0.02	12.3	13.5	14.6	15.5
2008	57	9.09	11.42	13.78	1.43	0.00	10.1	11.4	12.9	13.5
All	426	9.09	15.20	20.01	2.43	-0.35	13.6	15.4	17.0	19.0

Table 12. Annual summary of daily mean water temperature data observed at the Docee River fence during Sockeye migration (July-September). MEAN is average of daily mean temperatures for #DATES times per year. MIN and MAX are minimum and maximum of the daily mean temperatures (i.e., not recorded extremes).

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2004	92	8.80	12.23	14.96	1.68	-0.22	10.7	12.6	13.7	14.8
2005	92	9.23	11.61	14.12	1.31	0.10	10.6	11.5	12.6	13.8
All	184	8.80	11.92	14.96	1.53	0.03	10.6	12.0	13.1	14.3

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2004	92	8.04	11.11	13.43	1.55	-0.22	9.7	11.1	12.6	13.2
2005	92	8.09	10.84	13.40	1.49	0.09	9.7	10.6	12.1	13.2
All	184	8.04	10.98	13.43	1.52	-0.06	9.7	10.9	12.3	13.2

Table 13. Annual summary of daily mean water temperature data observed on the spawning grounds (Canoe Creek, top; Smokehouse Creek, bottom) during Sockeye migration (July-September). MEAN is average of daily mean temperatures for #DATES times per year. MIN and MAX are minimum and maximum of the daily mean temperatures (i.e., not recorded extremes).

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2003	0	27		
2004	142	98		
2005	142	98		
2006	13	0		
2007	0	0		
2008			0	0

Table 14. Number of annual water temperature observations available for Canoe Creek air/water temperature analyses, partitioned into warming and cooling seasons for seasonal relationships.

Canoe Air/Water Logistic (Intercept) Model - All Seasons 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	4297.3	1432.4	1239.84	<.0001
Error	516	596.2	1.1553		
Corrected Total	519	4893.5			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	19.0330	2.2044	14.7023	23.3638	1.6193
beta	14.1913	0.9360	12.3526	16.0301	1.5236
gamma	0.2684	0.0425	0.1850	0.3518	-0.1103
mu	3.4631	0.4616	2.5563	4.3699	-0.8429

Canoe Air/Water Logistic (Intercept) Model - Warming Season 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	2828.9	943.0	1356.15	<.0001
Error	293	203.7	0.6953		
Corrected Total	296	3032.6			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	15.4043	0.5973	14.2288	16.5797	0.7303
beta	13.1318	0.2257	12.6876	13.5760	0.5424
gamma	0.4691	0.0455	0.3796	0.5586	0.0206
mu	4.0424	0.2492	3.5520	4.5329	-0.4257

Canoe Air/Water Logistic (Intercept) Model - Cooling Season 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	17137.6	4284.4	11004.0	<.0001
Error	219	85.2675	0.3893		
Uncorrected Total	223	17222.9			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	19.2611	1.2811	16.7363	21.7859	0.7044	
beta	11.3884	0.8450	9.7230	13.0539	0.6151	
gamma	0.1676	0.0101	0.1478	0.1874	0.0354	
mu	0	0	0	0	.	
Bound0	0.0986	0.2401	-0.3716	0.5687	.	0 <= mu

Table 15. Logistic regression output for air/water temperature relationship between the *Port Hardy* 7d-CMAT (air temperature index) and calibration data for Canoe Creek daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} – NSC_{all}$ = 0.06).

---------------------- Site=Canoe Dataset=Calibration Season=Warming ----------------------

Pearson Correlation Coefficients, N = 297
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.96819 <.0001	0.94874 <.0001

Spearman Correlation Coefficients, N = 297
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.96128 <.0001	0.95906 <.0001

---------------------- Site=Canoe Dataset=Calibration Season=Cooling ----------------------

Pearson Correlation Coefficients, N = 223
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.97707 <.0001	0.97453 <.0001

Spearman Correlation Coefficients, N = 223
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.97223 <.0001	0.97184 <.0001

Table 16. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for Canoe Creek observed (*WaterT*) versus estimated (from logistic and linear models) daily mean water temperature for validation data years: warming season (top); cooling season (bottom). Analysis indicates equivalent predictive power for linear and logistic model types.

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2003	0	27		
2004	142	98		
2005	142	98		
2006	13	0		
2007	0	0		
2008			0	0

Table 17. Number of annual water temperature observations available for Smokehouse Creek air/water temperature analyses, partitioned into warming and cooling seasons for seasonal relationships.

Smoke Air/Water Logistic (Intercept) Model - All Seasons 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	37518.9	9379.7	11274.2	<.0001
Error	516	429.3	0.8320		
Uncorrected Total	520	37948.2			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	19.2255	1.2881	16.6950	21.7561	0.6919	
beta	13.1938	0.7575	11.7058	14.6819	0.5781	
gamma	0.1865	0.0102	0.1664	0.2066	0.0277	
mu	0	0	0	0	.	
Bound0	2.5562	0.7468	1.0931	4.0193	.	0 <= mu

Smoke Air/Water Logistic (Intercept) Model - Warming Season 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	2250.8	750.3	1025.98	<.0001
Error	293	214.3	0.7313		
Corrected Total	296	2465.1			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	15.0286	0.9162	13.2255	16.8317	1.1336
beta	13.1604	0.3629	12.4462	13.8746	0.9367
gamma	0.3866	0.0531	0.2821	0.4911	-0.0643
mu	3.5559	0.3835	2.8012	4.3107	-0.7562

Smoke Air/Water Logistic (Intercept) Model - Cooling Season 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	13233.9	3308.5	6368.31	<.0001
Error	219	113.8	0.5195		
Uncorrected Total	223	13347.6			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	13.1957	0.3978	12.4118	13.9797	0.3715	
beta	8.8915	0.2669	8.3655	9.4176	0.3527	
gamma	0.2793	0.0138	0.2520	0.3065	0.0676	
mu	0	0	0	0	.	
Bound0	2.6030	0.6972	1.2378	3.9681	.	0 <= mu

Table 18. Logistic regression output for air/water temperature relationship between the *Port Hardy* 7d-CMAT (air temperature index) and calibration data for Smokehouse Creek daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} – NSC_{all}$ = 0.017).

------------------------ Site=Smoke Dataset=Calibration Season=Warming ------------------------

Pearson Correlation Coefficients, N = 297
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.95562	0.94594
Daily MWT	<.0001	<.0001

Spearman Correlation Coefficients, N = 297
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.95251	0.95280
Daily MWT	<.0001	<.0001

------------------------ Site=Smoke Dataset=Calibration Season=Cooling ------------------------

Pearson Correlation Coefficients, N = 223
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.97306	0.97300
Daily MWT	<.0001	<.0001

Spearman Correlation Coefficients, N = 223
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.97252	0.97199
Daily MWT	<.0001	<.0001

Table 19. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for Smokehouse Creek observed (*WaterT*) versus estimated (from logistic and linear models) daily mean water temperature for validation data years: warming season (top); cooling season (bottom). Analysis indicates equivalent predictive power for linear and logistic model types.

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2003			0	0
2004	142	98		
2005	142	98		
2006	142	98		
2007	142	98		
2008	142	8		

Table 20. Number of annual water temperature observations available for Docee River air/water temperature analyses, partitioned into warming and cooling seasons for seasonal relationships. Air/water temperature model calibration data years were selected based on strength of association between air and water time-series and range of temperature observations.

Docee Air/Water Logistic (Intercept) Model - All Seasons 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	163798	40949.6	7158.73	<.0001
Error	1106	6326.6	5.7202		
Uncorrected Total	1110	170125			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	18.7964	1.3454	16.1565	21.4362	1.4557
beta	11.2938	0.4911	10.3301	12.2574	0.6008
gamma	0.2895	0.0590	0.1738	0.4052	-0.0721
mu	4.8362	1.0214	2.8320	6.8403	-1.2447

Docee Air/Water Logistic (Intercept) Model - Warming Season 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	7706.9	2569.0	785.19	<.0001
Error	706	2309.9	3.2718		
Corrected Total	709	10016.8			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	21.6939	2.9373	15.9271	27.4607	2.2272
beta	12.6353	0.7849	11.0943	14.1764	1.8706
gamma	0.2342	0.0613	0.1139	0.3546	-0.3791
mu	2.1210	1.7064	-1.2291	5.4712	-1.8541

Docee Air/Water Logistic (Intercept) Model - Cooling Season 2003-2008 - Calibration

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	4053.2	1351.1	526.74	<.0001
Error	396	1015.7	2.5650		
Corrected Total	399	5069.0			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness
alpha	20.4937	1.4604	17.6225	23.3649	1.4854
beta	9.9126	0.4959	8.9377	10.8874	0.4036
gamma	0.2836	0.0601	0.1655	0.4018	-0.0512
mu	5.0287	1.2704	2.5312	7.5263	-1.2706

Table 21. Logistic regression output for air/water temperature relationship between the *Port Hardy* 7d-CMAT (air temperature index) and calibration data for Docee River daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} - NSC_{all} = 0.18$).

---- Site=Docee Dataset=Calibration Season=Warming ----

Pearson Correlation Coefficients, N = 710
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.87830 <.0001	0.87640 <.0001

Spearman Correlation Coefficients, N = 710
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.87264 <.0001	0.87264 <.0001

---- Site=Docee Dataset=Calibration Season=Cooling ----

Pearson Correlation Coefficients, N = 400
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.89757 <.0001	0.89443 <.0001

Spearman Correlation Coefficients, N = 400
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT Daily MWT	0.88488 <.0001	0.88488 <.0001

Table 22. Comparison of Pearson (least squares) and Spearman (rank) correlation coefficients for Docee River observed (*WaterT*) versus estimated (from logistic and linear models) daily mean water temperature for validation data years: warming season (top); cooling season (bottom). Analysis indicates equivalent predictive power for linear and logistic model types.

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2003			0	0
2004	142	98		
2005	142	98		
2006			142	98
2007			142	98
2008			142	8

Table 23. Number of annual water temperature observations used for air/water temperature calibration based on warm-phase PDO years only (2004-2005), partitioned into warming and cooling seasons for seasonal relationships.

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	27.4967	10.6272	6.5773	48.4162
beta	13.4676	2.4698	8.6059	18.3293
gamma	0.1718	0.1066	-0.0381	0.3817
mu	0.4140	5.6891	-10.7848	11.6128

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	24.9142	3.9462	17.1308	32.6976
beta	11.9742	0.9849	10.0316	13.9167
gamma	0.2357	0.0815	0.0750	0.3964
mu	4.9979	2.2739	0.5129	9.4829

Table 24. Logistic regression parameter output for air/water temperature relationship between the *Port Hardy* 7d-CMAT (air temperature index) and calibration data for Docee River daily mean water temperatures, **warm-phase PDO years only (2004-2005):** warming season (top), n=284; cooling season (bottom), n=196.

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2003			0	0
2004			142	98
2005			142	98
2006			142	98
2007	142	98		
2008	142	8		

Table 25. Number of annual water temperature observations used for air/water temperature calibration based on cool-phase PDO years only (2007-2008), partitioned into warming and cooling seasons for seasonal relationships.

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	13.9080	0.7938	12.3455	15.4705
beta	10.6971	0.3775	9.9540	11.4403
gamma	0.3715	0.0720	0.2299	0.5132
mu	3.3604	0.7538	1.8767	4.8442

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
alpha	15.5897	0.5273	14.5438	16.6356
beta	9.2493	0.2657	8.7223	9.7763
gamma	0.4873	0.0857	0.3173	0.6573
mu	5.4125	0.5751	4.2718	6.5531

Table 26. Logistic regression parameter output for air/water temperature relationship between the *Port Hardy* 7d-CMAT (air temperature index) and calibration data for Docee River daily mean water temperatures, **cool-phase PDO years only (2007-2008):** warming season (top), n=284; cooling season (bottom), n=106.

		Air Temp						Est'd Water Temp				
		N	Min	P10	Med	P95	Max	Min	P10	Med	P95	Max
Decade	Year											
1960s	1960	92	6.1	9.8	12.7	15.6	19.7	11.7	12.3	13.9	15.0	15.9
	1961	92	5.0	10.6	13.9	16.7	19.2	10.9	12.9	15.1	16.7	17.6
	1962	92	8.1	10.8	13.3	14.8	16.1	10.5	12.3	13.6	15.9	16.9
	1963	92	10.0	12.2	14.2	15.6	17.0	11.7	12.7	15.2	17.6	18.1
	1964	92	8.1	10.6	12.7	14.5	15.6	11.1	12.3	13.6	15.2	16.5
	1965	92	7.3	10.3	13.1	15.3	17.3	11.9	12.5	14.3	15.3	16.1
	1966	92	9.5	11.1	13.6	15.0	16.4	11.0	12.4	14.4	16.0	16.9
	1967	92	10.6	12.5	14.2	16.1	18.1	12.4	13.2	15.2	17.7	18.4
	1968	92	7.8	11.2	13.6	15.6	17.8	12.4	13.1	14.5	16.2	17.0
	1969	92	8.9	10.9	12.5	14.8	16.4	11.0	12.5	13.6	15.5	16.3
	Total	920	5.0	10.8	13.4	15.6	19.7	10.5	12.5	14.2	16.2	18.4
1970s	Year											
	1970	92	6.7	10.0	12.5	14.5	18.3	11.4	11.8	13.4	14.5	15.2
	1971	92	6.7	10.0	13.3	16.4	18.4	9.6	11.6	14.5	16.3	16.8
	1972	92	3.9	8.4	13.0	15.6	17.3	9.2	11.4	13.7	16.2	17.2
	1973	92	8.6	10.3	12.5	14.7	16.1	10.6	11.3	13.3	15.9	16.7
	1974	92	7.8	10.8	13.1	15.3	17.0	10.3	11.1	14.4	17.4	18.0
	1975	92	8.9	10.6	12.8	14.2	17.8	11.3	12.1	13.7	15.1	15.5
	1976	92	8.9	10.9	12.8	14.8	17.0	11.5	11.8	13.1	16.4	17.3
	1977	92	7.1	9.8	12.9	15.5	17.7	10.4	11.3	14.5	15.9	16.9
	1978	92	9.4	10.6	13.3	15.1	17.4	10.9	12.9	14.0	15.7	16.6
	1979	92	9.6	11.7	14.1	16.0	17.8	11.9	13.3	14.8	17.1	17.8
	Total	920	3.9	10.3	13.0	15.3	18.4	9.2	11.8	14.0	16.1	18.0
1980s	Year											
	1980	92	9.4	10.9	13.1	14.9	19.4	11.5	12.2	14.6	15.4	15.9
	1981	92	8.0	10.8	13.9	16.4	19.7	11.1	12.6	15.1	16.6	17.4
	1982	92	8.6	11.4	13.2	14.9	17.1	12.0	12.5	14.1	16.0	17.1
	1983	92	6.2	10.3	13.8	15.5	16.9	11.5	12.5	14.3	16.8	17.5
	1984	92	7.4	10.2	13.3	14.8	16.3	11.3	12.0	14.2	15.7	16.6
	1985	92	7.1	9.7	13.2	16.0	16.9	12.0	12.8	14.2	15.5	16.6
	1986	92	8.4	10.2	13.7	16.2	17.4	10.8	12.7	14.2	17.2	17.7
	1987	92	8.2	11.5	13.7	15.6	17.4	12.6	13.1	14.5	16.8	17.6
	1988	92	7.3	10.7	13.5	15.4	19.3	11.1	12.0	14.5	16.9	17.4
	1989	92	9.7	11.6	14.0	15.9	17.2	12.5	13.6	14.7	16.8	17.1
	Total	920	6.2	10.8	13.5	15.6	19.7	10.8	12.6	14.5	16.4	17.7

Table 27. Statistics for regional mean air temperature (*Port Hardy*) and estimated water temperature in Docee River for the months of July-September, 1960-2012.

		Air Temp						Est'd Water Temp				
		N	Min	P10	Med	P95	Max	Min	P10	Med	P95	Max
Decade												
1990s	Year											
	1990	92	9.9	11.9	14.8	16.9	19.6	13.3	14.3	15.6	16.8	17.9
	1991	92	8.6	11.7	13.9	15.9	19.0	12.3	13.0	14.9	16.6	16.9
	1992	92	7.0	10.9	13.9	15.9	19.0	11.9	13.6	14.6	16.1	16.7
	1993	92	8.6	10.8	13.7	15.6	19.0	12.8	13.3	14.4	16.0	16.6
	1994	92	10.0	12.5	14.3	15.9	17.2	11.5	13.1	15.3	16.7	17.4
	1995	92	10.1	12.2	13.8	15.6	18.2	12.5	13.5	14.7	16.7	17.0
	1996	92	6.8	10.7	13.2	15.2	18.7	11.7	12.6	13.9	15.8	17.7
	1997	92	9.2	12.4	14.8	16.7	19.4	13.4	14.3	15.6	17.3	17.9
	1998	92	10.2	12.1	14.2	16.3	19.0	13.1	13.6	15.4	17.4	18.3
	1999	92	7.7	11.1	13.5	15.7	19.4	11.9	12.6	14.5	16.8	18.0
	Total	920	6.8	11.5	14.0	16.0	19.6	11.5	13.2	14.9	16.7	18.3
2000s	Year											
	2000	92	8.6	10.5	13.8	15.7	18.5	11.6	13.0	14.8	16.2	17.1
	2001	92	9.0	11.7	13.6	15.0	16.8	12.1	12.7	14.3	16.4	17.4
	2002	92	10.5	11.1	13.8	16.4	18.1	11.0	13.4	14.9	16.7	18.2
	2003	92	8.7	11.2	14.1	15.9	17.3	12.0	13.6	14.6	16.5	16.8
	2004	92	8.4	11.9	15.1	17.2	18.6	12.5	13.6	15.9	17.6	18.2
	2005	92	8.4	12.0	14.5	16.1	17.7	13.2	14.0	15.1	17.1	17.5
	2006	92	8.5	11.6	13.5	15.7	22.1	12.2	13.1	14.8	16.5	17.6
	2007	92	8.0	12.2	14.1	16.4	18.5	12.6	13.7	15.0	16.6	17.2
	2008	92	7.8	11.3	13.0	15.4	17.6	11.7	12.2	14.3	16.0	17.1
	2009	92	8.8	11.6	14.1	16.5	19.3	11.4	12.1	15.5	17.2	17.7
	2010	92	8.7	11.6	13.6	15.7	19.7	10.8	13.4	14.8	16.2	17.2
	2011	92	8.6	11.4	13.7	15.8	19.0	11.1	11.7	14.2	17.1	18.1
	2012	92	8.6	10.5	13.7	15.3	17.6	11.3	13.2	14.4	16.3	16.9
	Total	1196	7.8	11.4	13.8	16.2	22.1	10.8	13.0	14.8	16.8	18.2
Total		4876	3.9	10.9	13.6	15.8	22.1	9.2	12.5	14.5	16.5	18.4

Table 27, cont'd. Statistics for regional mean air temperature (*Port Hardy*) and estimated water temperature in Docee River for the months of July-September, 1960-2012.

	Observed Water Level (m)						
	N	Min	P10	Med	P95	Max	Std
Year							
1998	92	1.16	1.20	1.28	1.33	1.40	0.06
1999	92	1.18	1.21	1.32	1.47	1.49	0.09
2000	92	0.90	1.00	1.50	2.00	2.50	0.38
2001	92	1.20	1.28	1.36	1.45	1.50	0.07
2002	92	1.20	1.23	1.30	1.38	1.45	0.06
2003	92	1.14	1.19	1.30	1.37	1.40	0.06
2004	92	0.65	1.00	1.27	1.35	1.38	0.16
2005	92	1.04	1.10	1.20	1.35	1.43	0.08
2006	92	1.05	1.09	1.18	1.35	1.41	0.10
2007	92	1.04	1.10	1.23	1.67	1.85	0.22
2008	92	0.99	1.10	1.29	1.42	1.48	0.12
2009	92	1.11	1.14	1.29	1.38	1.39	0.09
2010	92	1.00	1.07	1.27	1.40	1.45	0.11
2011	92	1.10	1.15	1.30	1.42	1.64	0.11
2012	85	1.07	1.09	1.24	1.44	1.45	0.13
Total	1373	0.65	1.11	1.28	1.44	2.50	0.16

Table 28. Statistics for observed water level at the Meziadin fishway, July-September, 1998-2012.

Decadal Mean Monthly MAT Peaks > 17c

Site: Port Hardy Air

	Years in Decade	Mean No. Days			Mean Annual Total
		Jul	Aug	Sep	
Decade					
1940s	6	0.2		0.2	0.3
1950s	10	0.6	0.7	0.1	1.4
1960s	10	0.5	0.6		1.1
1970s	10	0.6	0.5		1.1
1980s	10	0.8	0.7	0.1	1.6
1990s	10	0.7	2.4	0.3	3.4
2000s	13	1.8	1.2	0.2	3.2

Annual Frequency & Mean Duration (days) for POT17c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1940s	2	1	1.0	1	0.0
1950s	13	1	1.2	2	0.4
1960s	16	1	1.1	2	0.3
1970s	18	1	1.1	2	0.2
1980s	13	1	1.4	3	0.7
1990s	26	1	1.3	3	0.6
2000s	30	1	1.5	5	0.9
Total	118	1	1.3	5	0.6

Table 29. Frequency analysis of decadal mean number of dates per month (July-September) in which regional daily mean air temperature at PORT HARDY weather station exceeded 17°C (top); min., mean and max. length (days) and total frequency of periods in which regional daily mean air temperature continuously exceeded 17°C (July-September), by decade (bottom).

Decadal Mean Monthly MWT Peaks > 17c

Site: Docee River

	Years in Decade	Mean No. Days			Mean Annual Total
		Jul	Aug	Sep	
Decade					
1940s	6		3.3	1.3	4.7
1950s	10		1.6	0.5	2.1
1960s	10		2.2	2.9	5.1
1970s	10		1.8	0.8	2.6
1980s	10		2.9	1.6	4.5
1990s	10		3.0	1.4	4.4
2000s	13	0.3	4.1	1.9	6.3

Annual Frequency & Mean Duration (days) for POT17c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1960s	5	3	10.0	19	6.0
1970s	5	1	4.8	11	4.1
1980s	10	1	4.4	11	3.7
1990s	8	1	5.5	12	4.0
2000s	14	1	5.7	25	6.0
Total	42	1	5.8	25	5.0

Table 30. Frequency analysis of decadal mean number of dates per month (July-September) in which estimated mean water temperature in the Docee River exceeded 17°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 17°C (July-September), by decade (bottom).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1960s	1960	0				
	1961	1	9	9.0	9	
	1962	0				
	1963	2	3	11.0	19	11.3
	1964	0				
	1965	0				
	1966	0				
	1967	2	7	9.5	12	3.5
	1968	0				
	1969	0				
	Total	5	3	10.0	19	6.0
1970s	Year					
	1970	0				
	1971	0				
	1972	1	1	1.0	1	
	1973	0				
	1974	1	11	11.0	11	
	1975	0				
	1976	1	2	2.0	2	

(Continued)

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1970s	1977	0				
	1978	0				
	1979	2	3	5.0	7	2.8
	Total	5	1	4.8	11	4.1
1980s	Year					
	1980	0				
	1981	2	1	2.5	4	2.1
	1982	1	1	1.0	1	
	1983	1	8	8.0	8	
	1984	0				
	1985	0				
	1986	1	11	11.0	11	
	1987	1	9	9.0	9	
	1988	3	1	2.3	5	2.3
	1989	1	3	3.0	3	
	Total	10	1	4.4	11	3.7
1990s	Year					
	1990	1	3	3.0	3	
	1991	0				

(Continued)

Table 31. Min., mean and max. length (days) and number of periods in which estimated mean Docee River water temperature continuously exceeded 17°C (July-September), by year (1960-2012).

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1990s	1992	0				
	1993	0				
	1994	1	4	4.0	4	
	1995	1	1	1.0	1	
	1996	1	6	6.0	6	
	1997	2	3	7.5	12	6.4
	1998	1	11	11.0	11	
	1999	1	4	4.0	4	
	Total	8	1	5.5	12	4.0
2000s	Year					
	2000	1	1	1.0	1	
	2001	1	3	3.0	3	
	2002	1	7	7.0	7	
	2003	0				
	2004	1	25	25.0	25	
	2005	2	4	5.0	6	1.4
	2006	1	4	4.0	4	
	2007	1	3	3.0	3	
	2008	1	2	2.0	2	

(Continued)

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
2000s	2009	2	6	7.0	8	1.4
	2010	1	1	1.0	1	
	2011	2	3	5.0	7	2.8
	2012	0				
	Total	14	1	5.7	25	6.0
Total		42	1	5.8	25	5.0

Table 31. Min., mean and max. length (days) and number of periods in which estimated mean Docee River water temperature continuously exceeded 17°C (July-September), by year (1960-2012).

Monthly and Annual No. Dates < 20 cm

		Freq POT20 cm Dates		Total Days
		Jul	Aug	
Decade	Year			
1980s	1986			
	1987			
	1988			
	1989			
1990s	1990	3	9	12
	1991			
	1992	16	6	22
	1997			
	1998		16	16
2000s	2000		2	2
	2010	8	30	38
	2011			
	2012			

Monthly and Annual No. Dates > 120 cm

		Freq POT120 cm Dates		Total Days
		Jul	Aug	
Decade	Year			
1980s	1986	13		13
	1987	7		7
	1988	16	3	19
	1989			
1990s	1990			
	1991			
	1992			
	1997	4		4
	1998			
2000s	2000	4		4
	2010			
	2011	12	1	13
	2012			

Decadal Mean Monthly Water Level < 20 cm

Site: Docee River

	Years in Decade	Mean No. Days		Mean Annual Total
		Jul	Aug	
Decade				
1980s	4			
1990s	5	3.8	6.2	10.0
2000s	4	2.0	8.0	10.0

Decadal Mean Monthly Water Level > 120 cm

Site: Docee River

	Years in Decade	Mean No. Days		Mean Annual Total
		Jul	Aug	
Decade				
1980s	4	9.0	0.8	9.8
1990s	5	0.8		0.8
2000s	4	4.0	0.3	4.3

Table 32. Annual mean number of dates per month (July-August) in which observed water level at the Docee fence was less than 0.2 m (~10^{th} percentile; left); or greater than 1.2 m (~90^{th} percentile; right). Restricted to "high quality" data years: 1986-1992, 1997, 1998, 2000, 2010-2012.

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1990s	1990	2	4	6.0	8	2.8
	1992	1	22	22.0	22	
	1998	2	6	10.5	15	6.4
	Total	5	4	11.0	22	7.4
2000s	Year					
	2000	1	1	1.0	1	
	2010	1	38	38.0	38	
	Total	2	1	19.5	38	26.2
Total		7	1	13.4	38	13.0

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1986	2	6	6.5	7	0.7
	1987	1	1	1.0	1	
	1988	4	3	4.8	10	3.5
	Total	7	1	4.7	10	3.1
1990s	Year					
	1997	1	4	4.0	4	
	Total	1	4	4.0	4	
2000s	Year					
	2000	1	4	4.0	4	
	2011	3	1	4.3	8	3.5
	Total	4	1	4.3	8	2.9
Total		12	1	4.5	10	2.7

Table 33. Min., mean and max. length (days) and number of periods in which observed water level at the Docee fence (July-August) was less than 0.2 m (~10th percentile; left); or greater than 1.2 m (~90th percentile; right). Restricted to “high quality” data years: 1986-1992, 1997, 1998, 2000, 2010-2012.

Decadal Mean Monthly Water Level < 250 cm

Site: Owikeno River

	Years in Decade	Mean No. Days		Mean Annual Total
		Jul	Aug	
Decade				
1960s	9	0.2	1.4	1.7
1970s	10	0.1	2.4	2.5
1980s	10	0.8	7.4	8.2
1990s	10	0.4	4.2	4.6
2000s	13	0.8	5.6	6.5

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1960s	1963	1	1	1.0	1	
	1965	1	31	31.0	31	
	1968	2	2	7.5	13	7.8
	1969	1	13	13.0	13	
	Total	5	1	12.0	31	12.1
1970s	Year					
	1970	1	9	9.0	9	
	1973	1	18	18.0	18	
	1975	1	2	2.0	2	
	1977	1	1	1.0	1	
	1978	1	4	4.0	4	
	Total	5	1	6.8	18	7.0
1980s	Year					
	1980	2	3	3.5	4	0.7
	1981	2	2	2.5	3	0.7
	1982	2	1	5.0	9	5.7
	1983	2	1	8.5	16	10.6
	1985	1	40	40.0	40	
	1986	1	2	2.0	2	

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1987	1	14	14.0	14	
	1989	3	5	14.7	34	16.7
	Total	14	1	9.9	40	12.4
1990s	Year					
	1990	1	36	36.0	36	
	1992	1	30	30.0	30	
	1993	3	1	12.7	33	17.7
	1994	1	12	12.0	12	
	1995	1	35	35.0	35	
	1998	1	8	8.0	8	
	Total	8	1	19.9	36	15.0
2000s	Year					
	2000	1	9	9.0	9	
	2002	2	3	4.5	6	2.1
	2003	1	1	1.0	1	
	2005	1	5	5.0	5	
	2006	1	61	61.0	61	
	2008	1	2	2.0	2	
	2009	2	2	7.0	12	7.1

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
2000s	2010	2	4	19.0	34	21.2
	2011	1	3	3.0	3	
	Total	12	1	11.8	61	17.9
Total		44	1	12.1	61	14.1

(Continued)

Table 34. Annual mean number of dates per month (July-August) in which observed water level in Owikeno Lake was less than 2.5 m (10^{th} percentile; top left); Min., mean and max. duration (days) of $POT_{<2.5\ m}$ periods, by year.

Decadal Mean Monthly Water Level > 340 cm

Site: Owikeno River

	Years in Decade	Mean No. Days		Mean Annual Total
		Jul	Aug	
Decade				
1960s	9	4.9	1.7	6.6
1970s	10	5.5	3.7	9.2
1980s	10	1.3		1.3
1990s	10	2.1	1.3	3.4
2000s	13	5.9	1.6	7.5

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1960s	1961	3	2	2.7	4	1.2
	1962	1	4	4.0	4	
	1964	1	16	16.0	16	
	1965	1	3	3.0	3	
	1966	1	2	2.0	2	
	1967	1	3	3.0	3	
	1968	2	1	3.5	6	3.5
	1969	2	2	5.5	9	4.9
	Total	12	1	4.5	16	4.2
1970s	Year					
	1971	3	4	7.3	12	4.2
	1972	3	1	6.0	11	5.0
	1975	2	1	6.5	12	7.8
	1976	4	2	7.3	17	6.8
	1977	1	2	2.0	2	
	1978	1	5	5.0	5	
	Total	14	1	6.4	17	4.9
1980s	Year					
	1984	1	2	2.0	2	

(Continued)

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1985	1	2	2.0	2	
	Total	2	2	2.0	2	0.0
1990s	Year					
	1991	2	2	3.0	4	1.4
	1995	1	1	1.0	1	
	1996	1	1	1.0	1	
	1997	1	3	3.0	3	
	1999	6	1	3.5	6	2.2
	Total	11	1	2.9	6	1.9
2000s	Year					
	2000	1	2	2.0	2	
	2002	2	3	3.0	3	0.0
	2004	1	4	4.0	4	
	2005	2	2	3.5	5	2.1
	2007	2	4	13.0	22	12.7
	2008	2	7	8.0	9	1.4
	2009	1	5	5.0	5	
	2011	1	5	5.0	5	
	2012	2	3	12.5	22	13.4
2000s		14	2	6.9	22	6.7
Total		53	1	5.2	22	4.9

Table 35. Decadal mean number of dates per month (July-August) in which observed water level in Owikeno Lake exceeded 3.4 m (~90th percentile; top left); Min., mean and max. duration (days) of $POT_{>3.4\ m}$ periods, by year.

FIGURES

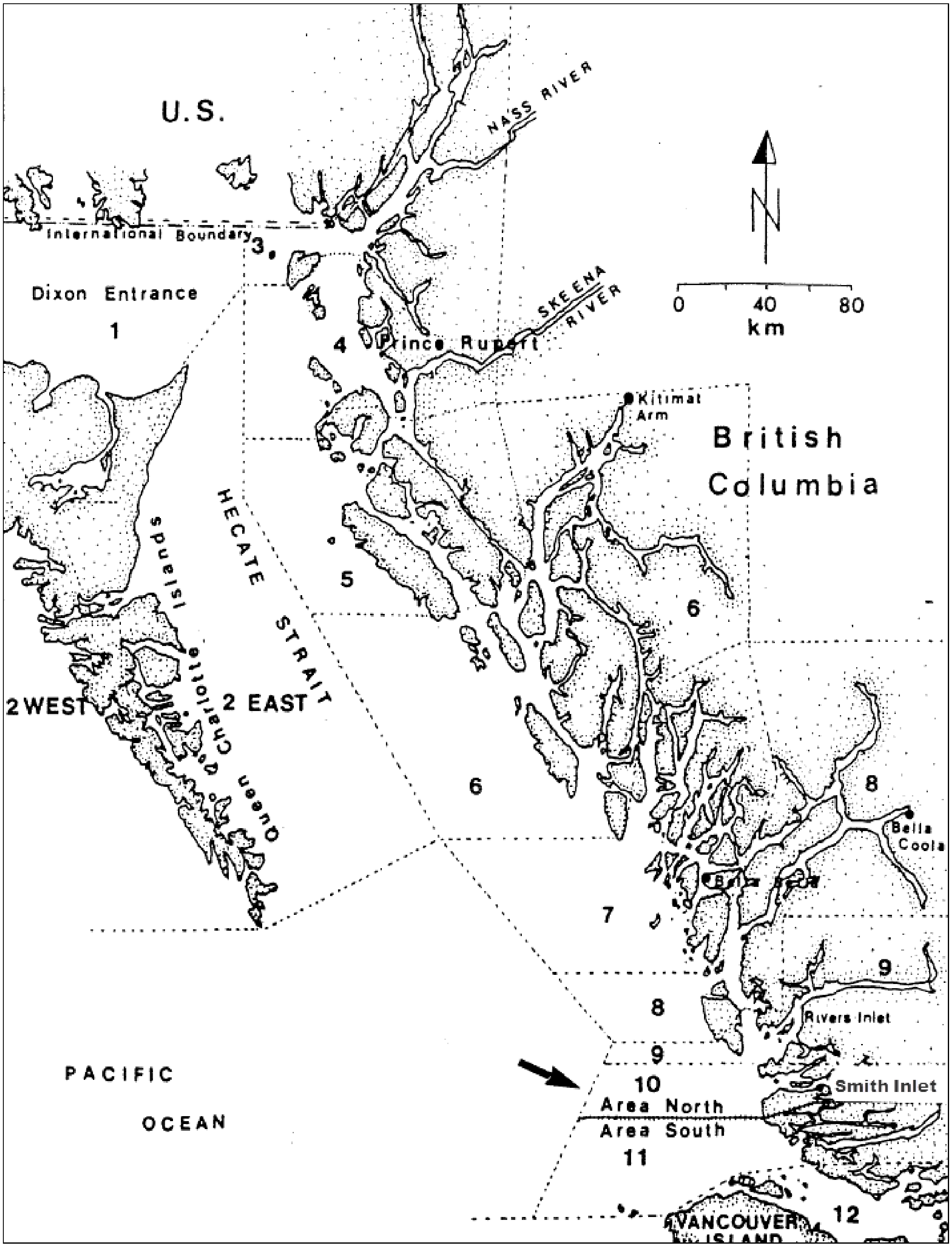


Figure 1. Smith Inlet, Area 10, British Columbia.

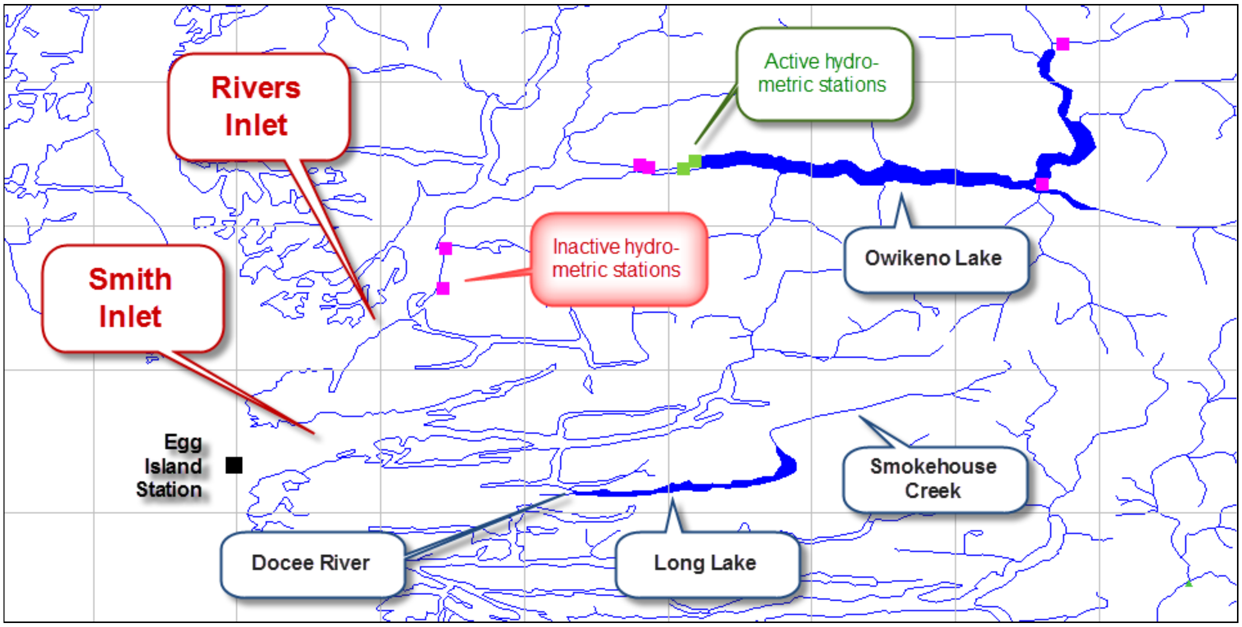


Figure 2. Environmental monitoring stations.

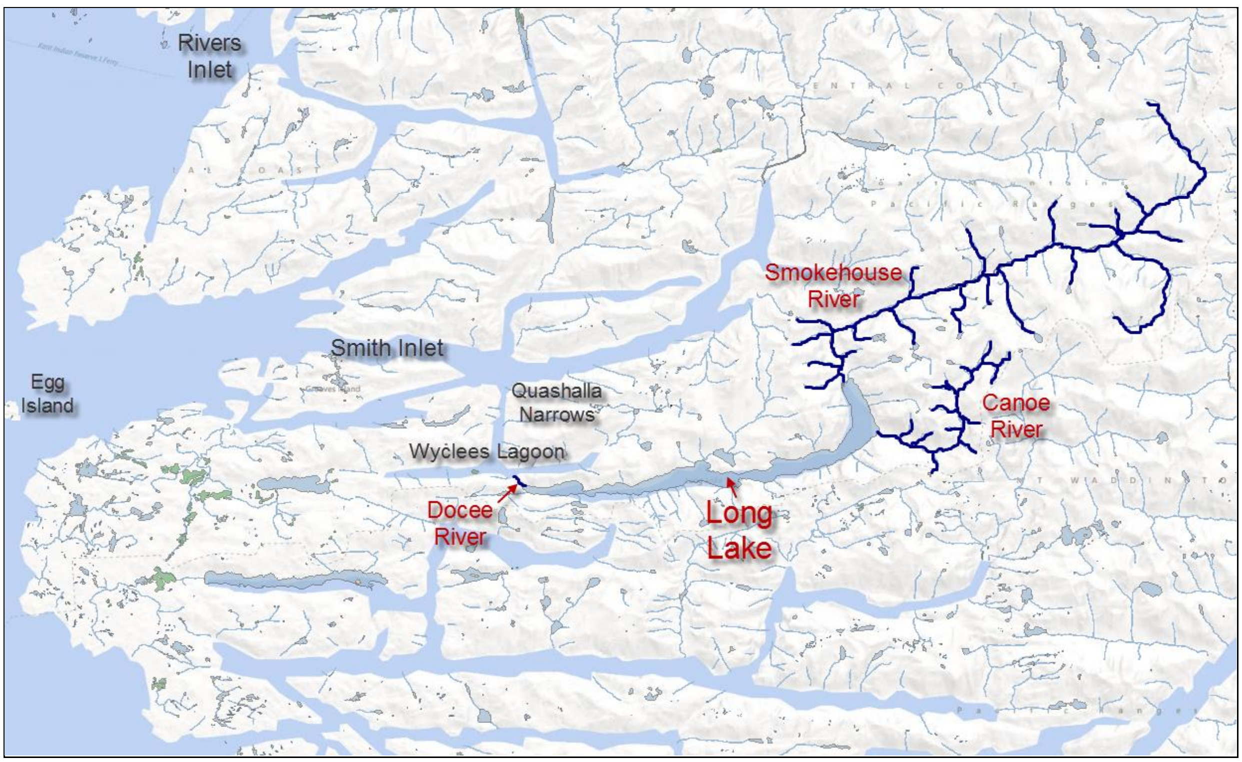


Figure 3. Long Lake watershed and principle Sockeye spawning streams.

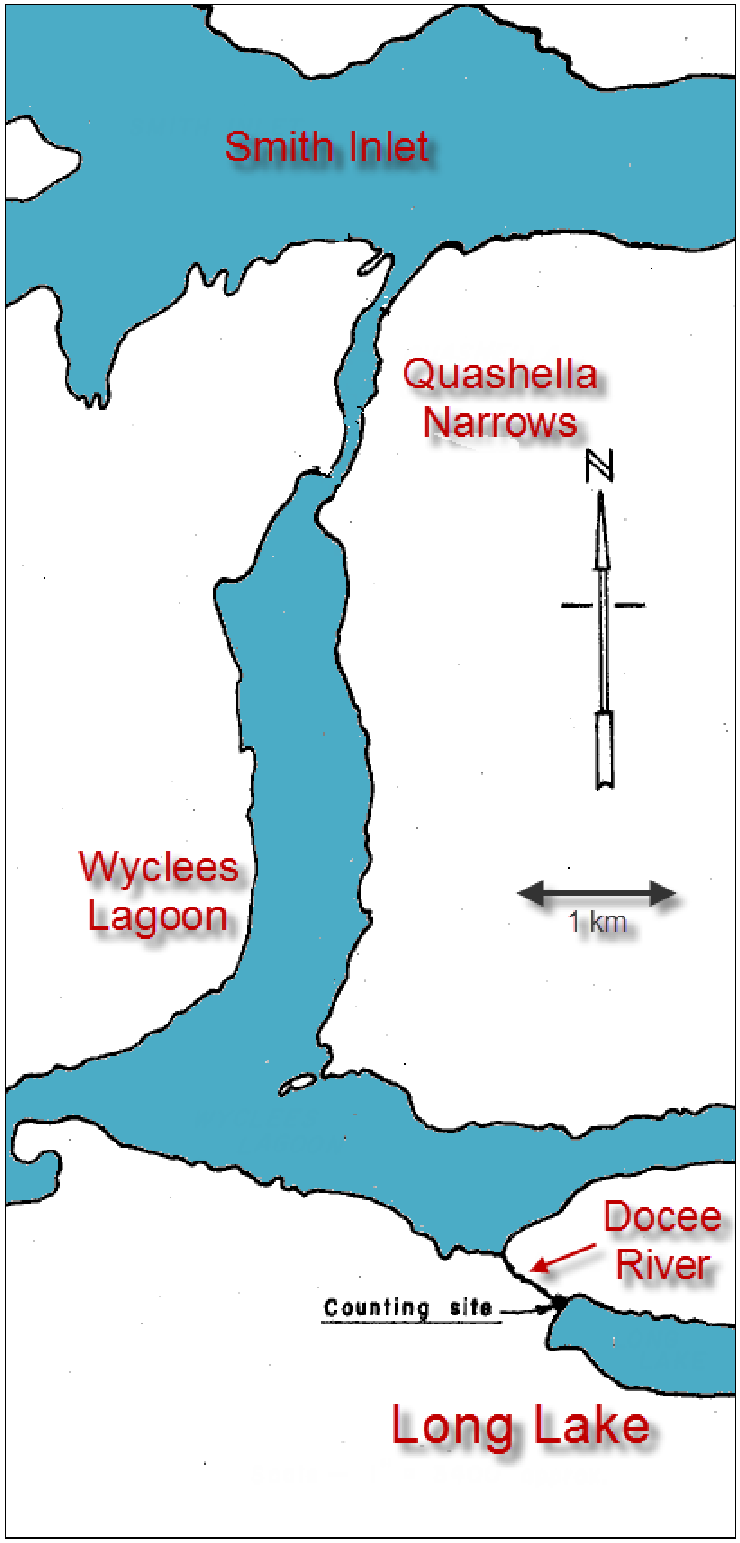
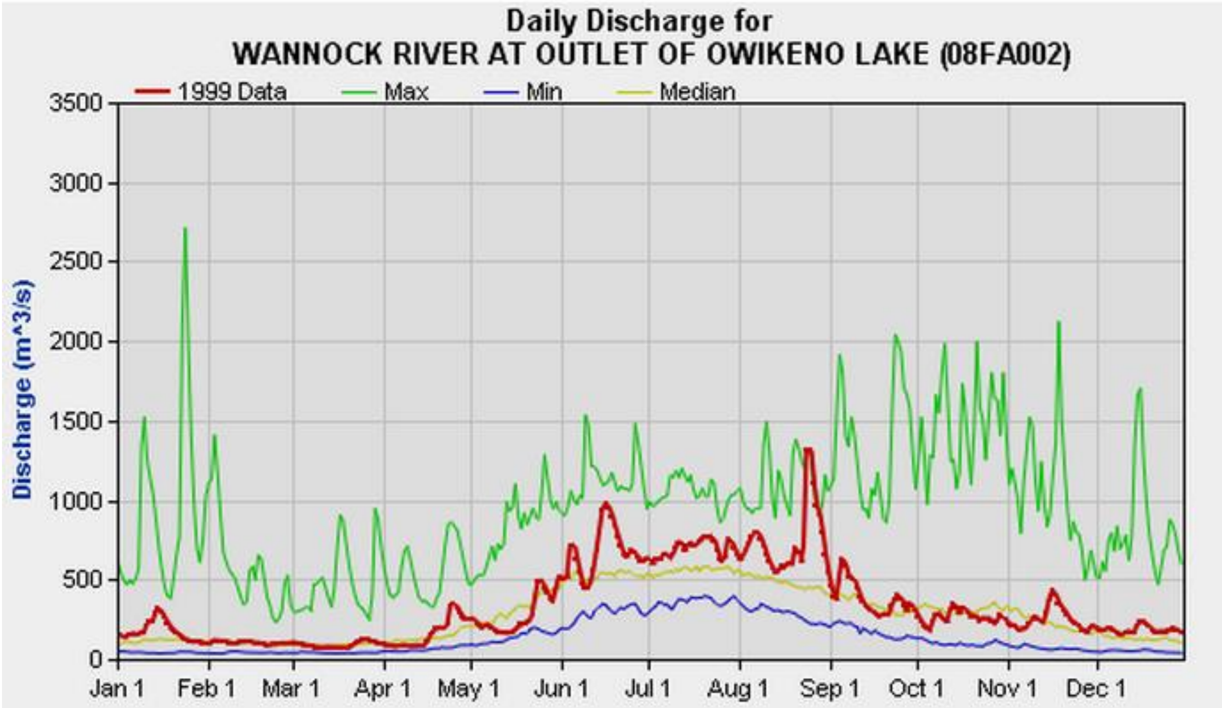


Figure 4. Docee River fence location at outlet of Long Lake.



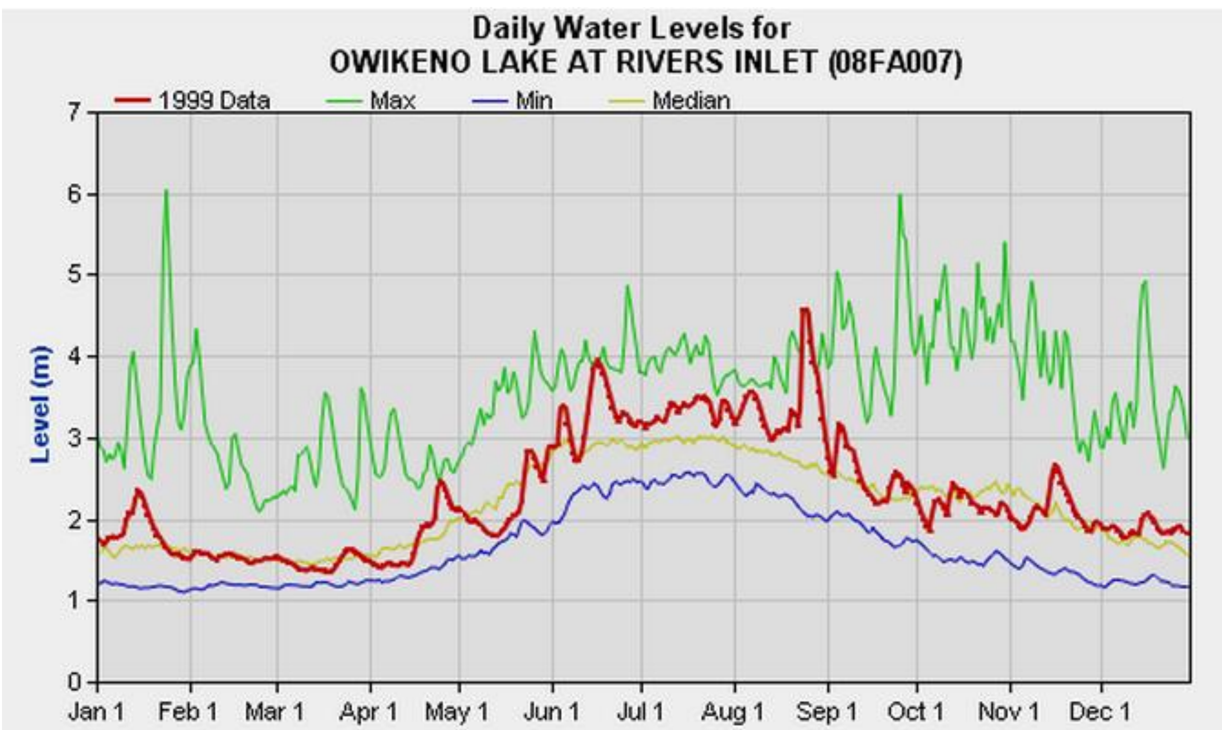


Figure 5. Historical annual hydrographs of Wannock River (WSC Station 08FA007) discharge (1927 to 2011; top) and Owikeno Lake (WSC Station 08FA002) water level (1961 to 2010; bottom). Red line is annual hydrograph for 1999.

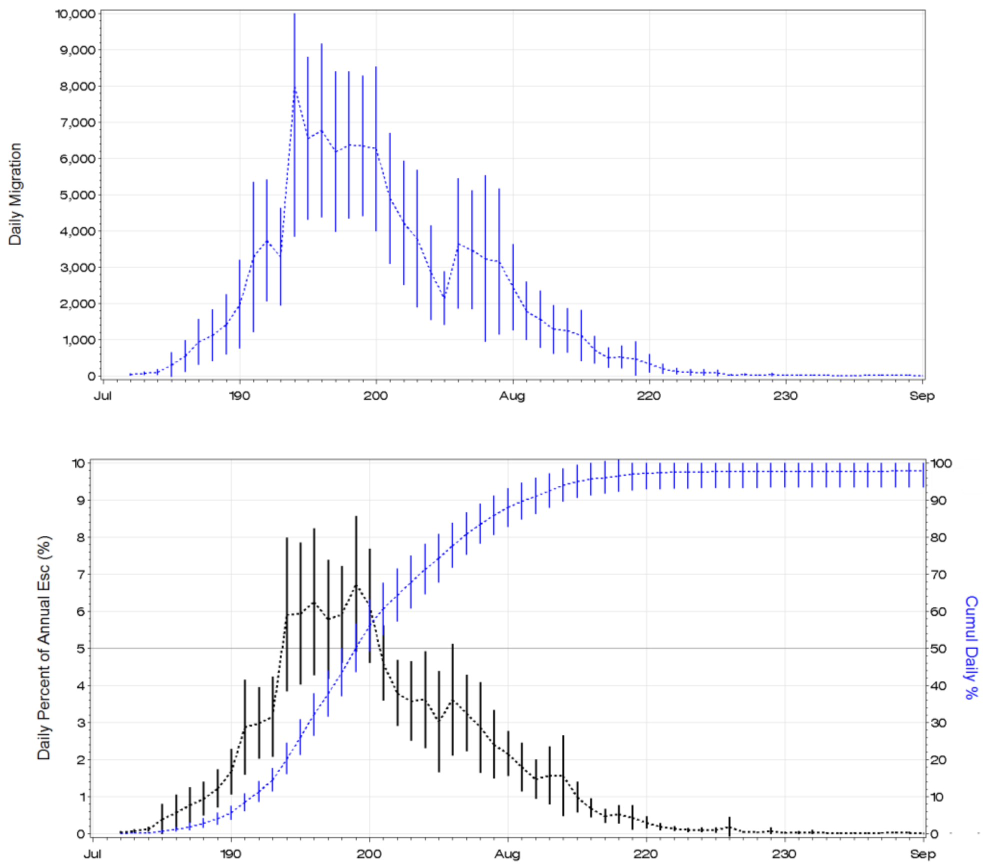


Figure 6. Historical mean daily adult Long Lake Sockeye migration timing through the Docee River fence, 1972-2012. Mean and variance (95% CI) of daily migrants (top) and mean daily % and cumulative % of total annual escapement (bottom). Time-to-50% ~ day 199 ~ July 18th (Source: DFO North Coast, unpub. data).

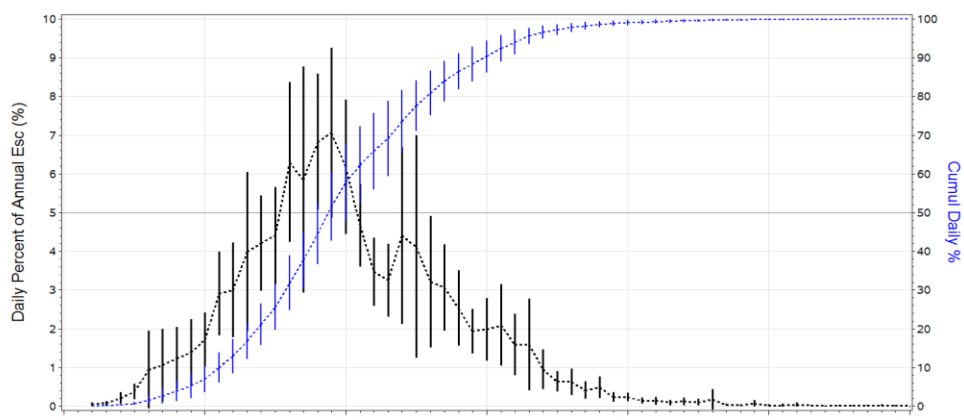


Figure 7. Mean daily and cumulative Sockeye migration rate (% of total annual escapement) through the Docee River fence, for low harvest rate (<30%) years: 1977, 1980, 1984, 1997-2012. Time-to-50% ~ day 199 ~ July 18th.

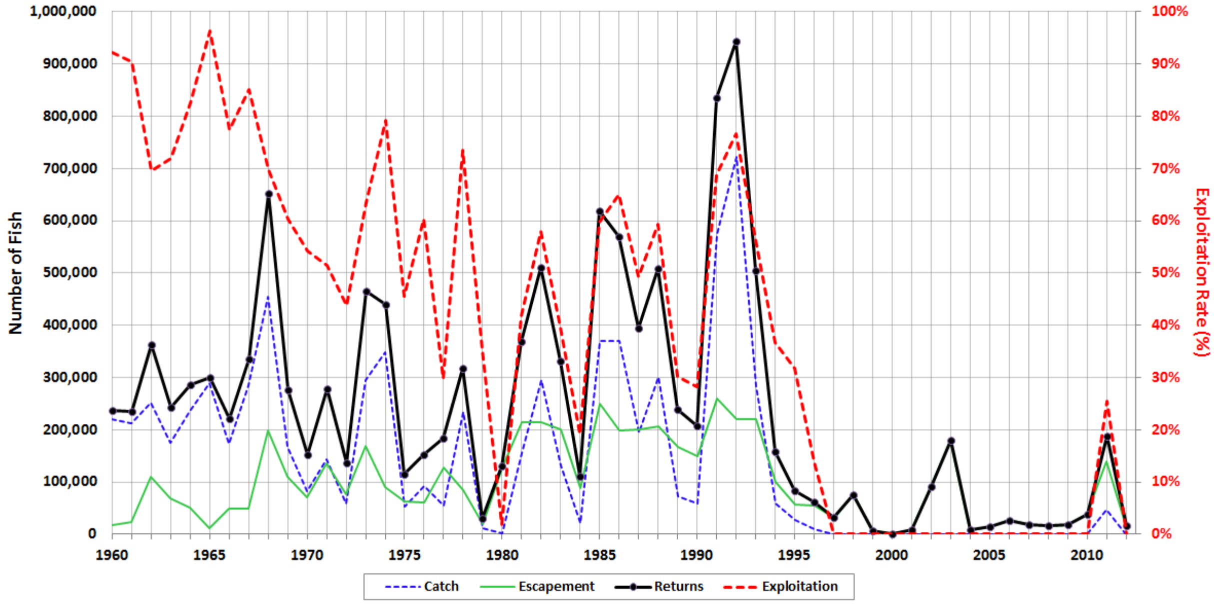


Figure 8. Annual Long Lake sockeye returns (black line) and exploitation rate (dashed red line), 1960-2012. The commercial gillnet fishery in Area 10 was closed from 1997 to 2010, and 2012. (Source: DFO North Coast, unpub. data). First Nation harvests represent less than 1% of the total stock (Rutherford and Wood 2000) and the impacts on migration timing may be considered negligible.

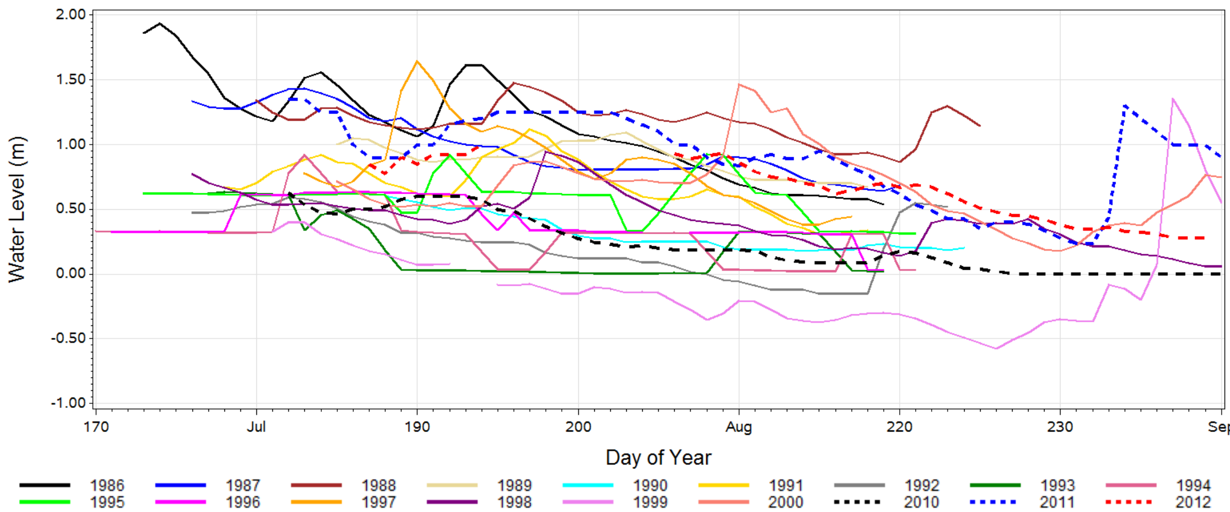


Figure 9. Observed daily mean water level (m) at the Docee River fence, by year 1986-2000, 2010-2012 (all available years).

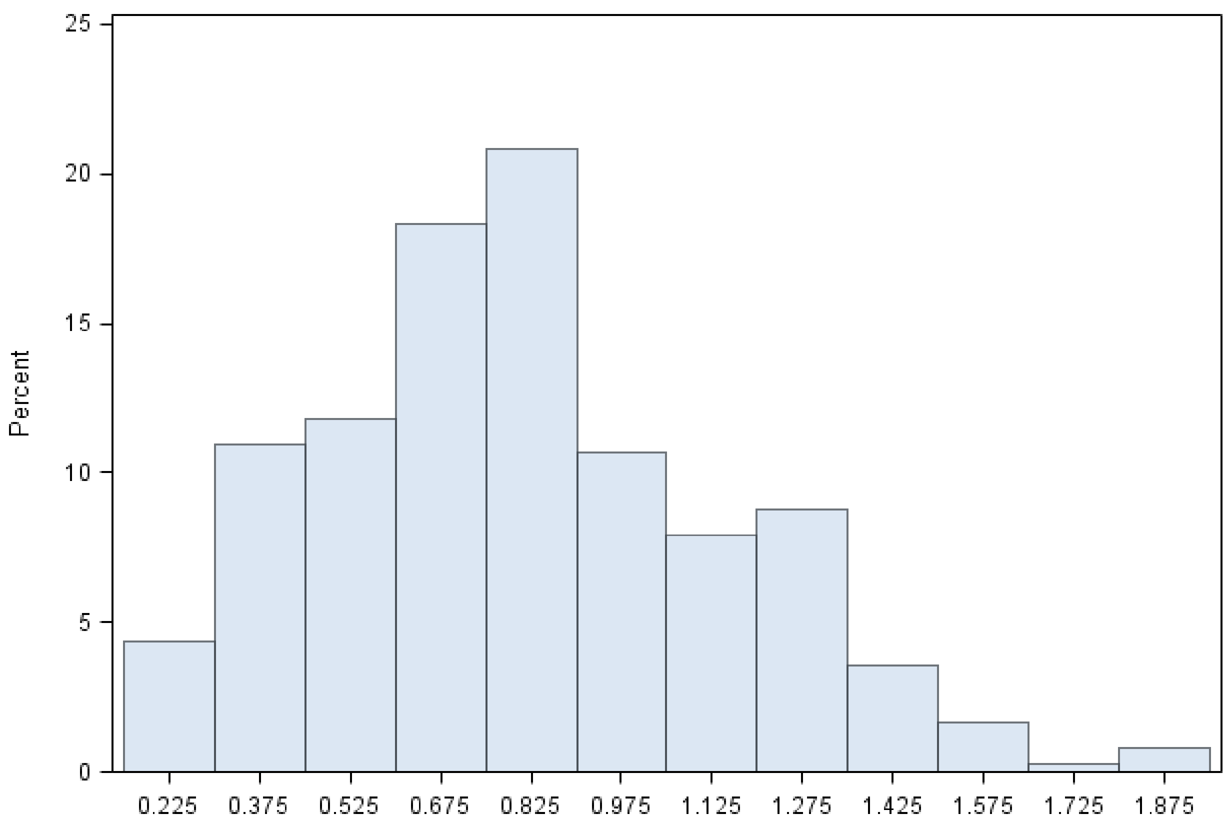


Figure 10. Distribution of observed daily mean water level (m) at the Docee River fence during the Sockeye migration period, 1986-1992, 1998, 2000, 2010-2012.

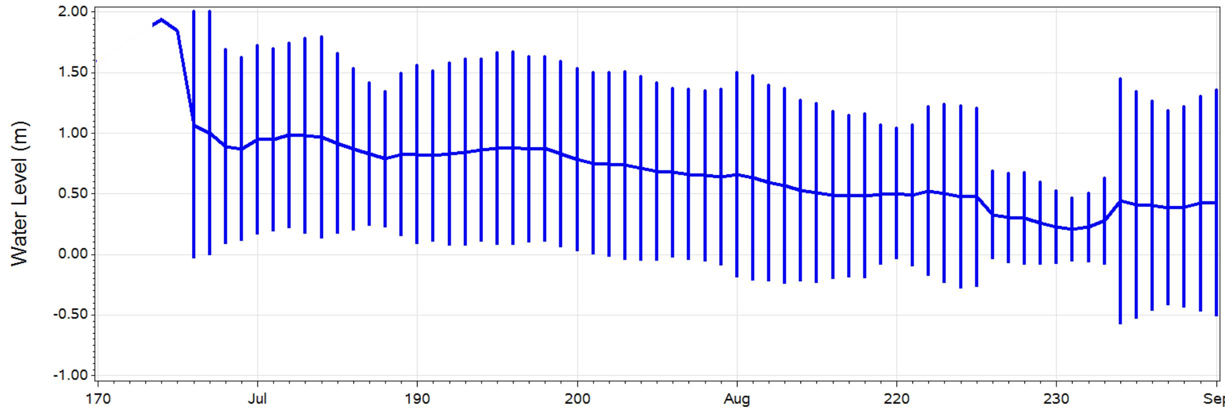


Figure 11. Observed daily mean water level (m) ± two standard deviations at Docee River fence for “best” years (1986-1992, 1998, 2000, 2010-2012).

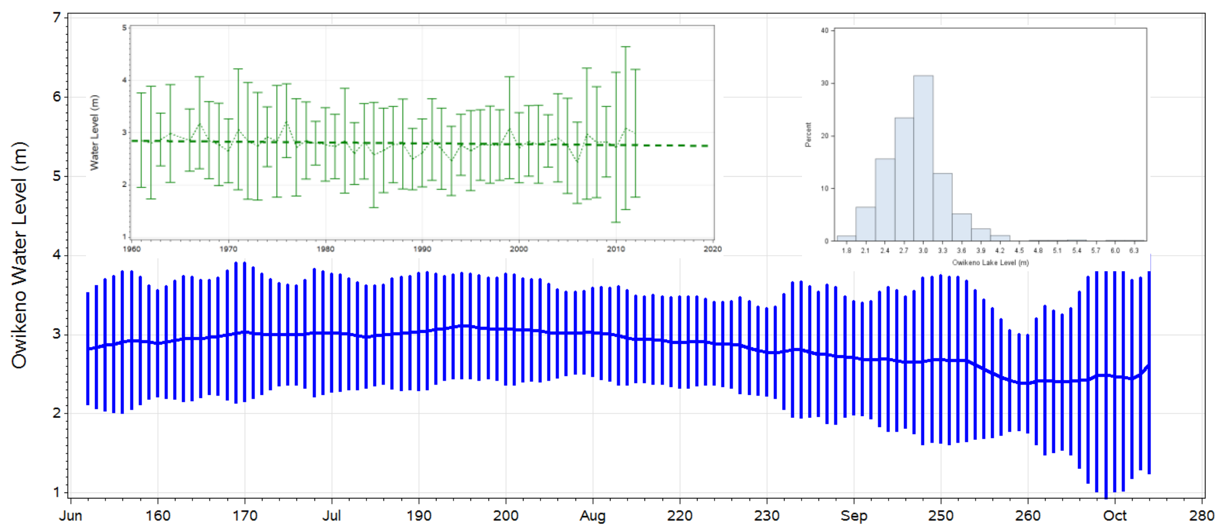
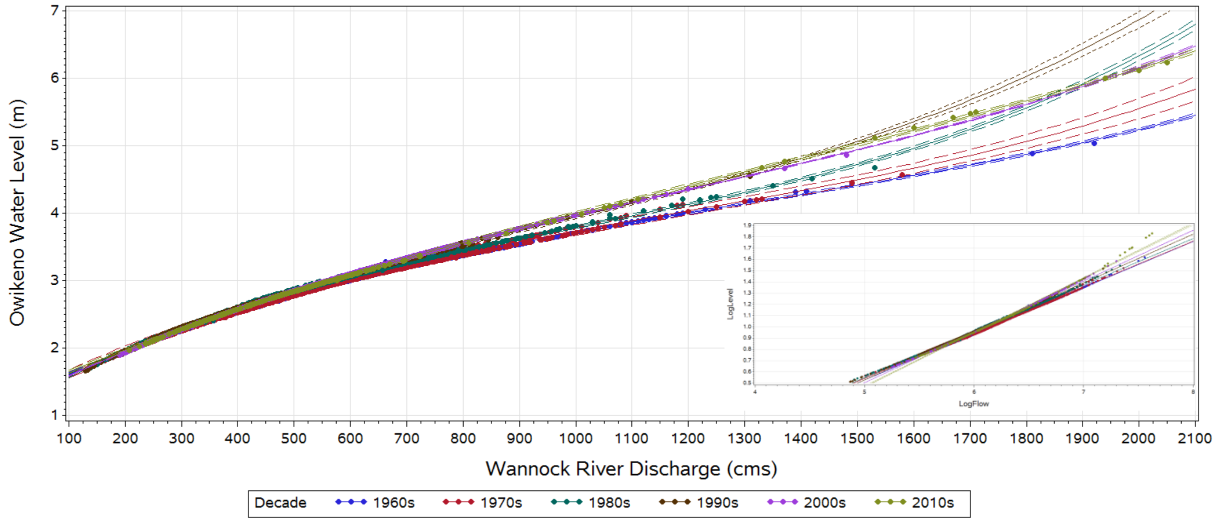


Figure 12. Observed daily mean water level (m) ± two standard deviations at *Owikeno Lake* (WSC Station 08FA007) during the Long Lake Sockeye migration period (Jun-Sep), 1961-2012, with trend (inset) and frequency distribution of observations.



Model: MODEL4
Dependent Variable: LogLevel

Number of Observations Read	6322
Number of Observations Used	6133
Number of Observations with Missing Values	189

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	143.74503	143.74503	636983	<.0001
Error	6131	1.38356	0.00022567		
Lack of Fit	787	0.71171	0.00090434	7.19	<.0001
Pure Error	5344	0.67184	0.00012572		
Corrected Total	6132	145.12858			

Root MSE	0.01502	R-Square	0.9905
Dependent Mean	1.02896	Adj R-Sq	0.9905
Coeff Var	1.45994		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-1.56248	0.00325	-480.38	<.0001
LogFlow		1	0.41917	0.00052520	798.11	<.0001

Figure 13. Mean daily mean water level (m) at *Owikeno Lake* (WSC Station 08FA007) as a function of daily mean discharge in the *Wannock River* (WSC Station 08FA002) (1961-2011; top), with log-log regression relationship (inset) and statistics (bottom). Final model: *Owikeno* = $e^{-1.56}$ * *Wannock* $^{0.419}$; P < .0001.

Figure 14. Mean daily mean water level (m) observed at the Docee River fence as a function of daily mean water level (m) measured at *Owikeno Lake* based on select years where annual $r^2 > 50\%$ (1986, 1987, 1991, 1992, 1997, 1999, 2000, 2011, 2012; r = 0.45) (top); 1999 omitted (middle; r = 0.55); and log-log relation (bottom; r = 0.54).

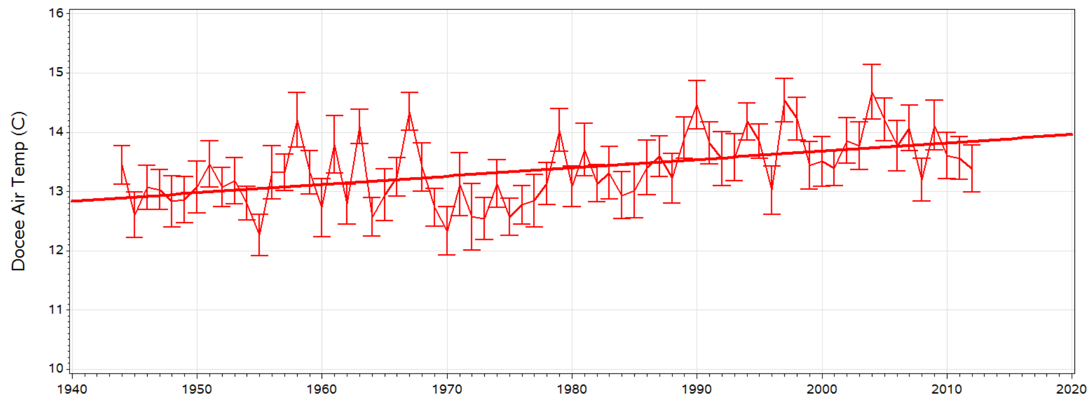


Figure 15. Observed PORT HARDY mean air temperature ± 2 standard errors of the mean, July-September 1944-2012. Long-term warming trend is evident (Y = -14.4 + 0.014 * Year; r = 0.020; P < .0001).

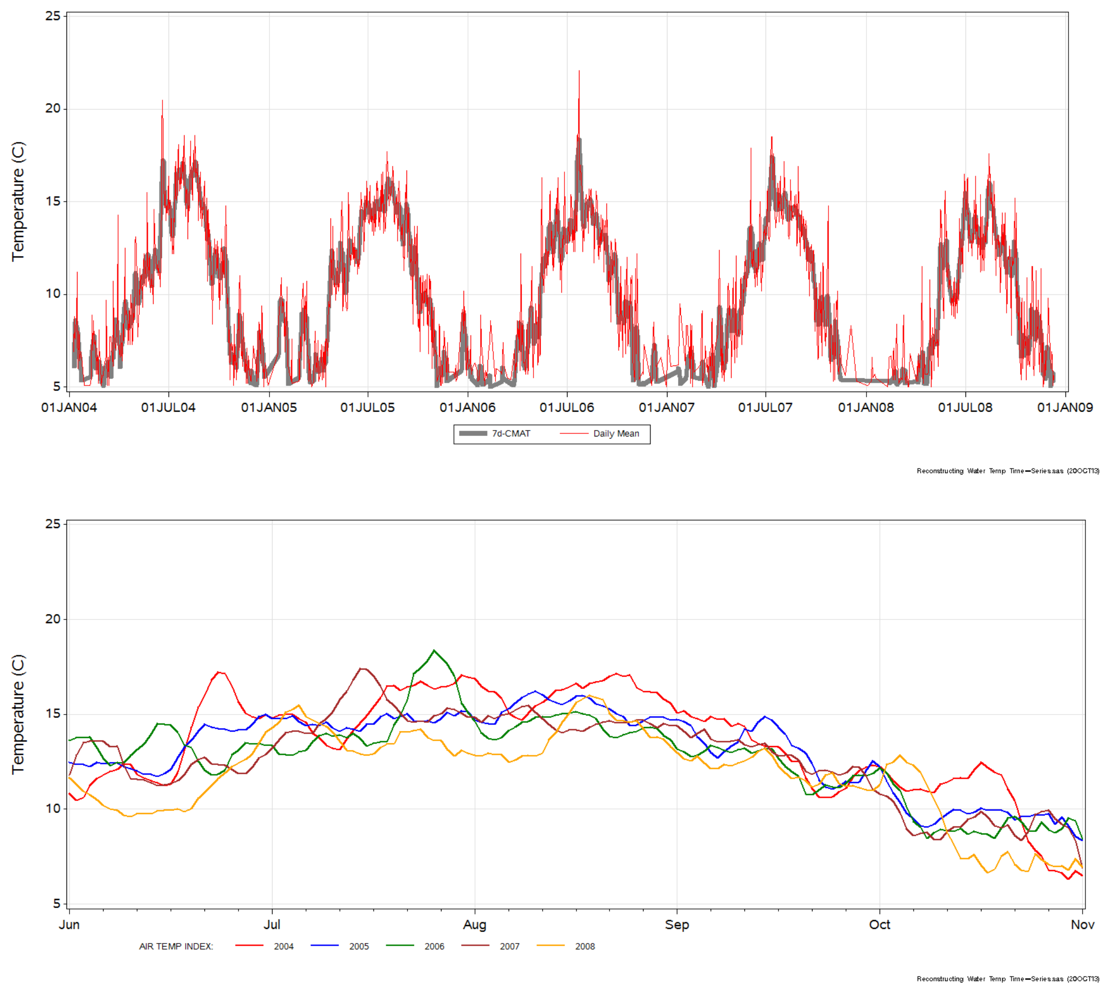
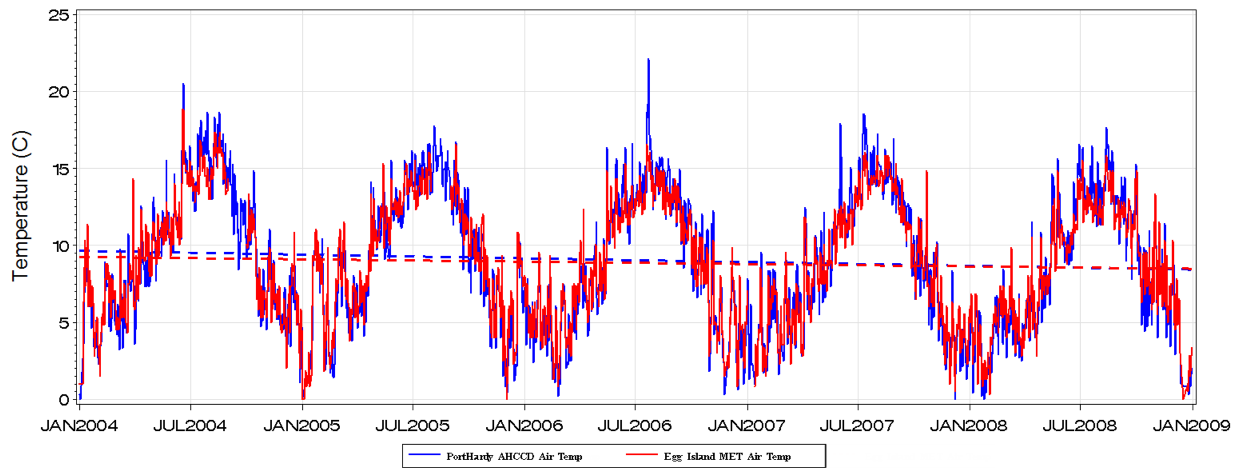


Figure 16. Port Hardy daily mean air temperature (top) and 7-day centered moving average temperature index (7dCMAT) for the Sockeye migratory period, 2004 – 2008.



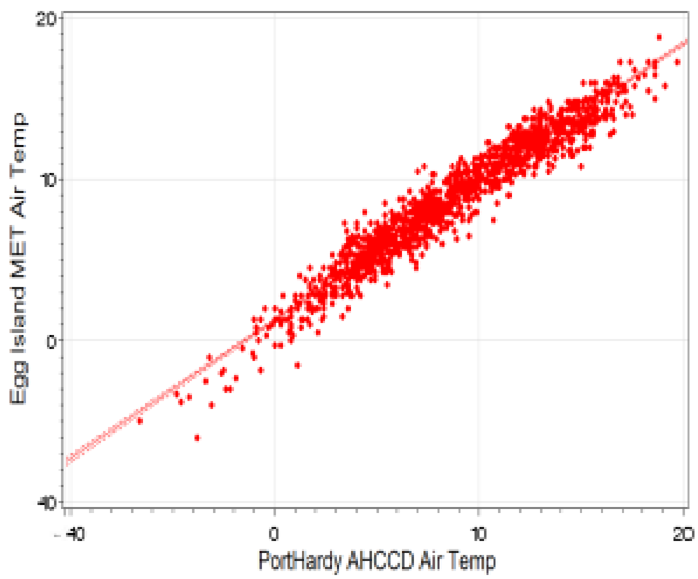


Figure 17. Port Hardy daily mean air temperature versus Egg Island daily mean air temperature, 2004 – 2008, with trend lines (not significantly different between locations (slope m ~ -0.0003), top); Correlation between air temperature time-series: r = 0.97, bottom.

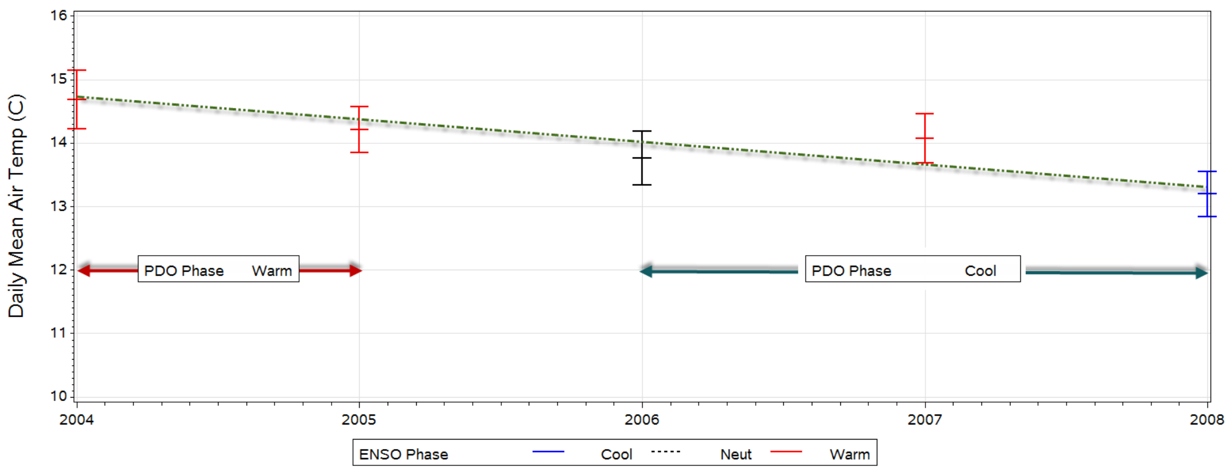


Figure 18. Trend in Port Hardy daily mean air temperature for the Sockeye migratory period, and shifts in ocean conditions (PDO and ENSO phase) 2004 – 2008.

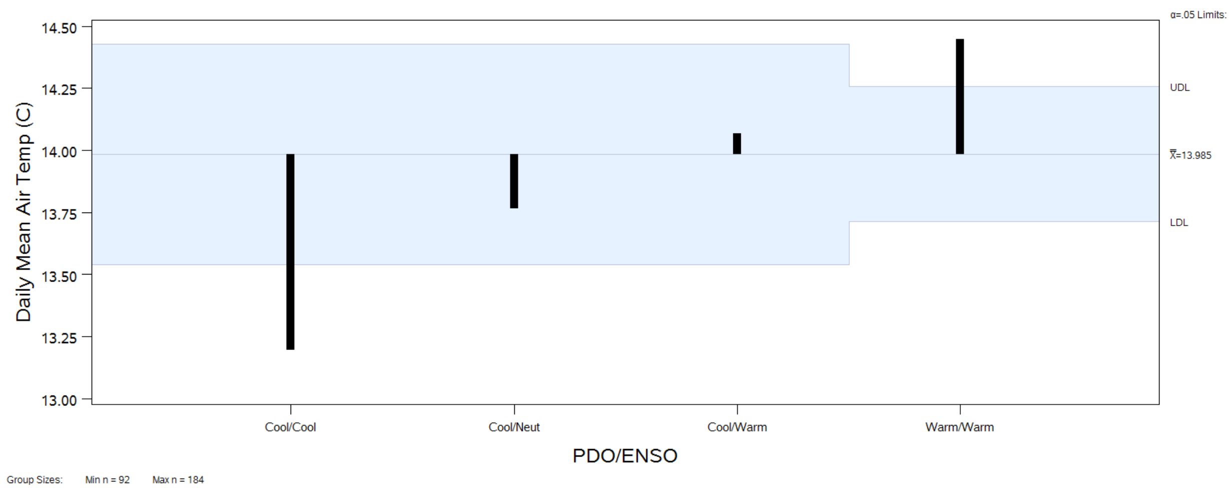


Figure 19. Port Hardy daily mean air temperature classified by combined PDO and ENSO phase for the Sockeye migratory period, 2004 – 2008. Reinforcing PDO/ENSO phases (cool/cool and warm/warm) are significantly different from the overall mean (~14.0ºC) during this time frame.

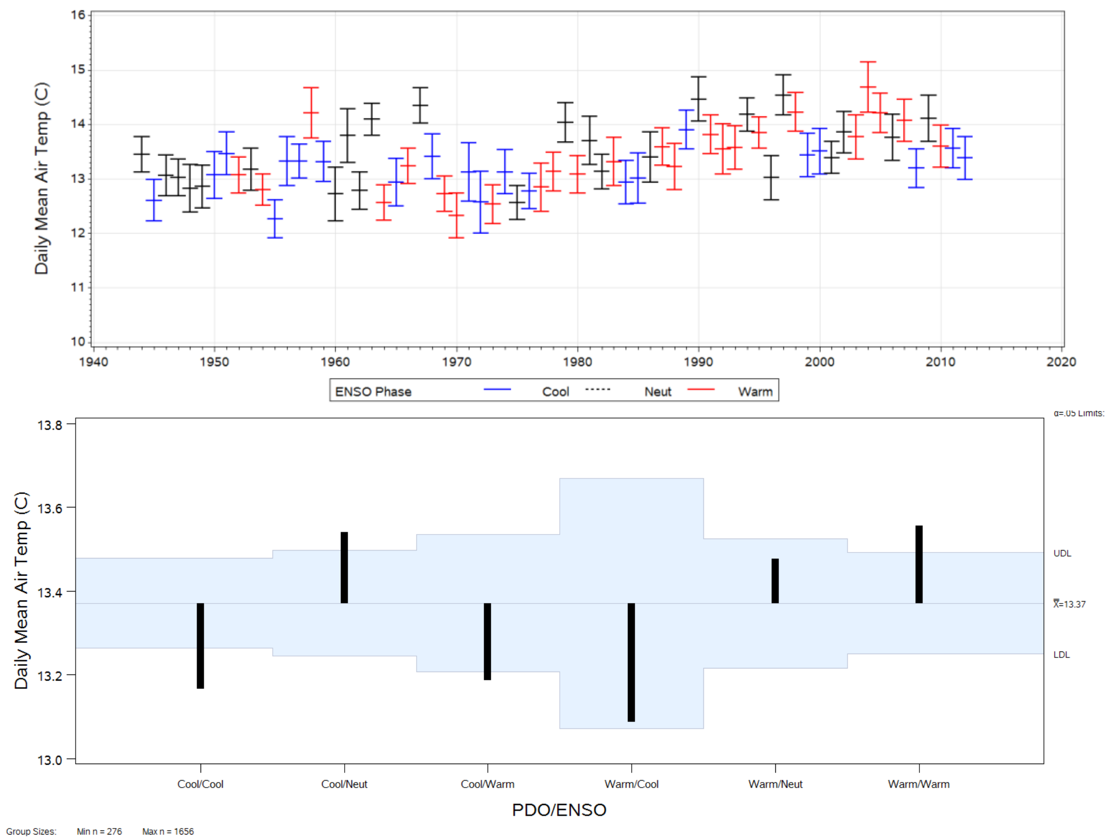


Figure 20. Port Hardy daily mean air temperature classified by combined PDO/ENSO phase for the Sockeye migratory period, 1944 – 2012, resembles Figure 19, except that warm regional air temperature conditions during “cool/neutral” PDO/ENSO years (1963, 1967, 1979, 1981, 1990, 1994, and 1997; top) appear to be driving the anomalous mean temperature needle for the “cool/neutral” classification (bottom).

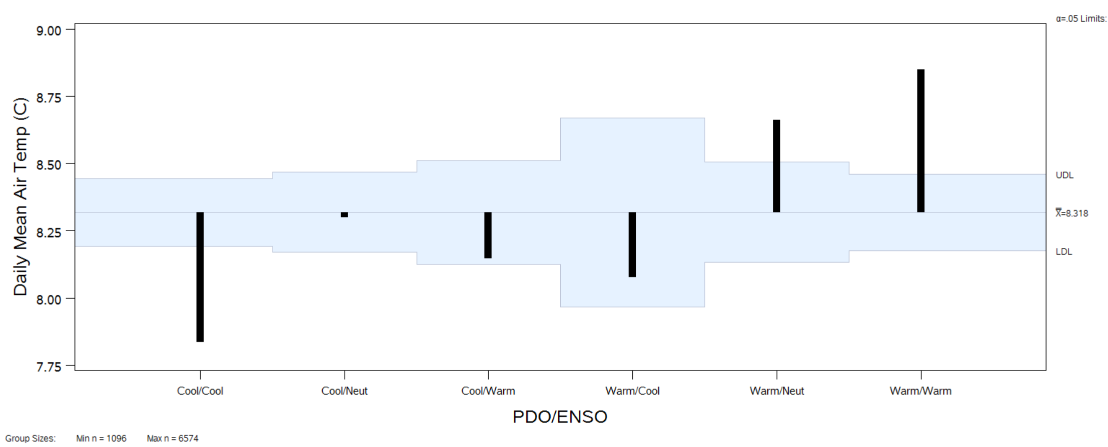


Figure 21. Port Hardy daily mean air temperature classified by combined PDO and ENSO phase for all seasons, 1944 – 2012. Reinforcing PDO/ENSO phases (cool/cool and warm/warm) are significantly different from the overall mean (~8.3ºC) during this time frame.

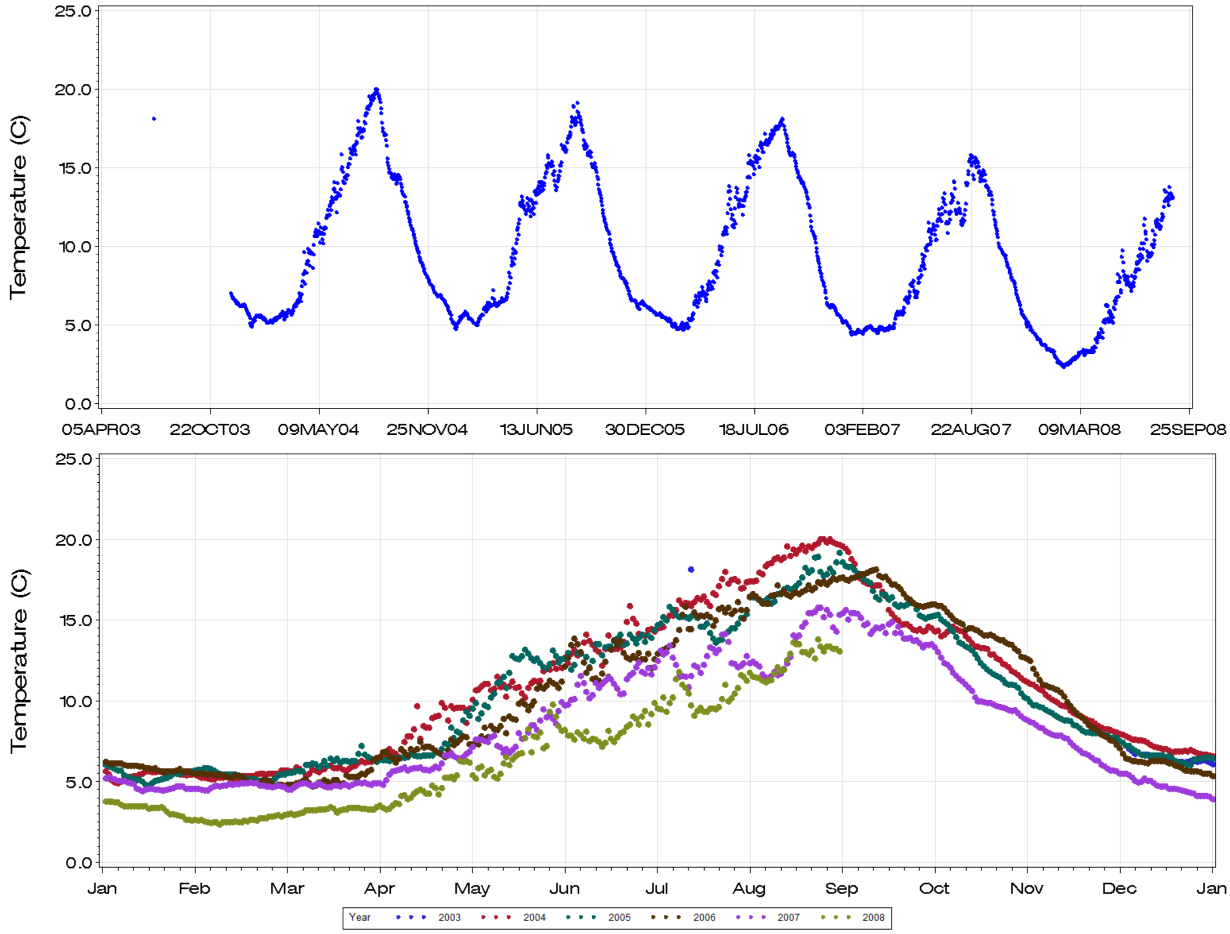


Figure 22. Docee River daily mean water temperature from data loggers at the counting fence, October 2003 – August 2008.

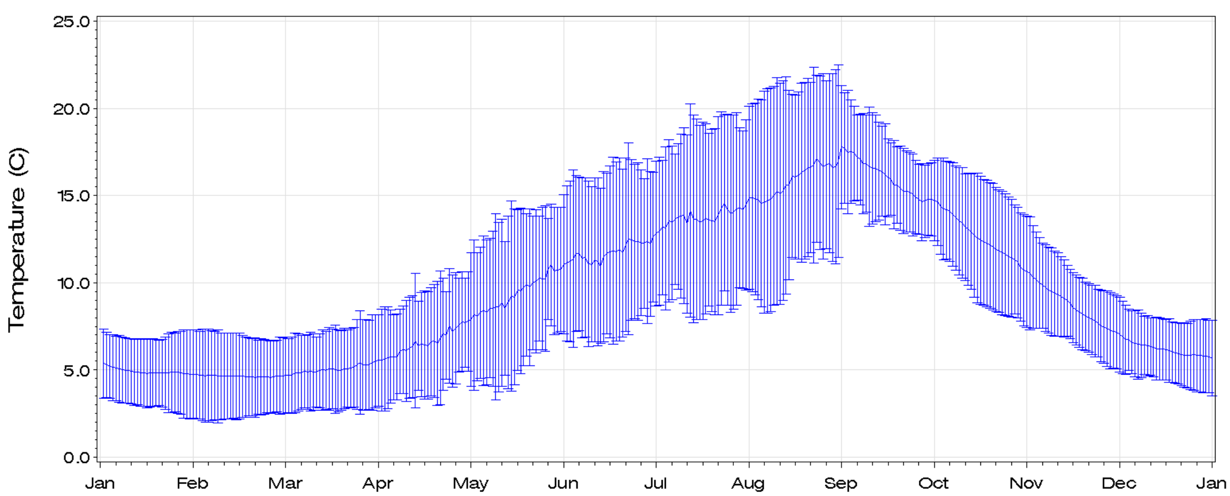


Figure 23. Annual thermograph of daily mean water temperature ± 2 standard deviations for Docee River at the fishway, 2003-2008.

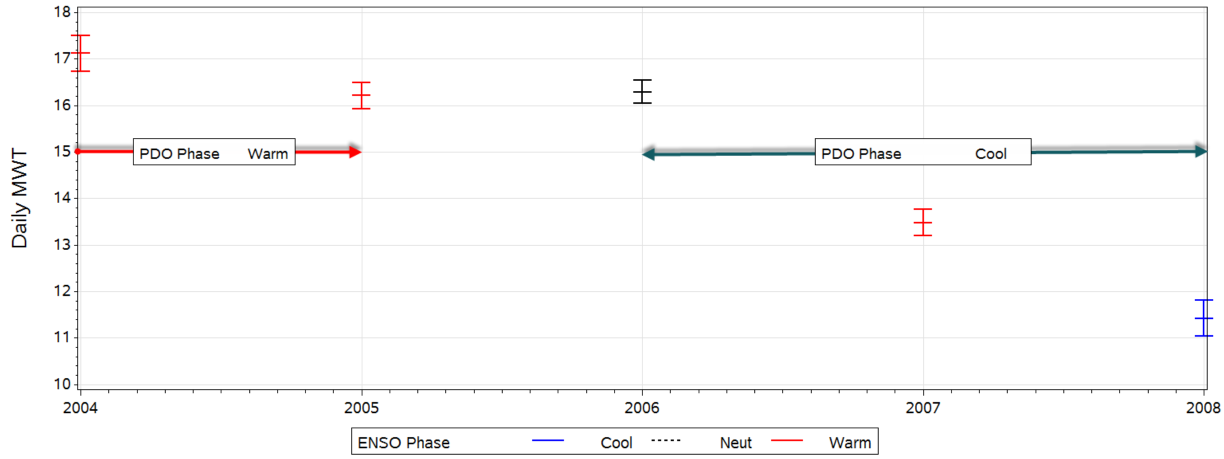


Figure 24. Trend in observed Docee River daily mean water temperature for the Sockeye migratory period (July-September), classified by phase in PDO and ENSO ocean conditions, 2004 – 2008.

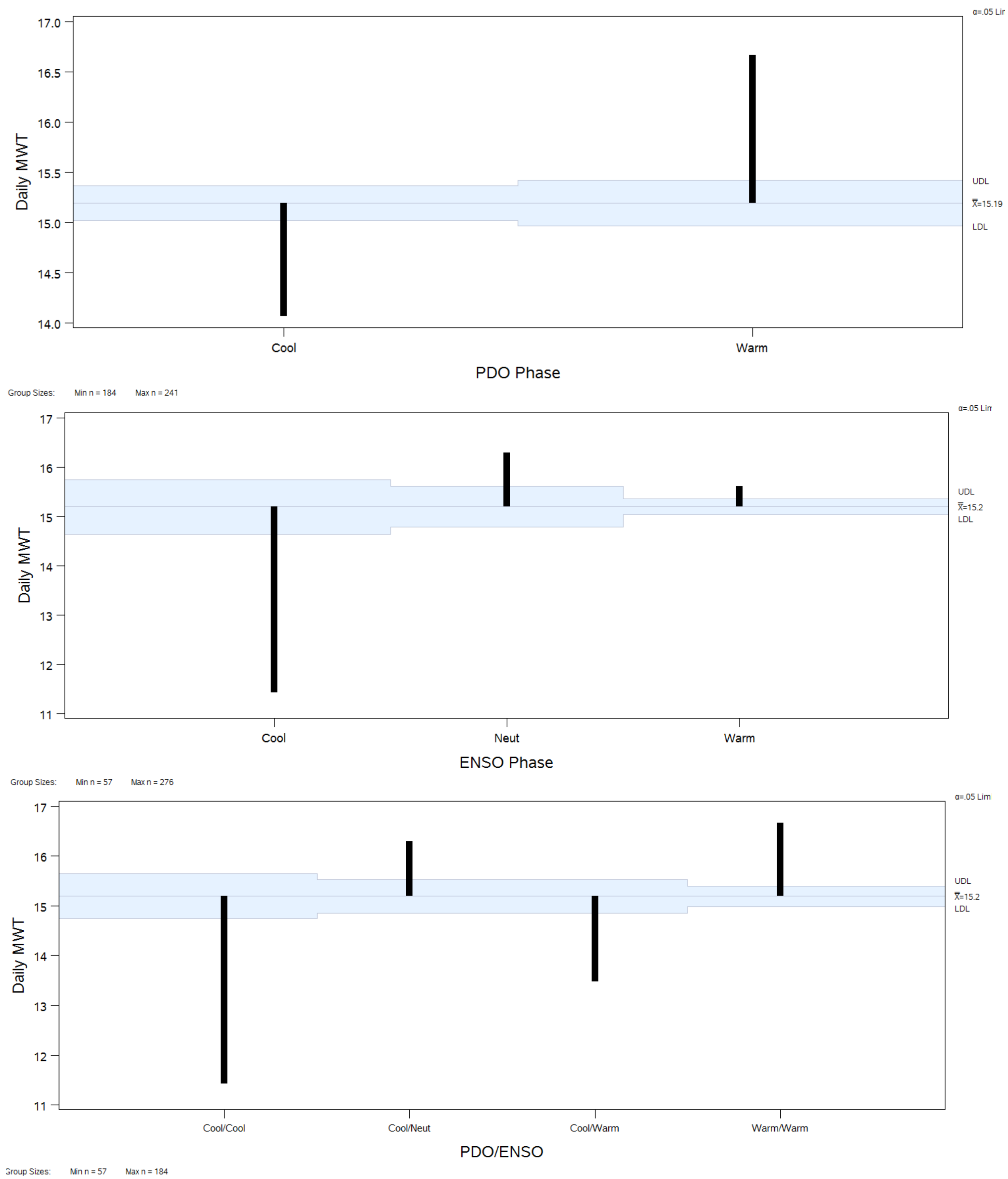


Figure 25. Docee River observed daily mean water temperature (July-September, 2004-2008) classified by combined PDO phase (top), ENSO phase (middle), and combined PDO/ENSO phases (bottom).

Figure 26. Canoe Creek daily mean data logger water temperature, Oct 03 – Apr-06.

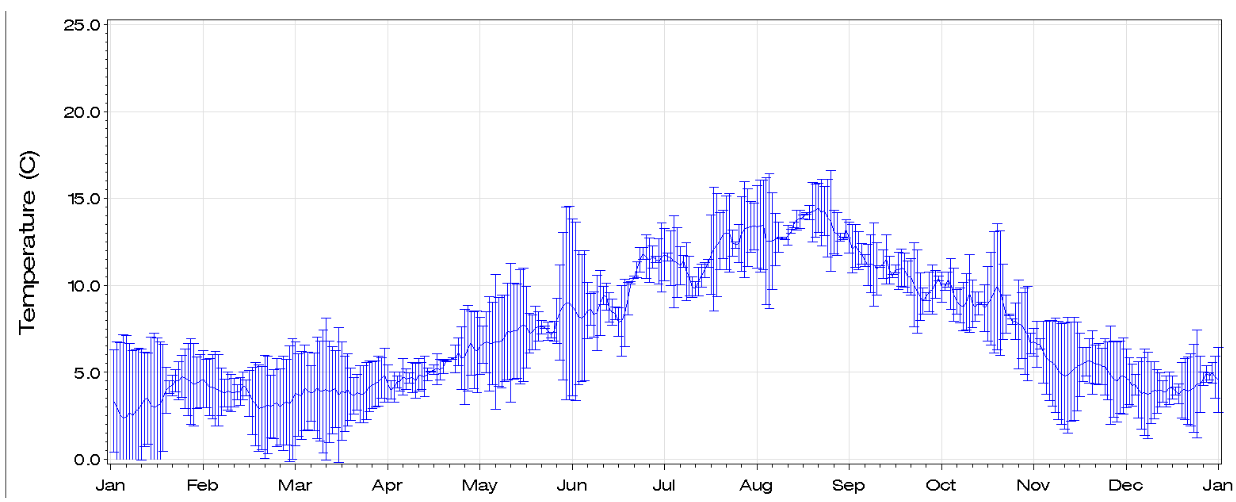
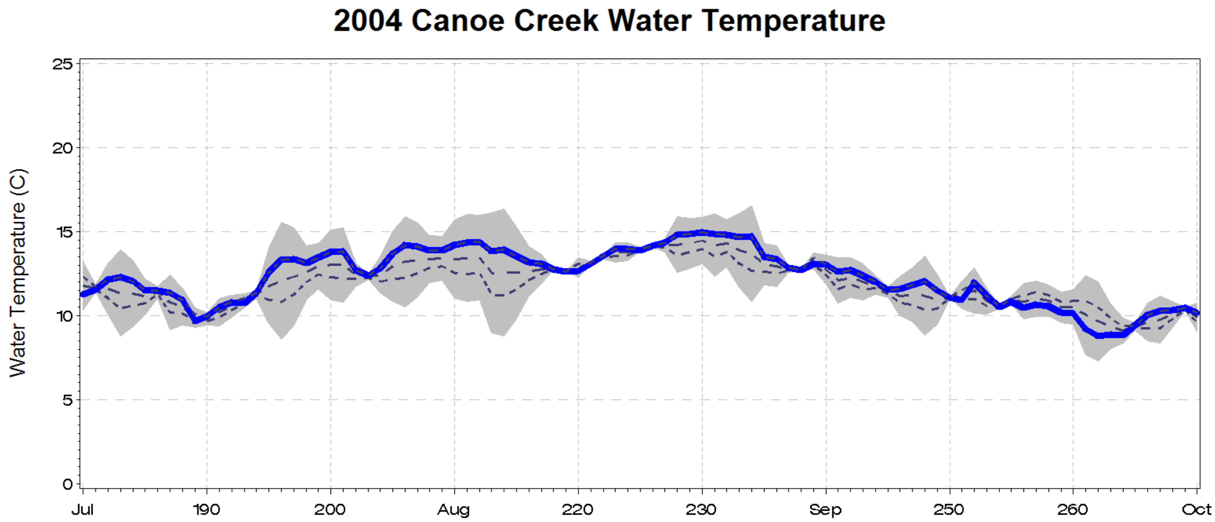


Figure 27. Annual thermograph of daily mean water temperature ± 2 standard deviations for Canoe Creek, 2003-2006.



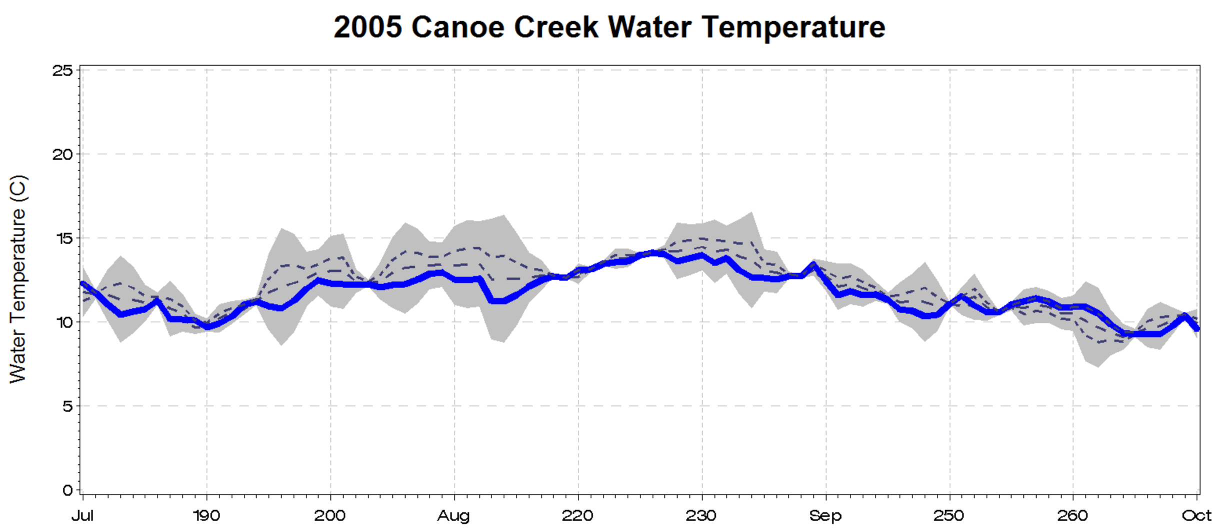


Figure 28. Canoe Creek daily mean water temperature (blue line) from hourly data logger recordings, during the Sockeye migration period, 2004 and 2005.

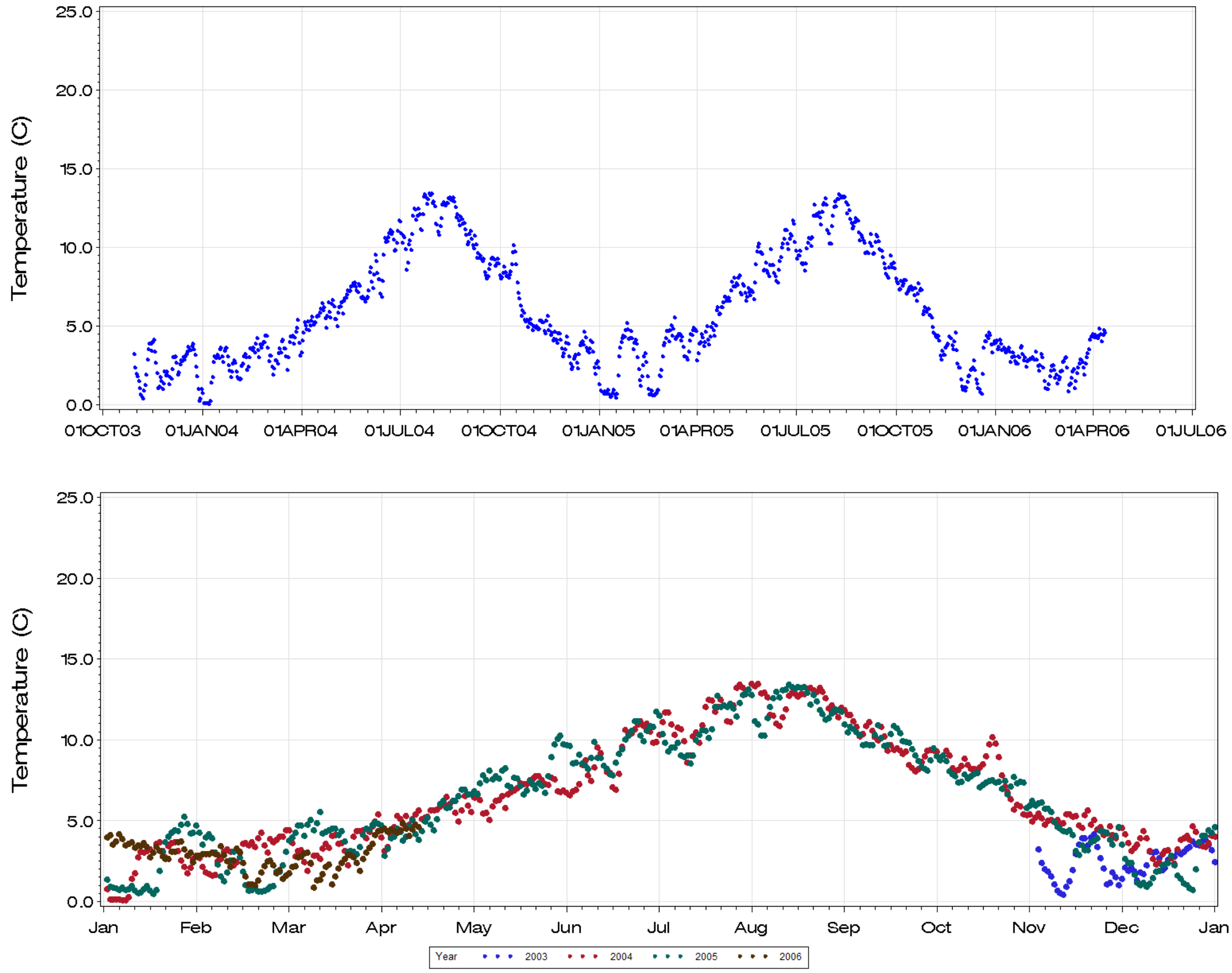


Figure 29. Observed Smokehouse Creek daily mean water temperature, Oct 2003 – Apr-2006.

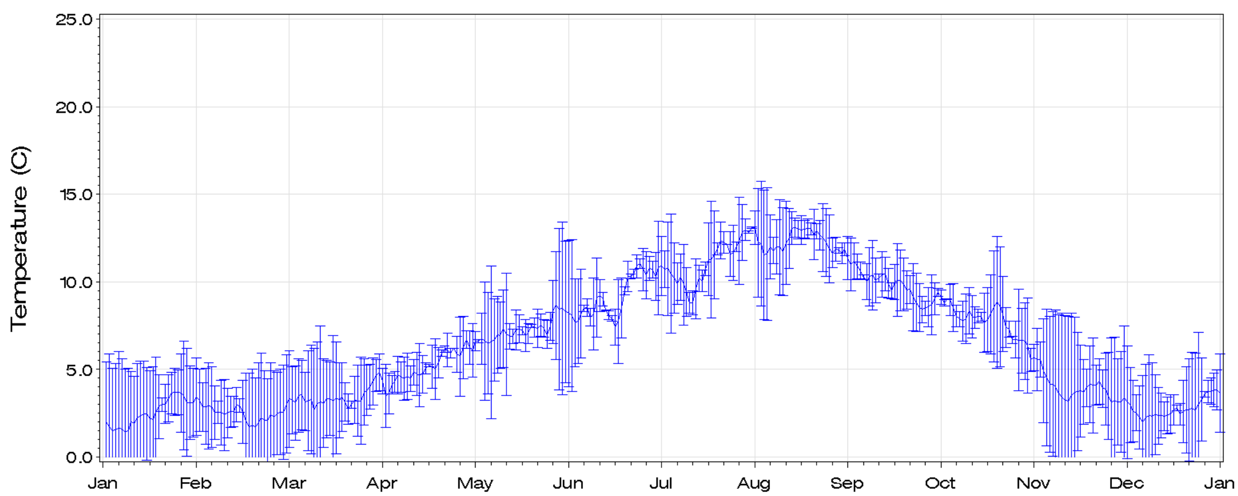
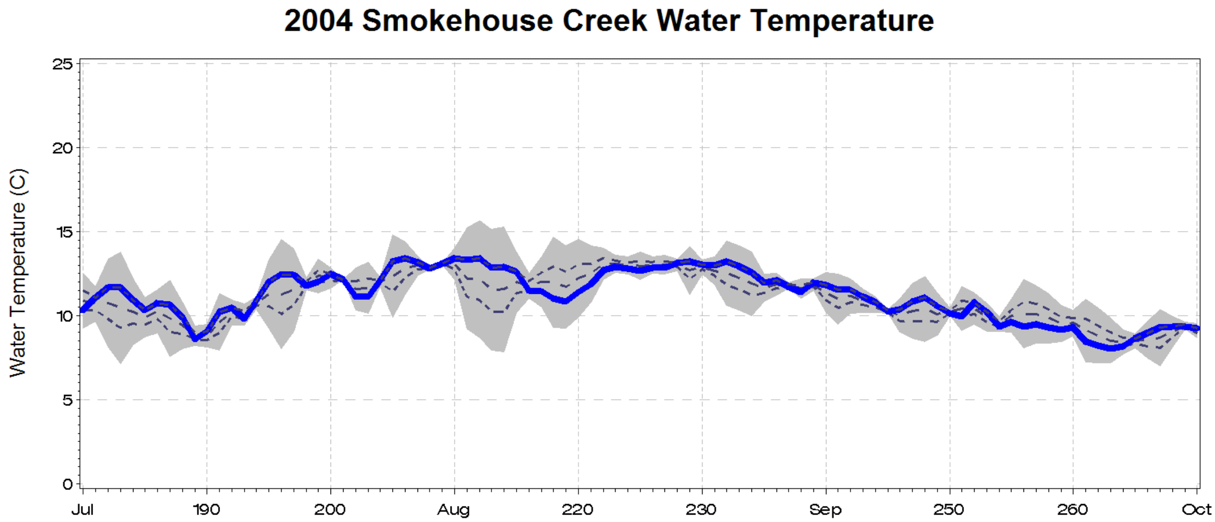


Figure 30. Annual thermograph of daily mean water temperature ± 2 standard deviations for Smokehouse Creek, 2003-2006.



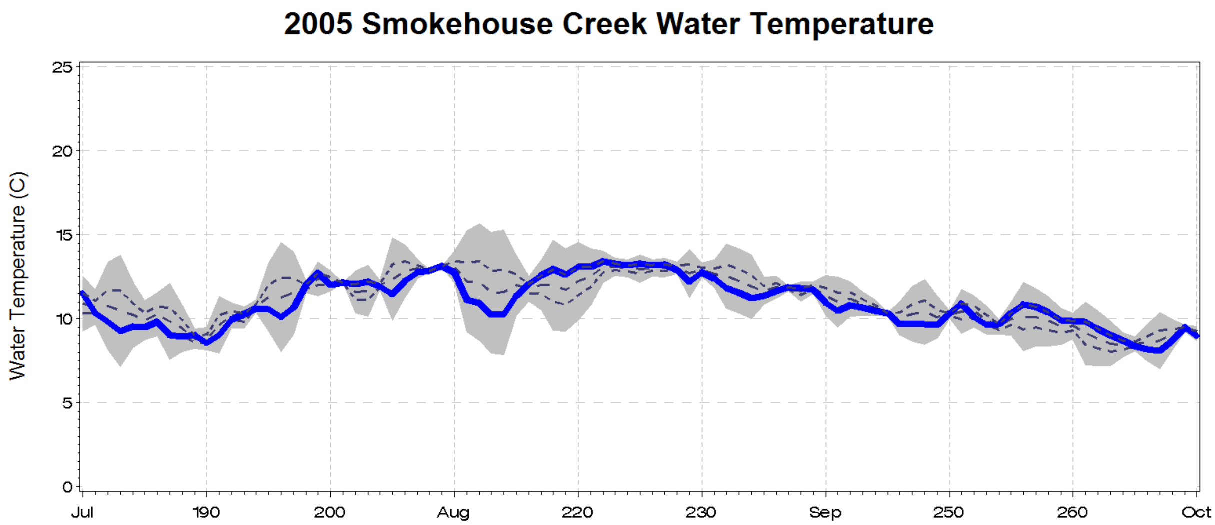


Figure 31. Smokehouse Creek daily mean water temperature (blue line) from hourly data logger recordings, during the Sockeye migration period, 2004 and 2005.

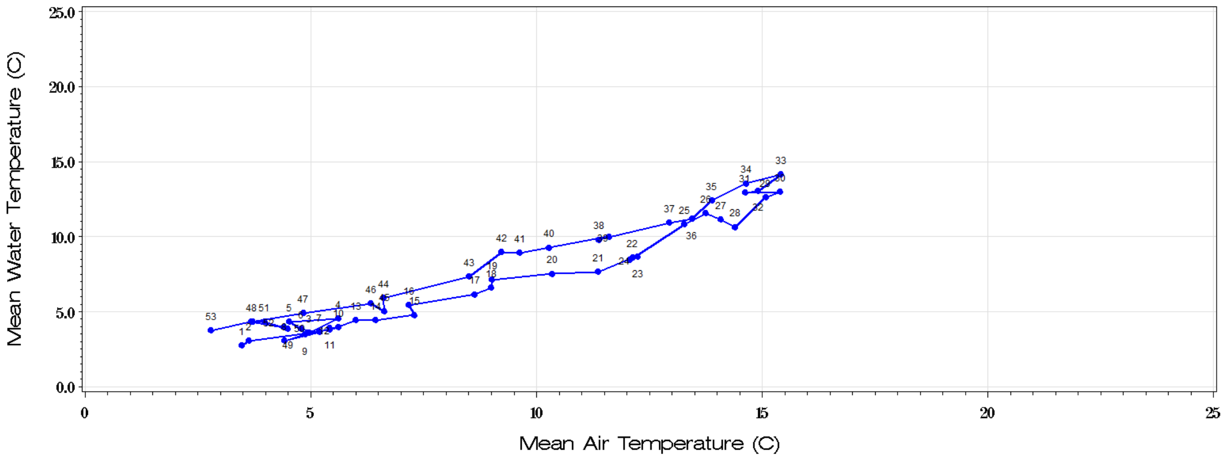


Figure 32. Derivation of seasonal turn-around point for Canoe Creek, based on maximum weekly mean air and water temperature data. The seasonal turn-around point is in week 33, approximately August 18th. The “warming season” therefore extends from April 1 to August 18th, followed by the “cooling season” from August 19th – November 24th.

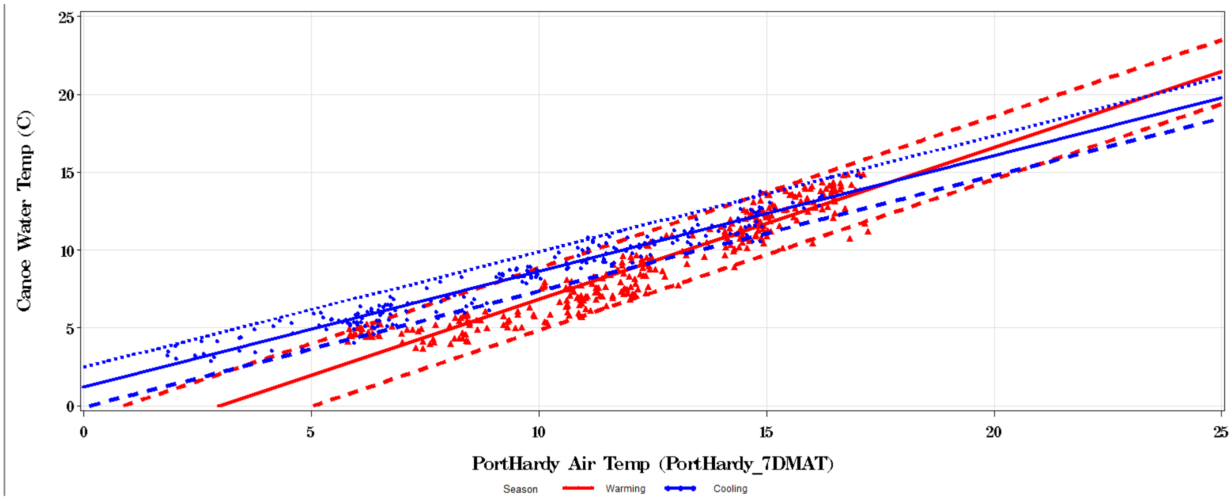


Figure 33. Linear regression fits for air/water temperature relationship for Canoe Creek daily mean water temperatures as a function of the PORT HARDY 7d-CMAT (air temperature index), by season (warming season (red) and cooling season (blue)).

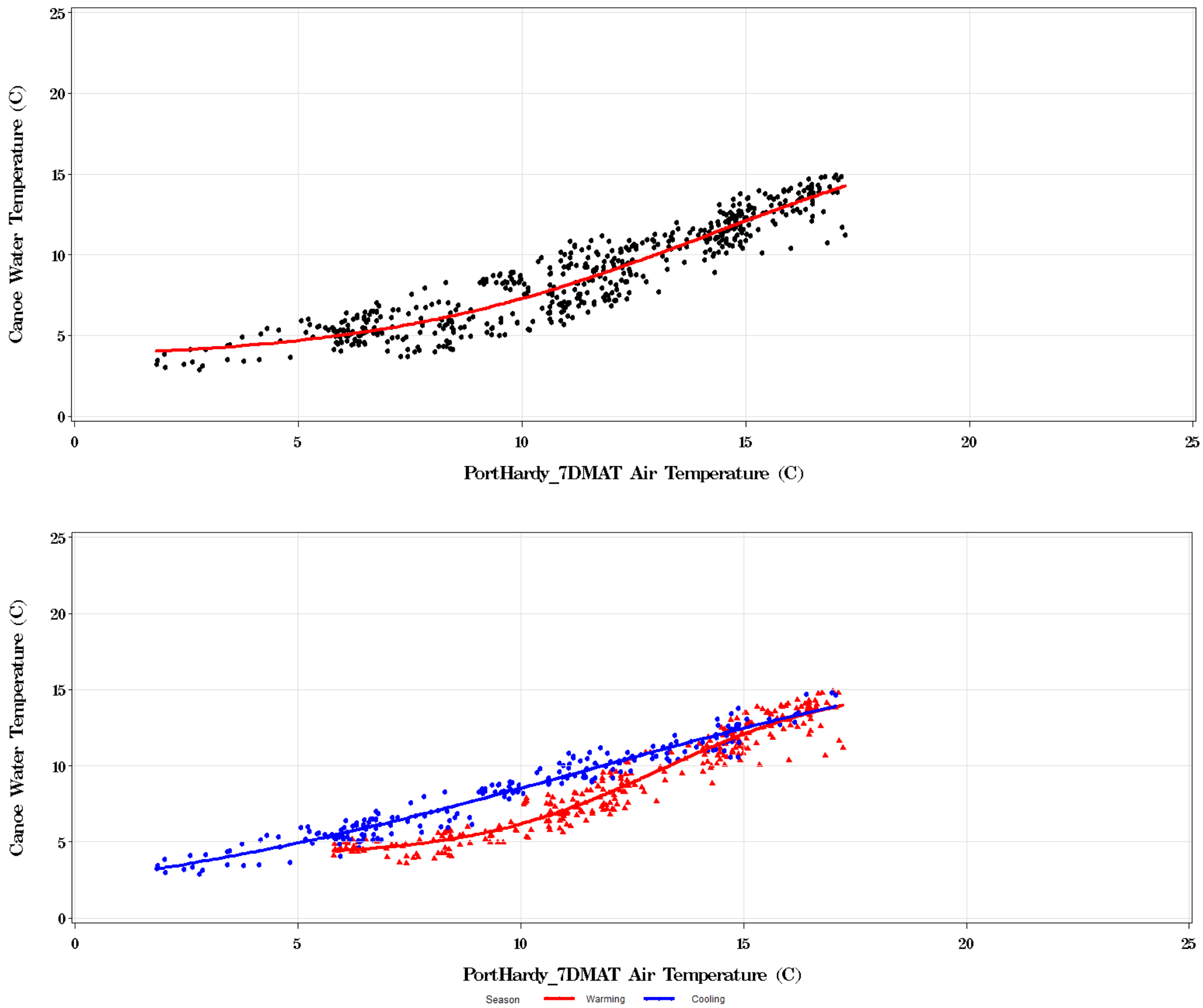


Figure 34. Logistic regression fits for air/water temperature relationship for Canoe Creek daily mean water temperatures as a function of the PORT HARDY 7d-CMAT (air temperature index): seasons combined (top); separate warming season (red) and cooling seasons (blue)(bottom).

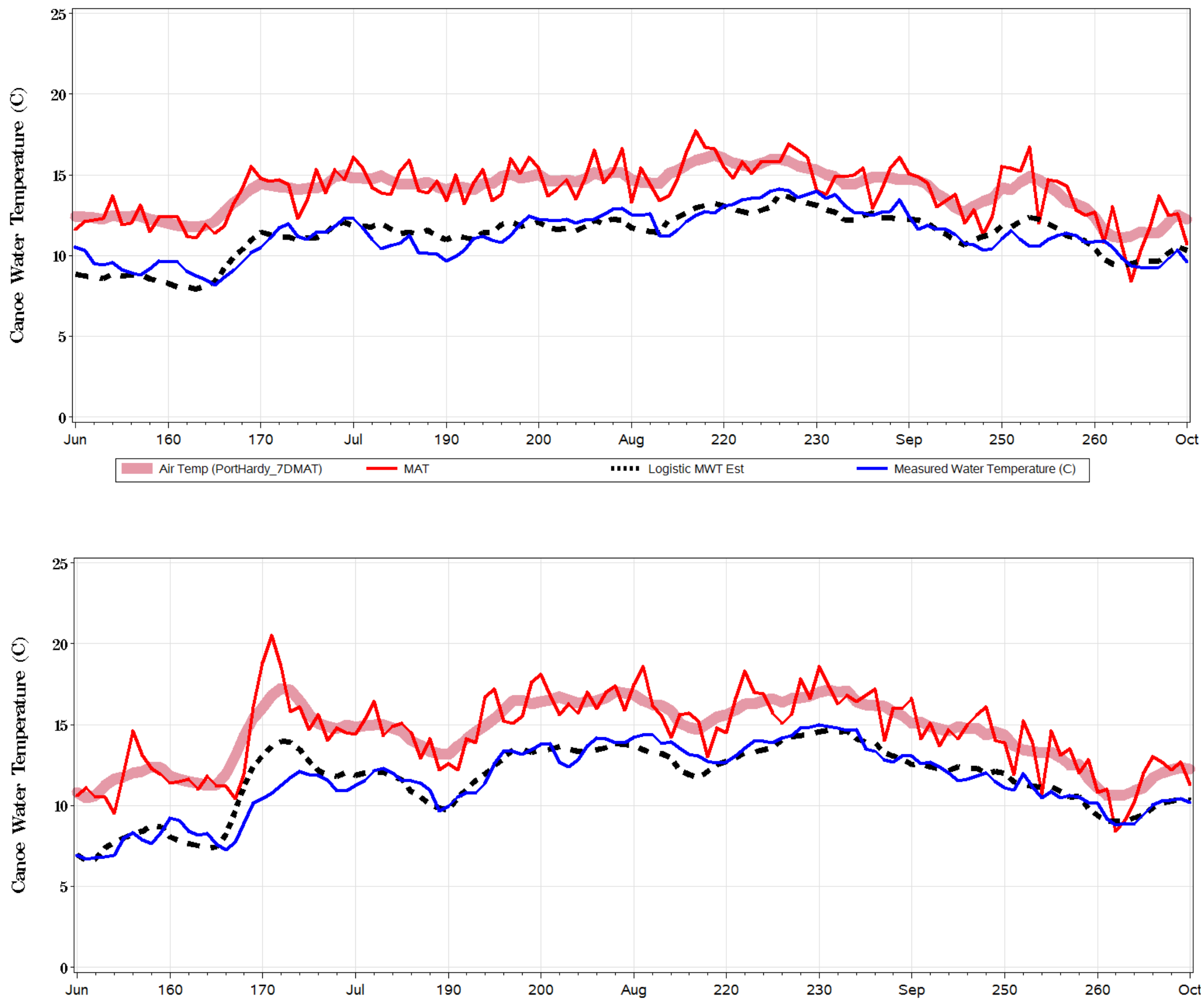


Figure 35. Validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for Canoe Creek, 2004 (top), 2005 (bottom).

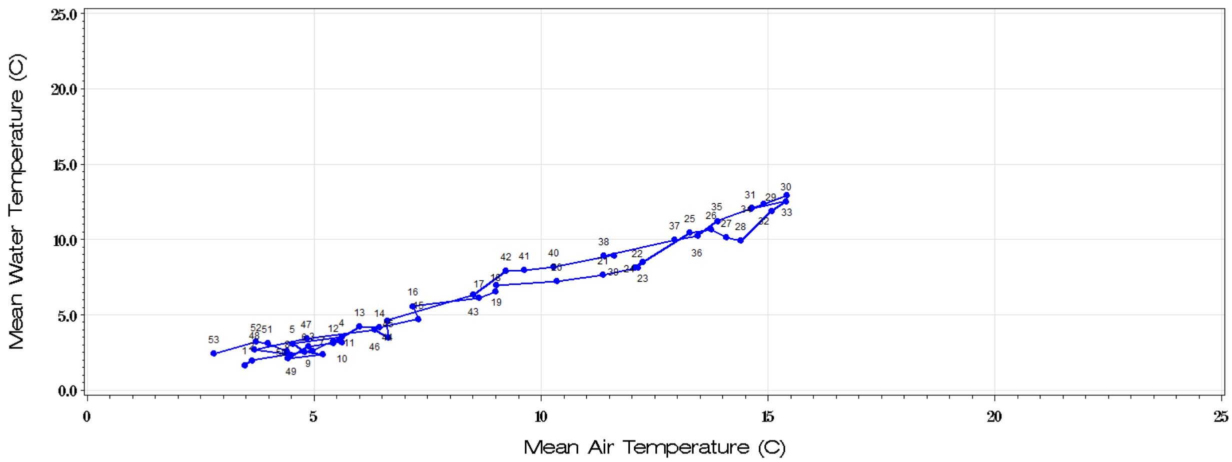


Figure 36. Derivation of seasonal turn-around point for Smokehouse Creek, based on maximum weekly mean air and water temperature data. The seasonal turn-around point is in week 33, approximately August 18th. The "warming season" therefore extends from April 1 to August 18th, followed by the "cooling season" from August 19th – November 24th.

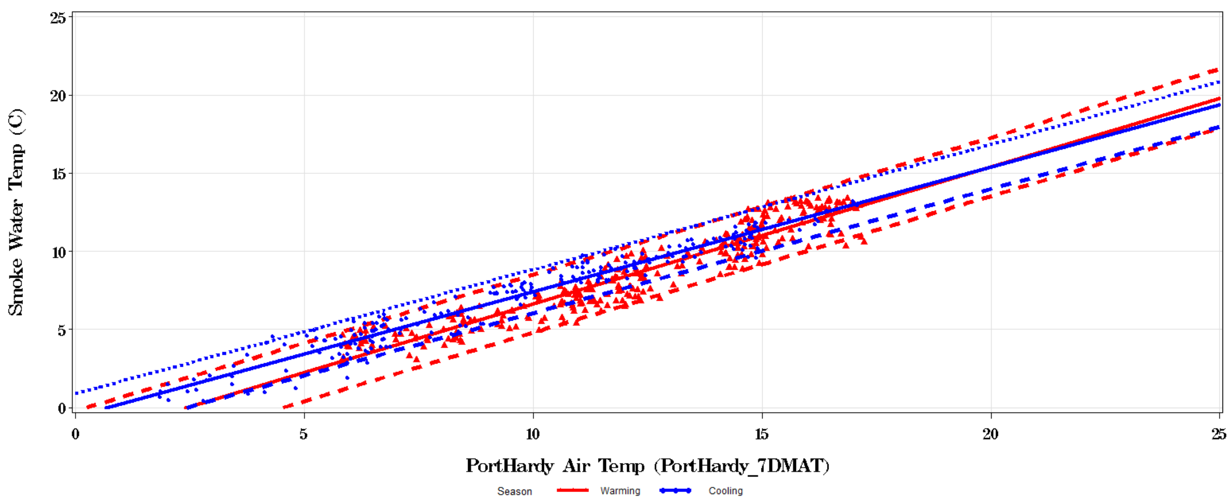


Figure 37. Linear regression fits for air/water temperature relationship for Smokehouse Creek daily mean water temperatures as a function of the PORT HARDY 7d-CMAT (air temperature index), by season (warming season (red) and cooling season (blue)).

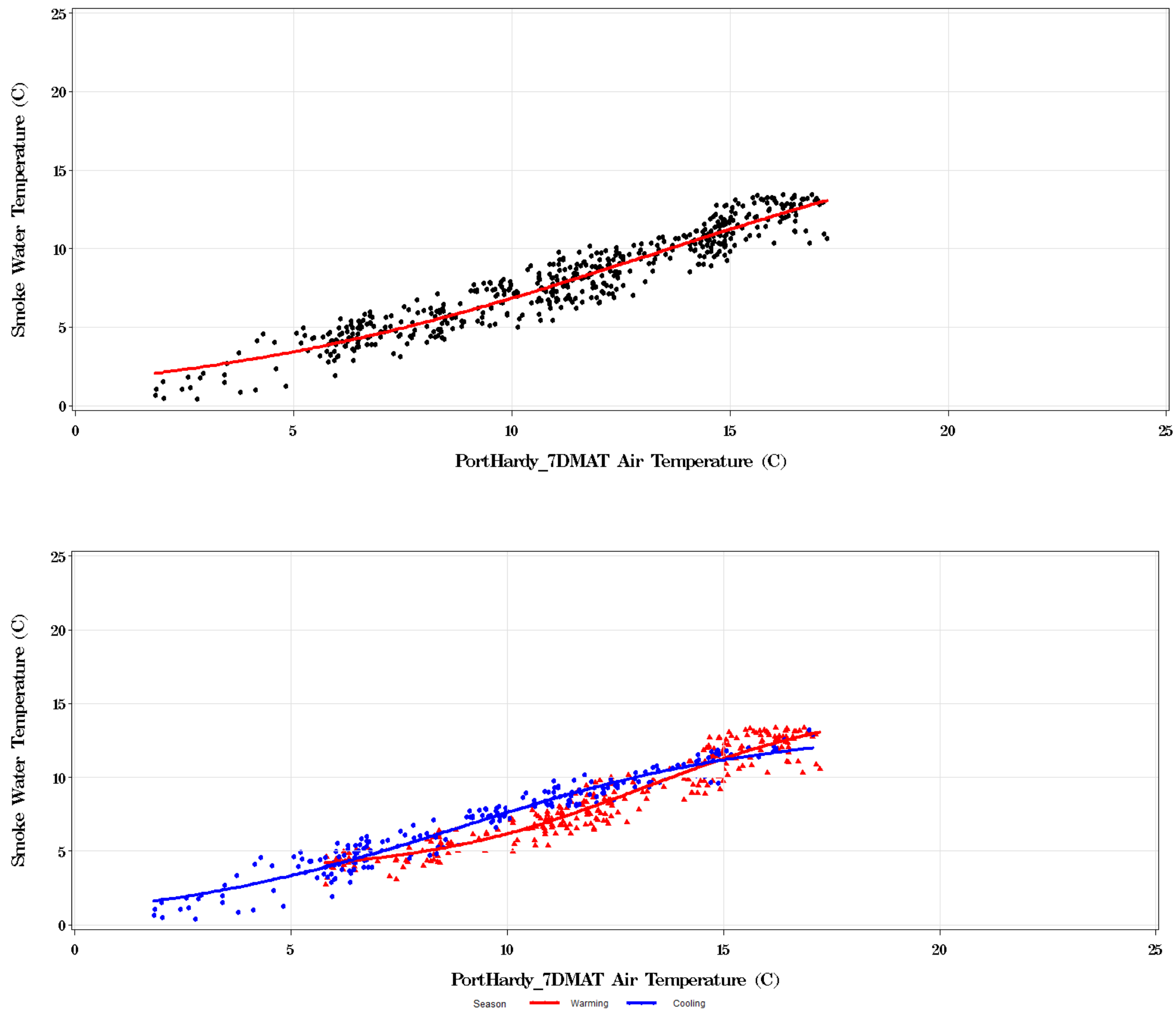
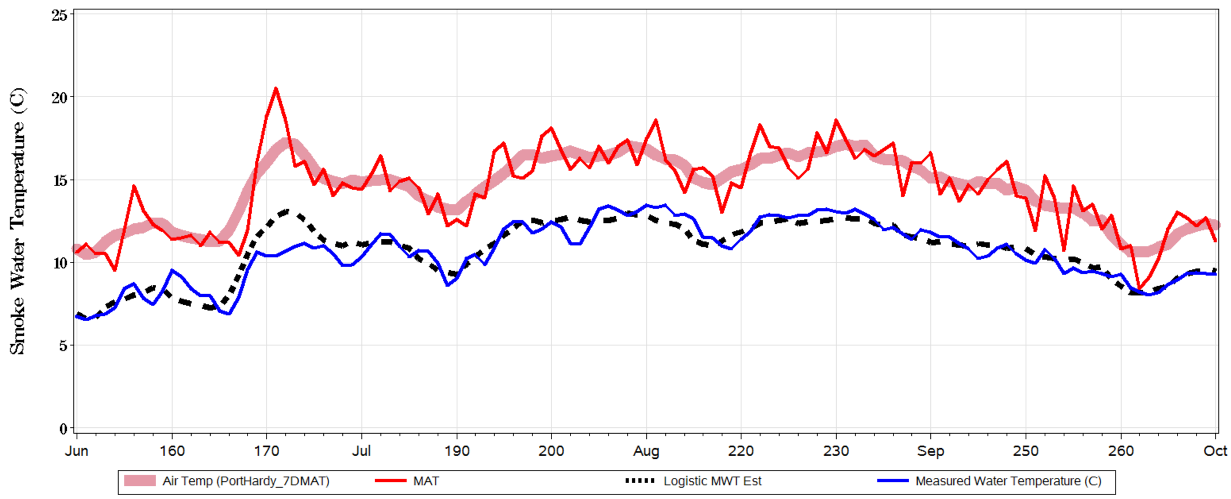


Figure 38. Logistic regression fits for air/water temperature relationship for Smokehouse Creek daily mean water temperatures as a function of the PORT HARDY 7d-CMAT (air temperature index): seasons combined (top); separate warming season (red) and cooling seasons (blue)(bottom).



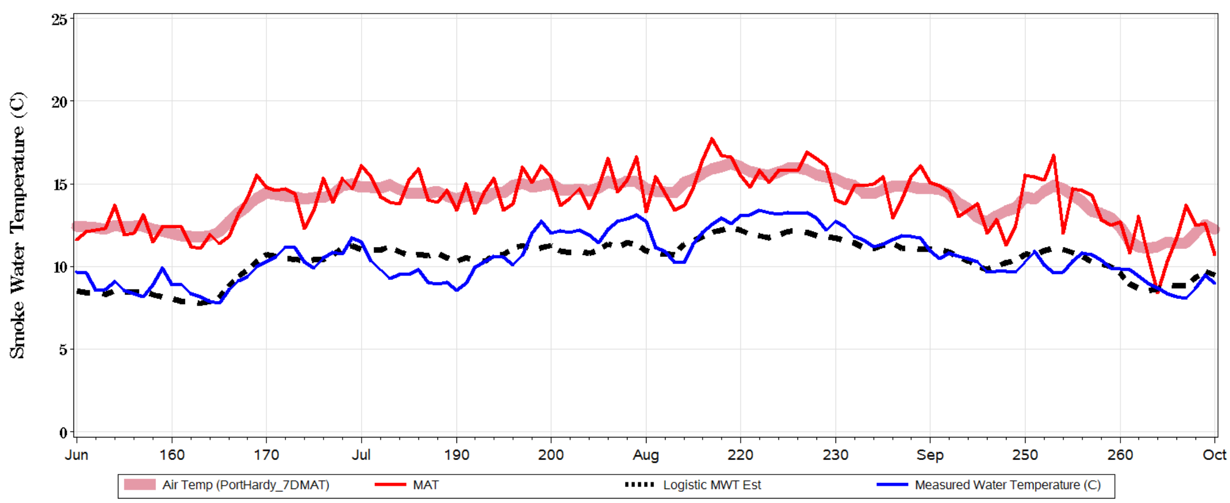


Figure 39. Validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for Smokehouse Creek, 2004 (top), 2005 (bottom).

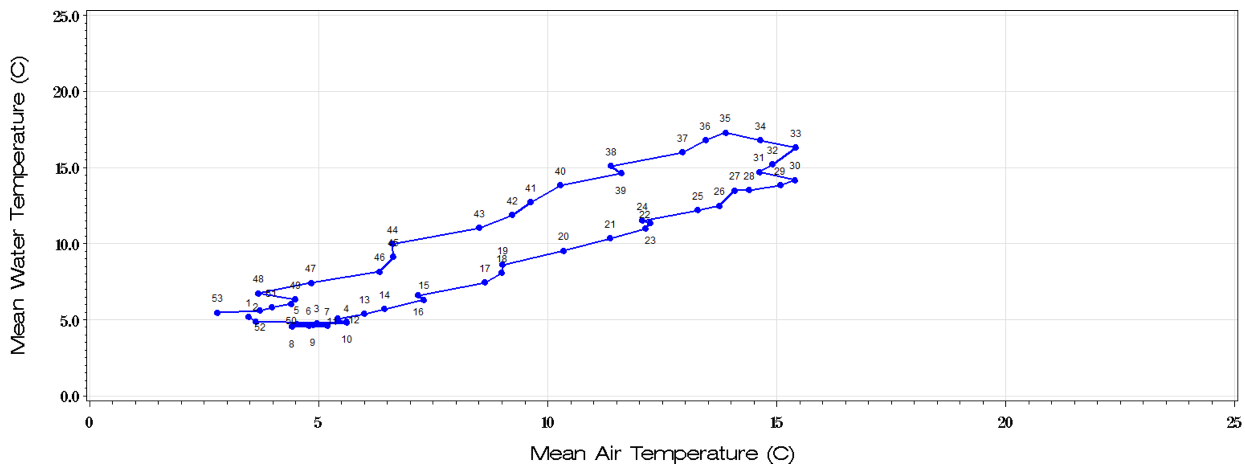


Figure 40. Derivation of seasonal turn-around point for Docee River, based on maximum weekly mean air and water temperature data. The seasonal turn-around point is in week 33, approximately August 18th. The "warming season" therefore extends from April 1 to August 18th, followed by the "cooling season" from August 19th – November 24th.

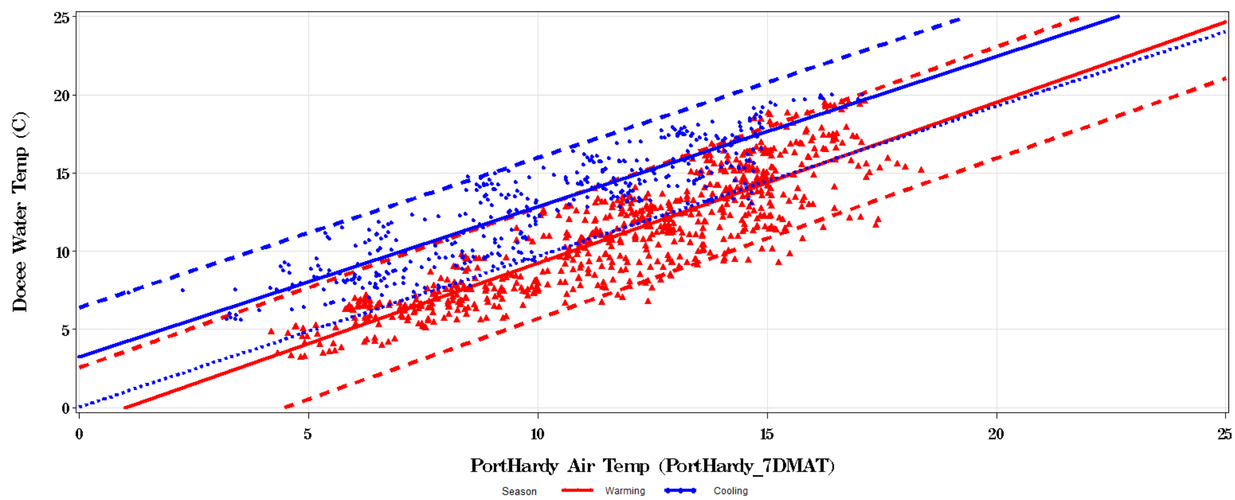


Figure 41. Linear regression fits for air/water temperature relationship for Docee River daily mean water temperatures as a function of the PORT HARDY 7d-CMAT (air temperature index), by season (warming season (red) and cooling season (blue)).

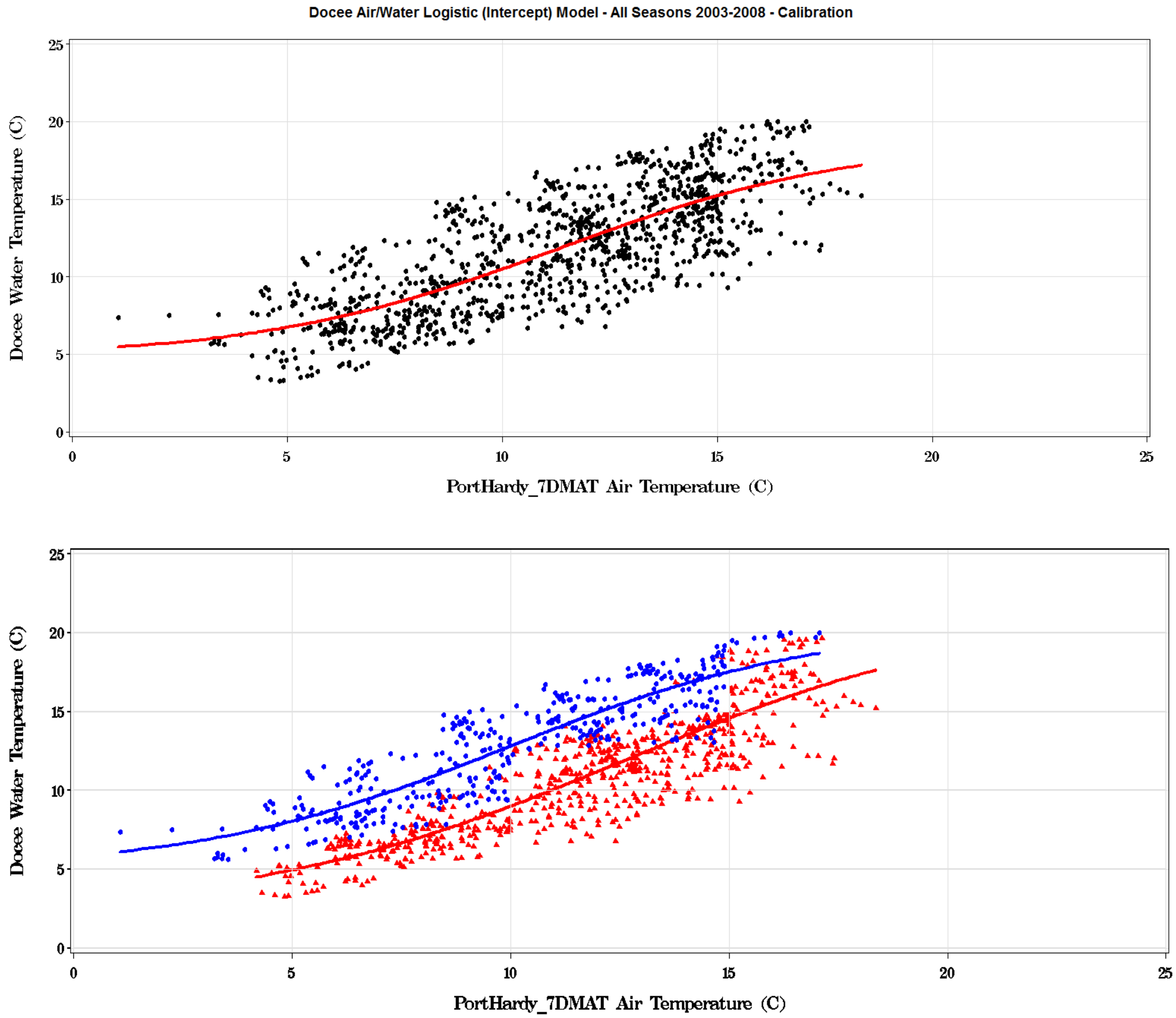


Figure 42. Logistic regression fits for air/water temperature relationship for Docee River daily mean water temperatures as a function of the PORT HARDY 7d-CMAT (air temperature index): seasons combined (top); separate warming season (red) and cooling seasons (blue)(bottom).

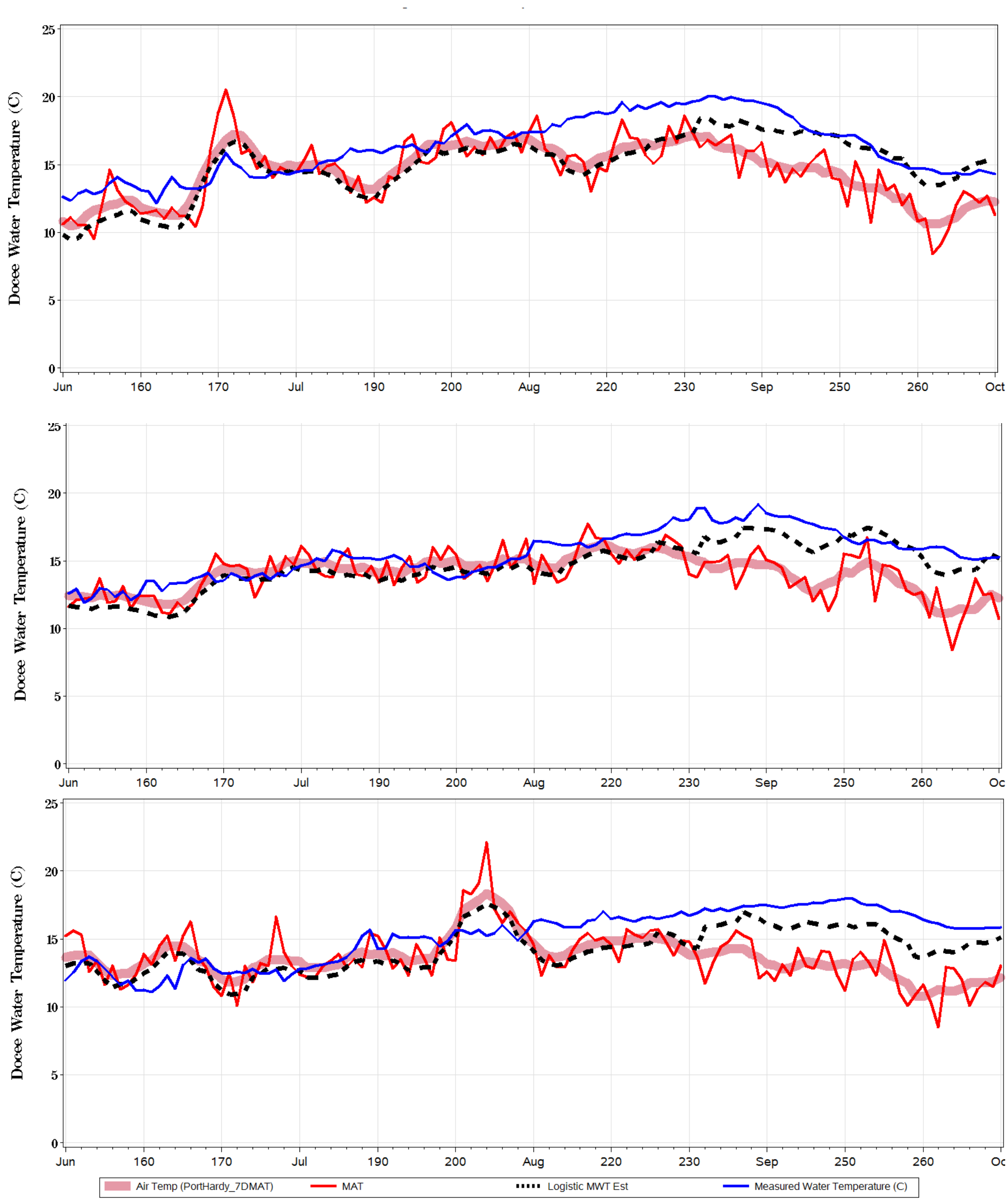


Figure 43. Validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for Docee River, 2004 (top), 2005 (middle), 2006 (bottom).

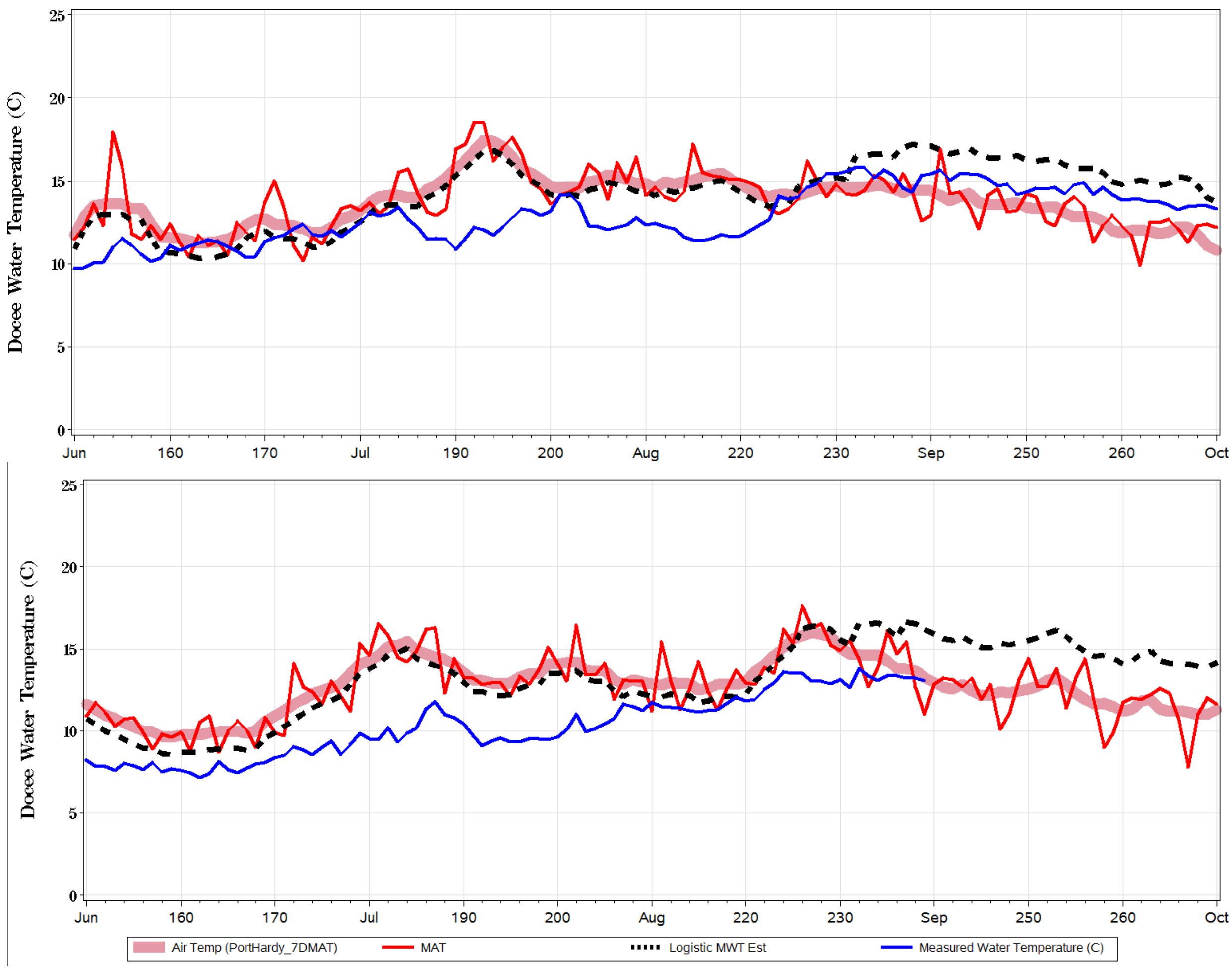


Figure 44. Validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for Docee River, 2007 (top), 2008 (bottom).

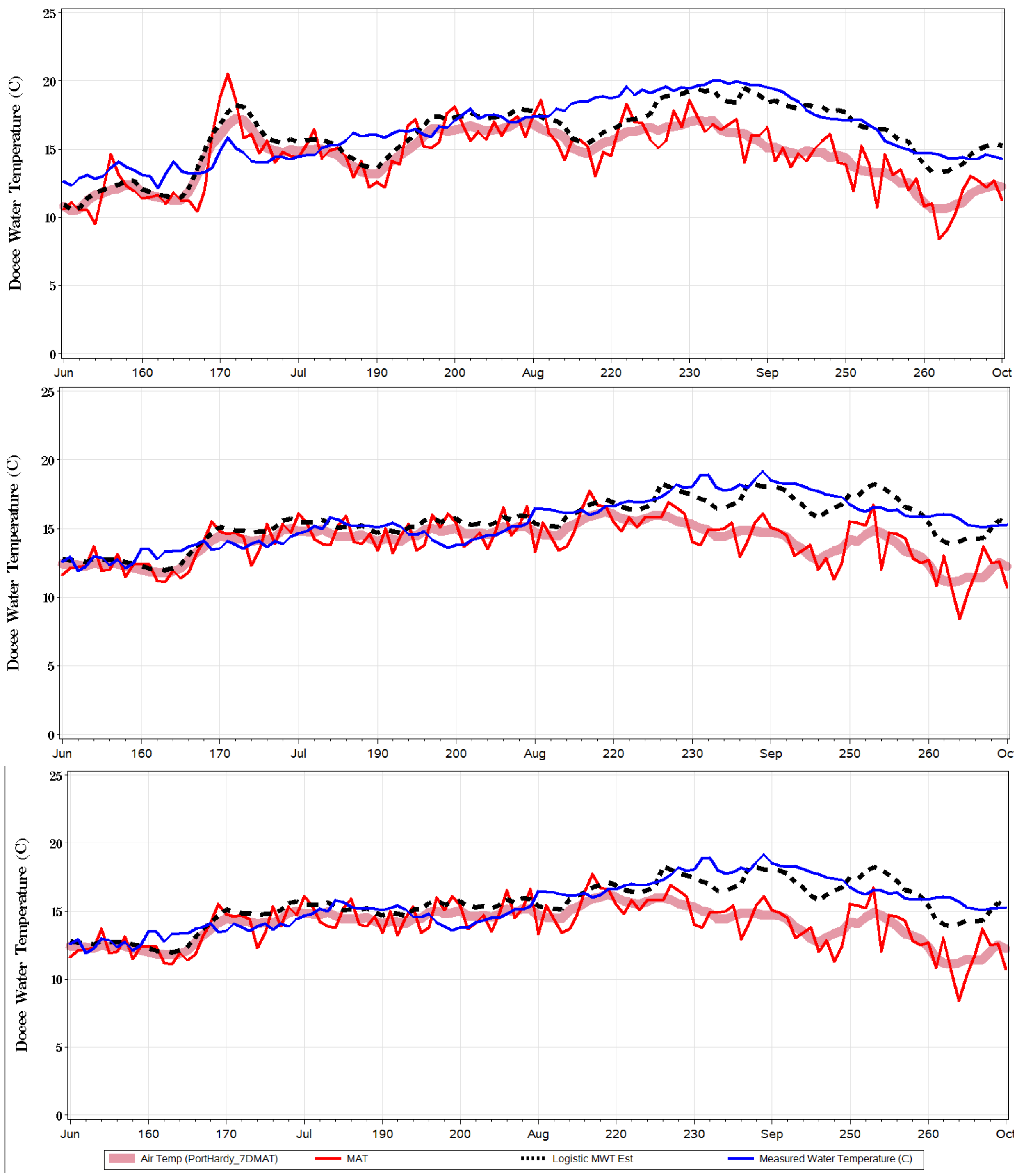


Figure 45. Sample validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature for Docee River (blue solid line) and estimated Docee MWT (black dashed line based on seasonal logistic regression models **calibrated only on warm-phase PDO years** 2004 (top), 2005 (middle)). Spearman correlation between observed and estimated MWTs $r_S > 0.93$.

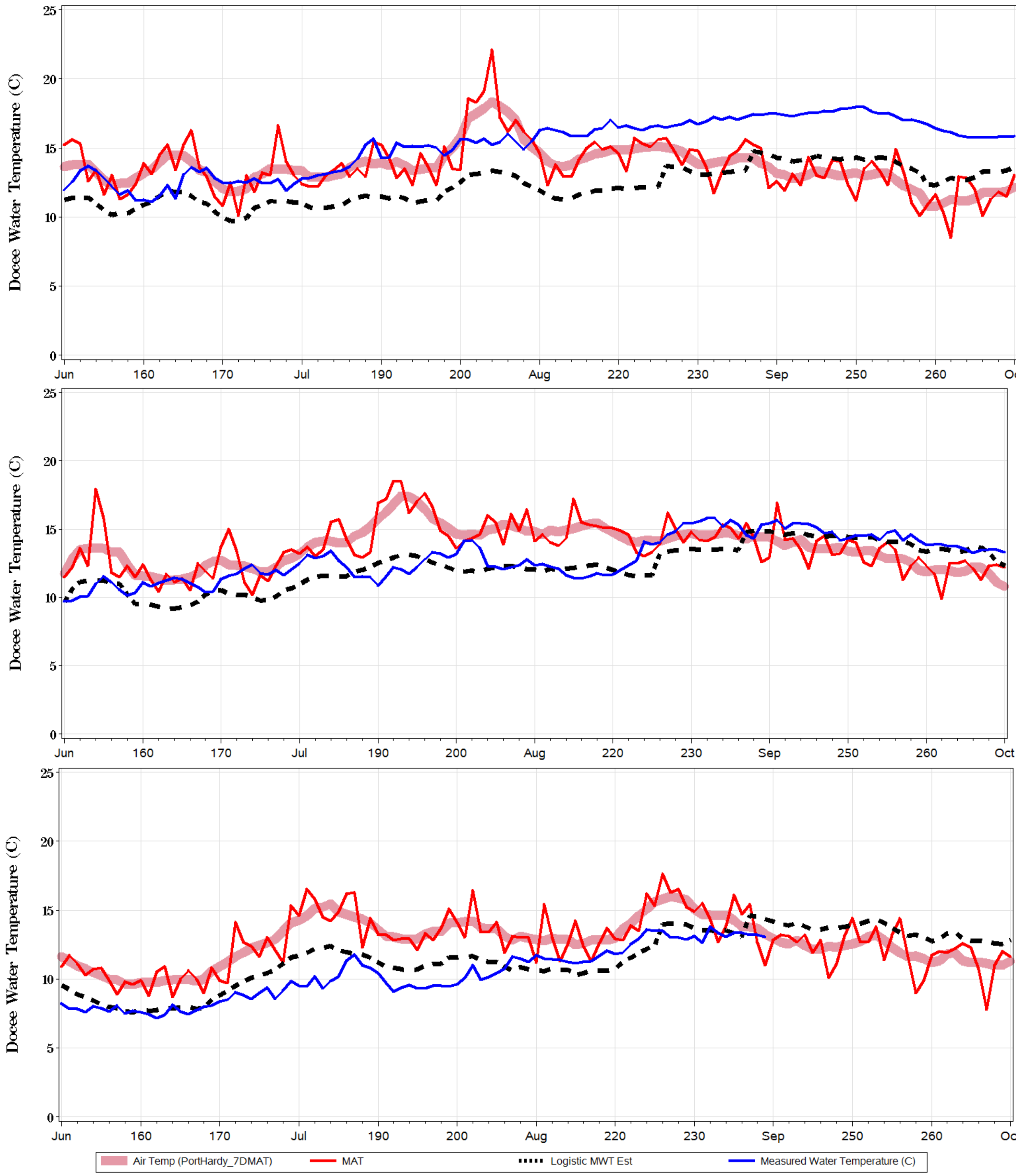


Figure 46. Sample validation plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature for Docee River (blue solid line) and estimated Docee MWT (black dashed line based on seasonal logistic regression models **calibrated only on cool PDO years** 2006 (top), 2007 (middle), 2008 (bottom)). Spearman correlation between observed and estimated MWTs rS > 0.90.

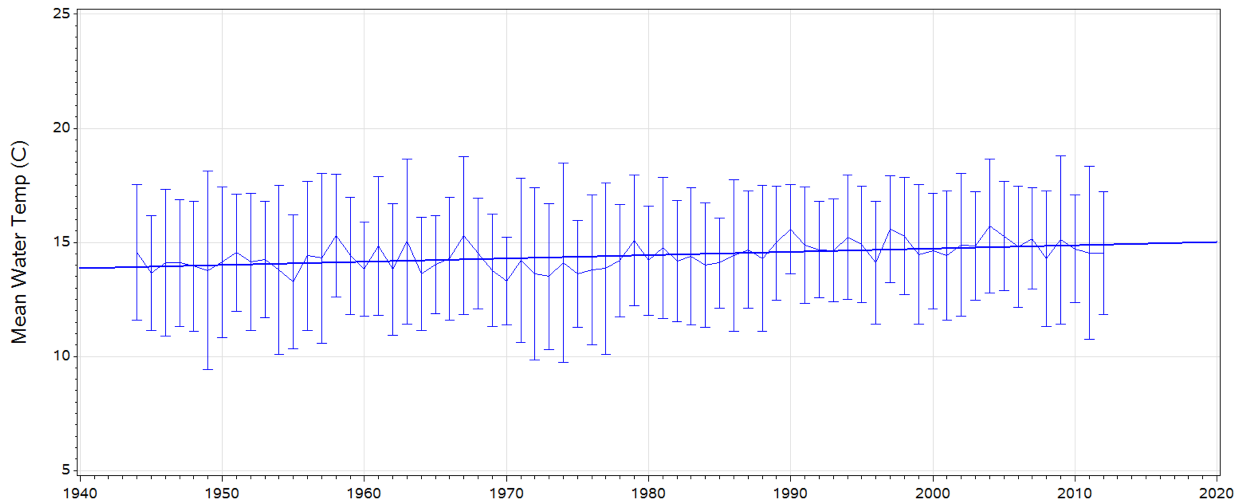


Figure 47. Estimated Docee River mean water temperature ± 2 std deviations, July-September 1944-2012, based on seasonal logistic air/water temperature regression models. Significant long-term trend is evident (Y = -14.0 + 0.014 * Year; r = 0.034; P < .0001).

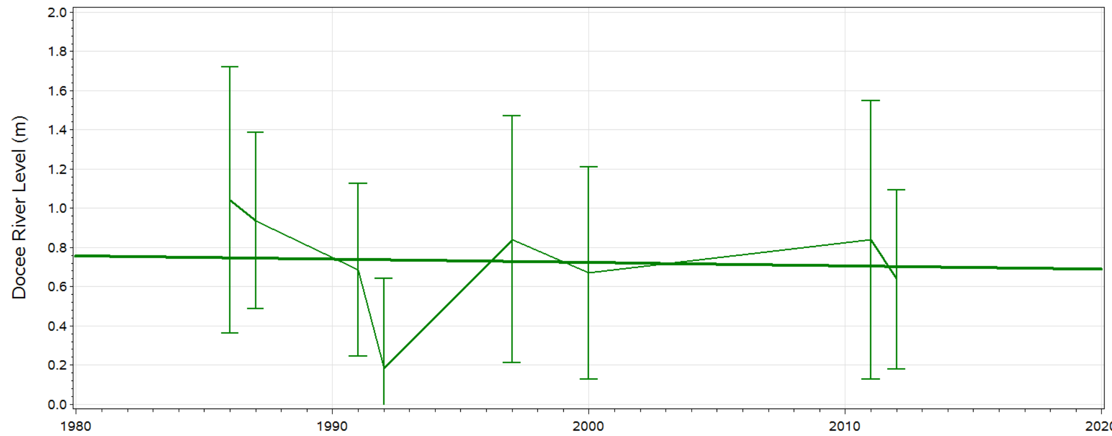


Figure 48. Observed Docee River mean water level ± 2 std deviations, July-September 1986-2012. Insufficient data to detect trend.

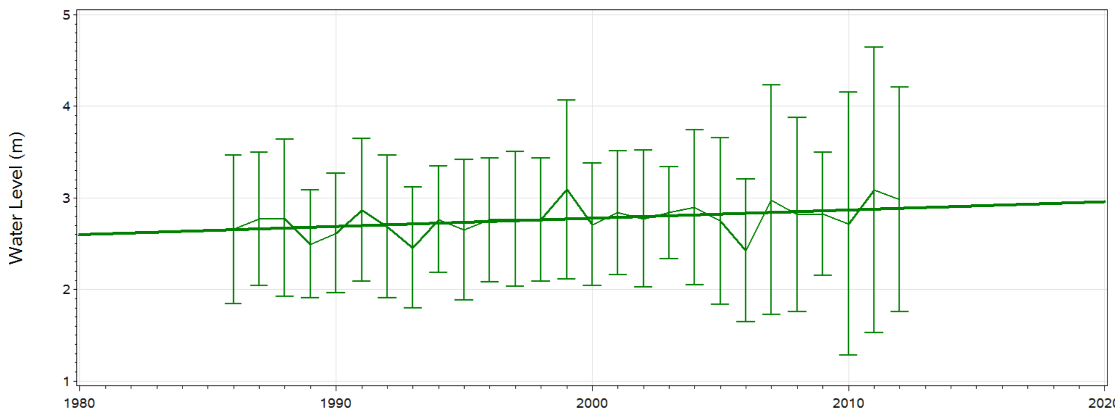


Figure 49. Owikeno Lake mean water level ± 2 std deviations, July-September 1986-2012. Positive trend is evident in time-series (Y = 15.3 + 0.009 * Year; r = 0.14; P < .001).

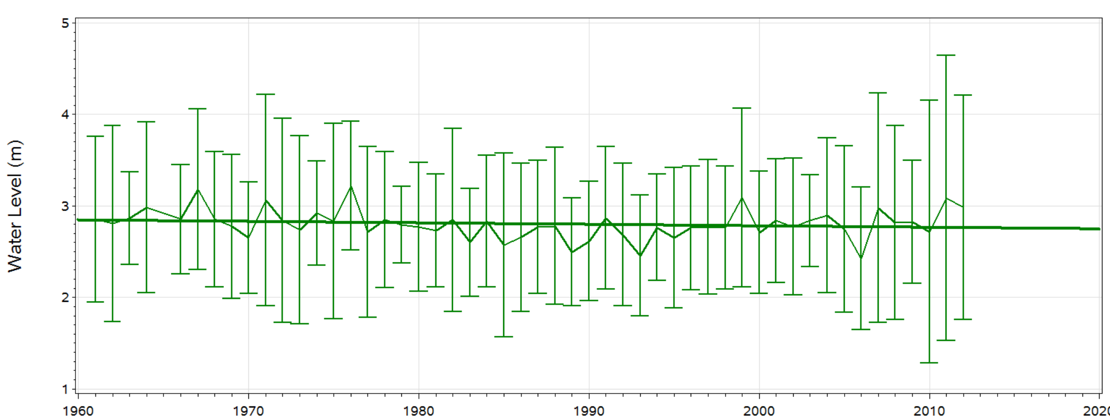
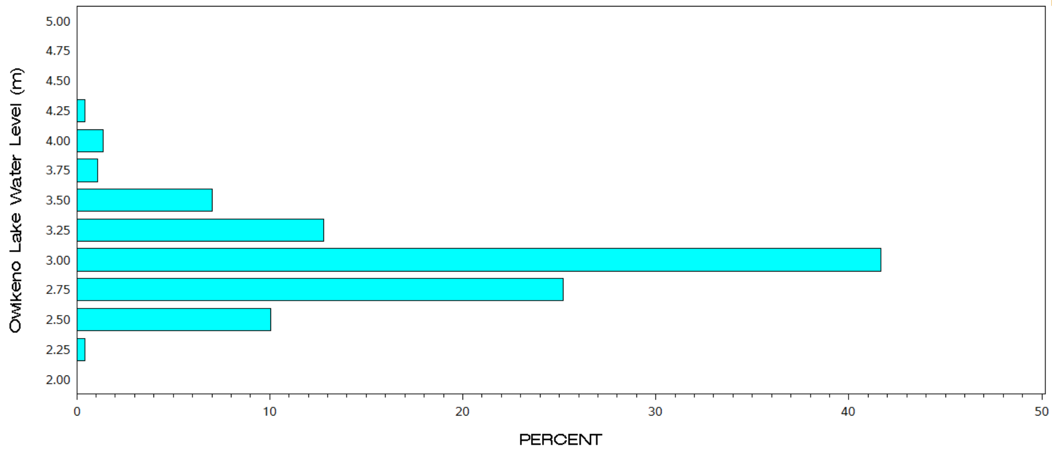
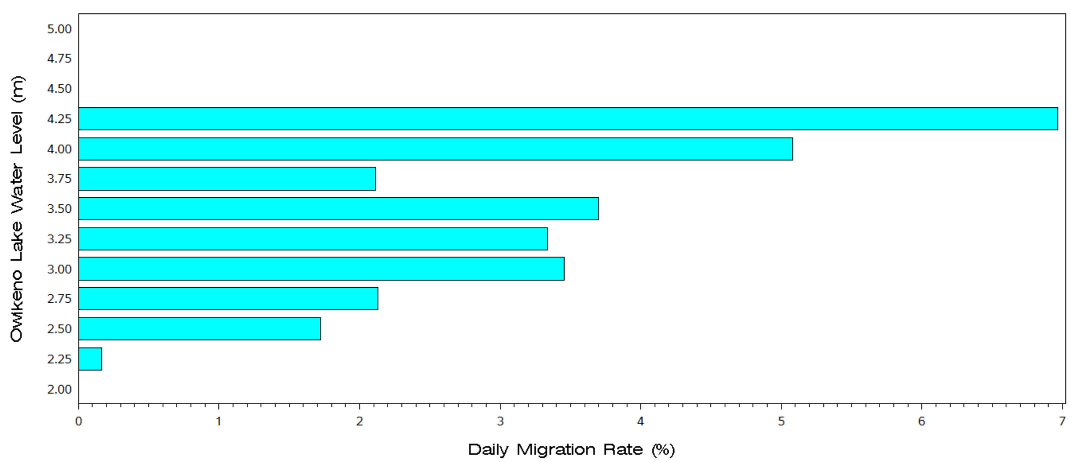


Figure 50. Owikeno Lake mean water level ± 2 std deviations, July-September 1961-2012. Weak negative trend is evident (Y = 6.0 - 0.0016 * Year; r = -0.04; P < .01).



FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
0	1385	0.00	100.00
0	1385	0.00	100.00
0	1385	0.00	100.00
6	1385	0.43	100.00
19	1379	1.37	99.57
15	1360	1.08	98.19
97	1345	7.00	97.11
177	1248	12.78	90.11
577	1071	41.66	77.33
349	494	25.20	35.67
139	145	10.04	10.47
6	6	0.43	0.43
0	0	0.00	0.00

Figure 51. Frequency plot of historical Long Lake Sockeye non-zero migration (un-weighted tally of non-zero migration dates), at varying *Owikeno Lake* water level (as an indicator of Docee flow conditions). Most dates (67%) of migration in Docee River occur when depths at Owikeno Lake are ~2.75 – 3.0 m.



FREQ.	Daily Migration Rate (%)
0	0.00
0	0.00
0	0.00
6	6.97
19	5.08
15	2.11
97	3.70
177	3.34
577	3.46
349	2.13
139	1.72
6	0.17
0	0.00

Figure 52. Frequency plot of historical Long Lake Sockeye non-zero migration dates, weighted by daily migration rate, at varying *Owikeno Lake* water levels. Ignoring low-frequency occurrences (FREQ < 20), the highest daily migration rates (>3.4% per day) at the Meziadin fishway occur when depths at Owikeno Lake are ~3.0-3.5 m.

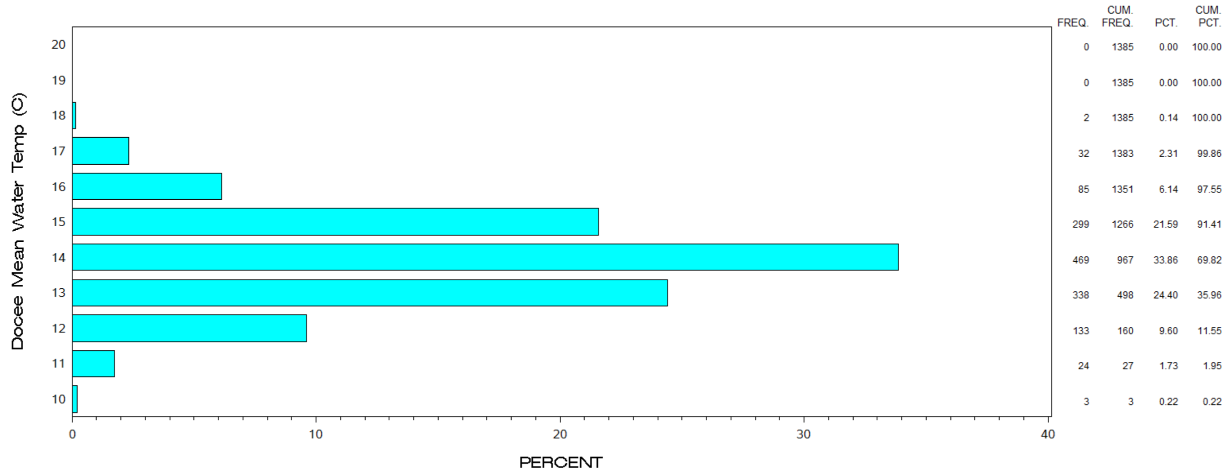


Figure 53. Frequency plot of historical Long Lake Sockeye migration (un-weighted tally of non-zero migration dates), at varying levels of Docee River mean daily water temperature. ~80% of dates of migration activity occurs at 13-15°C.

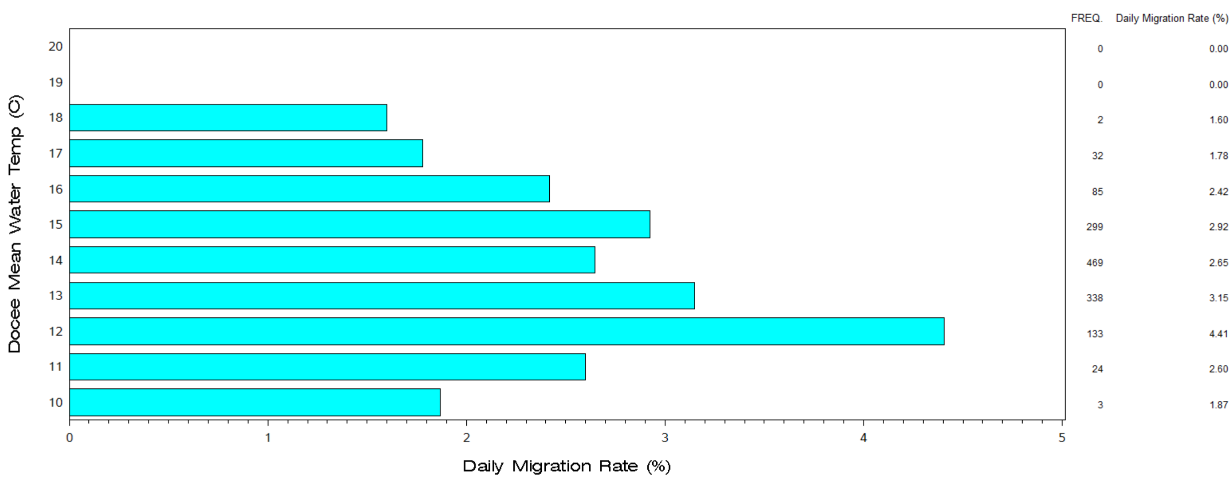


Figure 54. Frequency plot of historical Long Lake Sockeye non-zero migration dates, weighted by daily migration rate, at varying levels of Docee River water temperature. Highest migration rates (i.e., > 75th percentile, ~3.4%) are associated with temperatures of 12°C.

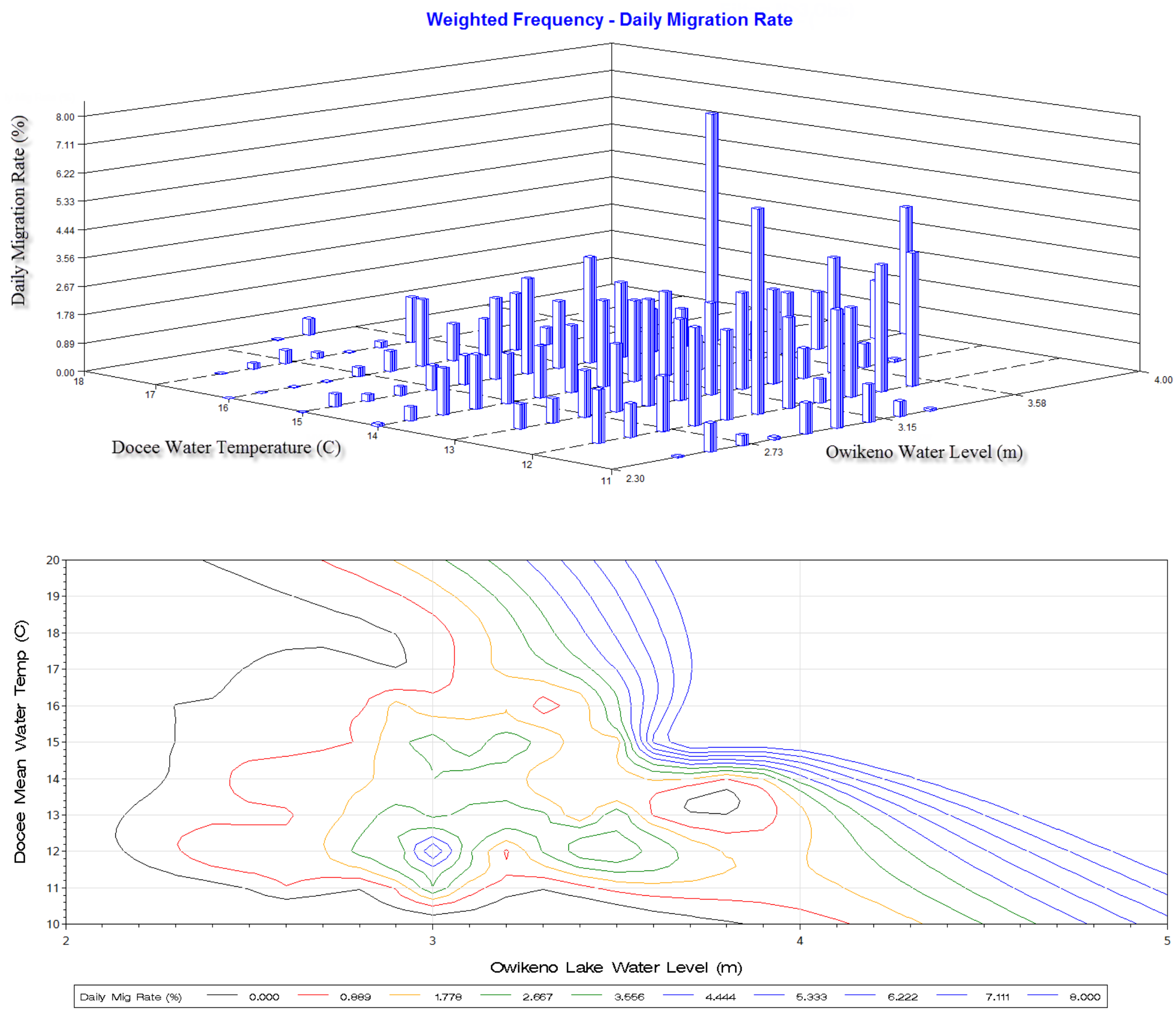


Figure 55. Distribution (top) and smoothed contour (bottom) of historical Long Lake Sockeye migration rates (daily % of annual escapement, 1972-2012), at varying levels of Docee River water temperature and Owikeno Lake water level (filtered for a minimum of 3-6 observations at each MWT x flow point). Ignoring ~25 observations where very high migration rates were associated with high water levels in 2007 and 2012, maximum migration rates are most commonly found at 12°C or less and centered on 3 m Owikeno depth, which translates into about 0.75 ± 0.02 m of Docee River depth.

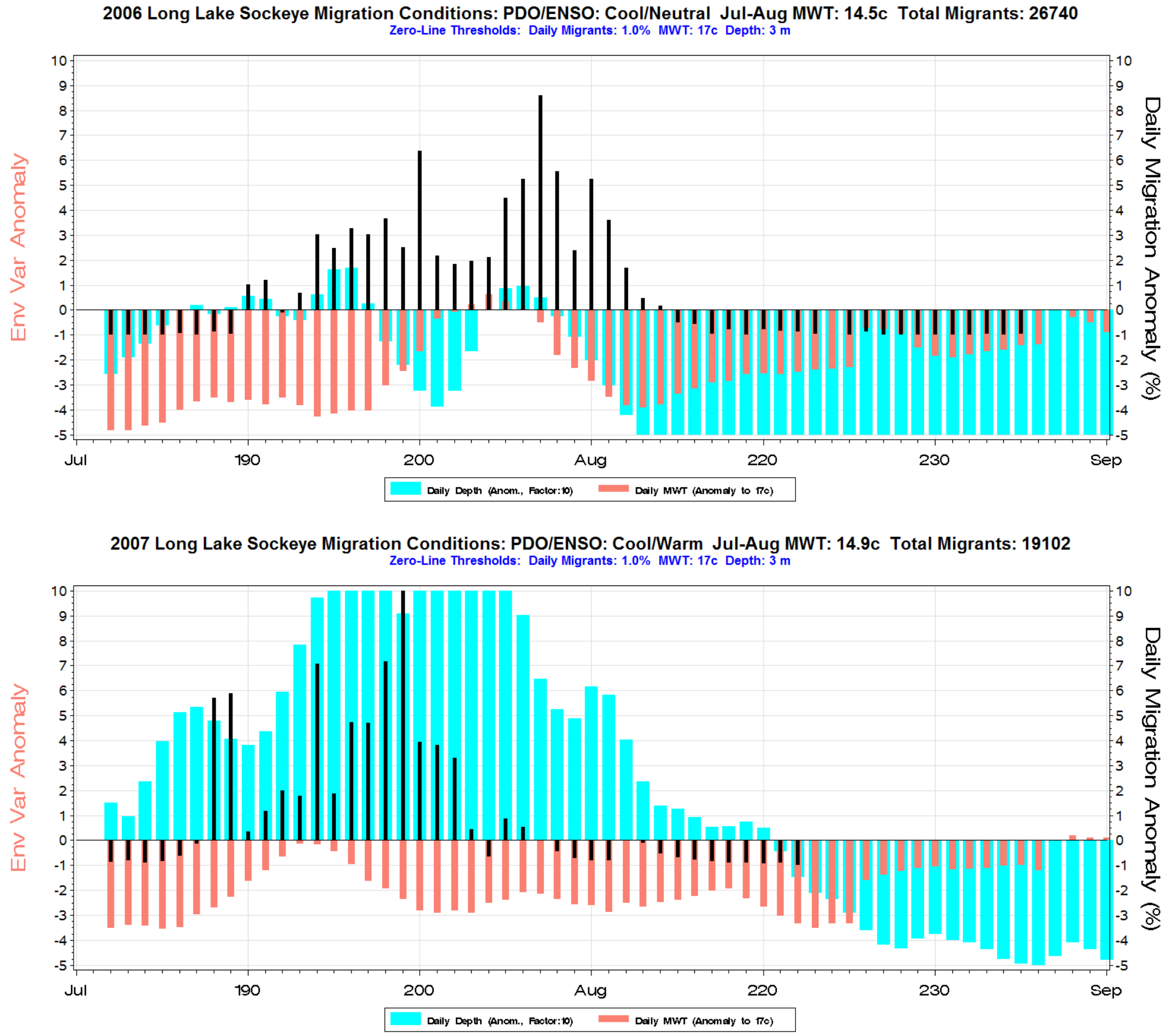
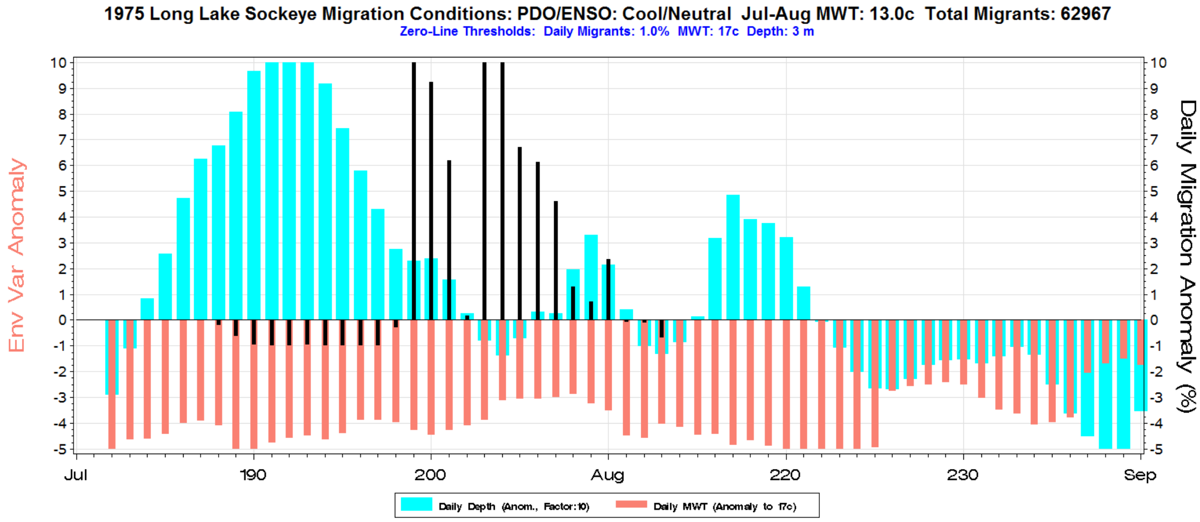


Figure 56. Sample anomaly plots for Long Lake Sockeye migration, Docee River water temperature (estimated), and recorded water level indicator variable *Owikeno Lake depth* (in meters, multiplied by a factor of 10 for readability). Zero-line thresholds: (a) Daily migration rate = 1.0% (50^{th} percentile of non-zero daily migration rates (1972-2012); (b) water temperature = 17°C (~95^{th} percentile); Owikeno depth = 3 m (~75^{th} percentile) ≈ 0.75 m at Docee. Shows weak evidence of reduced migration rate as temperature approaches 17°C (i.e., temperature anomaly of 0°C).



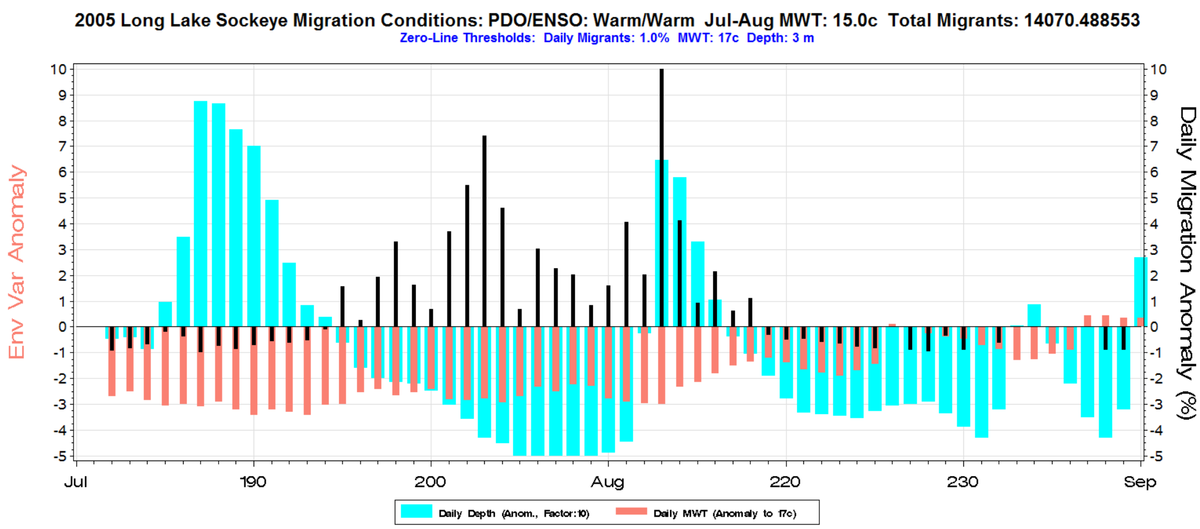


Figure 57. Sample anomaly plots for Long Lake Sockeye migration, Docee River water temperature (estimated), and recorded water level indicator variable *Owikeno Lake depth* (in meters, multiplied by a factor of 10 for readability). Zero-line thresholds: (a) Daily migration rate = 1.0% (50th percentile of non-zero daily migration rates (1972-2012); (b) water temperature = 17°C (~95th percentile); Owikeno depth = 3 m (~75th percentile) ≈ 0.75 m at Docee. Shows potential migration delays due to high water conditions in both years, but also shows high daily migration rates (>3.4%) during high flows in August 2005

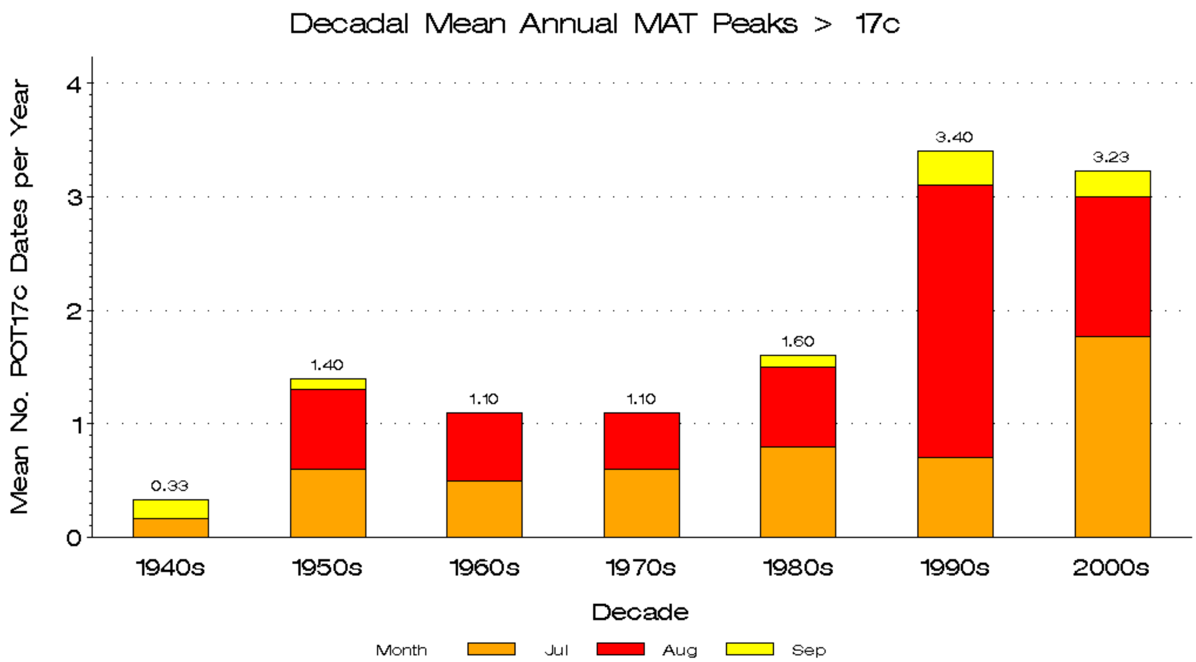


Figure 58. Frequency analysis of decadal mean number of dates per month in which regional daily mean air temperature (at *Port Hardy*) exceeded 17°C (Jul-Sep).

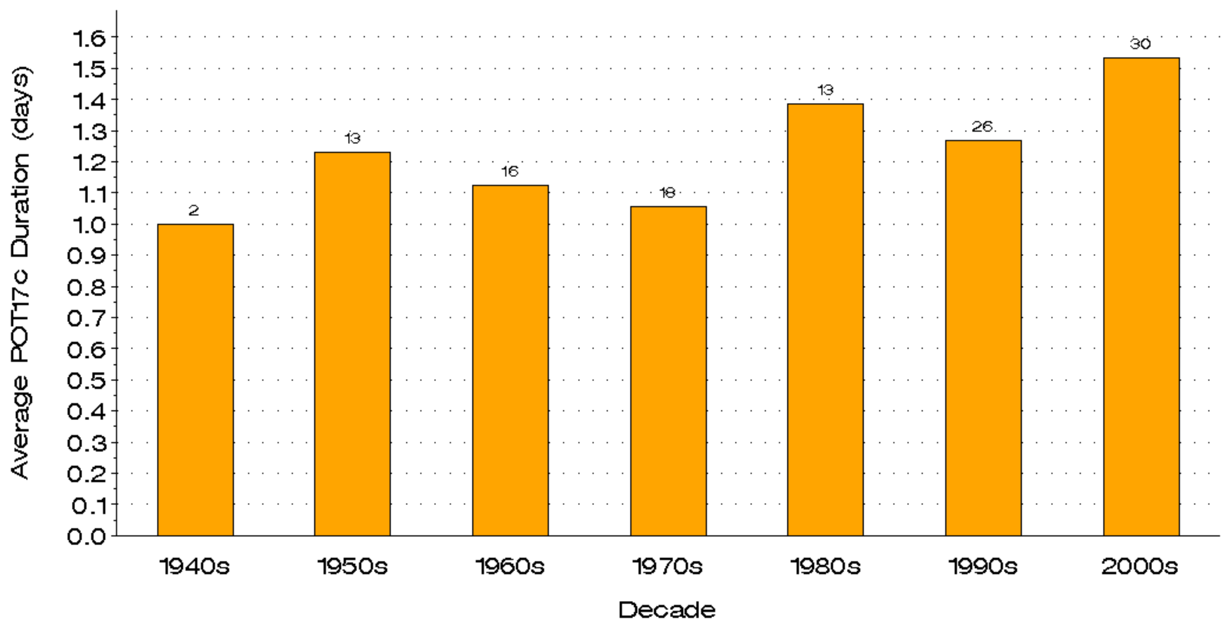


Figure 59. Mean length (days) and total decadal frequency of periods in which regional daily mean air temperature (at *Port Hardy*) exceeded 17°C during Jul-Sep.

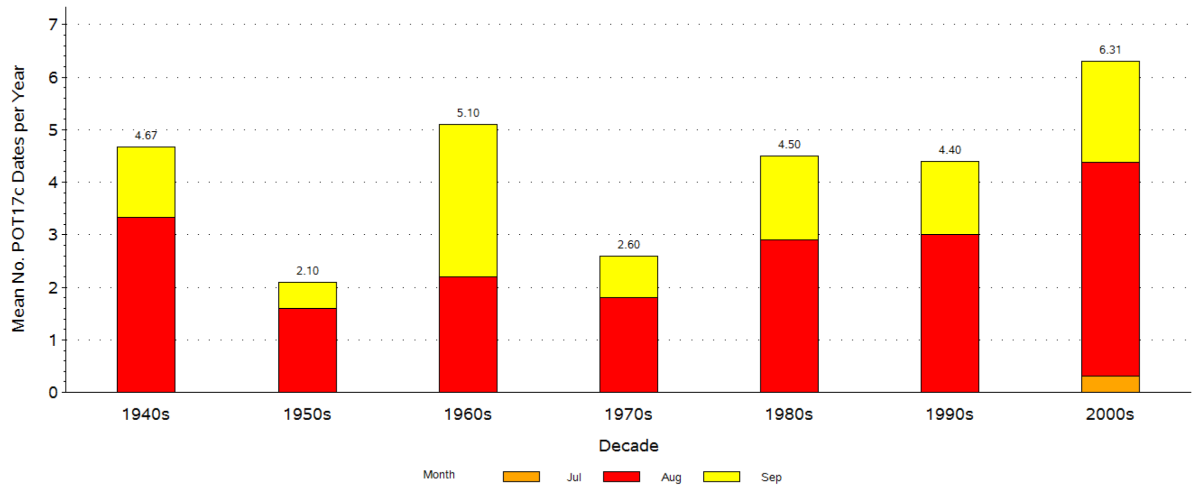


Figure 60. Frequency analysis of decadal mean number of dates per month (Jul-Sep) in which estimated mean water temperature in Docee River exceeded 17°C.

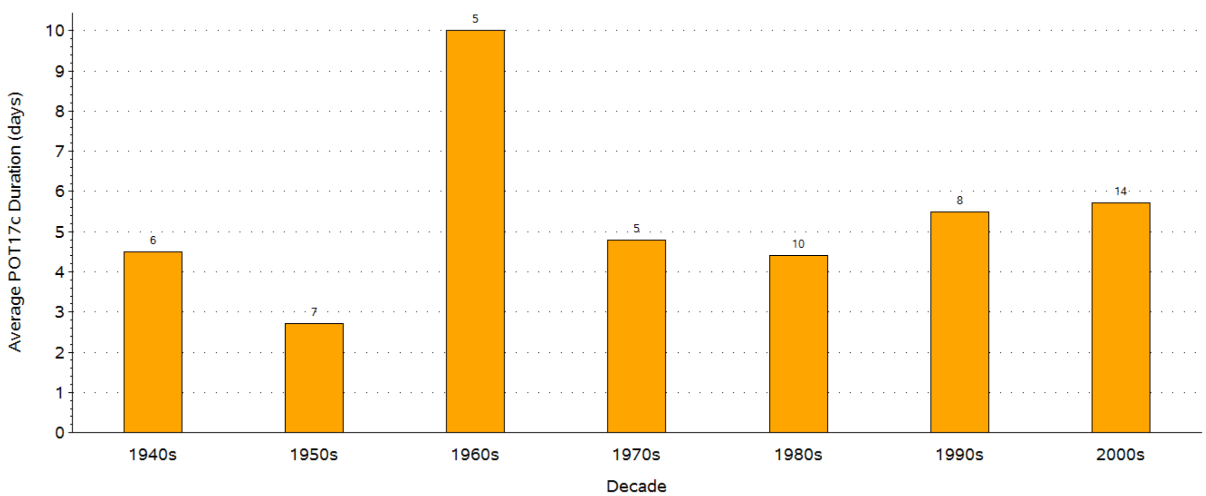


Figure 61. Mean length (days) and total decadal frequency of periods in which estimated daily mean water temperature (Jul-Sep) in Docee River continuously exceeded 17°C, by decade.

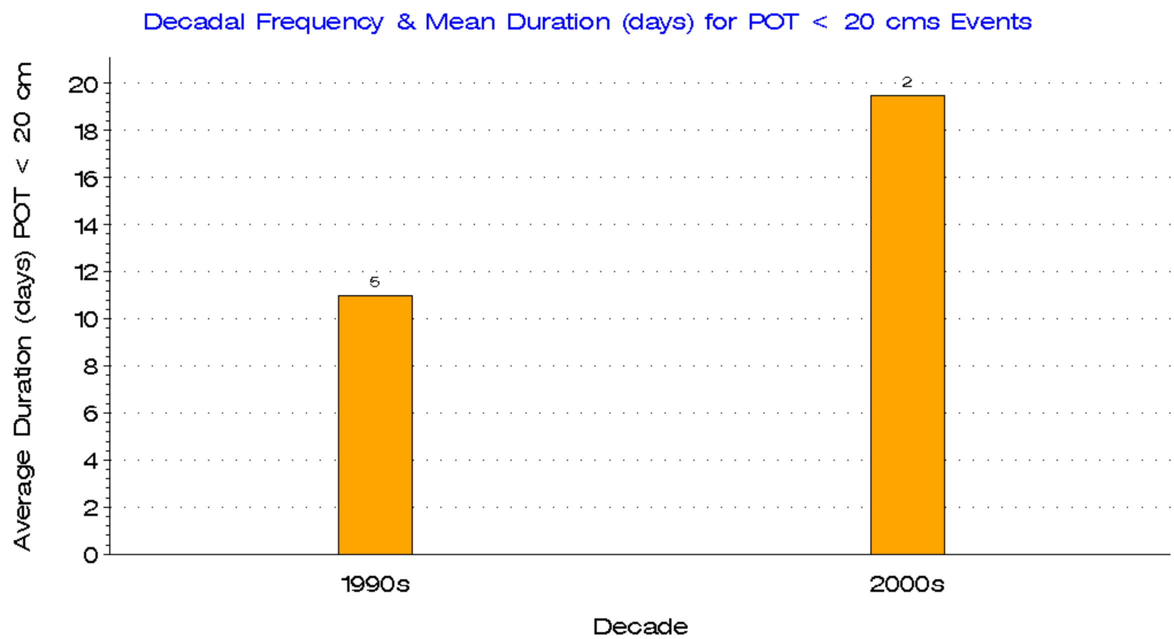


Figure 62. Mean length (days) and frequency of “low water level” periods in which Docee River water level continuously remained below 0.2 meters (i.e., 10th percentile of July-August levels). Restricted to “high quality” data years: 1986-1992, 1997, 1998, 2000, 2010-2012.

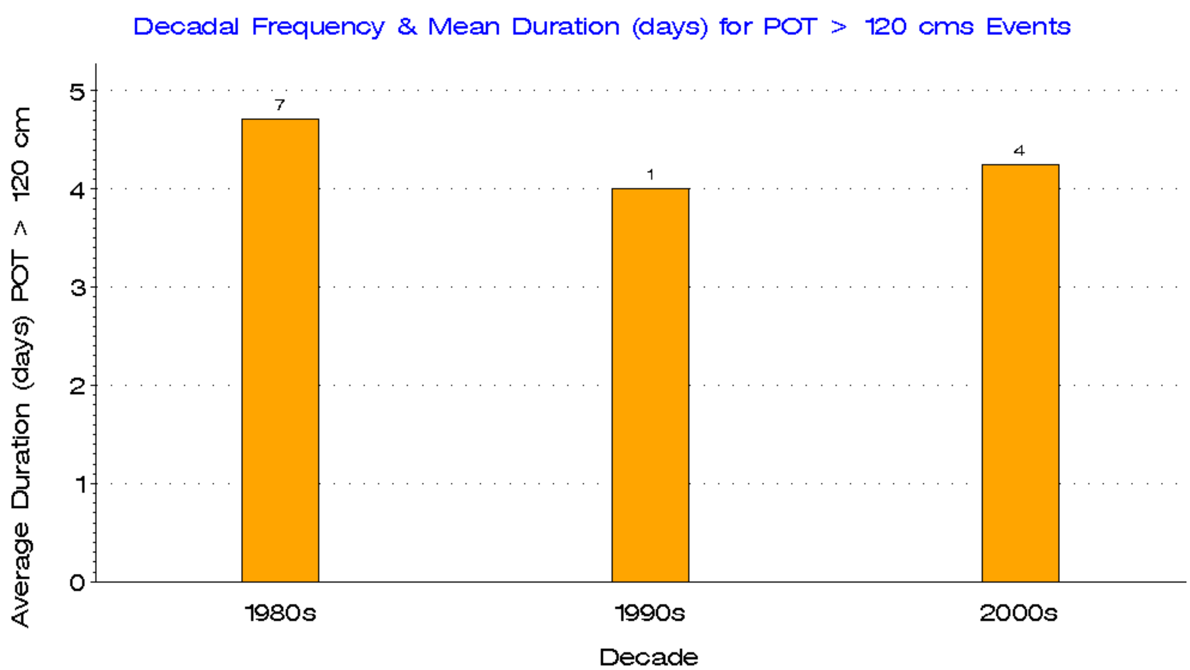


Figure 63. Mean length (days) and frequency of “high water level” periods in which Docee River water level continuously remained above 1.2 meters (i.e., 90th percentile of July-August levels) for the “high quality” data years: 1986-1992, 1997, 1998, 2000, 2010-2012.

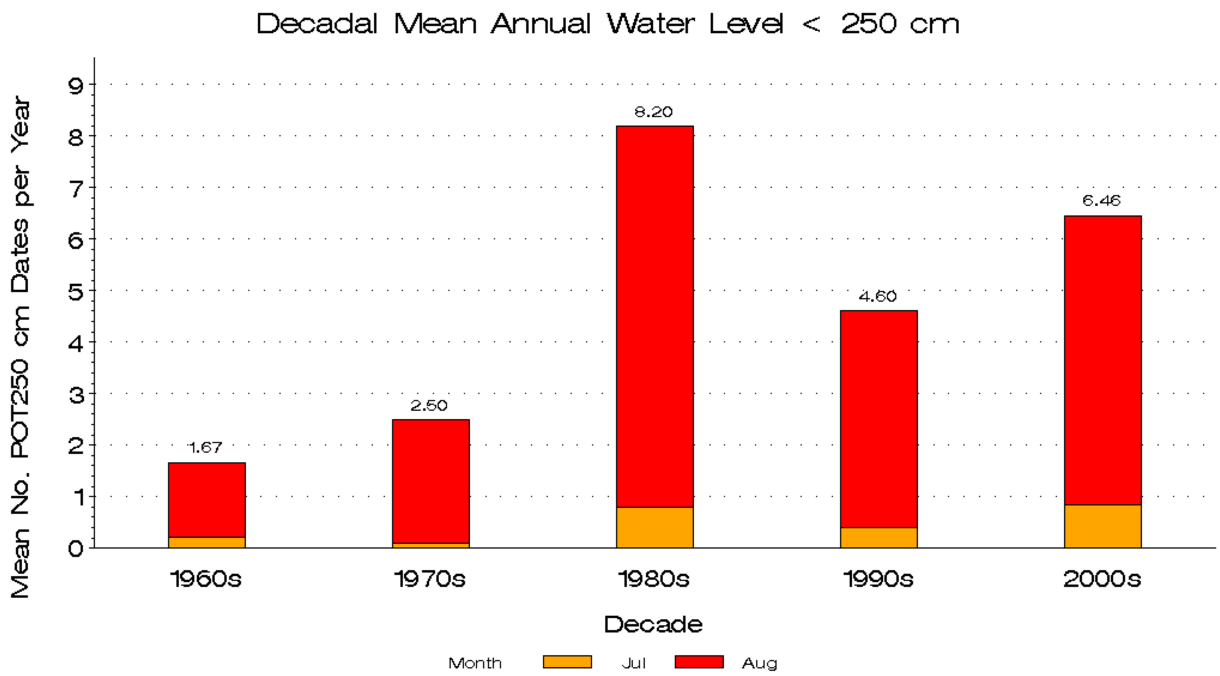


Figure 64. Frequency analysis of decadal mean number of “low water level” dates (i.e., < 10th percentile of July-August water levels, ~2.5 m) per month at *Owikeno Lake* (as an indicator of Docee River water levels).

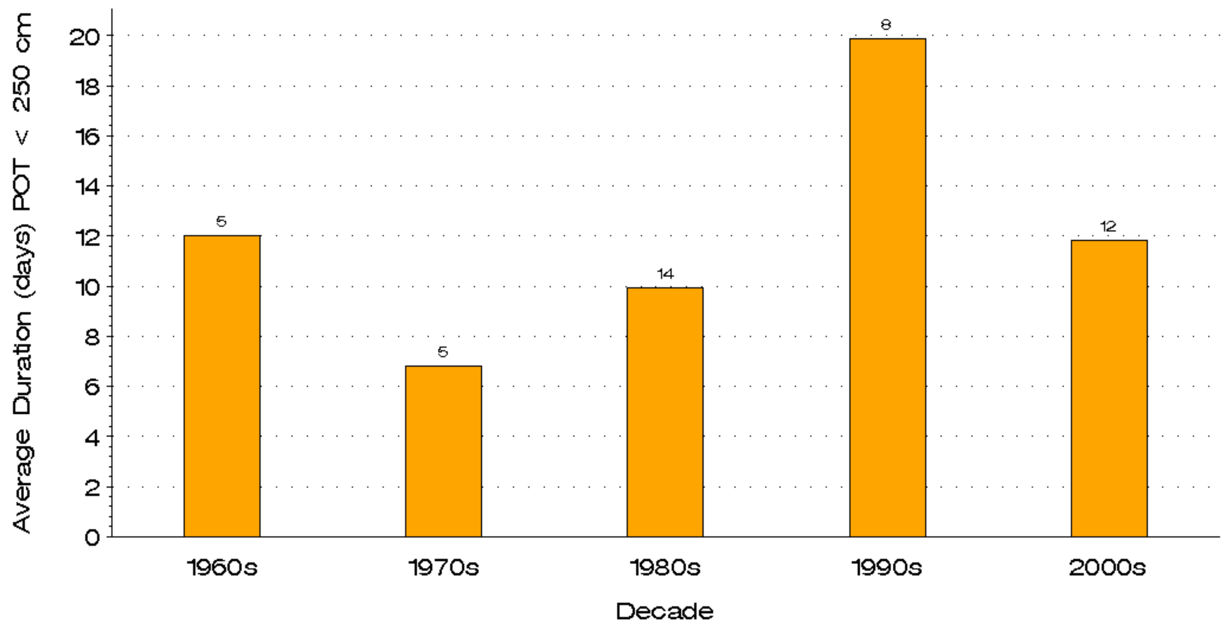


Figure 65. Mean length (days) and frequency of “low water level” periods in which *Owikeno Lake* water level continuously remained below the 10th percentile of July-August levels (~2.5 m).

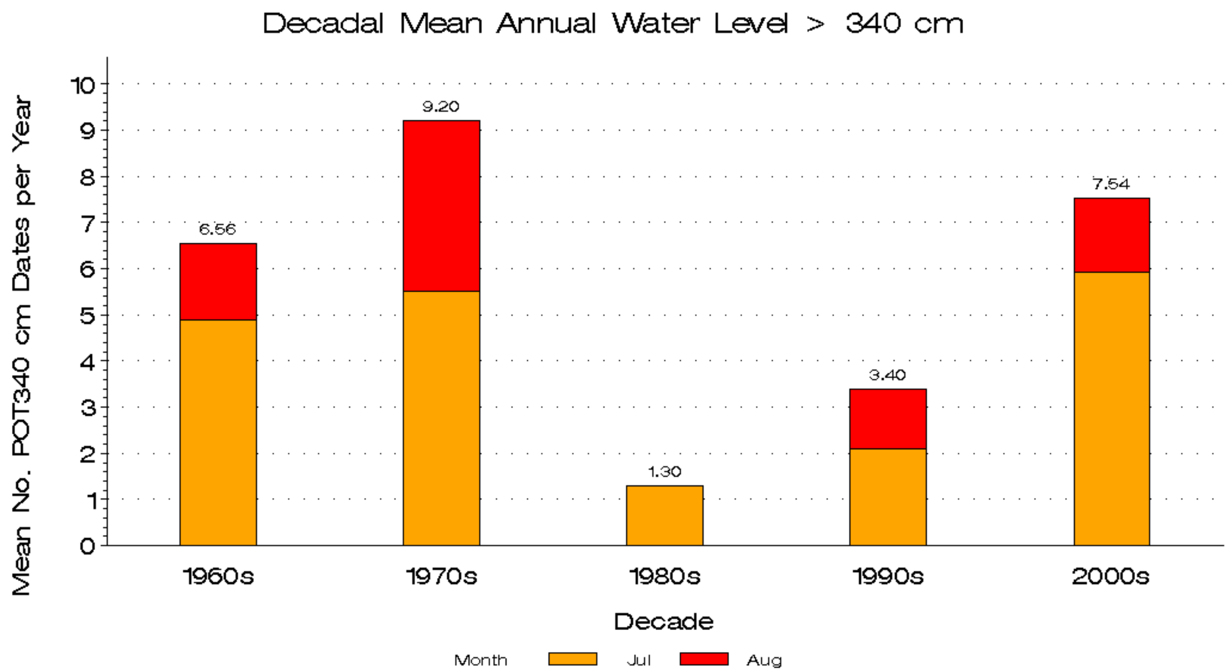


Figure 66. Frequency analysis of decadal mean number of “high water level” dates (i.e., > 90th percentile of July-August flows, ~3.4 m) per month at *Owikeno Lake* (as an indicator of Docee River water levels).

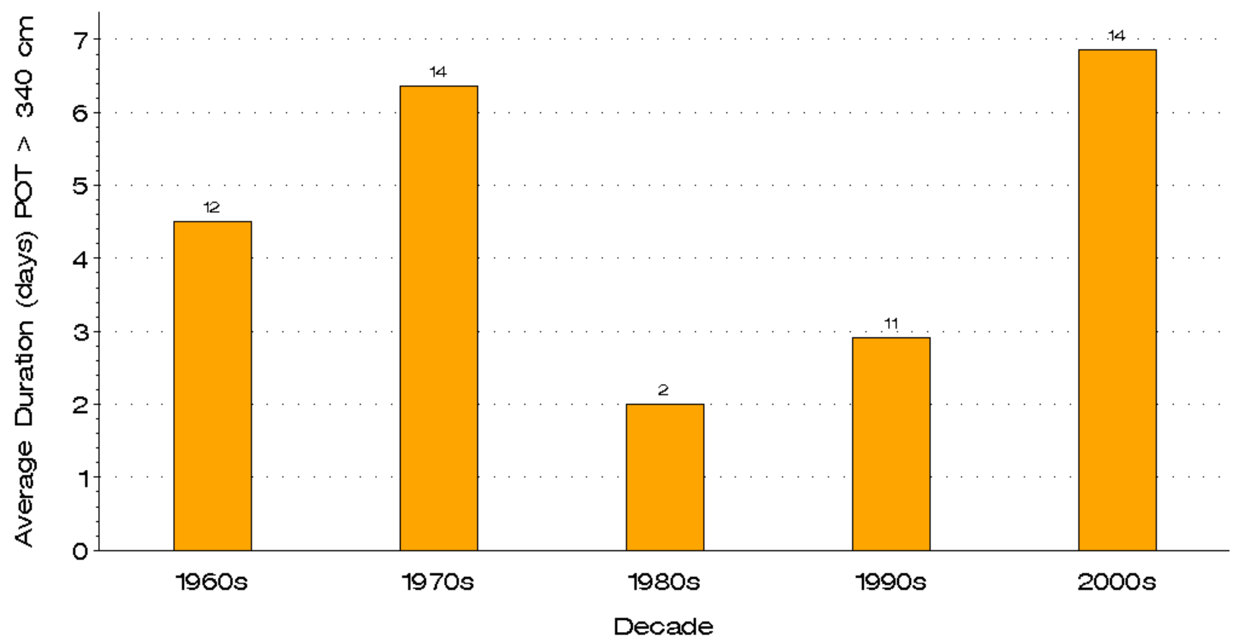
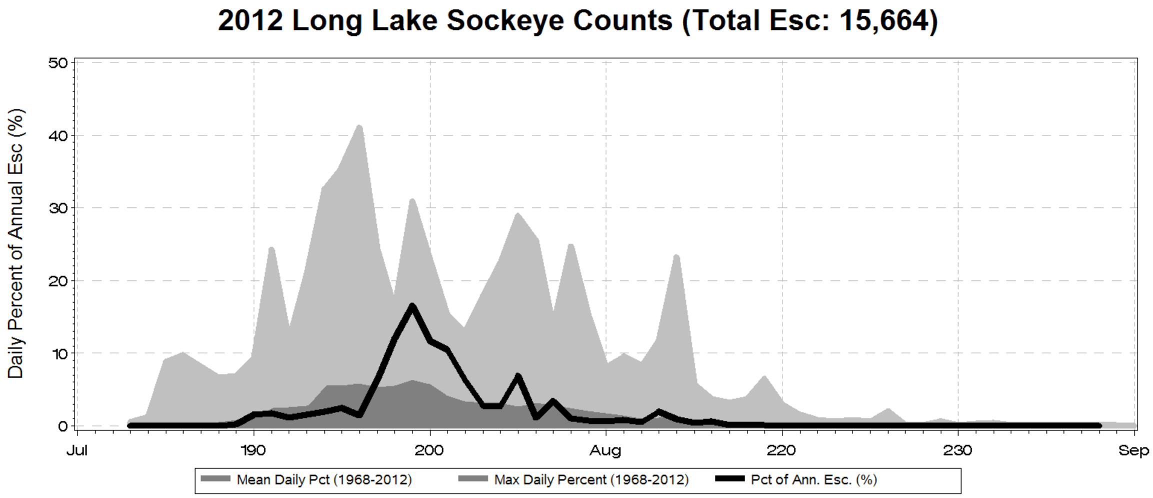


Figure 67. Mean length (days) and frequency of “high water level” periods in which *Owikeno Lake* discharge continuously remained above the 90th percentile of July-August water levels (~3.4 m).

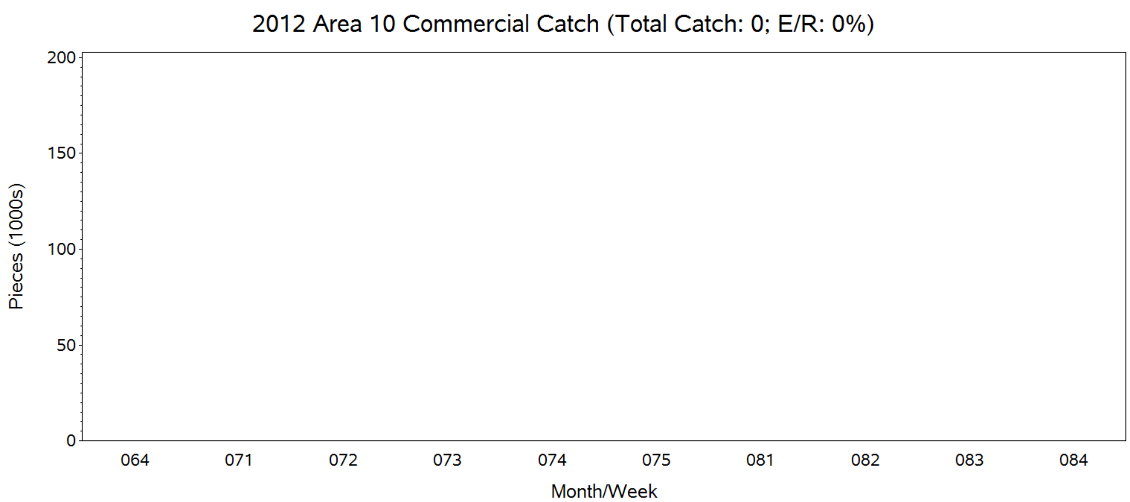
APPENDICES

Appendix A. Multi-panel plots of daily Long Lake Sockeye migration in relation to environmental variables and commercial harvest, by year, 1963, 1968-1971 (tower count years), 1972-2012 (fence count years).

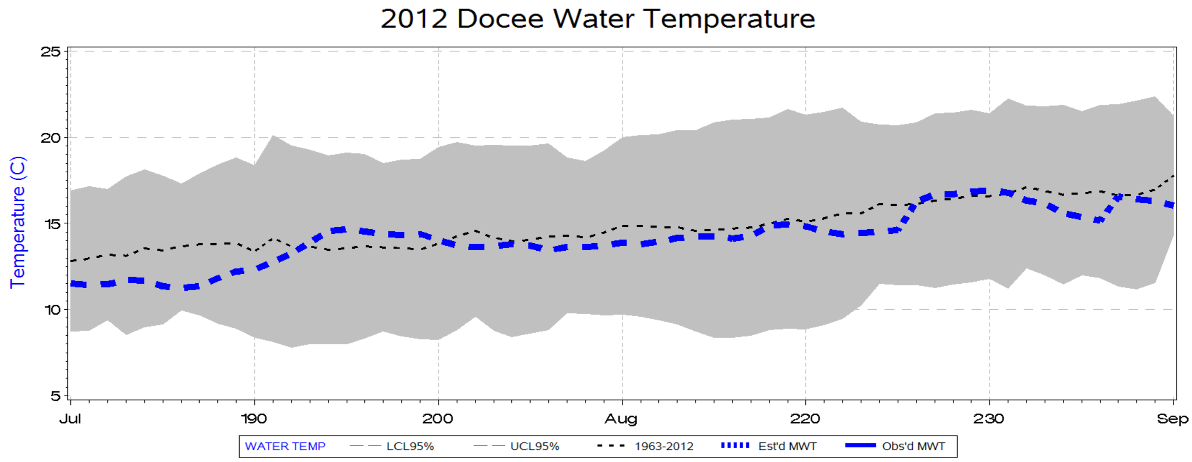
Sample plots for the year 2012 (below) display legend with vertical axis variates and horizontal axis with day of year (month label is *approximate* start of each month). Multi-panel plots (following pages) are organized for comparison of the following variates:



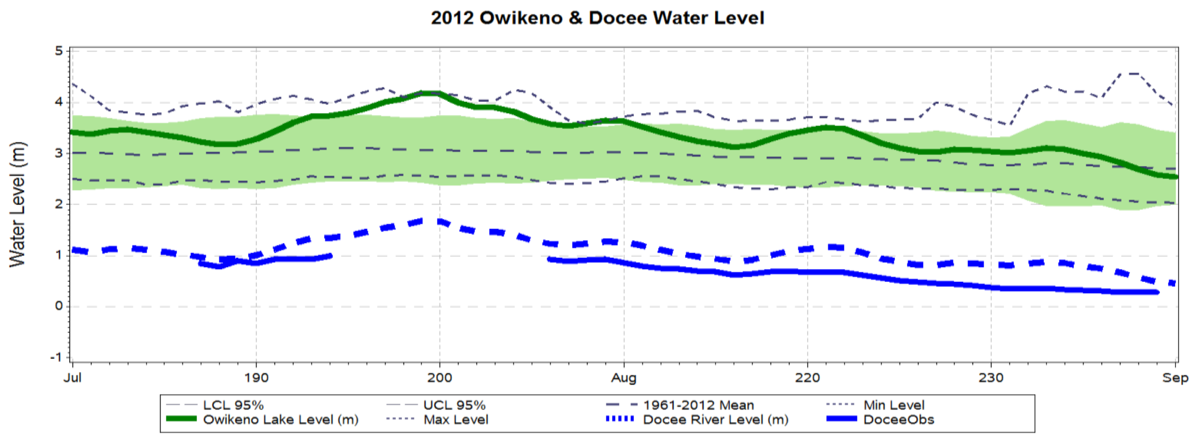
1. Daily migration rates as a percent (%) of annual stock escapement (black line), from daily Sockeye (adult + jack) migrants counted at the Docee fence. Historical mean daily migration rate (dark gray area) and maximum daily migration rate (light gray area) for years 1972-2012.



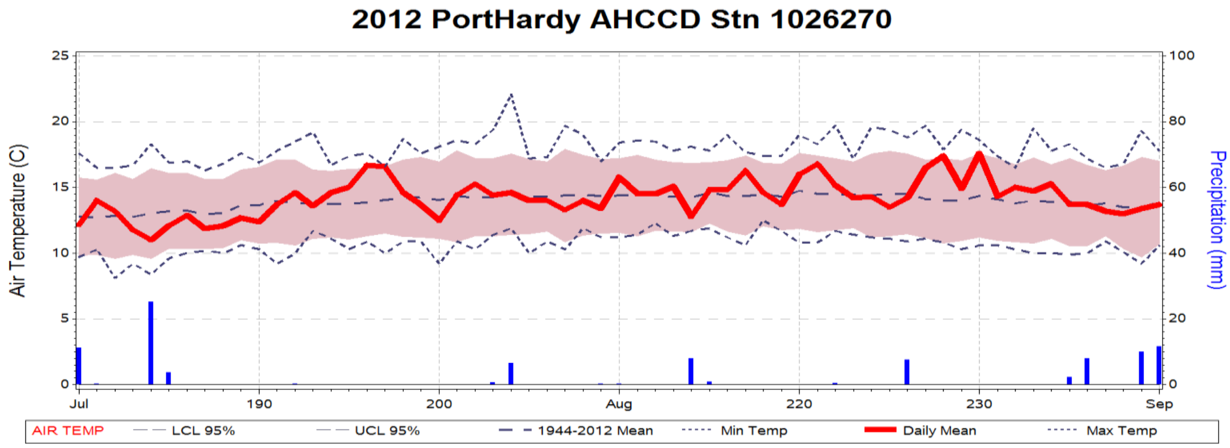
2. Annual Area 10 Sockeye commercial catch (thousand pieces), by month-week period (end of June to end of August), with total annual catch (pieces) and percent exploitation rate (E/R).



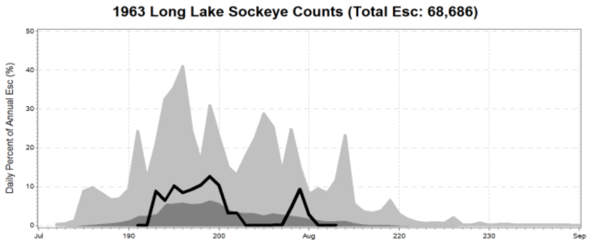
3. Observed (solid blue line) and estimated (dashed blue line) daily mean water temperature at the Docee fence, with historical daily MWT and variance (dashed line and gray area), 2004-2008.

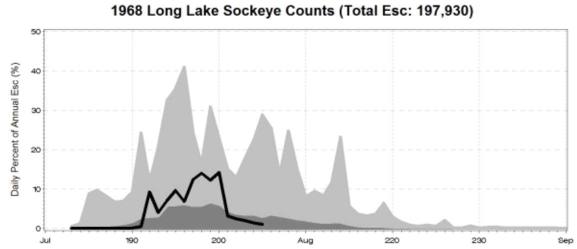


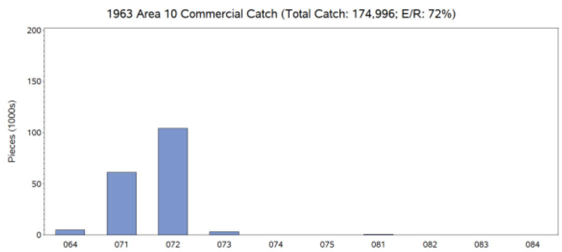
4. Daily mean water level (m) at the Docee River fence (observed: solid blue line; estimated: dashed blue line) and WSC station *Owikeno Lake* (green line), with historical daily mean and variance (dashed line and green area), 1961-2012.

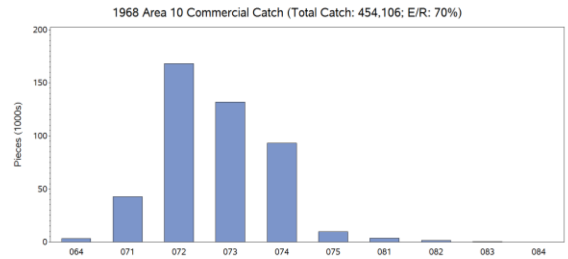


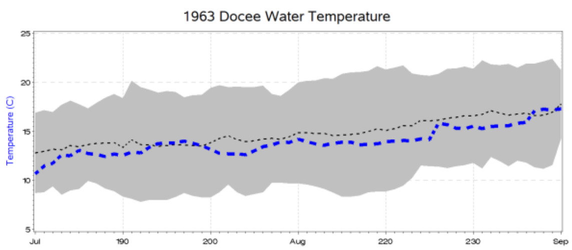
5. Total daily precipitation (mm, blue bars) and daily mean air temperature (°C, red line) at EC meteorological station *Port Hardy 1026270*, with historical daily mean and variance (dashed line and red area), 1944-2012.

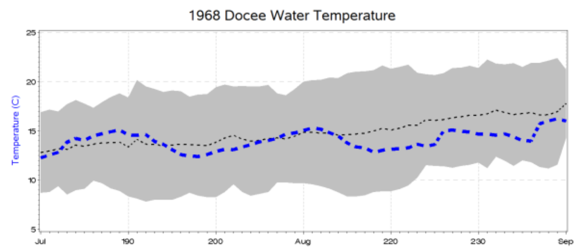

1963 Long Lake Sockeye Counts (Total Esc: 68,686)
Daily Percent of Annual Esc (%)

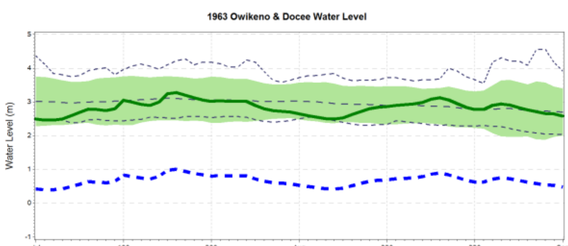

1968 Long Lake Sockeye Counts (Total Esc: 197,930)
Daily Percent of Annual Esc (%)

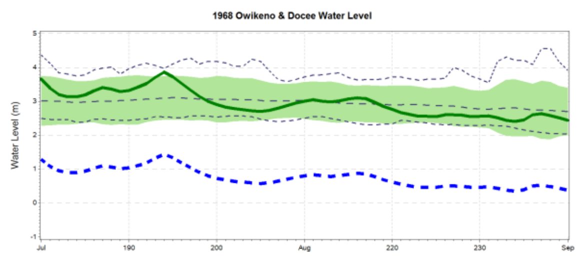

1963 Area 10 Commercial Catch (Total Catch: 174,996; E/R: 72%)
Pieces (1000s)

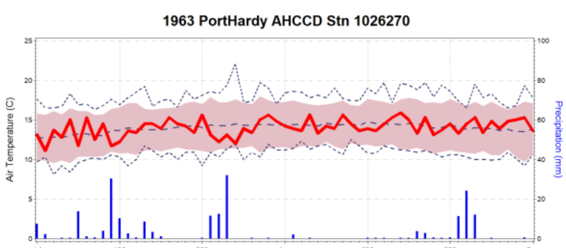

1968 Area 10 Commercial Catch (Total Catch: 454,106; E/R: 70%)
Pieces (1000s)

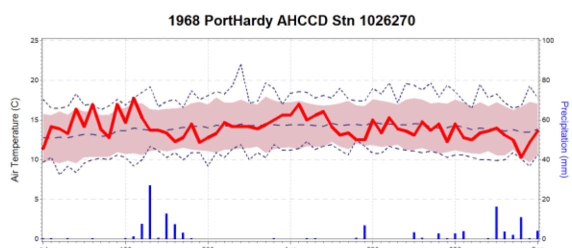

1963 Docee Water Temperature
Temperature (C)


1968 Docee Water Temperature
Temperature (C)

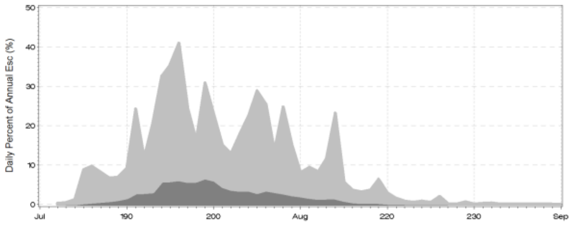

1963 Owikeno & Docee Water Level
Water Level (m)


1968 Owikeno & Docee Water Level
Water Level (m)

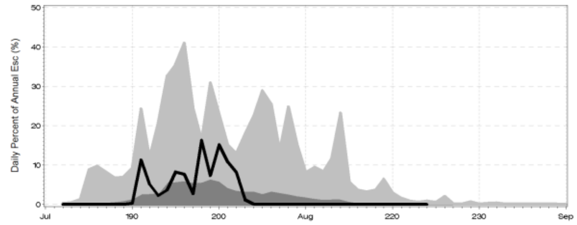

1963 PortHardy AHCCD Stn 1026270
Air Temperature (C)
Precipitation (mm)


1968 PortHardy AHCCD Stn 1026270
Air Temperature (C)
Precipitation (mm)

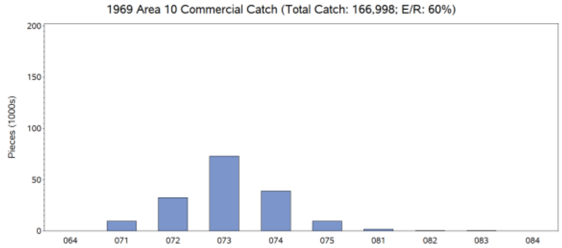
1969 Long Lake Sockeye Counts (Total Esc: .)



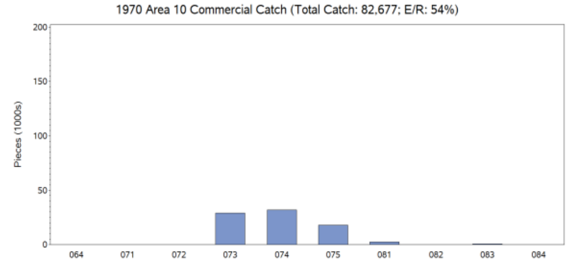
1970 Long Lake Sockeye Counts (Total Esc: 70,065)



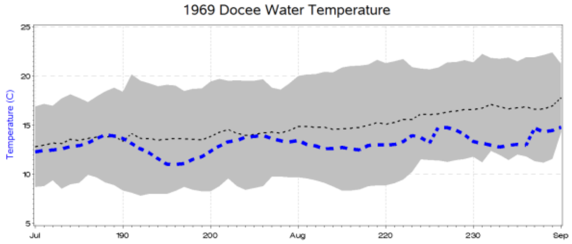
1969 Area 10 Commercial Catch (Total Catch: 166,998; E/R: 60%)



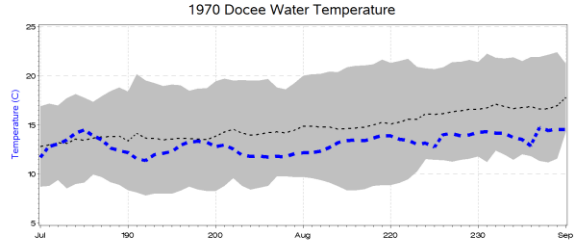
1970 Area 10 Commercial Catch (Total Catch: 82,677; E/R: 54%)



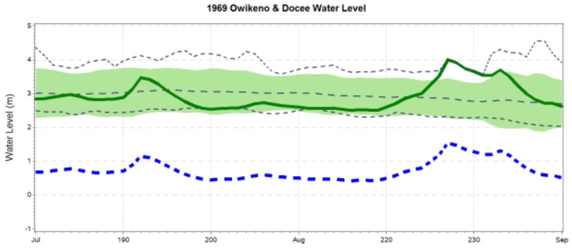
1969 Docee Water Temperature



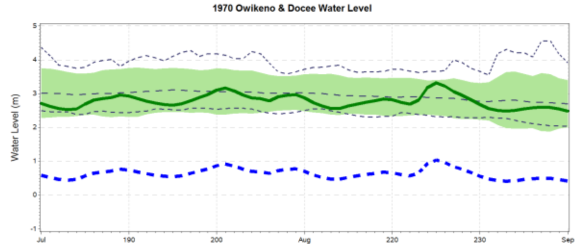
1970 Docee Water Temperature



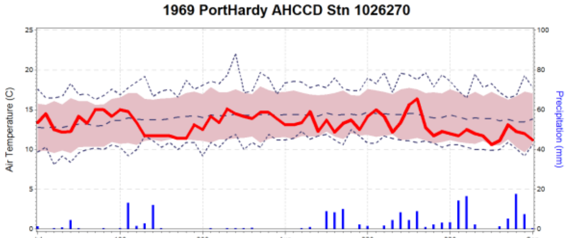
1969 Owikeno & Docee Water Level



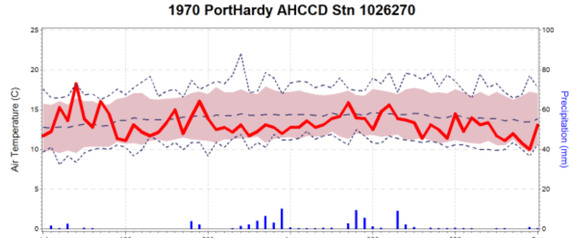
1970 Owikeno & Docee Water Level

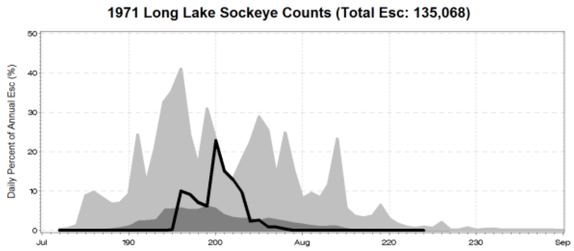


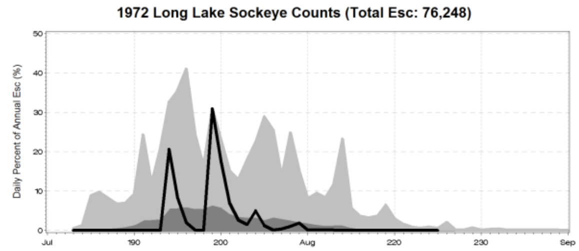
1969 PortHardy AHCCD Stn 1026270

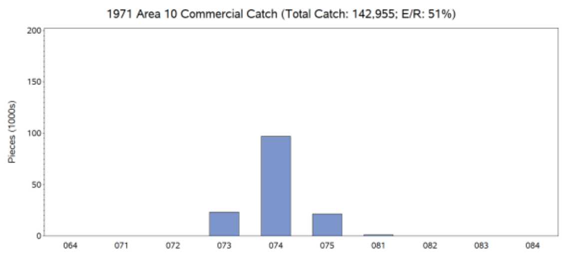


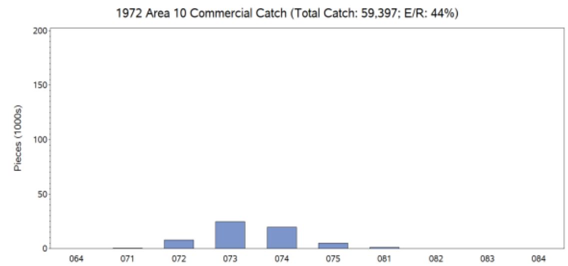
1970 PortHardy AHCCD Stn 1026270

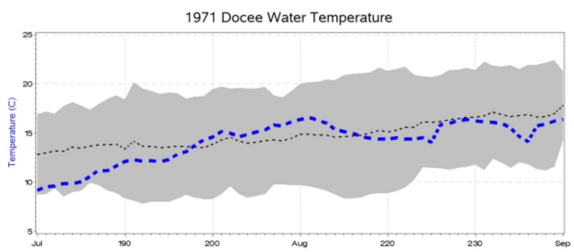


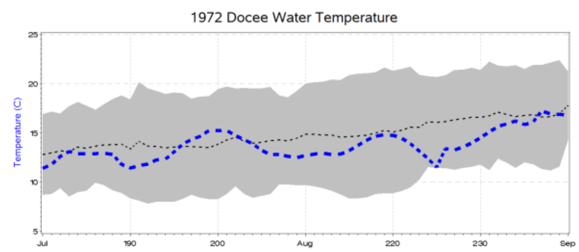

1971 Long Lake Sockeye Counts (Total Esc: 135,068)

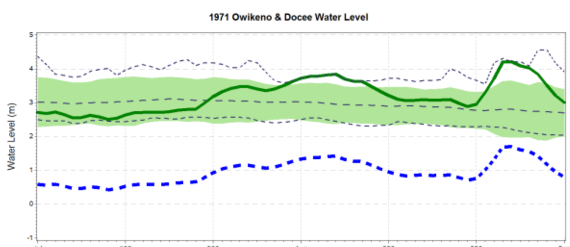

1972 Long Lake Sockeye Counts (Total Esc: 76,248)

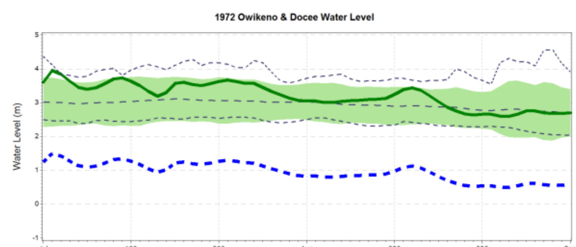

1971 Area 10 Commercial Catch (Total Catch: 142,955; E/R: 51%)

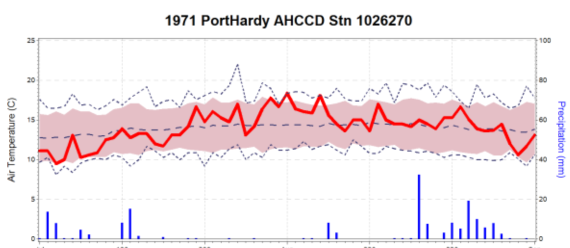

1972 Area 10 Commercial Catch (Total Catch: 59,397; E/R: 44%)

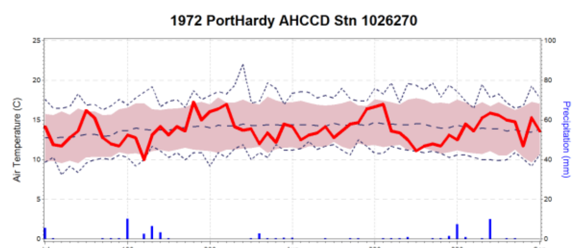

1971 Docee Water Temperature


1972 Docee Water Temperature

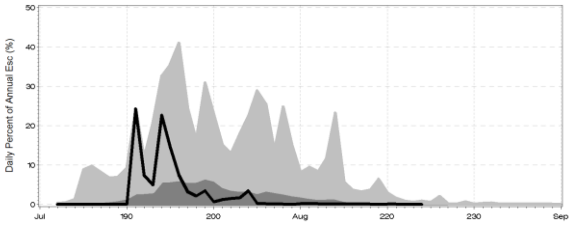

1971 Owikeno & Docee Water Level


1972 Owikeno & Docee Water Level

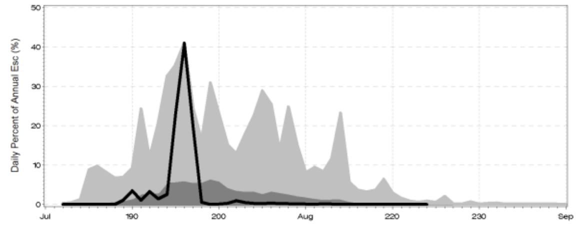

1971 PortHardy AHCCD Stn 1026270


1972 PortHardy AHCCD Stn 1026270

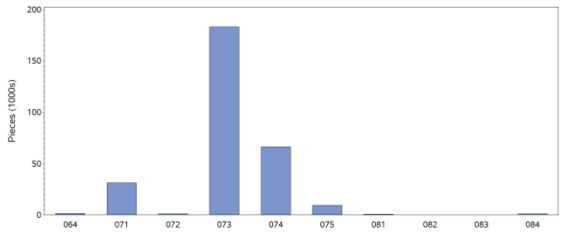
1973 Long Lake Sockeye Counts (Total Esc: 170,002)



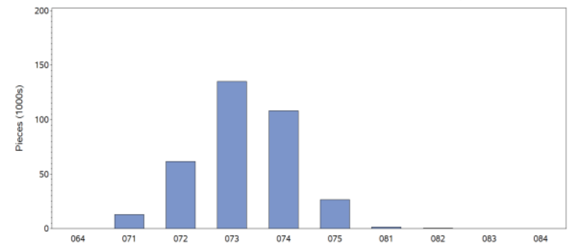
1974 Long Lake Sockeye Counts (Total Esc: 91,043)



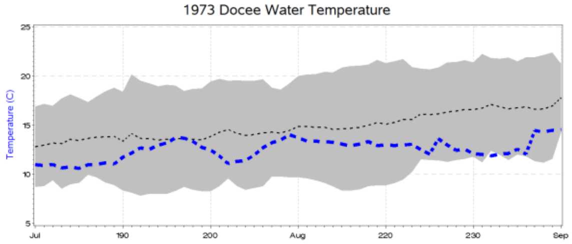
1973 Area 10 Commercial Catch (Total Catch: 294,693; E/R: 63%)



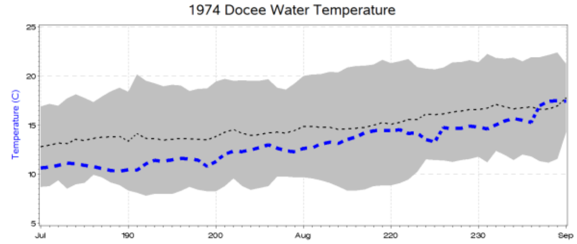
1974 Area 10 Commercial Catch (Total Catch: 347,705; E/R: 79%)



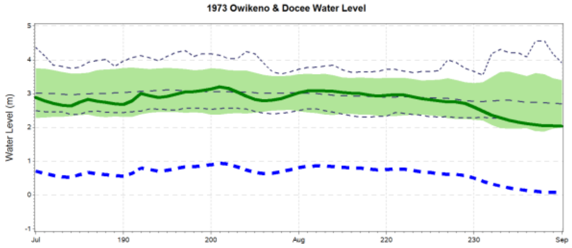
1973 Docee Water Temperature



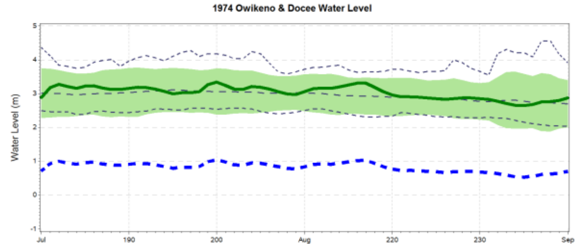
1974 Docee Water Temperature



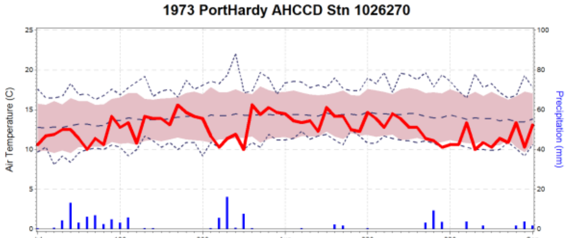
1973 Owikeno & Docee Water Level



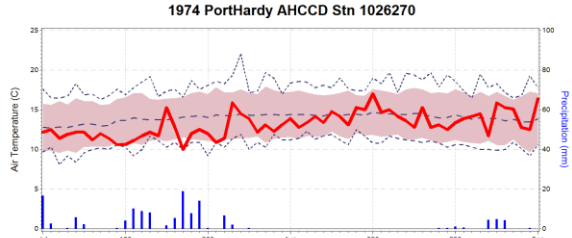
1974 Owikeno & Docee Water Level



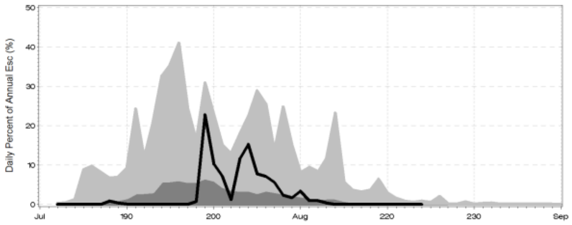
1973 PortHardy AHCCD Stn 1026270



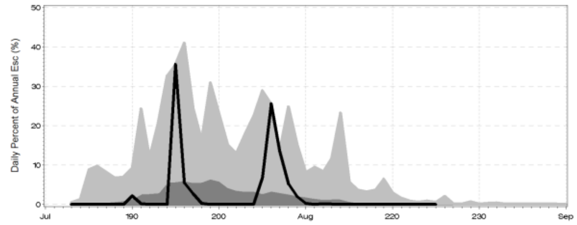
1974 PortHardy AHCCD Stn 1026270



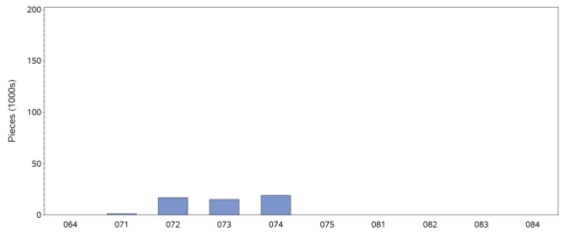
1975 Long Lake Sockeye Counts (Total Esc: 62,967)



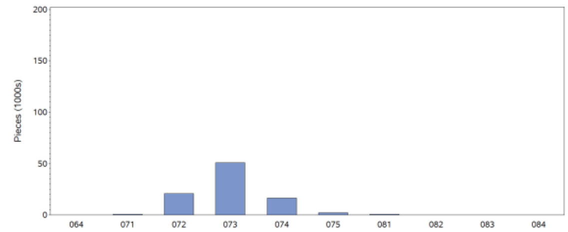
1976 Long Lake Sockeye Counts (Total Esc: 60,904)



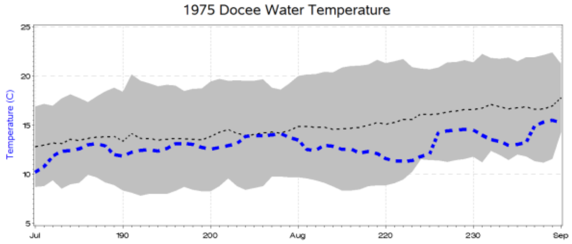
1975 Area 10 Commercial Catch (Total Catch: 52,673; E/R: 46%)



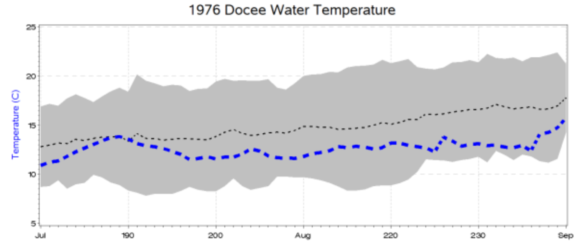
1976 Area 10 Commercial Catch (Total Catch: 92,189; E/R: 60%)



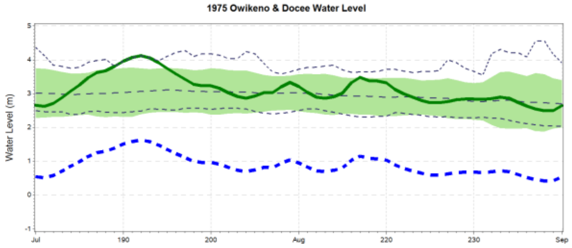
1975 Docee Water Temperature



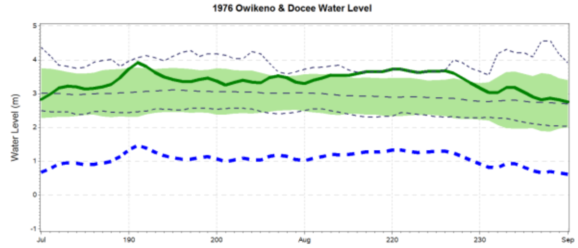
1976 Docee Water Temperature



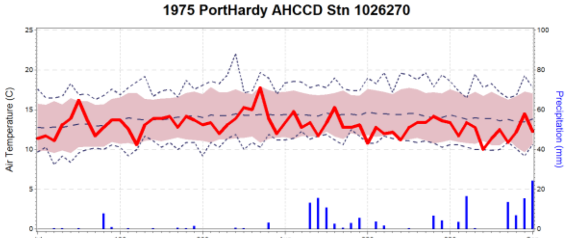
1975 Owikeno & Docee Water Level



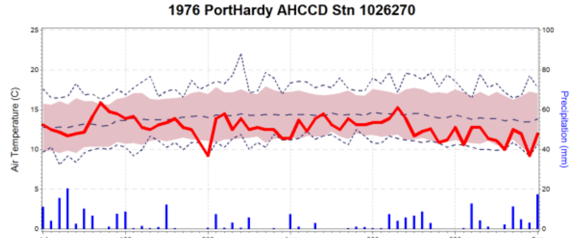
1976 Owikeno & Docee Water Level



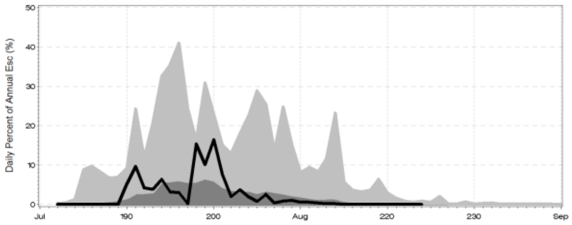
1975 PortHardy AHCCD Stn 1026270



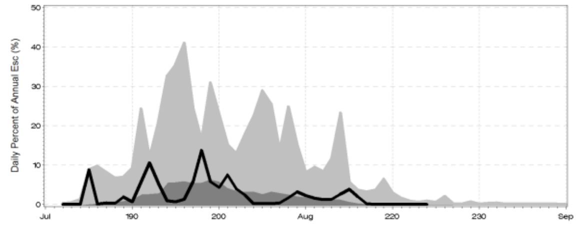
1976 PortHardy AHCCD Stn 1026270



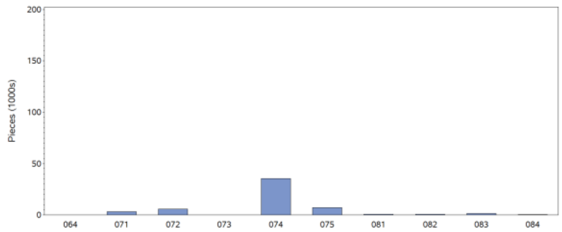
1977 Long Lake Sockeye Counts (Total Esc: 128,601)



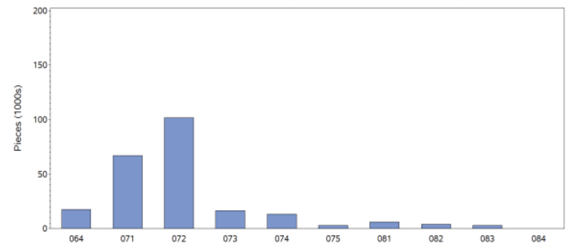
1978 Long Lake Sockeye Counts (Total Esc: 84,015)



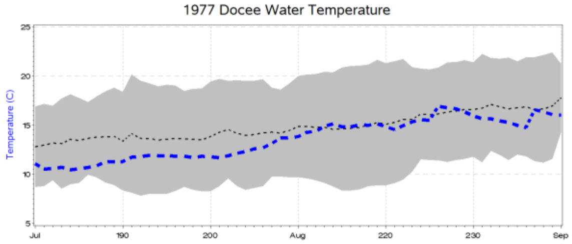
1977 Area 10 Commercial Catch (Total Catch: 54,828; E/R: 30%)



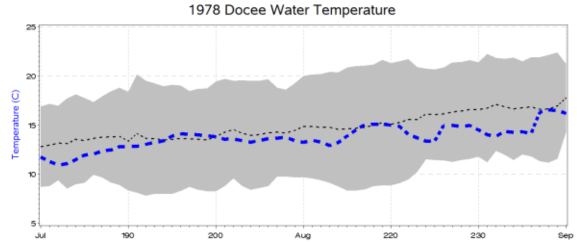
1978 Area 10 Commercial Catch (Total Catch: 233,522; E/R: 74%)



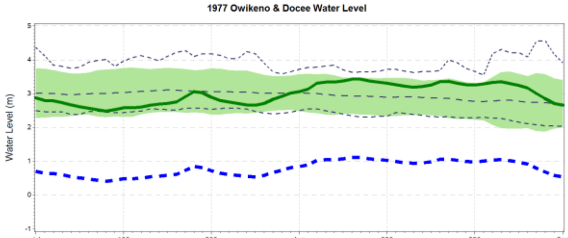
1977 Docee Water Temperature



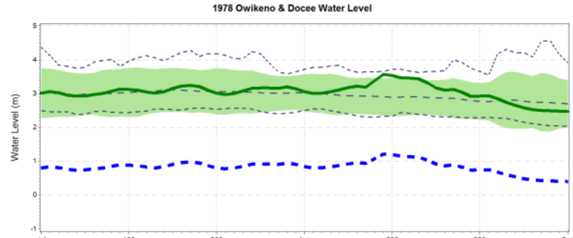
1978 Docee Water Temperature



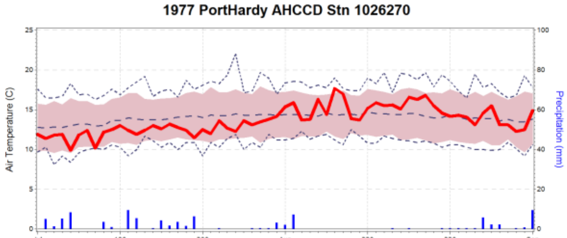
1977 Owikeno & Docee Water Level



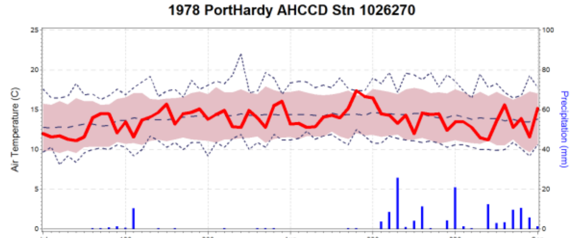
1978 Owikeno & Docee Water Level



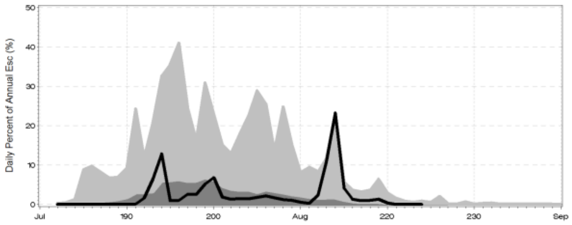
1977 PortHardy AHCCD Stn 1026270



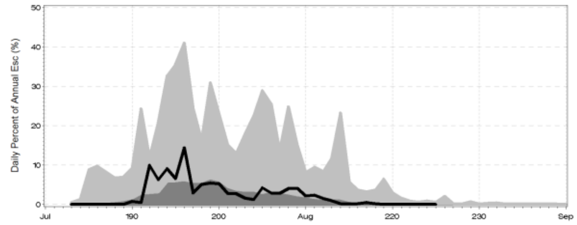
1978 PortHardy AHCCD Stn 1026270



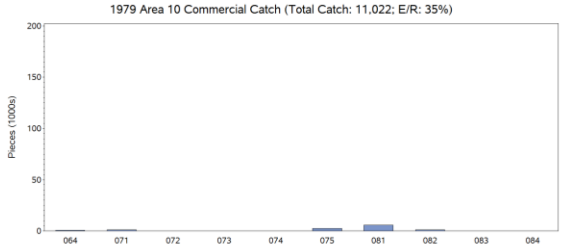
1979 Long Lake Sockeye Counts (Total Esc: 20,257)



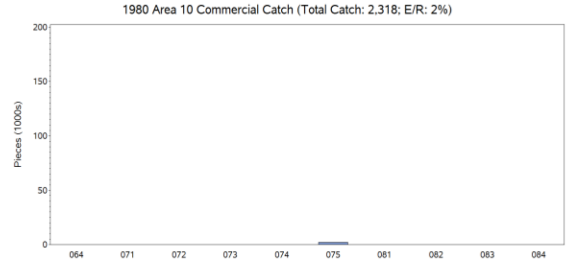
1980 Long Lake Sockeye Counts (Total Esc: 128,435)



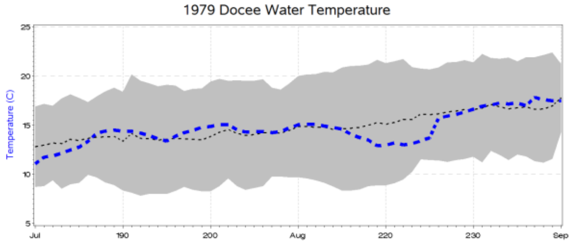
1979 Area 10 Commercial Catch (Total Catch: 11,022; E/R: 35%)



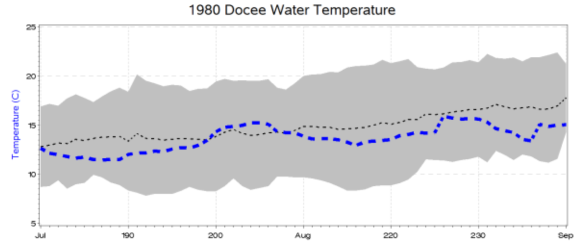
1980 Area 10 Commercial Catch (Total Catch: 2,318; E/R: 2%)



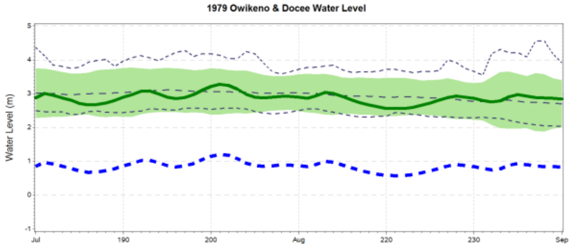
1979 Docee Water Temperature



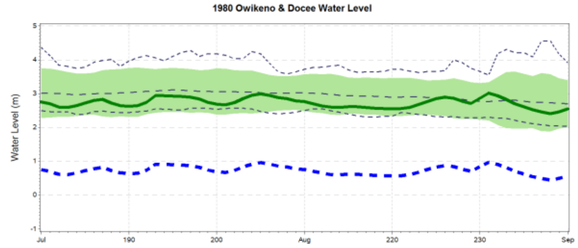
1980 Docee Water Temperature



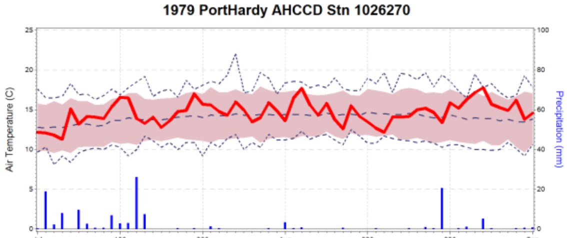
1979 Owikeno & Docee Water Level



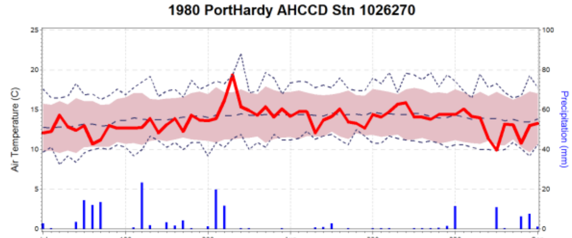
1980 Owikeno & Docee Water Level



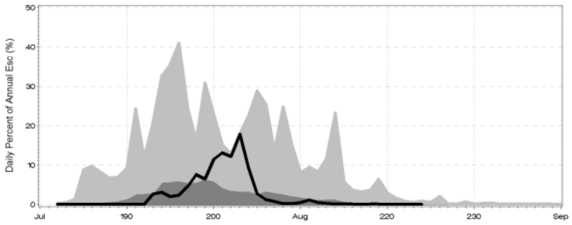
1979 PortHardy AHCCD Stn 1026270



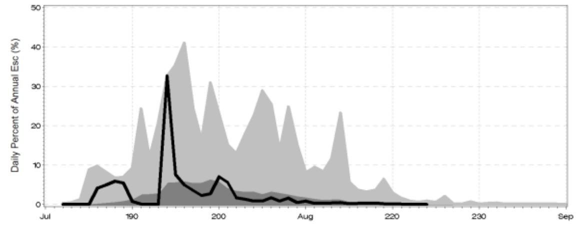
1980 PortHardy AHCCD Stn 1026270



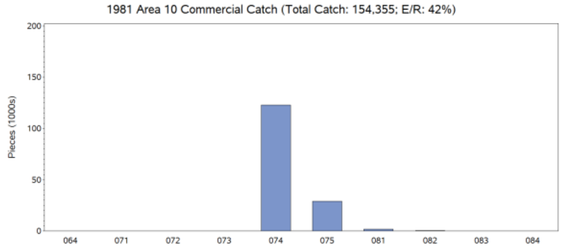
1981 Long Lake Sockeye Counts (Total Esc: 214,345)



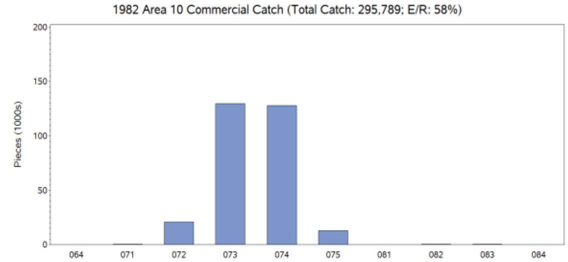
1982 Long Lake Sockeye Counts (Total Esc: 213,674)



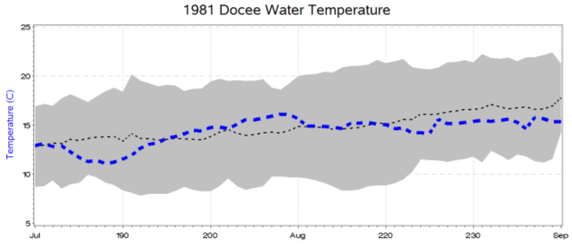
1981 Area 10 Commercial Catch (Total Catch: 154,355; E/R: 42%)



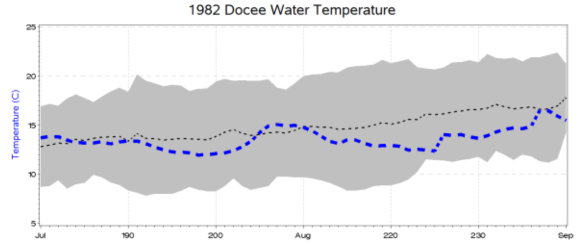
1982 Area 10 Commercial Catch (Total Catch: 295,789; E/R: 58%)



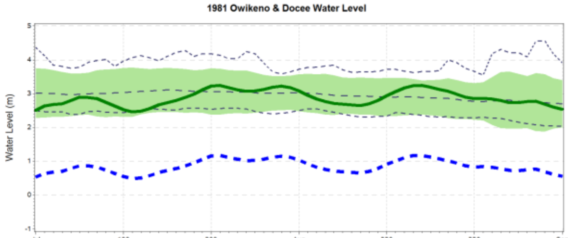
1981 Docee Water Temperature



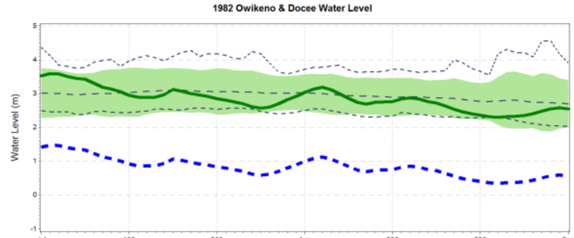
1982 Docee Water Temperature



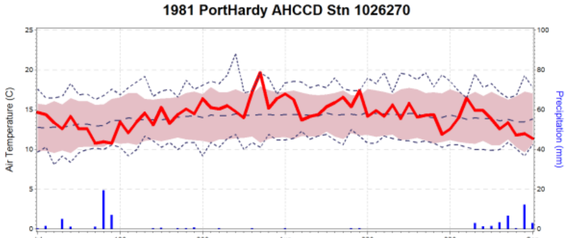
1981 Owikeno & Docee Water Level



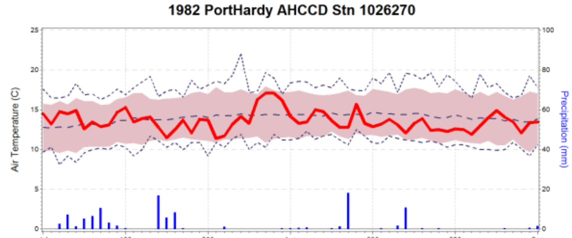
1982 Owikeno & Docee Water Level



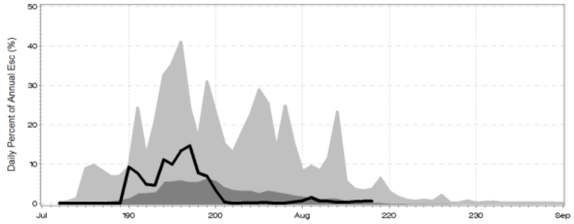
1981 PortHardy AHCCD Stn 1026270



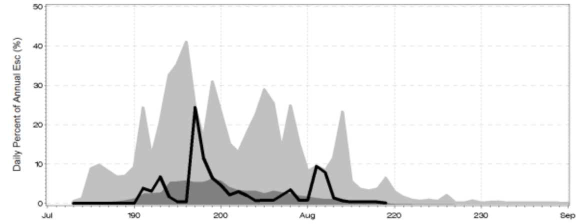
1982 PortHardy AHCCD Stn 1026270



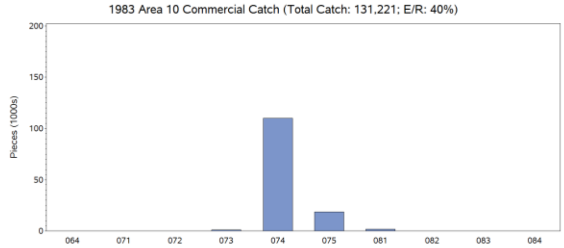
1983 Long Lake Sockeye Counts (Total Esc: 197,161)



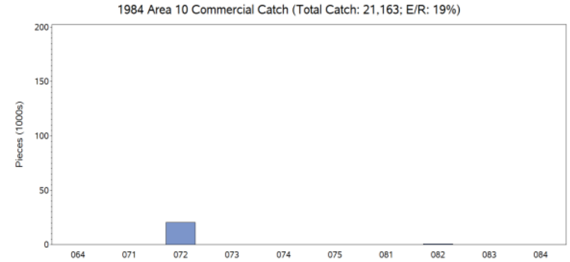
1984 Long Lake Sockeye Counts (Total Esc: 89,011)



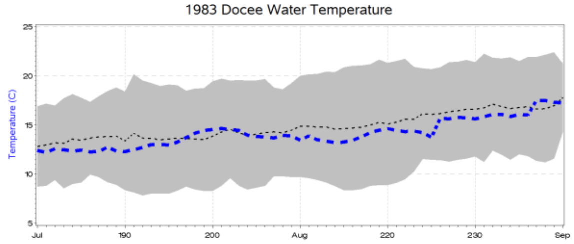
1983 Area 10 Commercial Catch (Total Catch: 131,221; E/R: 40%)



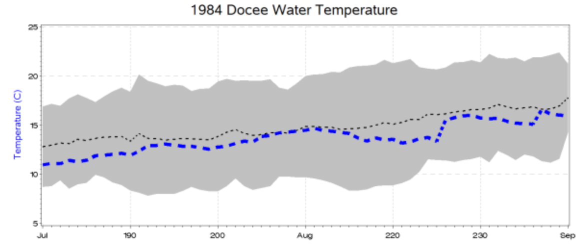
1984 Area 10 Commercial Catch (Total Catch: 21,163; E/R: 19%)



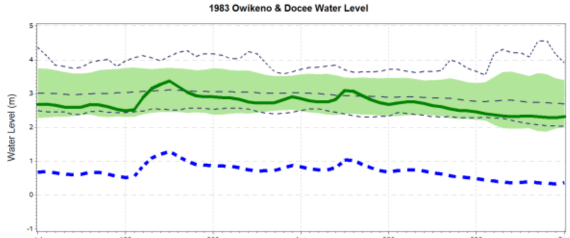
1983 Docee Water Temperature



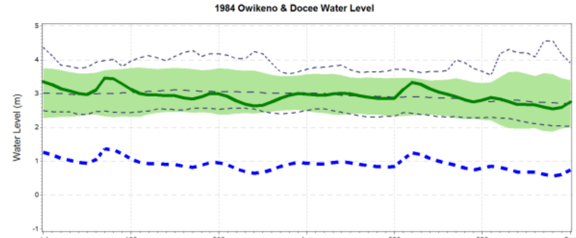
1984 Docee Water Temperature



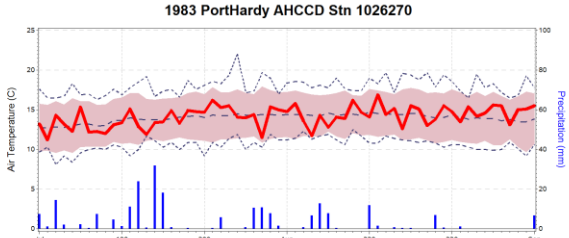
1983 Owikeno & Docee Water Level



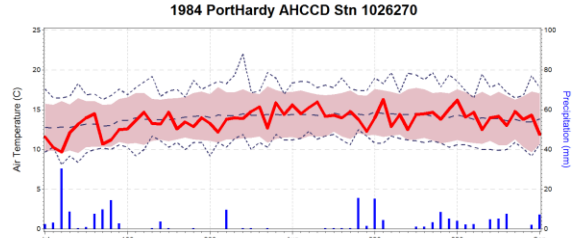
1984 Owikeno & Docee Water Level



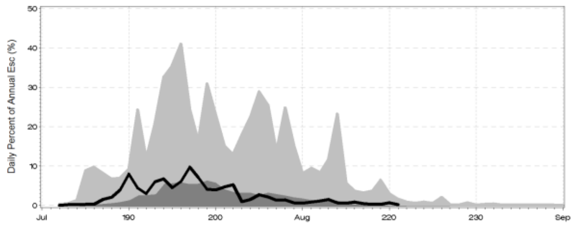
1983 PortHardy AHCCD Stn 1026270



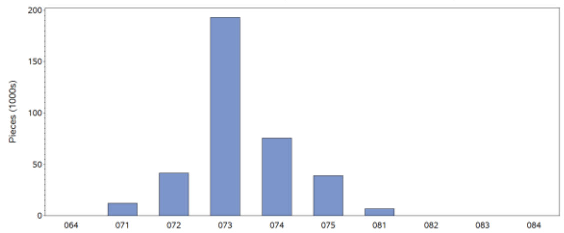
1984 PortHardy AHCCD Stn 1026270



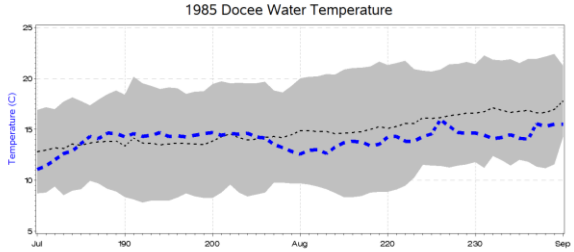
1985 Long Lake Sockeye Counts (Total Esc: 247,437)



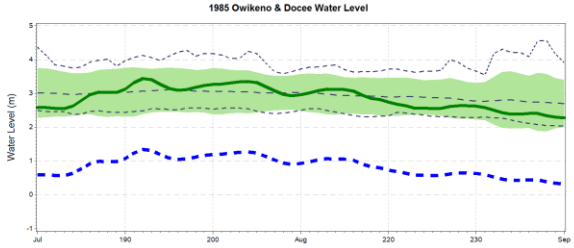
1985 Area 10 Commercial Catch (Total Catch: 369,178; E/R: 60%)



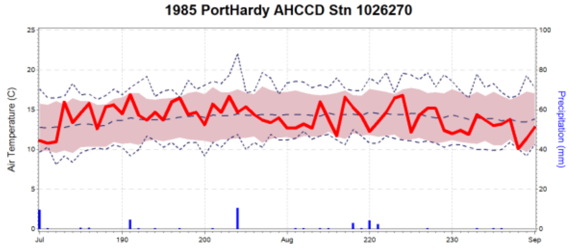
1985 Docee Water Temperature



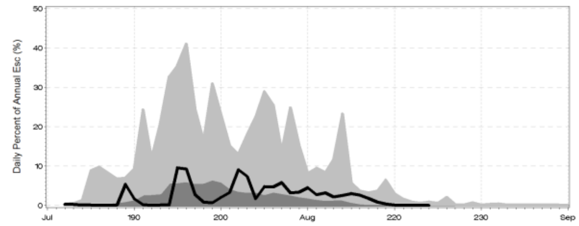
1985 Owikeno & Docee Water Level



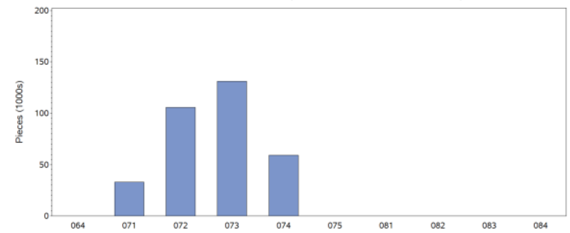
1985 PortHardy AHCCD Stn 1026270



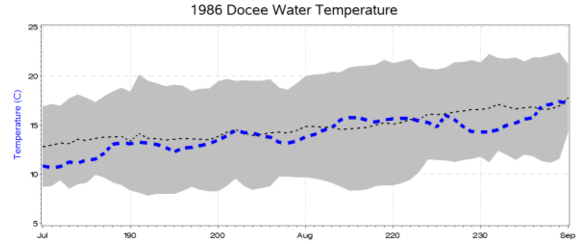
1986 Long Lake Sockeye Counts (Total Esc: 197,851)



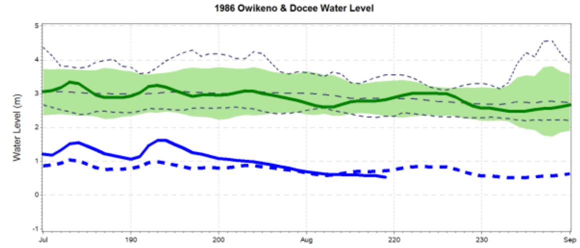
1986 Area 10 Commercial Catch (Total Catch: 369,854; E/R: 65%)



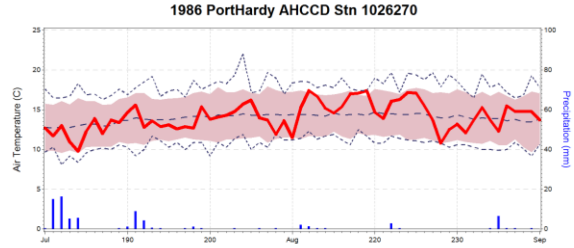
1986 Docee Water Temperature



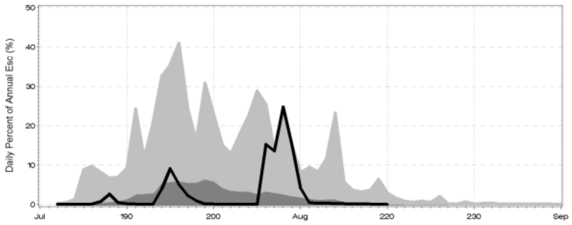
1986 Owikeno & Docee Water Level



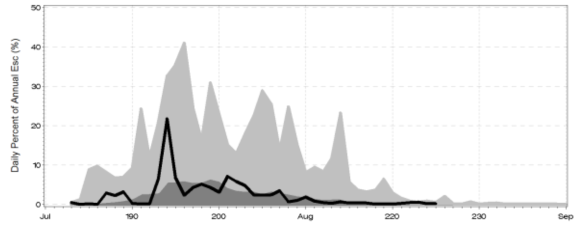
1986 PortHardy AHCCD Stn 1026270



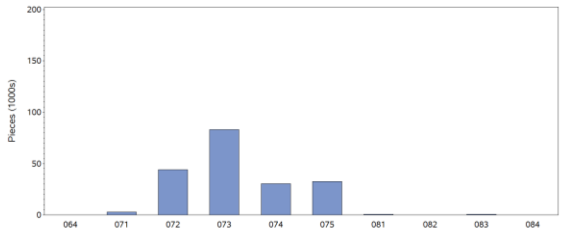
1987 Long Lake Sockeye Counts (Total Esc: 193,781)



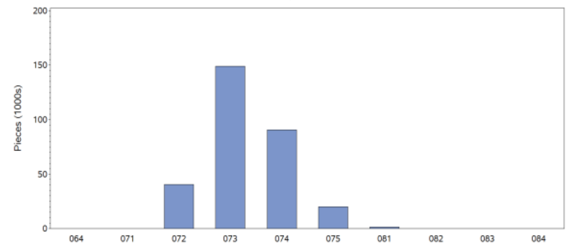
1988 Long Lake Sockeye Counts (Total Esc: 201,963)



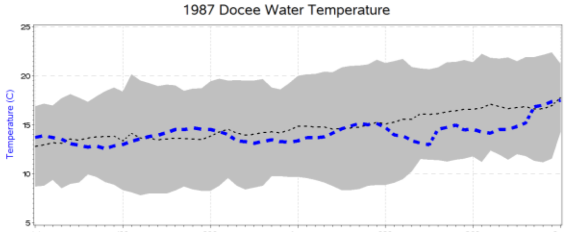
1987 Area 10 Commercial Catch (Total Catch: 194,926; E/R: 49%)



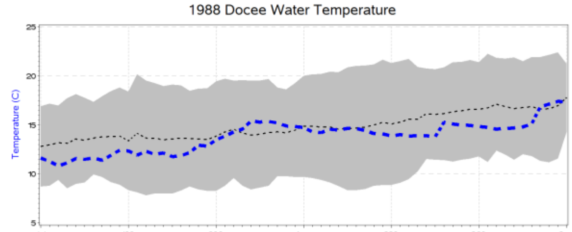
1988 Area 10 Commercial Catch (Total Catch: 301,731; E/R: 59%)



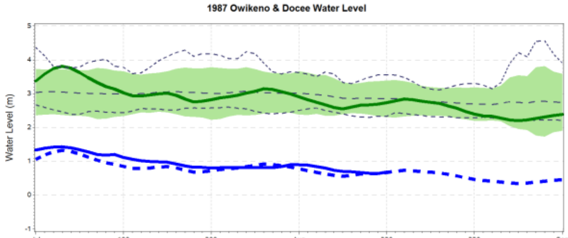
1987 Docee Water Temperature



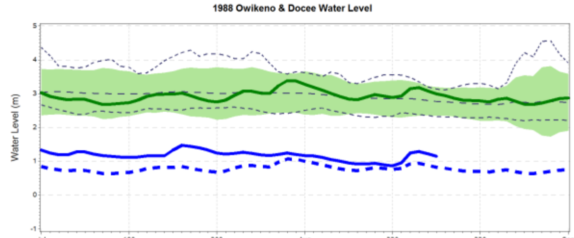
1988 Docee Water Temperature



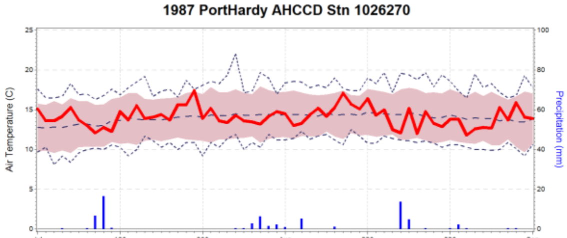
1987 Owikeno & Docee Water Level



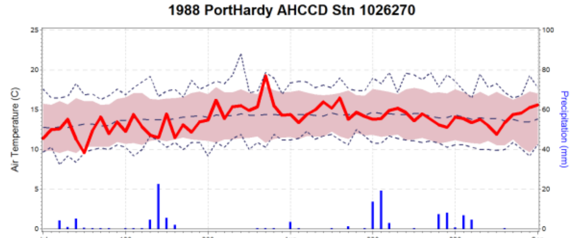
1988 Owikeno & Docee Water Level



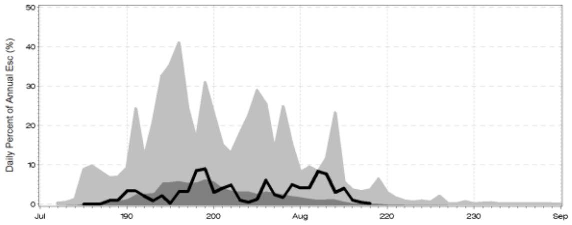
1987 PortHardy AHCCD Stn 1026270



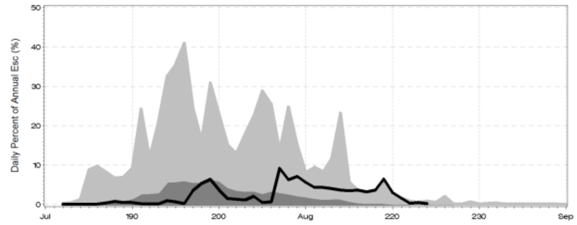
1988 PortHardy AHCCD Stn 1026270



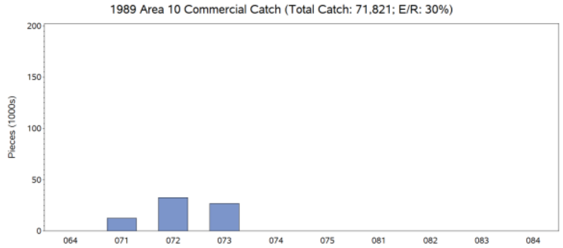
1989 Long Lake Sockeye Counts (Total Esc: 163,804)



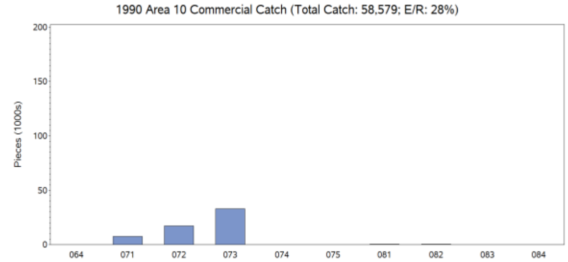
1990 Long Lake Sockeye Counts (Total Esc: 146,016)



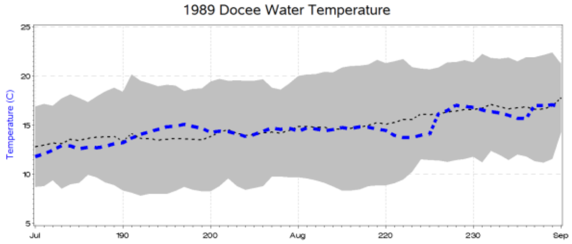
1989 Area 10 Commercial Catch (Total Catch: 71,821; E/R: 30%)



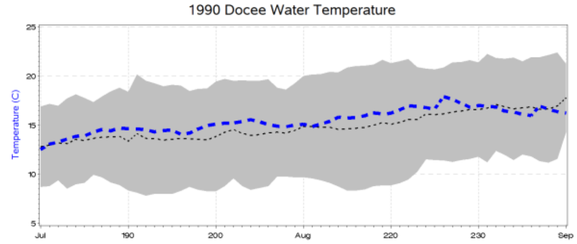
1990 Area 10 Commercial Catch (Total Catch: 58,579; E/R: 28%)



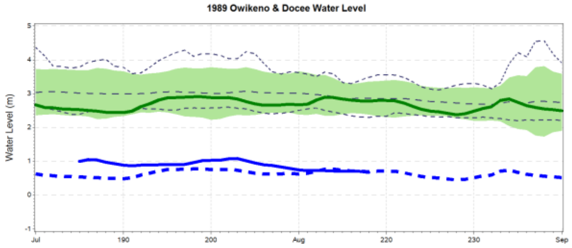
1989 Docee Water Temperature



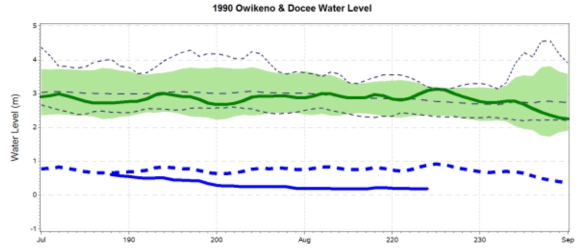
1990 Docee Water Temperature



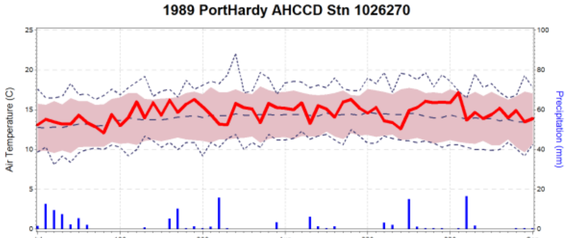
1989 Owikeno & Docee Water Level



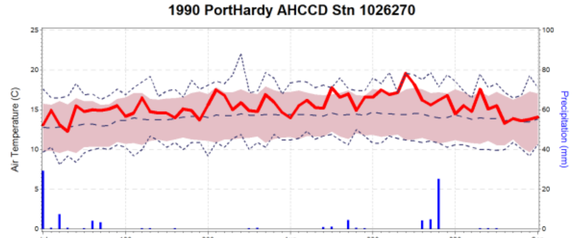
1990 Owikeno & Docee Water Level



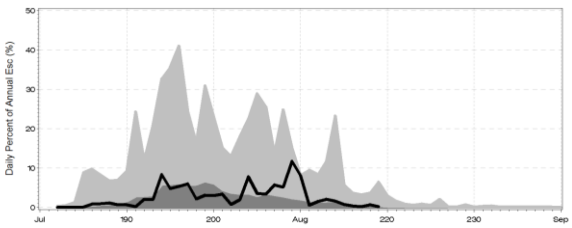
1989 PortHardy AHCCD Stn 1026270



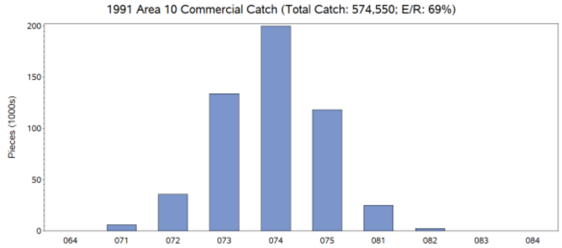
1990 PortHardy AHCCD Stn 1026270



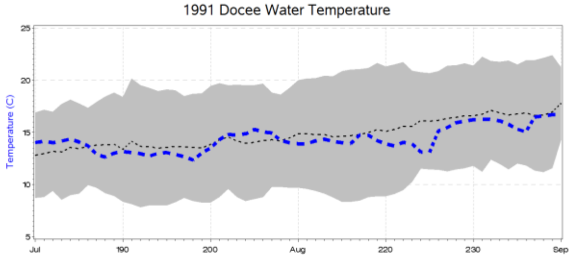
1991 Long Lake Sockeye Counts (Total Esc: 259,316)



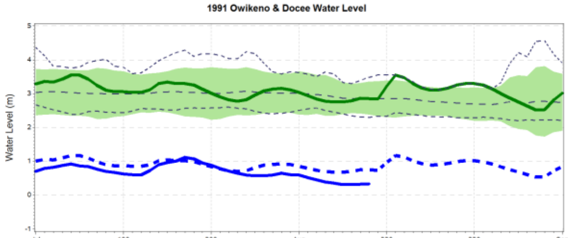
1991 Area 10 Commercial Catch (Total Catch: 574,550; E/R: 69%)



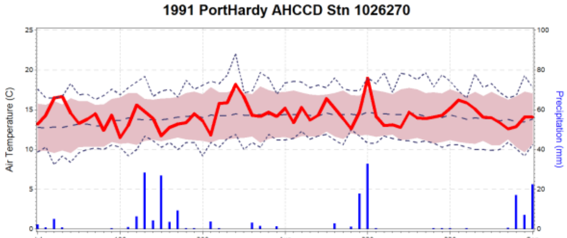
1991 Docee Water Temperature



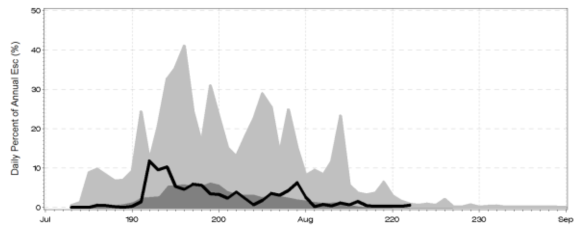
1991 Owikeno & Docee Water Level



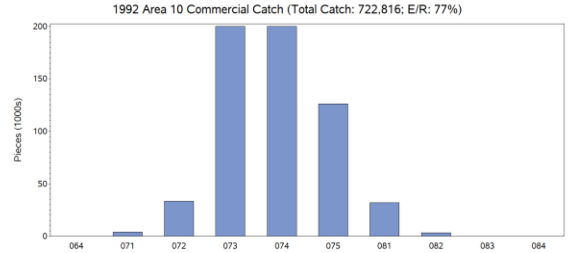
1991 PortHardy AHCCD Stn 1026270



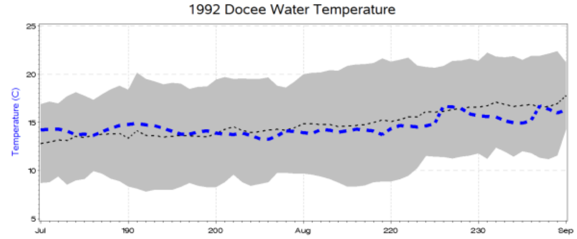
1992 Long Lake Sockeye Counts (Total Esc: 217,106)



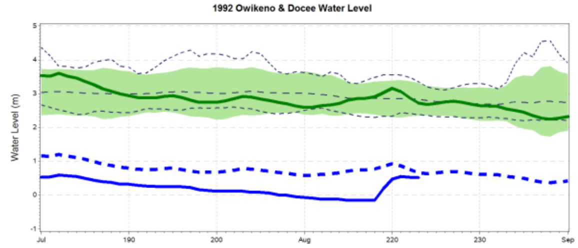
1992 Area 10 Commercial Catch (Total Catch: 722,816; E/R: 77%)



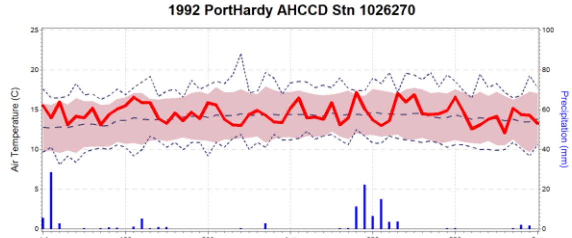
1992 Docee Water Temperature



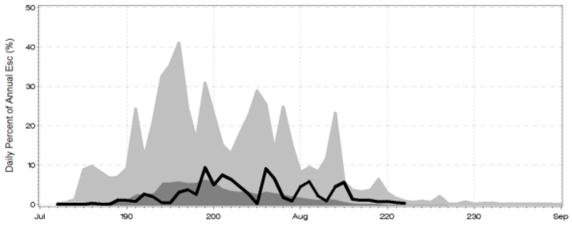
1992 Owikeno & Docee Water Level



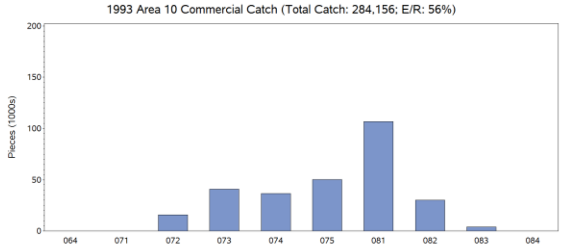
1992 PortHardy AHCCD Stn 1026270



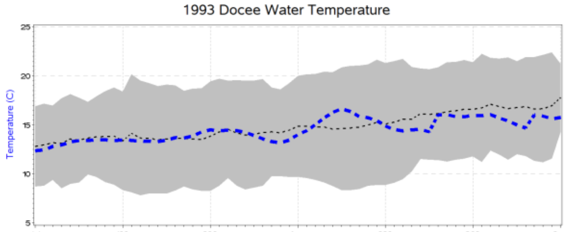
1993 Long Lake Sockeye Counts (Total Esc: 217,422)



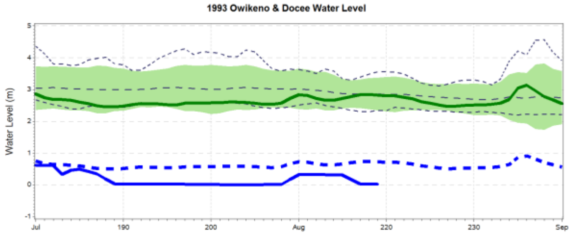
1993 Area 10 Commercial Catch (Total Catch: 284,156; E/R: 56%)



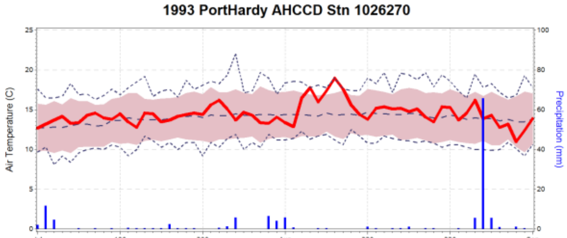
1993 Docee Water Temperature



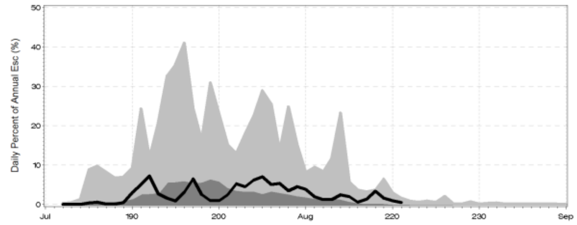
1993 Owikeno & Docee Water Level



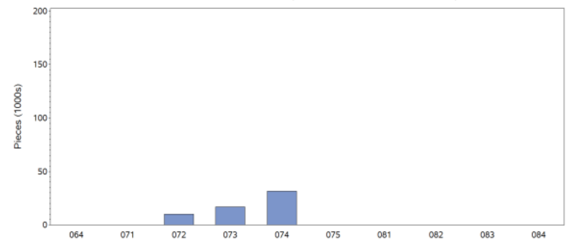
1993 PortHardy AHCCD Stn 1026270



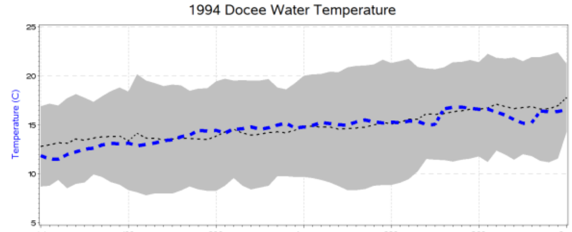
1994 Long Lake Sockeye Counts (Total Esc: 94,295)



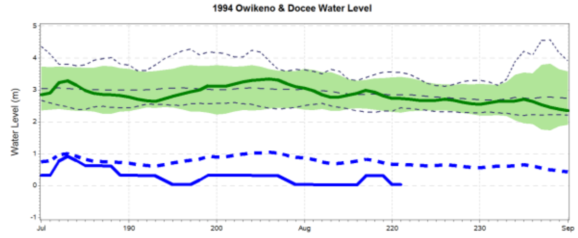
1994 Area 10 Commercial Catch (Total Catch: 58,094; E/R: 37%)



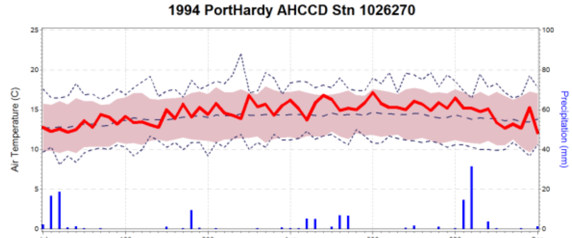
1994 Docee Water Temperature



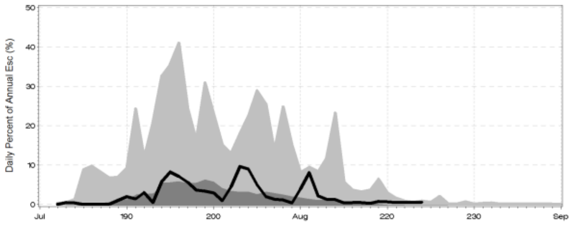
1994 Owikeno & Docee Water Level



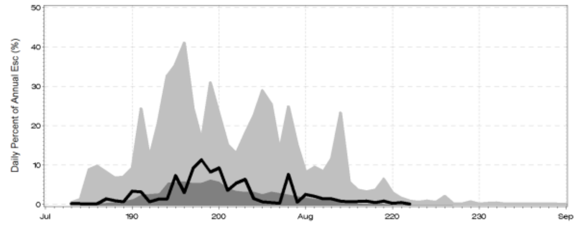
1994 PortHardy AHCCD Stn 1026270



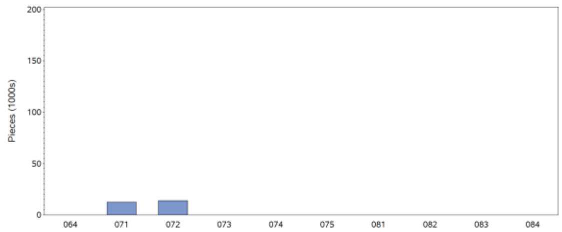
1995 Long Lake Sockeye Counts (Total Esc: 56,244)



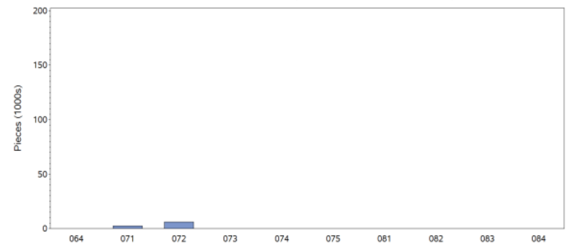
1996 Long Lake Sockeye Counts (Total Esc: 53,272)



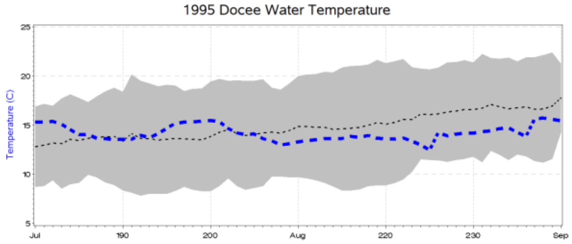
1995 Area 10 Commercial Catch (Total Catch: 26,428; E/R: 32%)



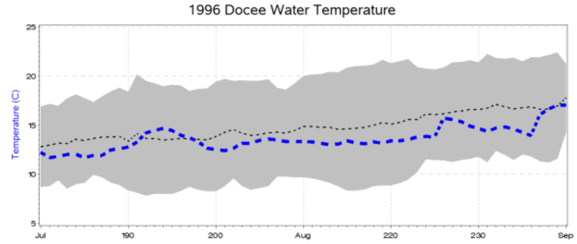
1996 Area 10 Commercial Catch (Total Catch: 8,702; E/R: 14%)



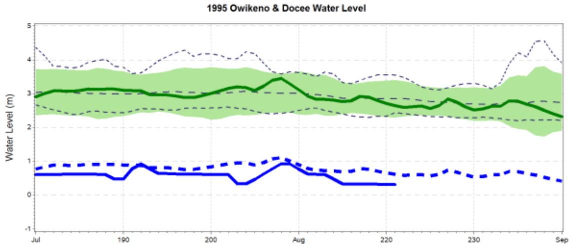
1995 Docee Water Temperature



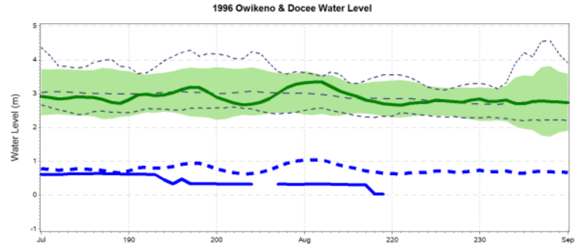
1996 Docee Water Temperature



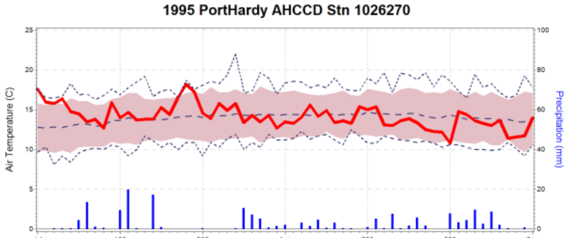
1995 Owikeno & Docee Water Level



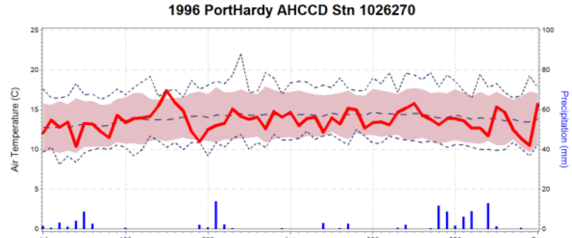
1996 Owikeno & Docee Water Level



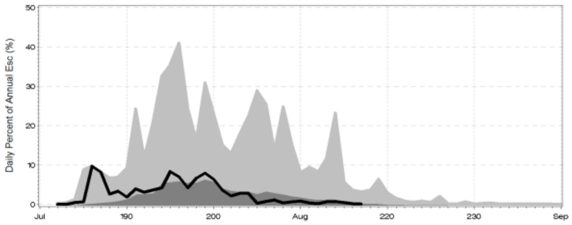
1995 PortHardy AHCCD Stn 1026270



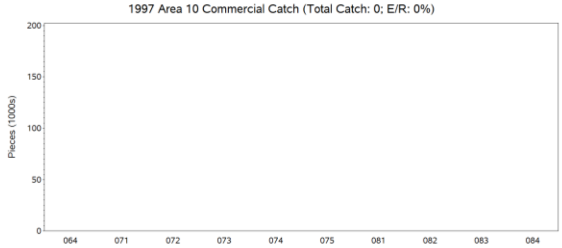
1996 PortHardy AHCCD Stn 1026270



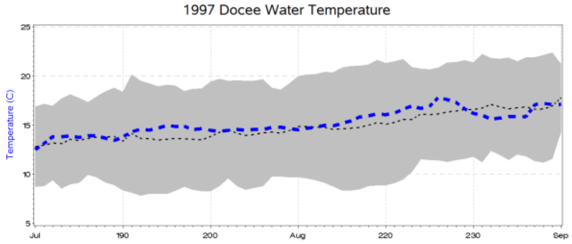
1997 Long Lake Sockeye Counts (Total Esc: 30,997)



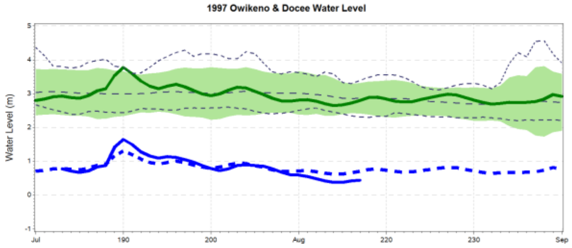
1997 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



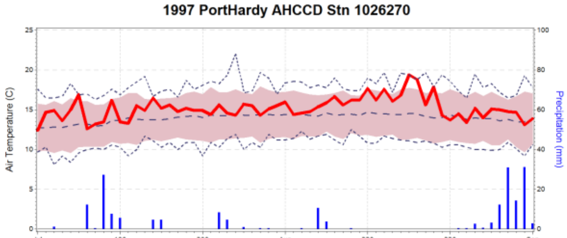
1997 Docee Water Temperature



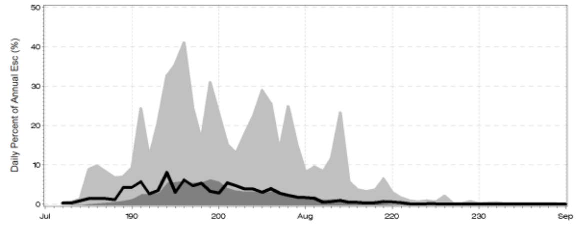
1997 Owikeno & Docee Water Level



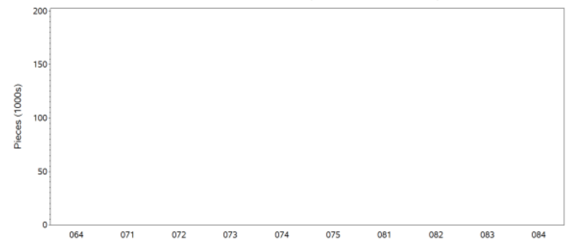
1997 PortHardy AHCCD Stn 1026270



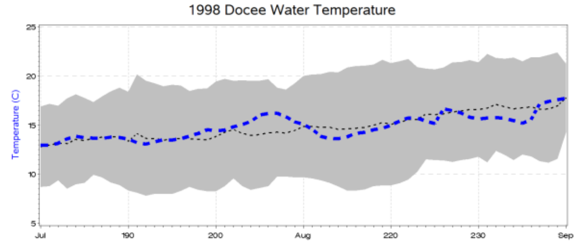
1998 Long Lake Sockeye Counts (Total Esc: 75,988)



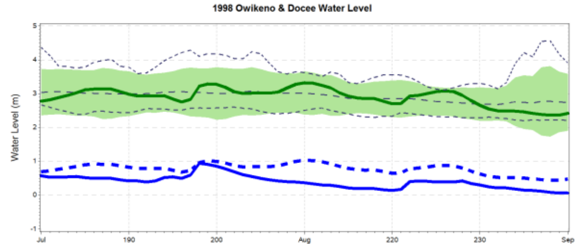
1998 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



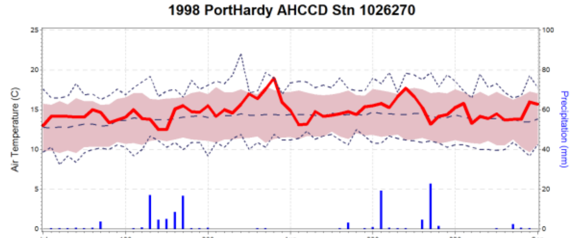
1998 Docee Water Temperature

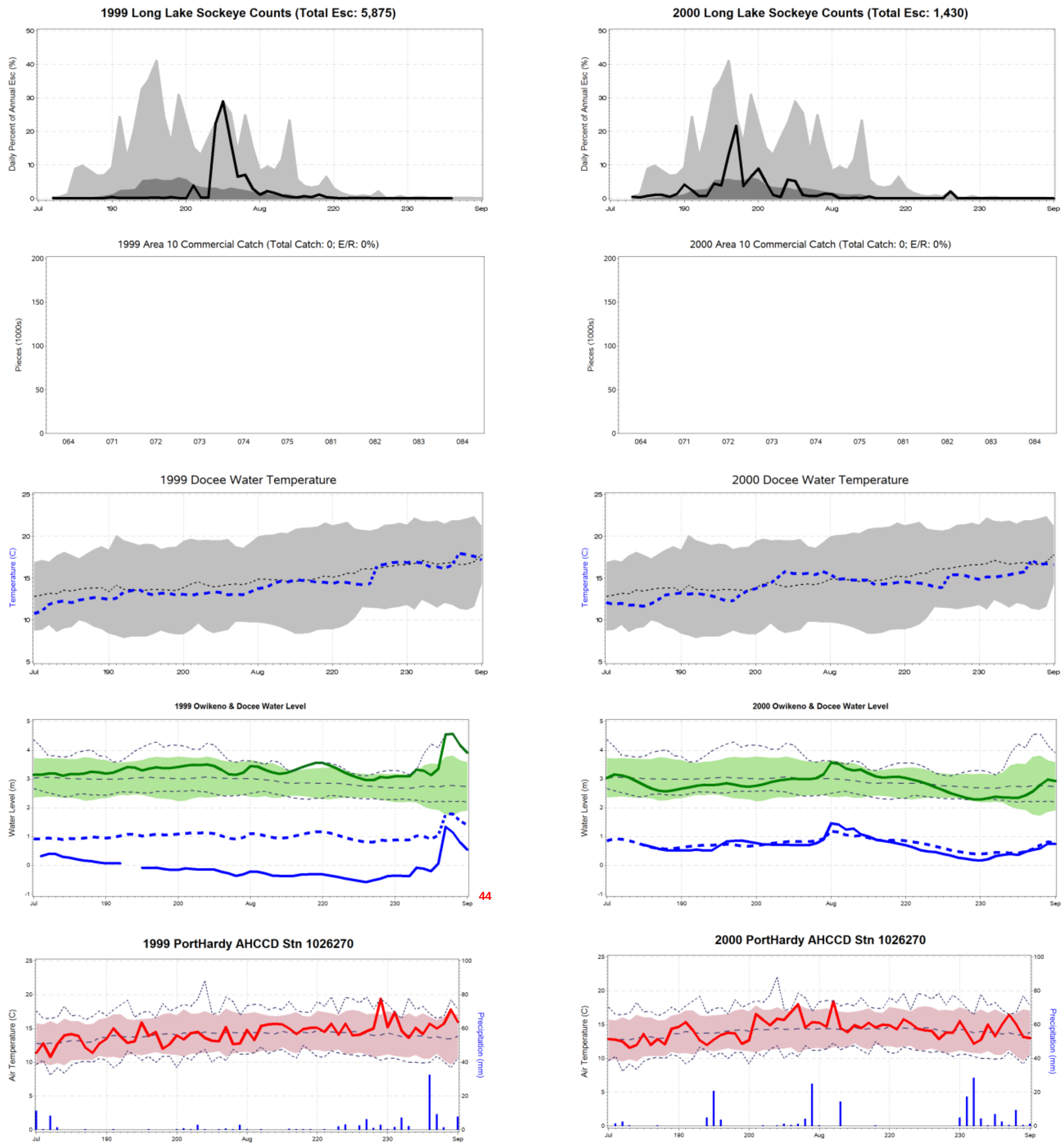


1998 Owikeno & Docee Water Level



1998 PortHardy AHCCD Stn 1026270





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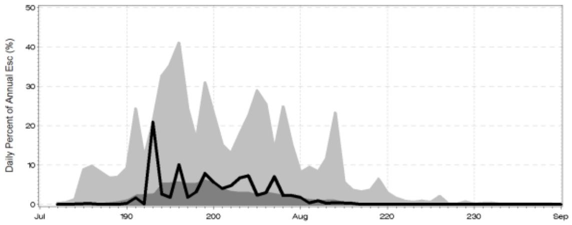
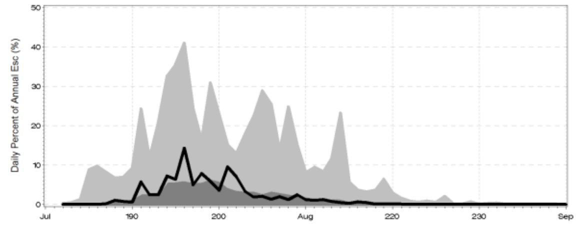
[44] Observed water levels recorded at the Docee River staff gauge were systematically below average in 1999 although conditions were not unusual regionally (i.e., Port Hardy precipitation in June - August was only 20 mm below the 1971-2000 climate norm; Owikeno water level was slightly above average).

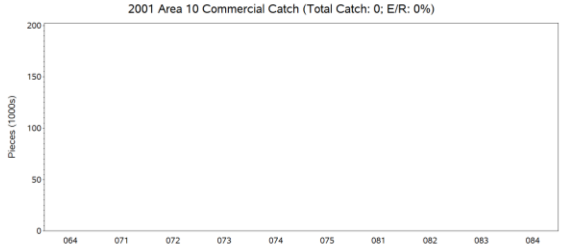
2001 Long Lake Sockeye Counts (Total Esc: 8,450)



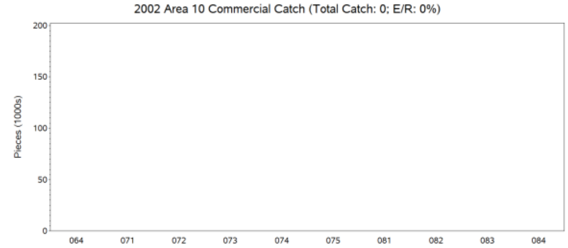
2002 Long Lake Sockeye Counts (Total Esc: 91,942)



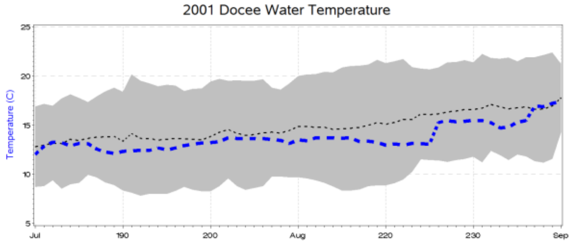
2001 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



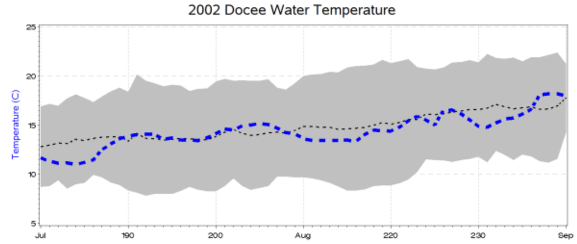
2002 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



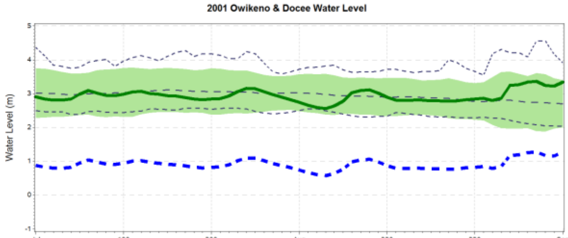
2001 Docee Water Temperature



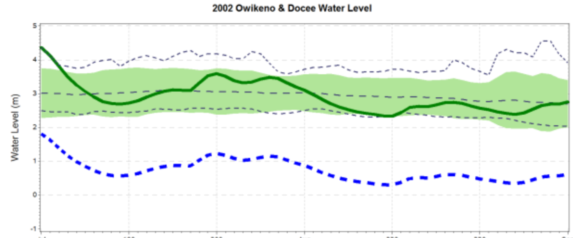
2002 Docee Water Temperature



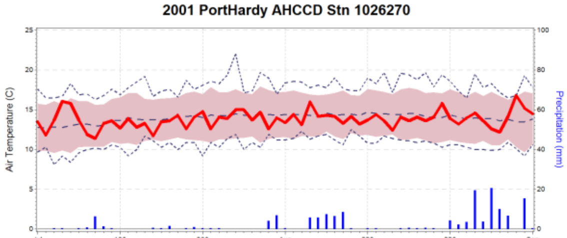
2001 Owikeno & Docee Water Level



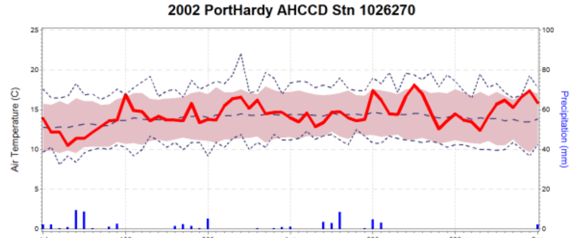
2002 Owikeno & Docee Water Level



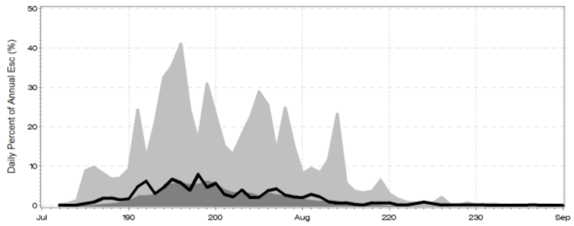
2001 PortHardy AHCCD Stn 1026270



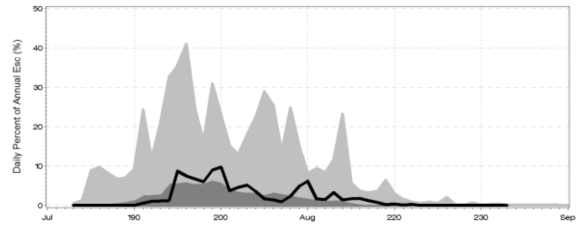
2002 PortHardy AHCCD Stn 1026270



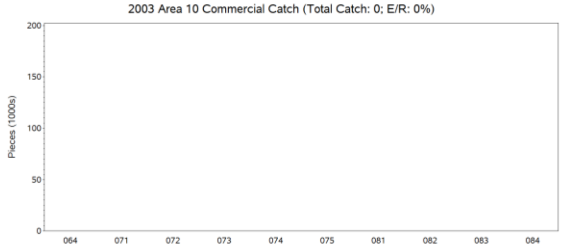
2003 Long Lake Sockeye Counts (Total Esc: 179,462)



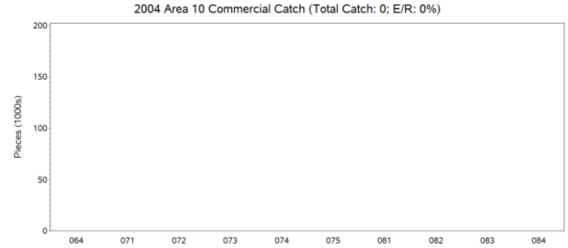
2004 Long Lake Sockeye Counts (Total Esc: 7,823)



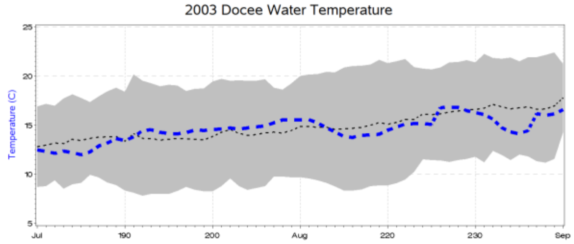
2003 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



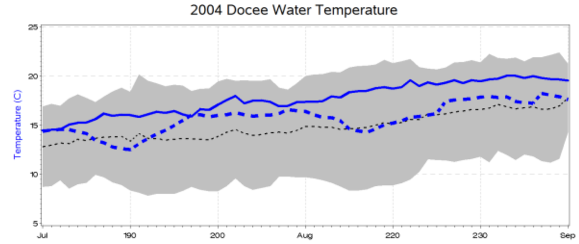
2004 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



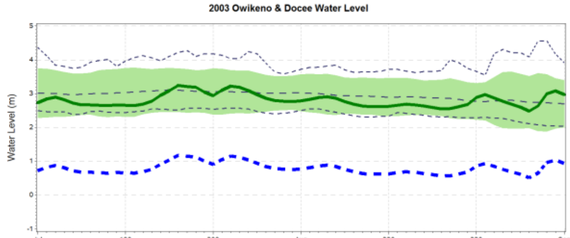
2003 Docee Water Temperature



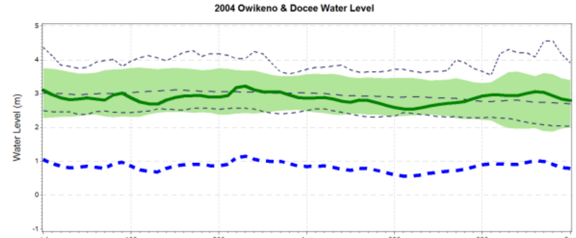
2004 Docee Water Temperature



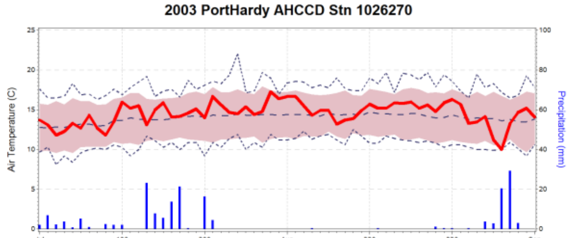
2003 Owikeno & Docee Water Level



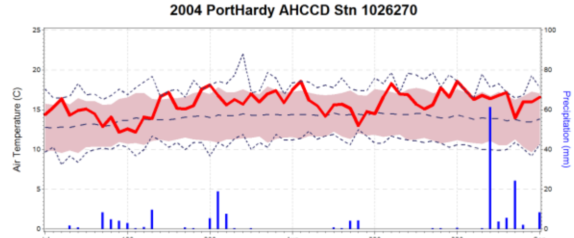
2004 Owikeno & Docee Water Level



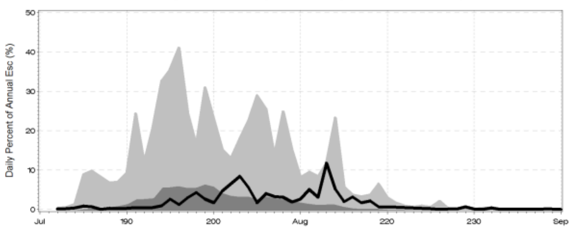
2003 PortHardy AHCCD Stn 1026270



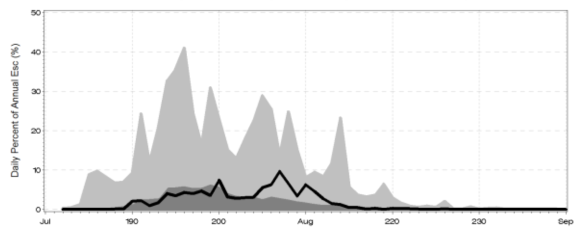
2004 PortHardy AHCCD Stn 1026270



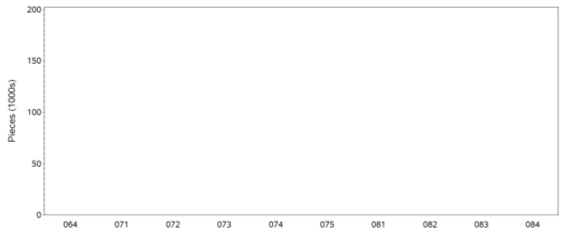
2005 Long Lake Sockeye Counts (Total Esc: 14,070)



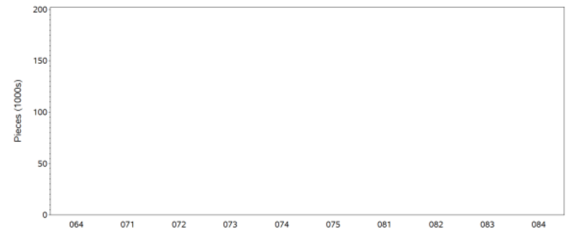
2006 Long Lake Sockeye Counts (Total Esc: 26,740)



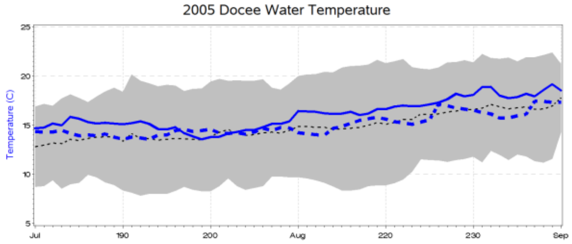
2005 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



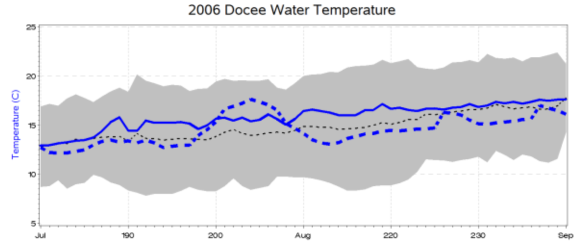
2006 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



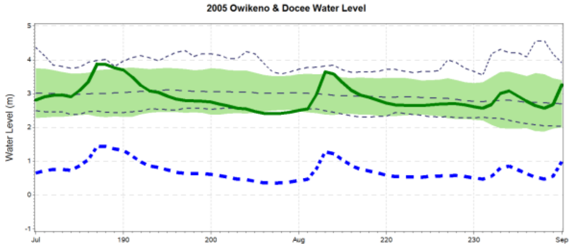
2005 Docee Water Temperature



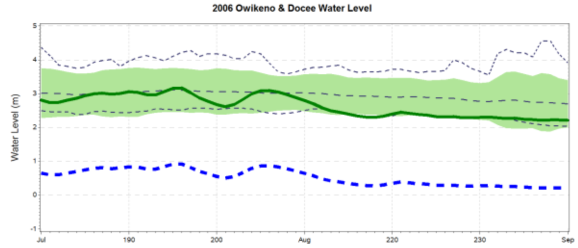
2006 Docee Water Temperature



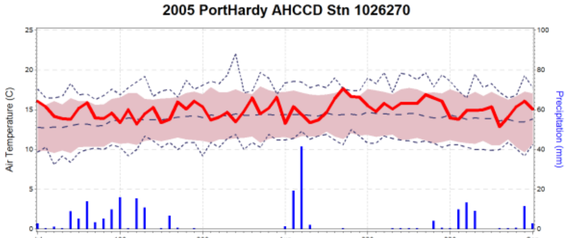
2005 Owikeno & Docee Water Level



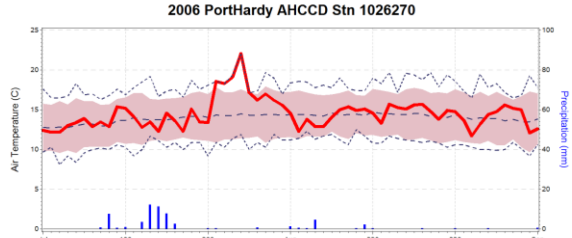
2006 Owikeno & Docee Water Level



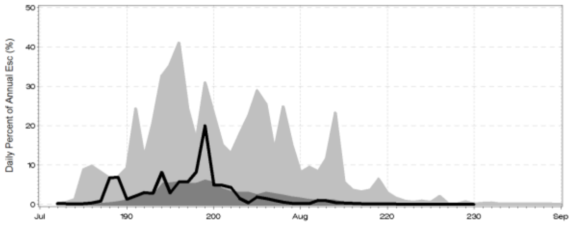
2005 PortHardy AHCCD Stn 1026270



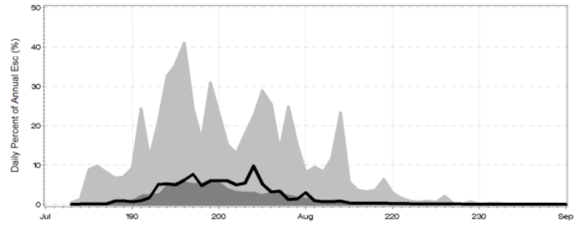
2006 PortHardy AHCCD Stn 1026270



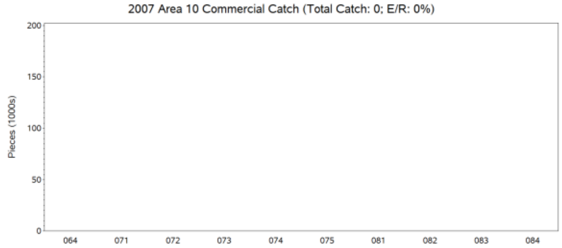
2007 Long Lake Sockeye Counts (Total Esc: 19,102)



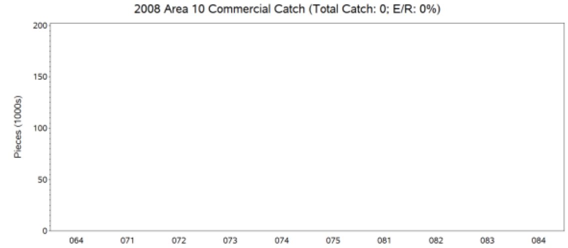
2008 Long Lake Sockeye Counts (Total Esc: 16,389)



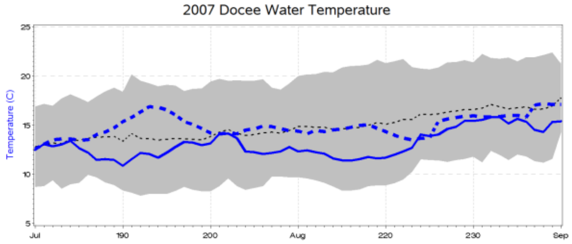
2007 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



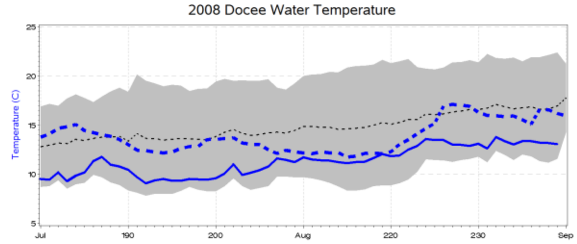
2008 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



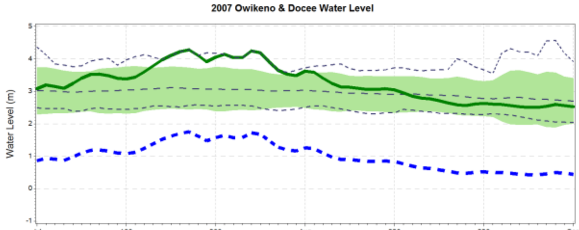
2007 Docee Water Temperature



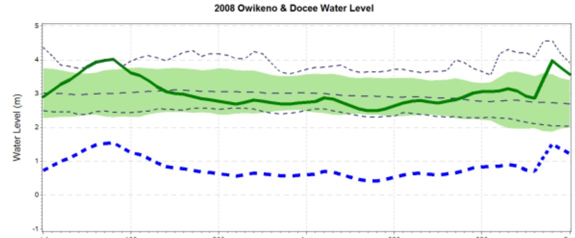
2008 Docee Water Temperature



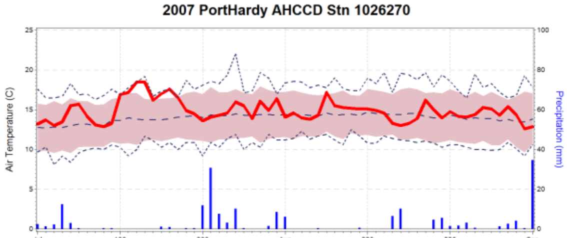
2007 Owikeno & Docee Water Level



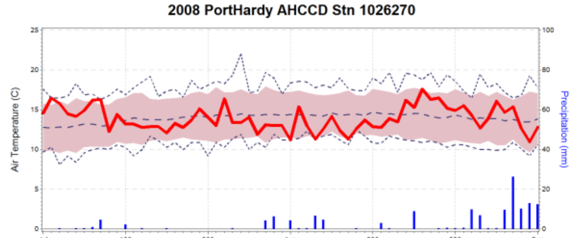
2008 Owikeno & Docee Water Level



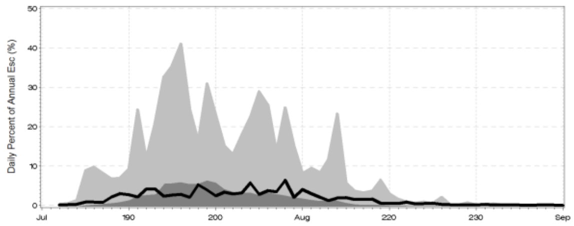
2007 PortHardy AHCCD Stn 1026270



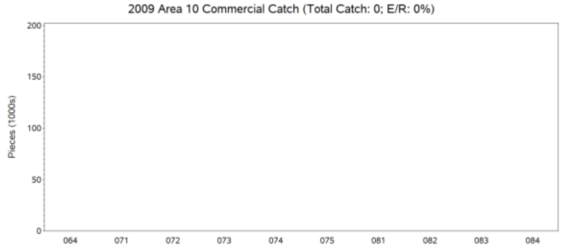
2008 PortHardy AHCCD Stn 1026270



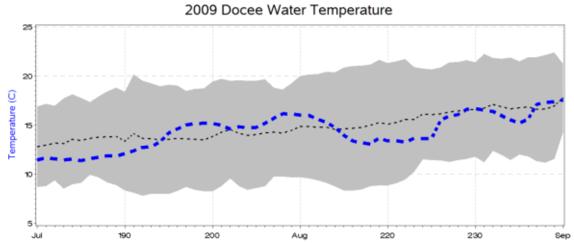
2009 Long Lake Sockeye Counts (Total Esc: 18,446)



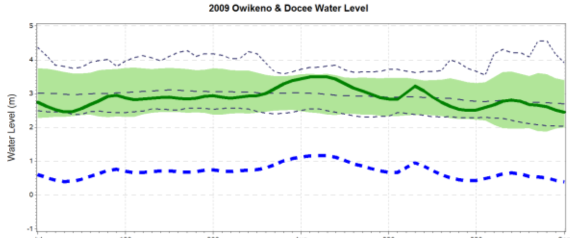
2009 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



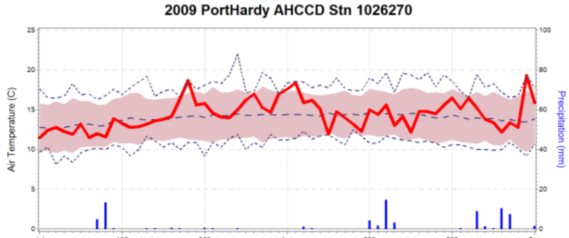
2009 Docee Water Temperature



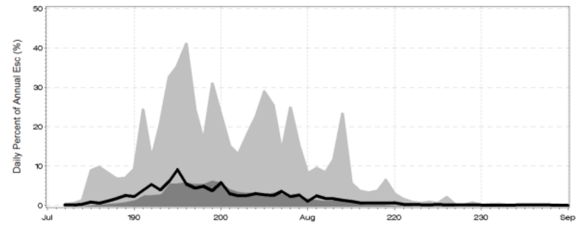
2009 Owikeno & Docee Water Level



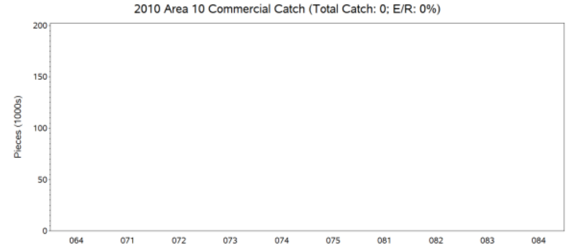
2009 PortHardy AHCCD Stn 1026270



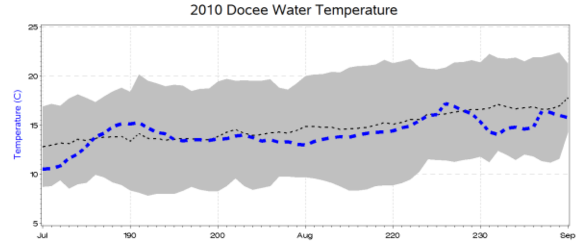
2010 Long Lake Sockeye Counts (Total Esc: 38,634)



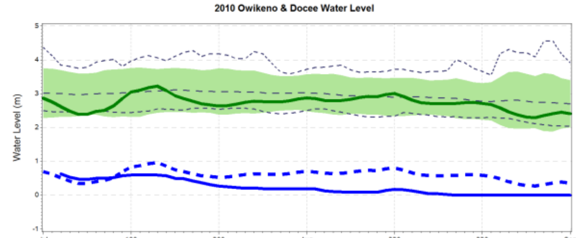
2010 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



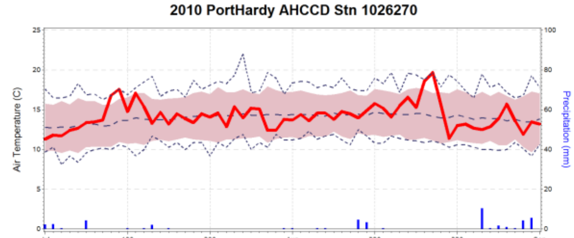
2010 Docee Water Temperature



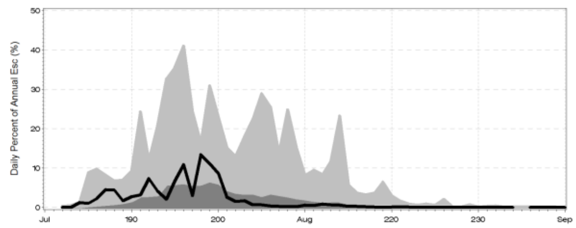
2010 Owikeno & Docee Water Level



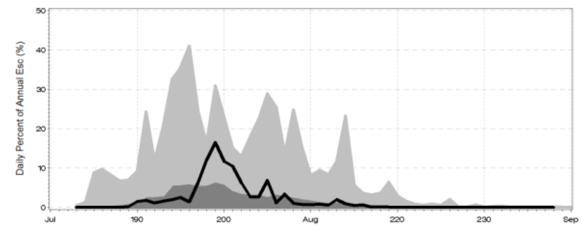
2010 PortHardy AHCCD Stn 1026270



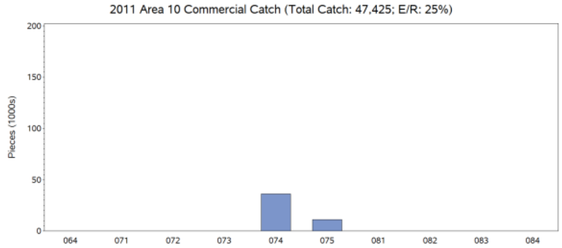
2011 Long Lake Sockeye Counts (Total Esc: 139,504)



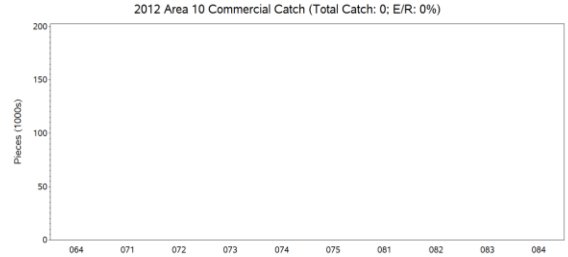
2012 Long Lake Sockeye Counts (Total Esc: 15,664)



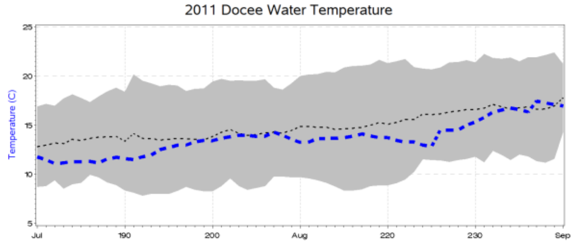
2011 Area 10 Commercial Catch (Total Catch: 47,425; E/R: 25%)



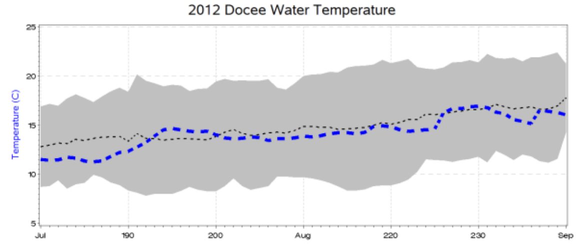
2012 Area 10 Commercial Catch (Total Catch: 0; E/R: 0%)



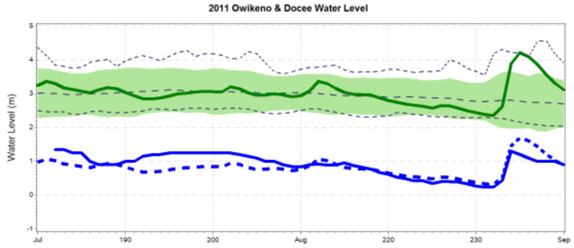
2011 Docee Water Temperature



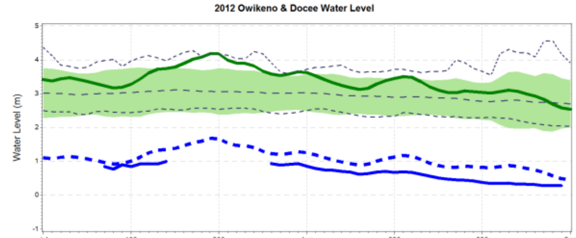
2012 Docee Water Temperature



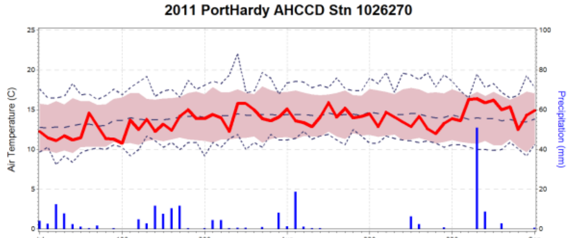
2011 Owikeno & Docee Water Level



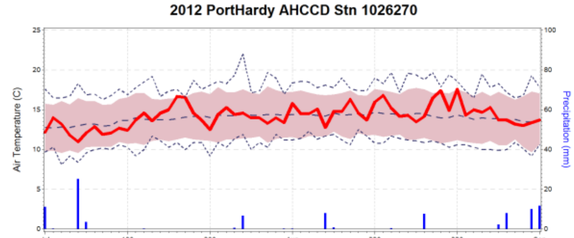
2012 Owikeno & Docee Water Level



2011 PortHardy AHCCD Stn 1026270



2012 PortHardy AHCCD Stn 1026270



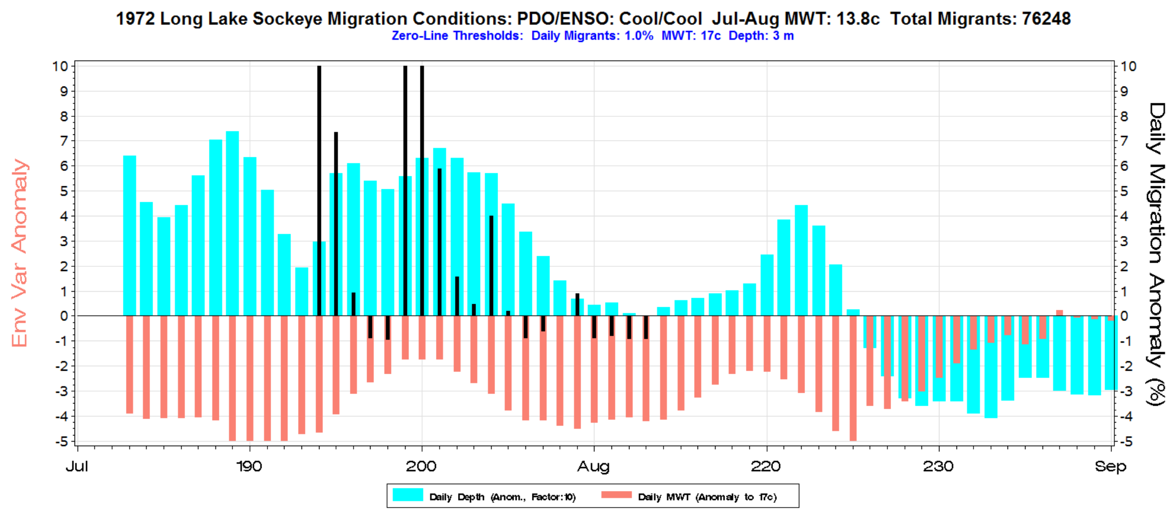
Appendix B. Annual anomaly plot for Long Lake Sockeye migration, Docee River water temperature (estimated), and recorded water level indicator variable *Owikeno Lake depth* (in meters, multiplied by a factor of 10 for readability).

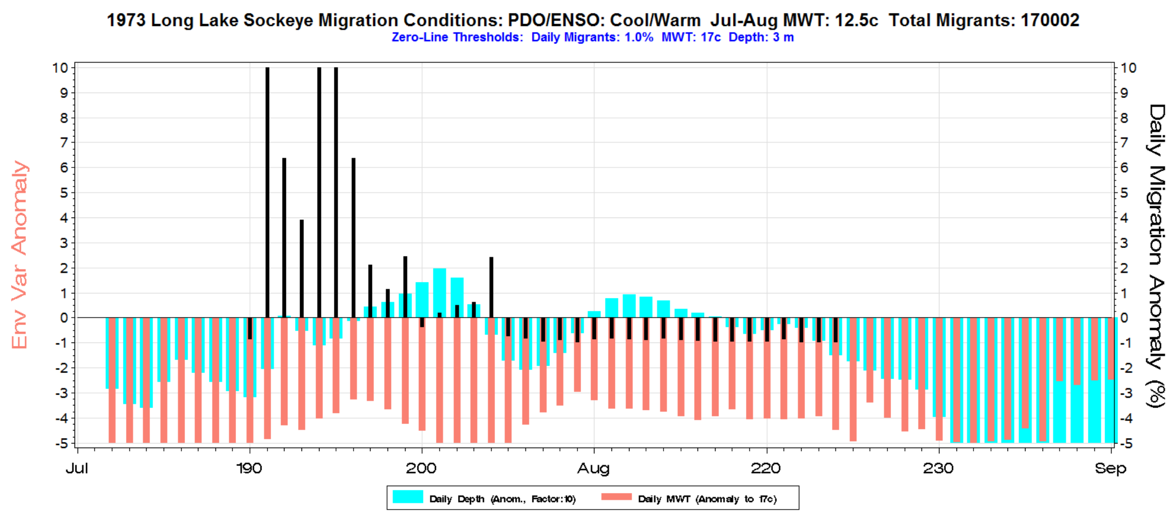
Zero-line thresholds: (a) Daily migration rate = 1.0% (50th percentile of non-zero daily migration rates (1972-2012); (b) Docee water temperature (estimated) = 17°C (~95th percentile); (c) Owikeno Lake depth = 3 m (~75th percentile).

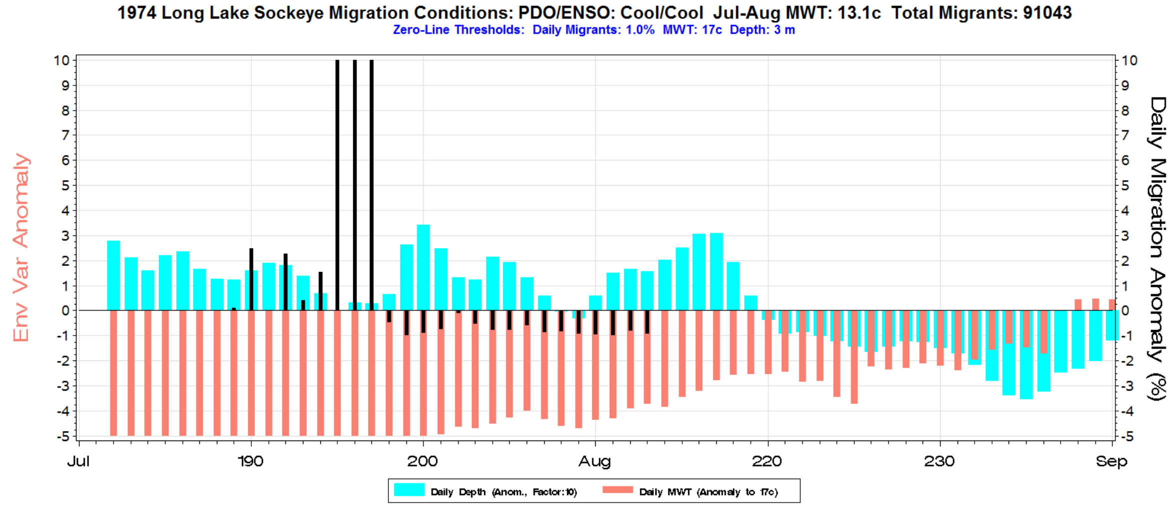
To convert anomalies to estimates, divide the bar height by the specified factor (if any) and add to the zero-line threshold:

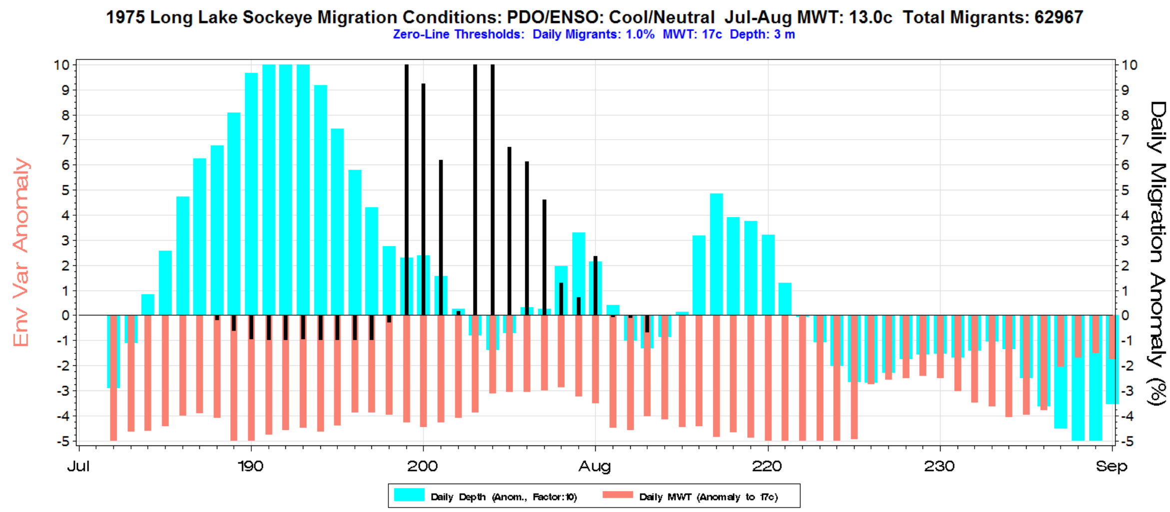
- first temperature bar (red) in 1972 represents -4 + 17 = 13°C
- first depth bar (blue) in 1972 represents 6.4/10 + 3 = 3.64 m
- second migration bar (black) represents 7.4 + 1.0 = 8.4%

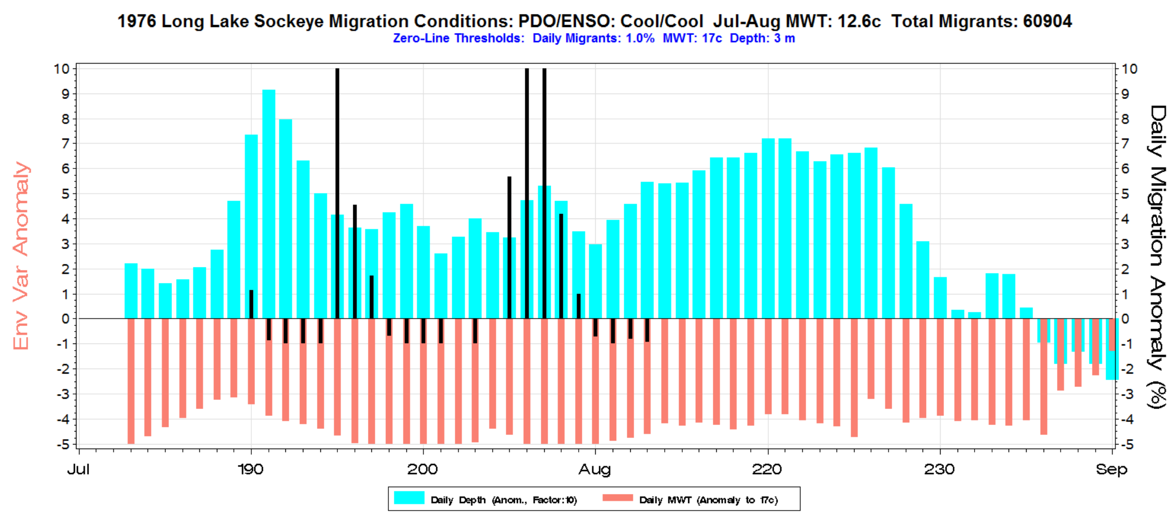
Note that bars extending beyond the vertical axis are truncated at the axis maxima.

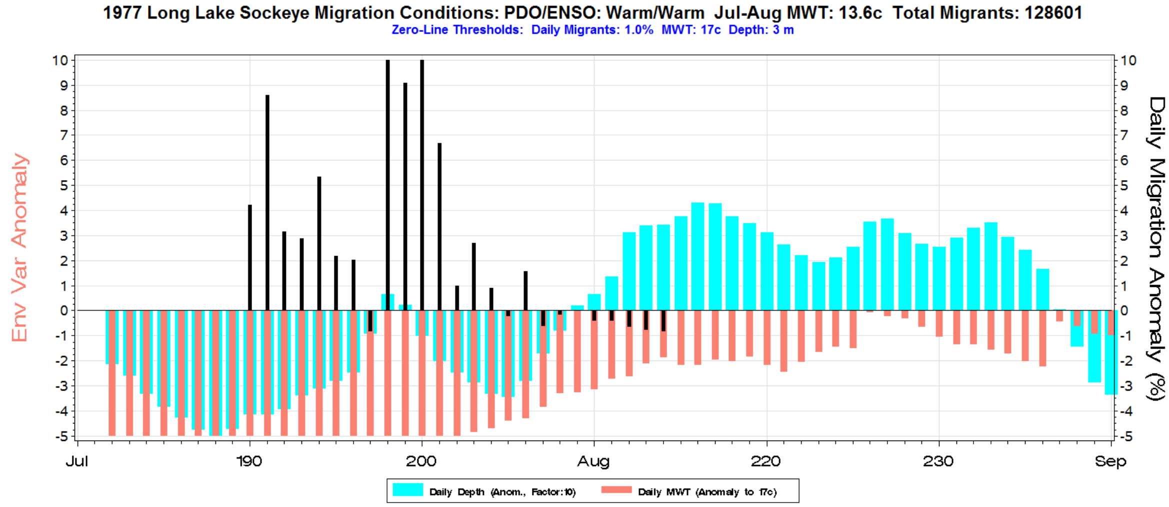




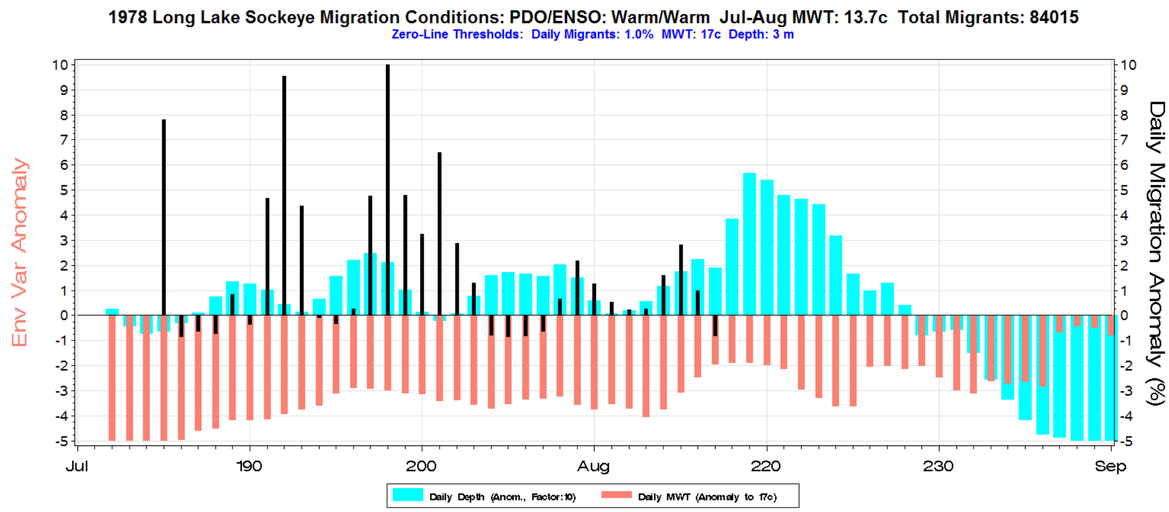

1974 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 13.1c Total Migrants: 91043
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


1975 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 13.0c Total Migrants: 62967
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

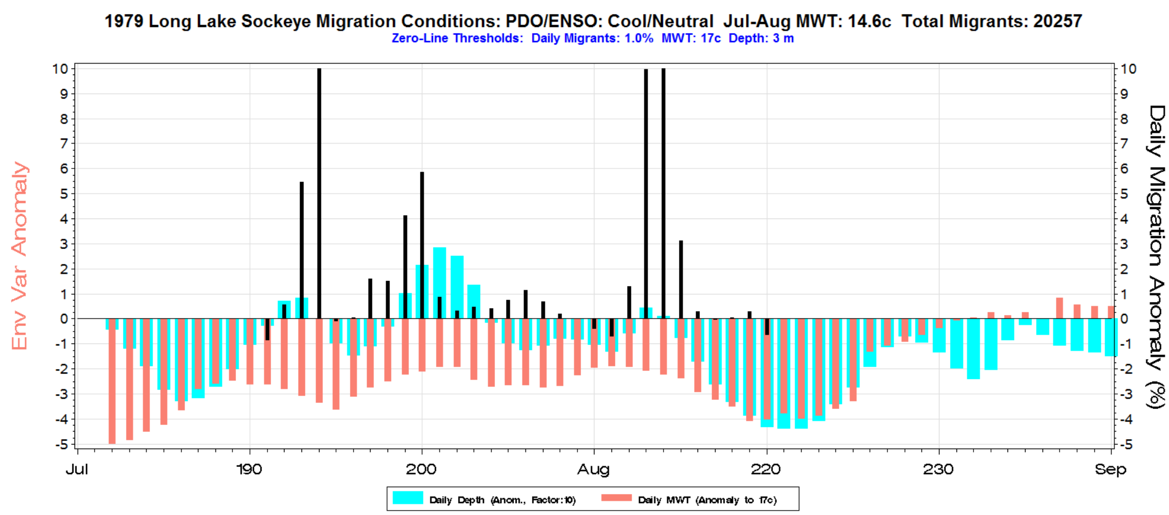

1976 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 12.6c Total Migrants: 60904
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)



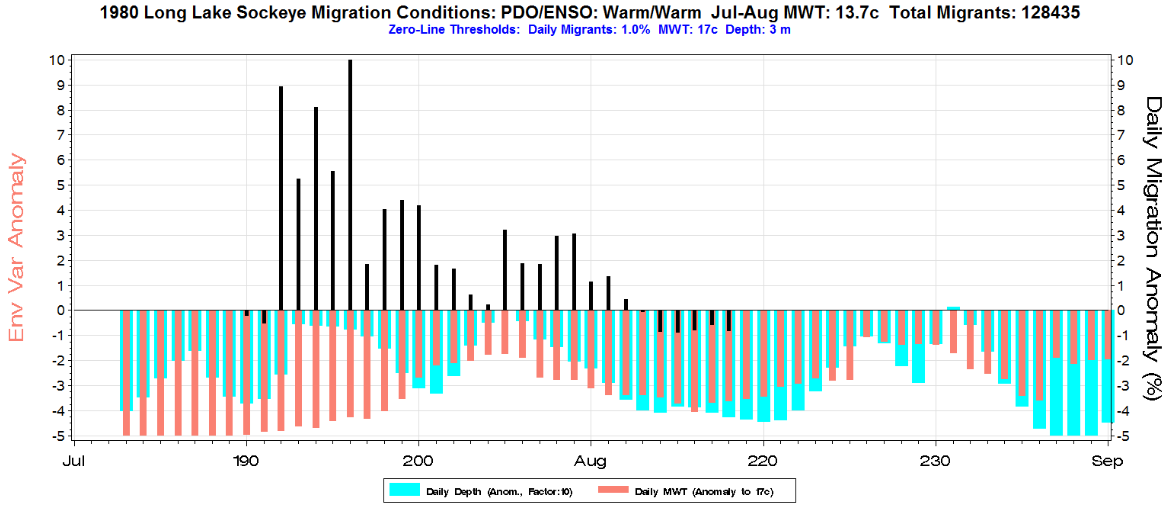
1977 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 13.6c Total Migrants: 128601
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

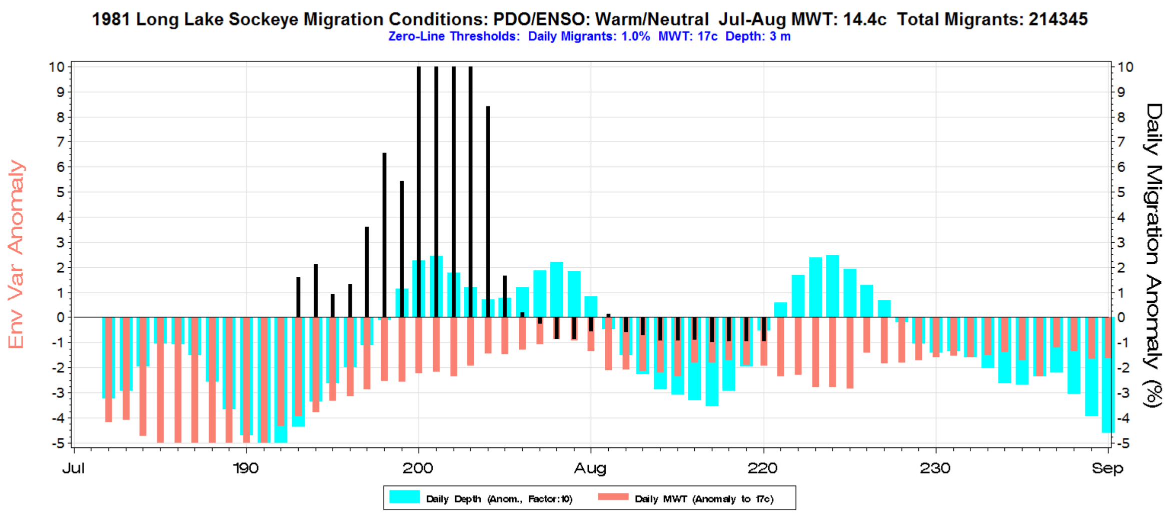


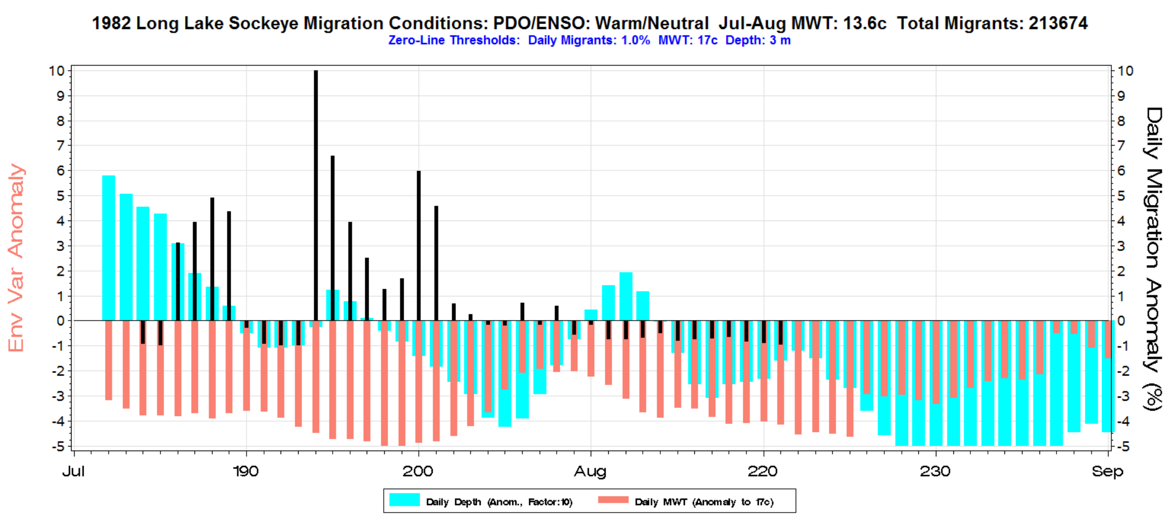
1978 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 13.7c Total Migrants: 84015
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

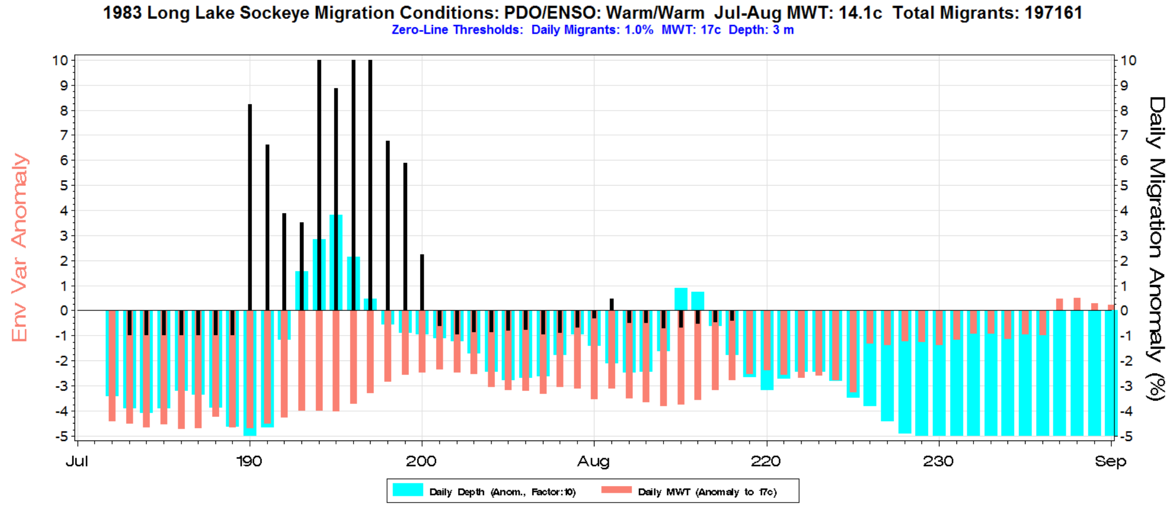


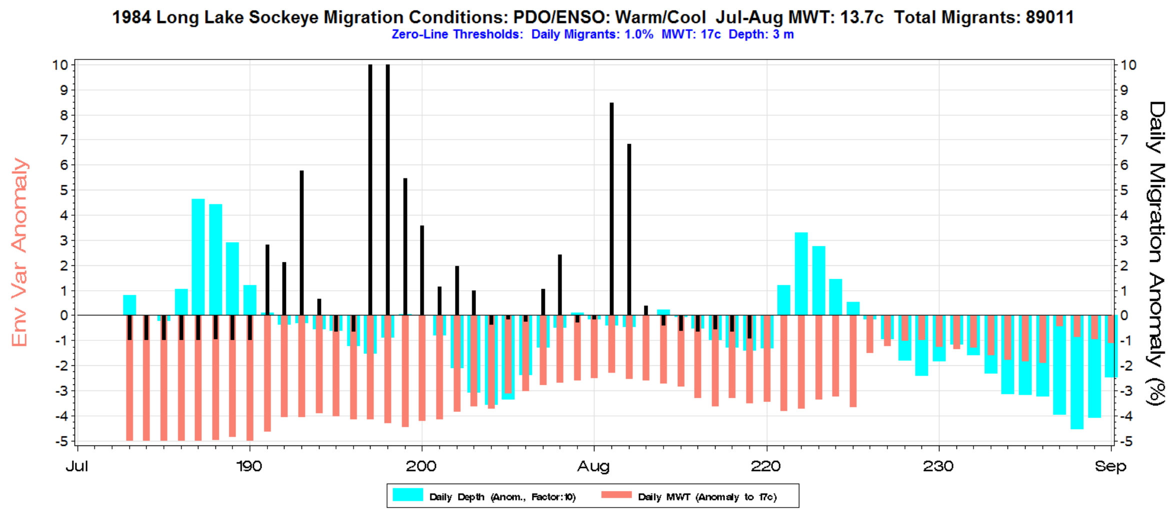
1979 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 14.6c Total Migrants: 20257
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

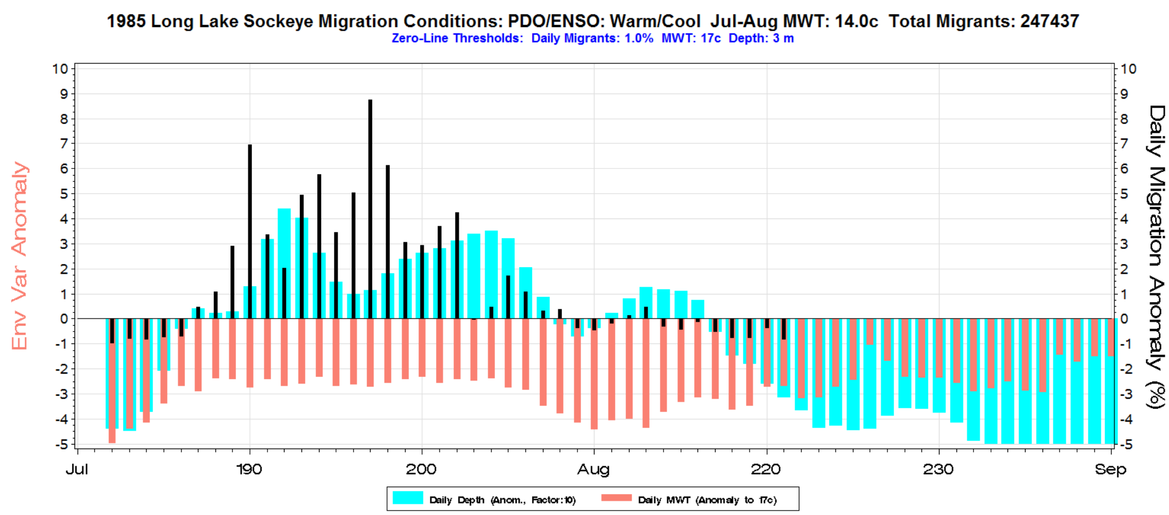

1980 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 13.7c Total Migrants: 128435
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


1981 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Aug MWT: 14.4c Total Migrants: 214345
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

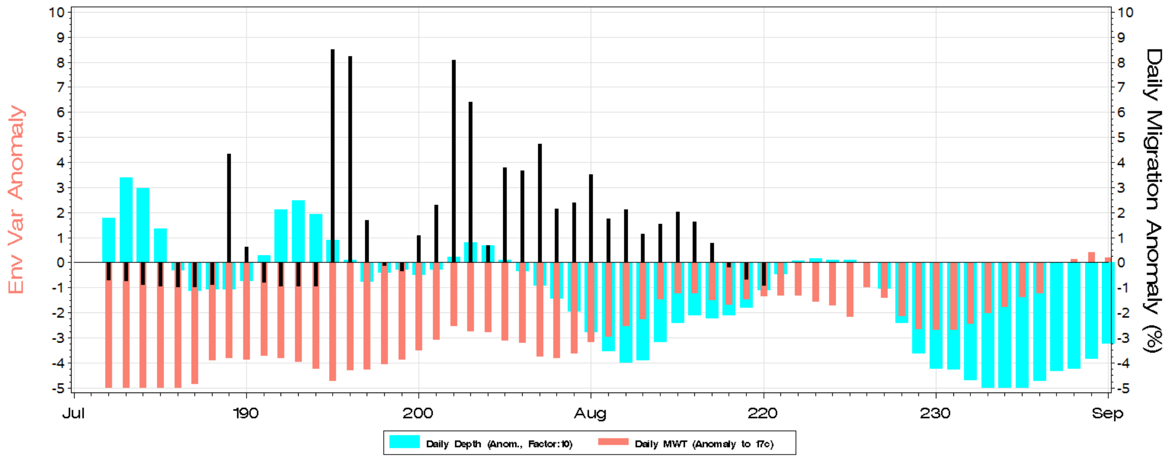

1982 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Aug MWT: 13.6c Total Migrants: 213674
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


1983 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.1c Total Migrants: 197161
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

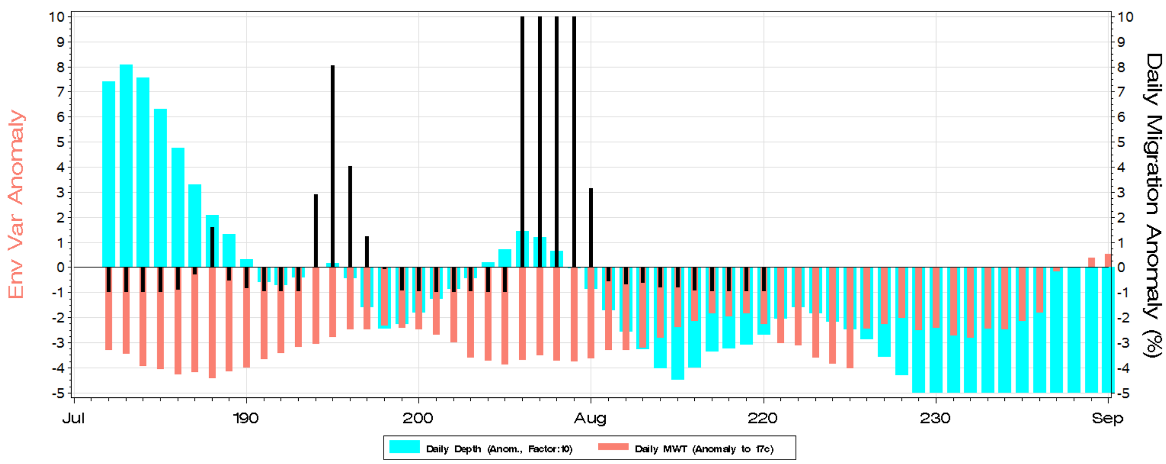

1984 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Cool Jul-Aug MWT: 13.7c Total Migrants: 89011
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


1985 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Cool Jul-Aug MWT: 14.0c Total Migrants: 247437
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

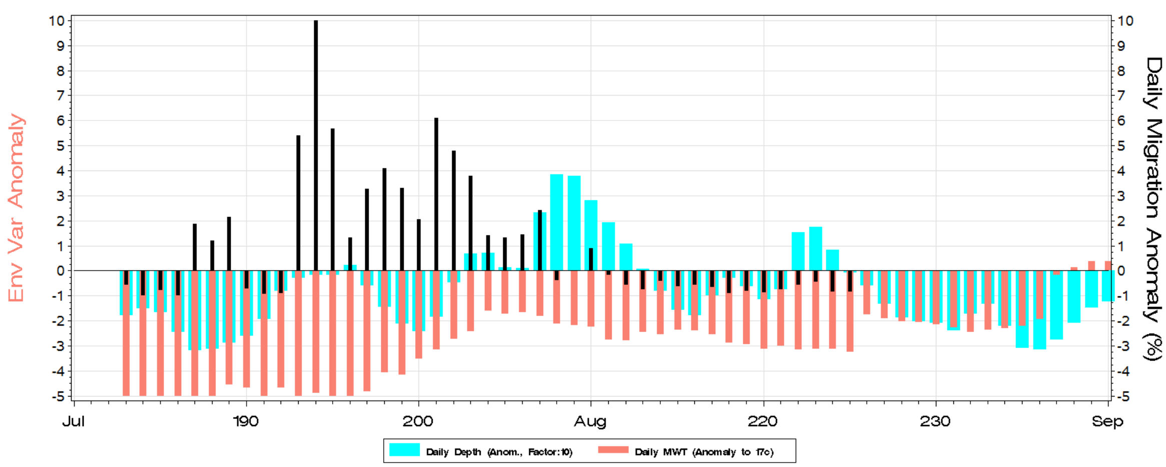
1986 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Aug MWT: 14.1c Total Migrants: 197851
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

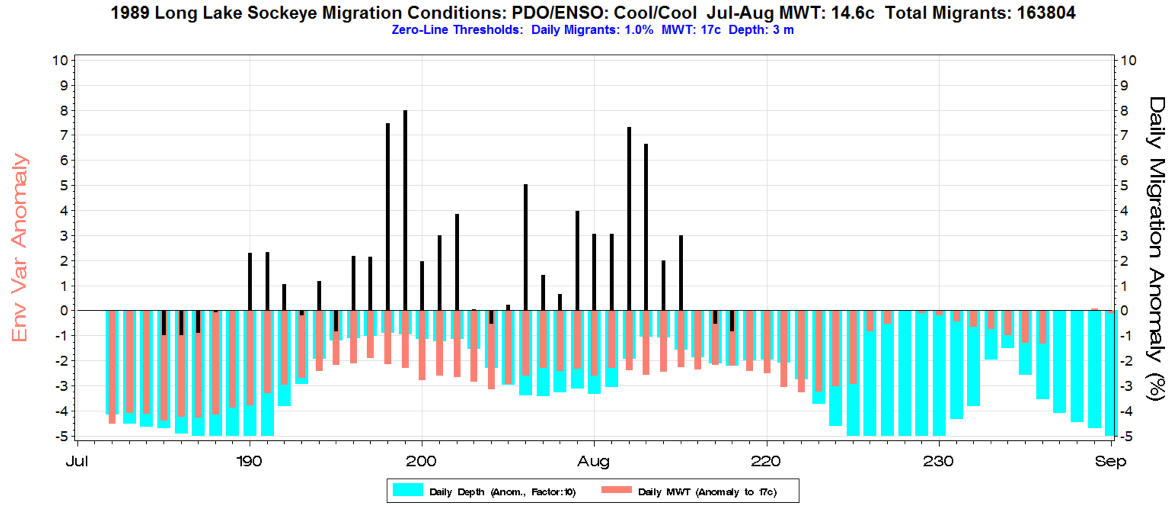


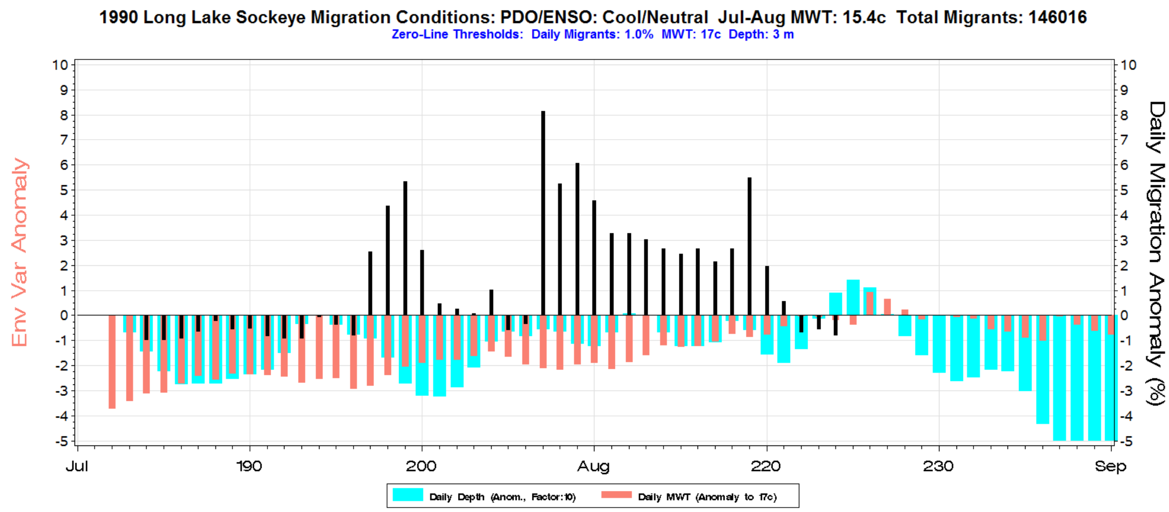
1987 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.1c Total Migrants: 193781
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

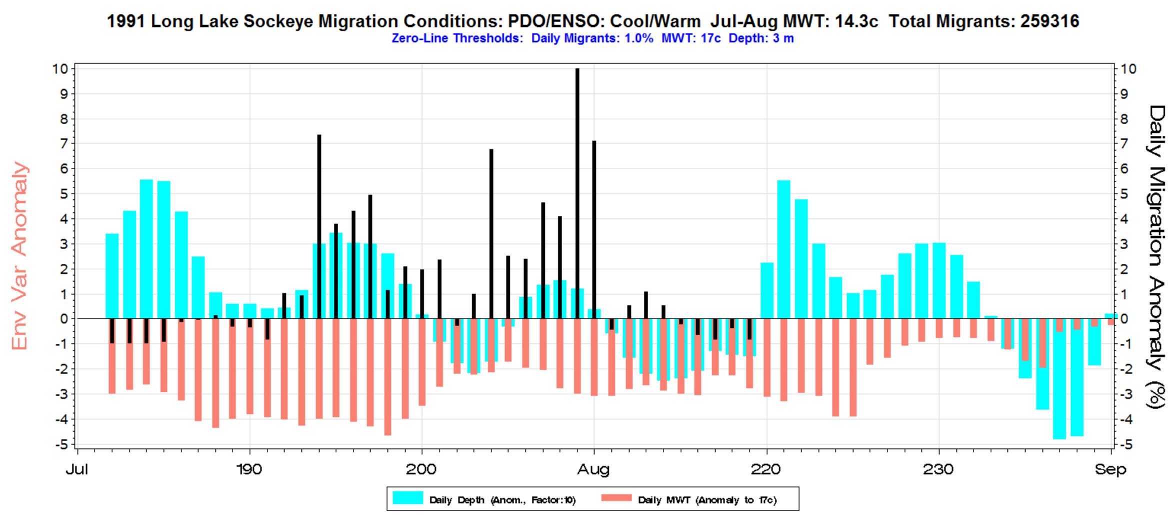


1988 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 13.8c Total Migrants: 201963
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

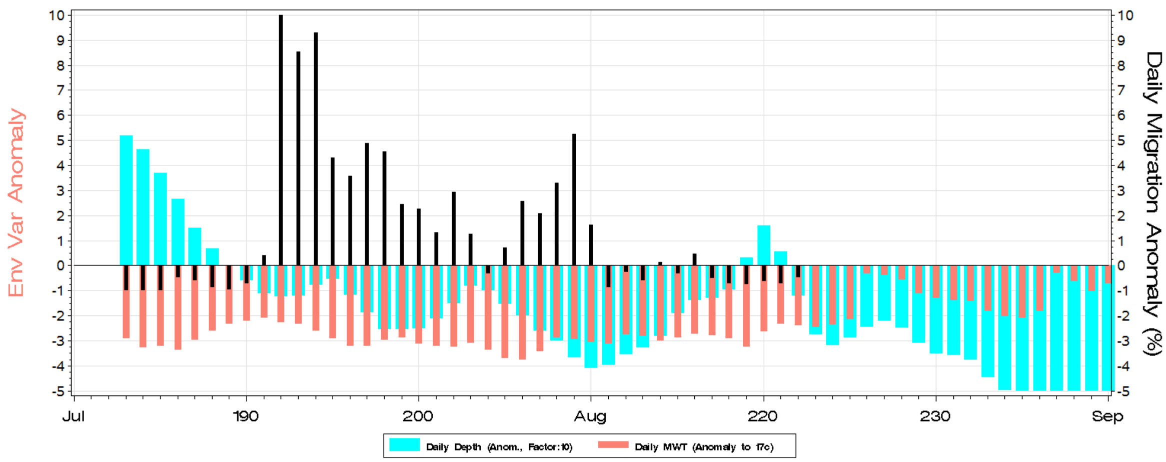



1989 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 14.6c Total Migrants: 163804
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

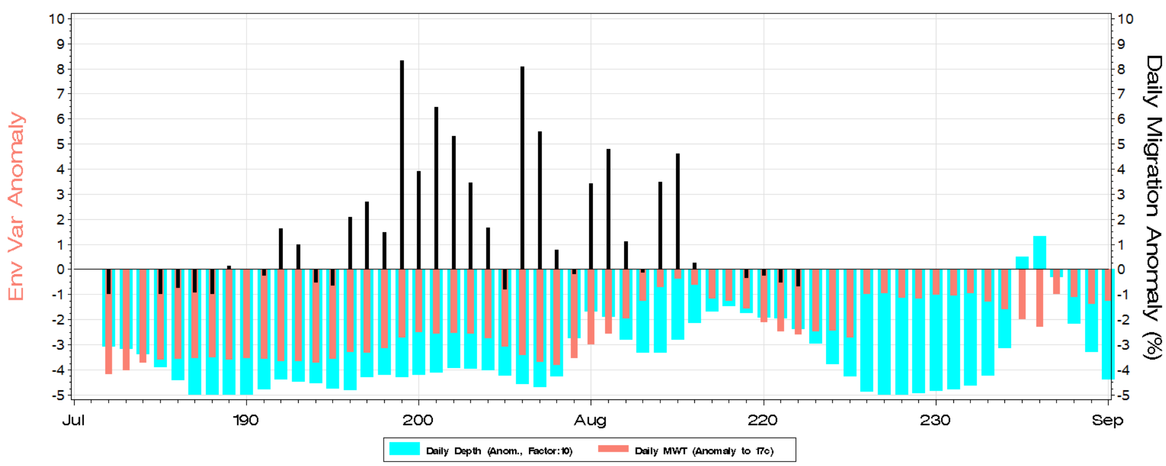

1990 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 15.4c Total Migrants: 146016
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


1991 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Aug MWT: 14.3c Total Migrants: 259316
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

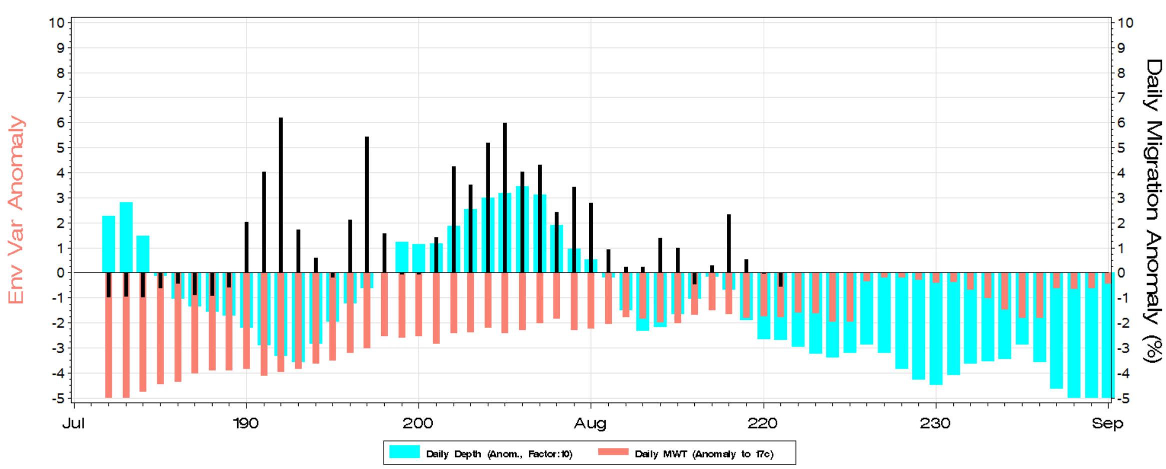
1992 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.6c Total Migrants: 217106
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m



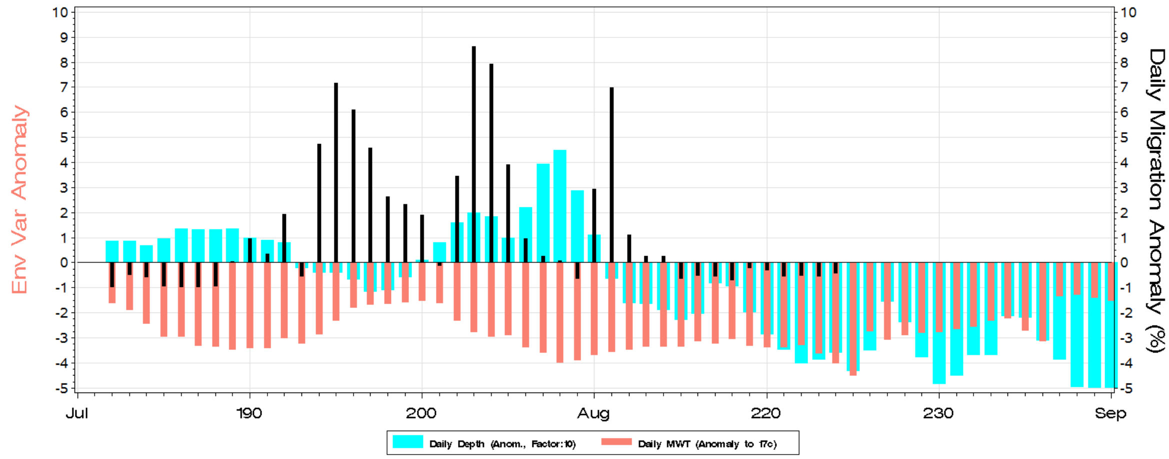
1993 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.5c Total Migrants: 217422
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m



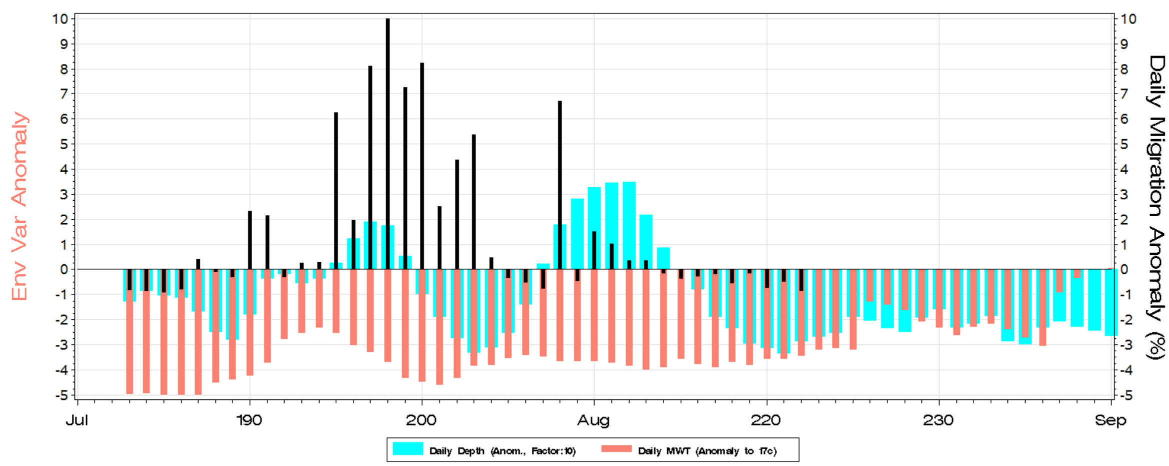
1994 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Aug MWT: 14.6c Total Migrants: 94295
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m



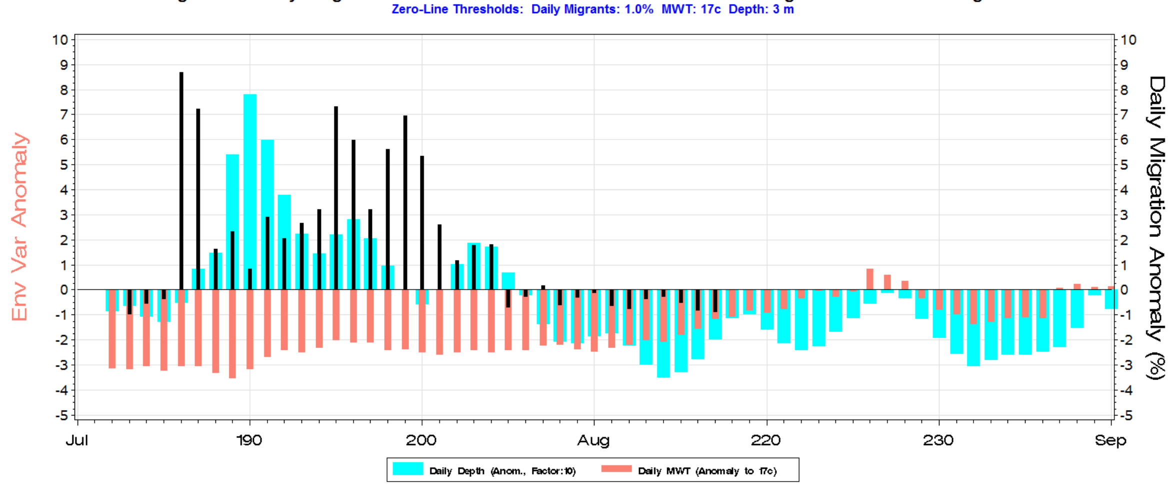
1995 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Aug MWT: 14.2c Total Migrants: 56244
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

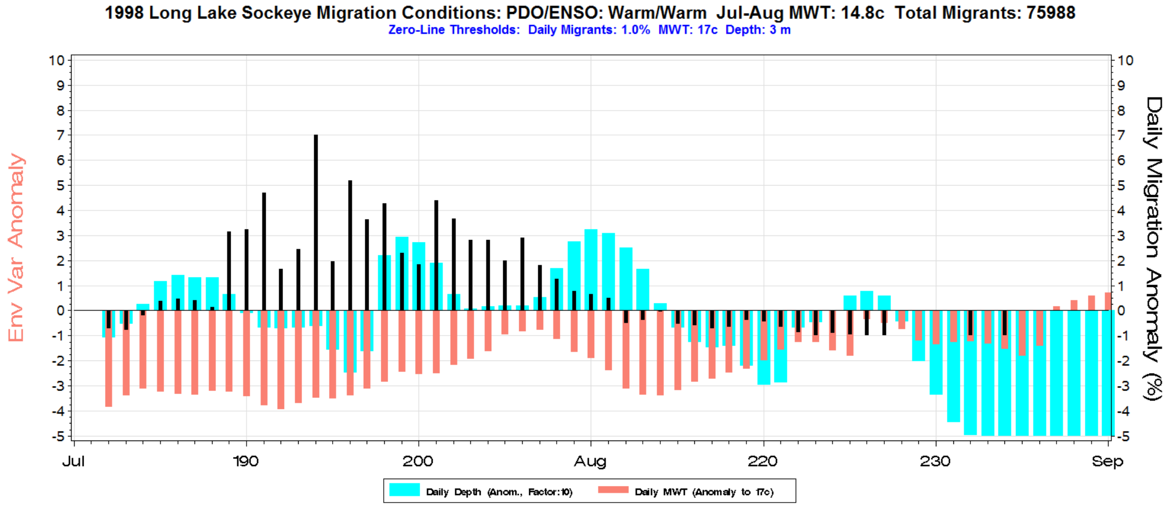


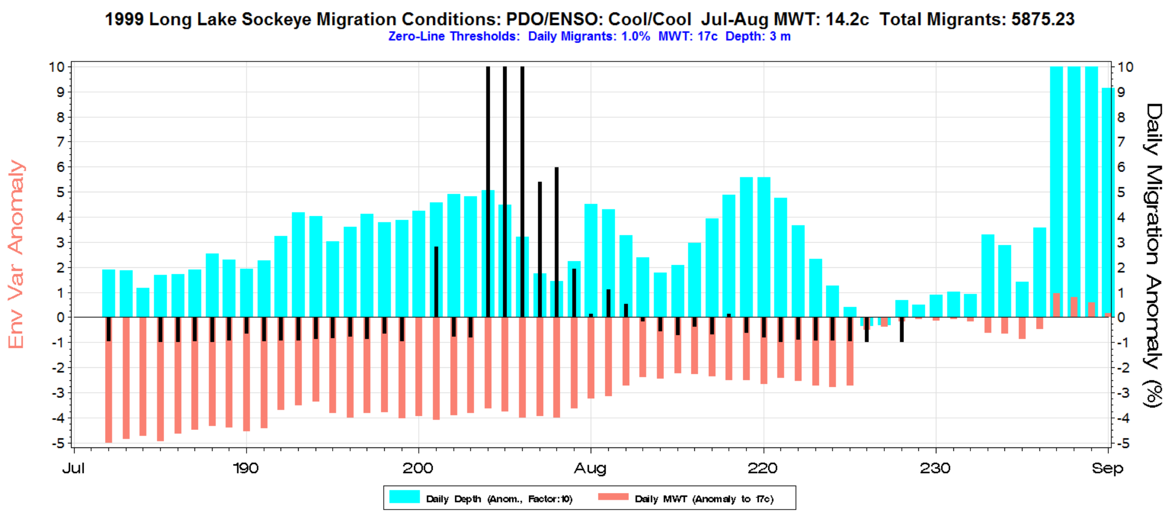
1996 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Aug MWT: 13.6c Total Migrants: 53272
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

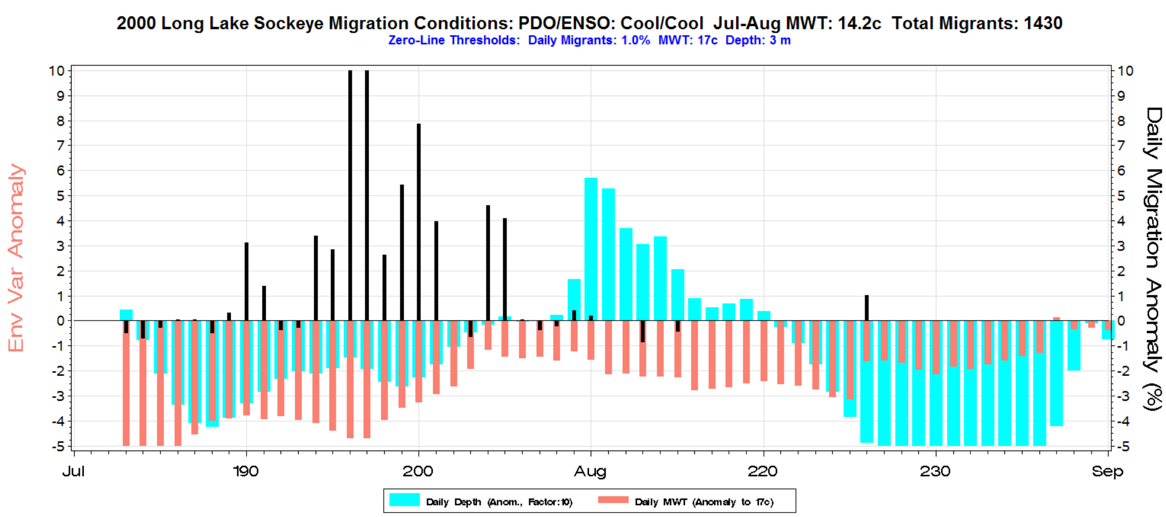


1997 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Jul-Aug MWT: 15.2c Total Migrants: 30997
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

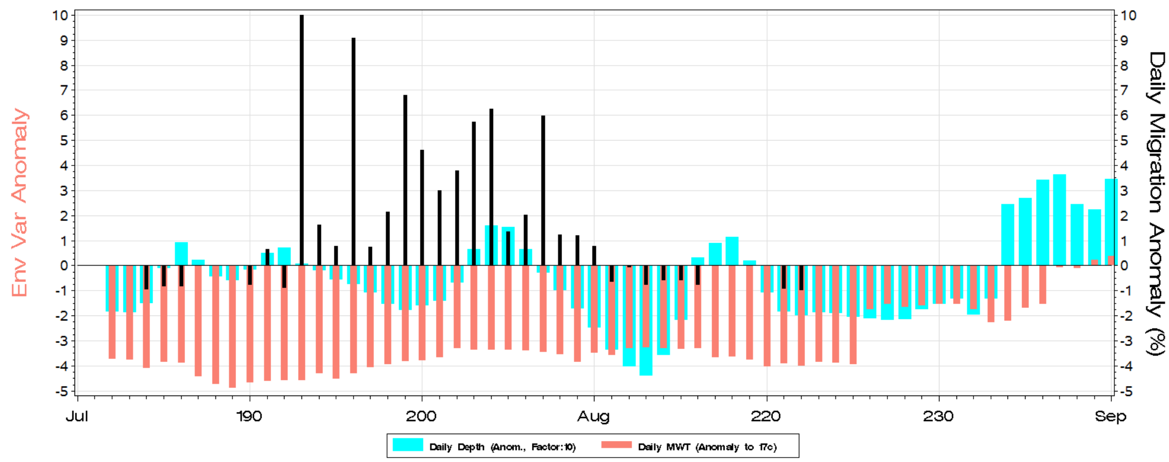



1998 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.8c Total Migrants: 75988
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

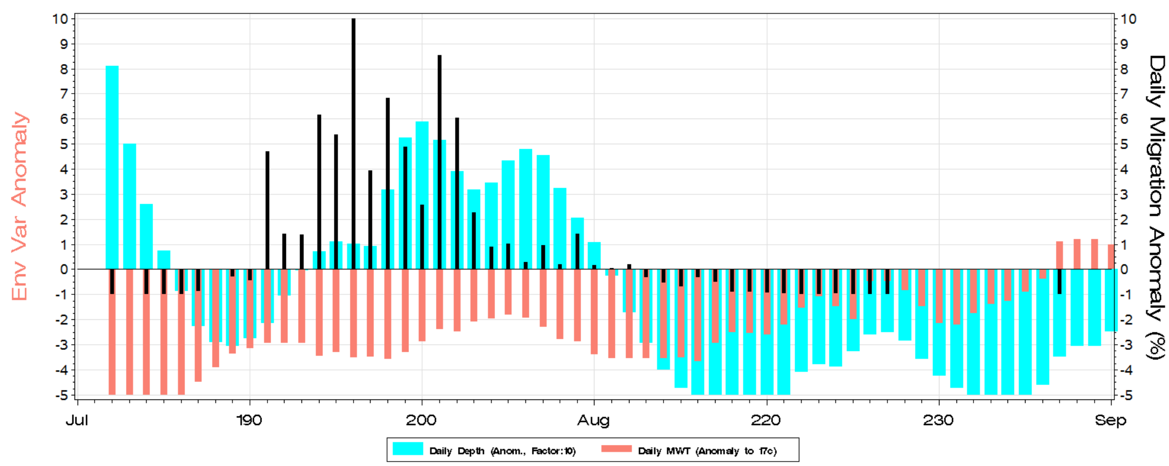

1999 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 14.2c Total Migrants: 5875.23
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


2000 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 14.2c Total Migrants: 1430
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)

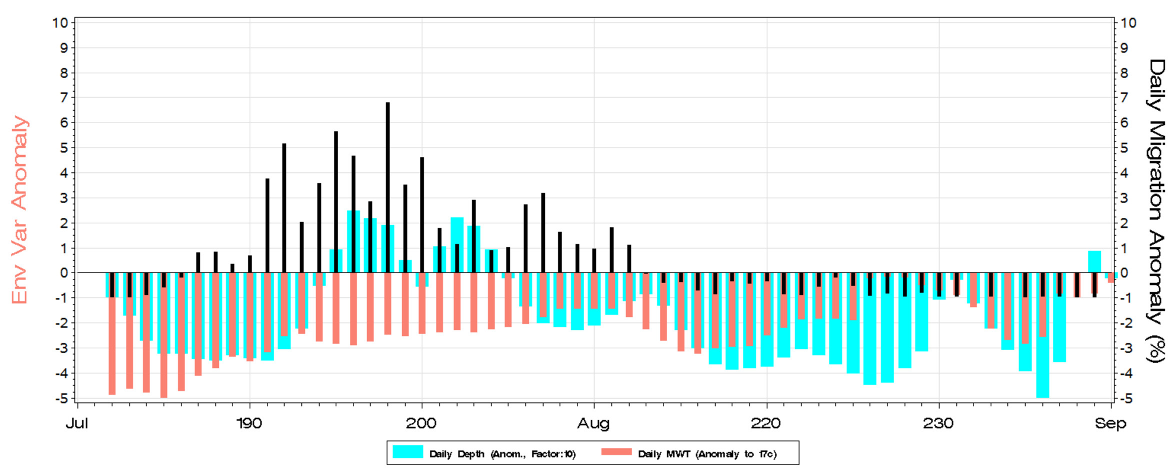
2001 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 13.8c Total Migrants: 8450
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m



2002 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 14.4c Total Migrants: 91942
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

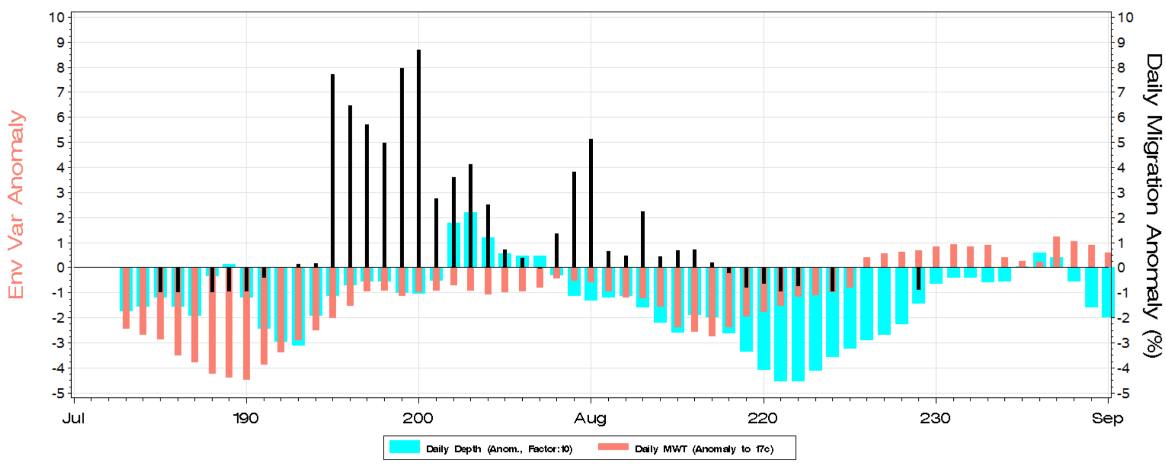


2003 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.6c Total Migrants: 179462
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m



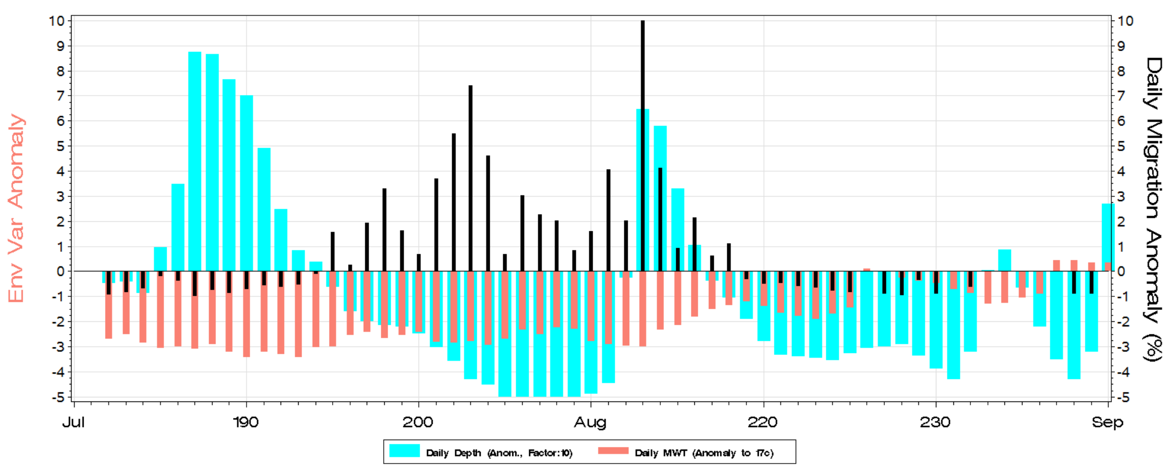
2004 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 15.7c Total Migrants: 7823

Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m



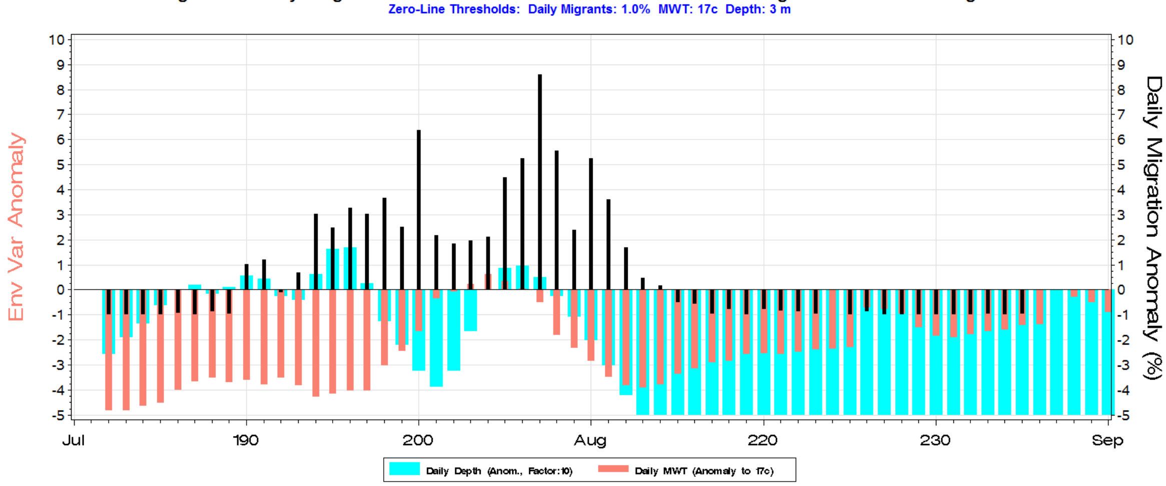
2005 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 15.0c Total Migrants: 14070.488553

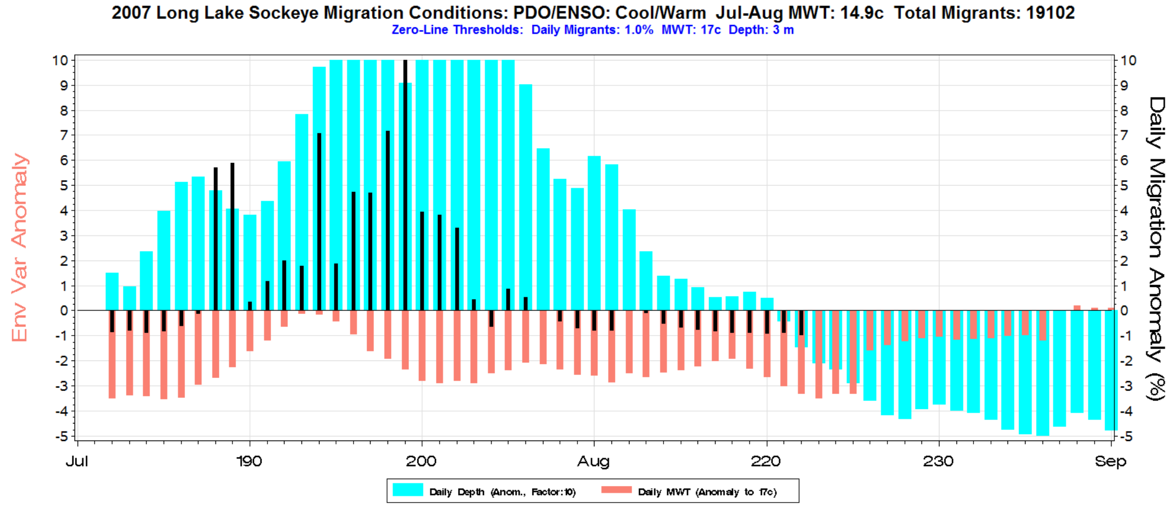
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

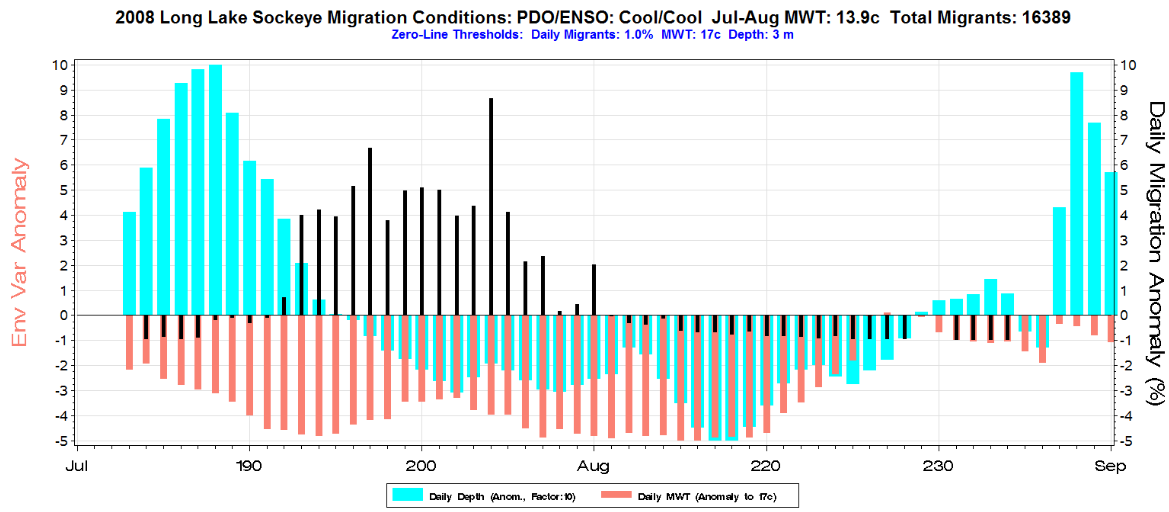


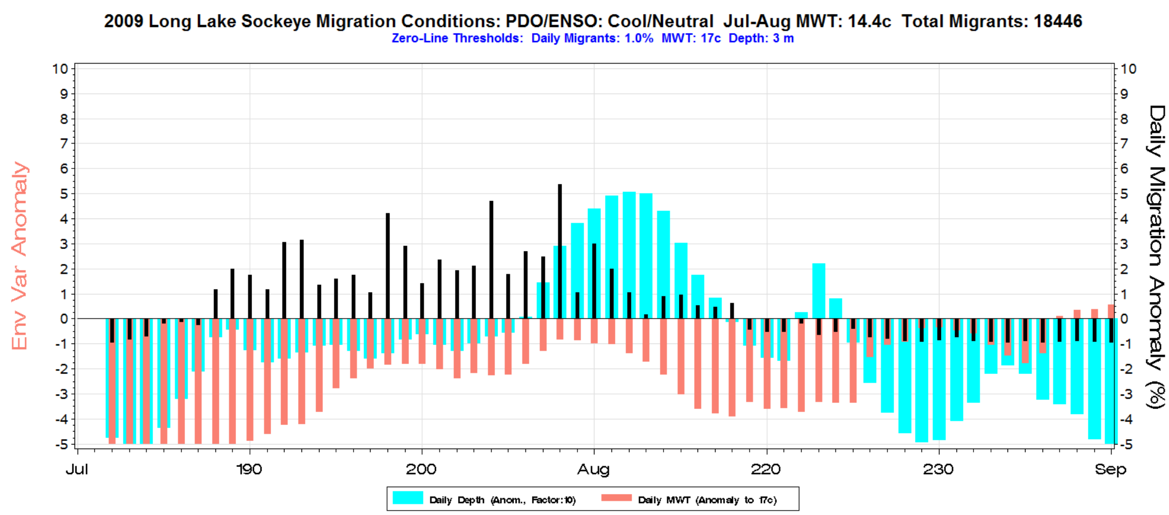
2006 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 14.5c Total Migrants: 26740

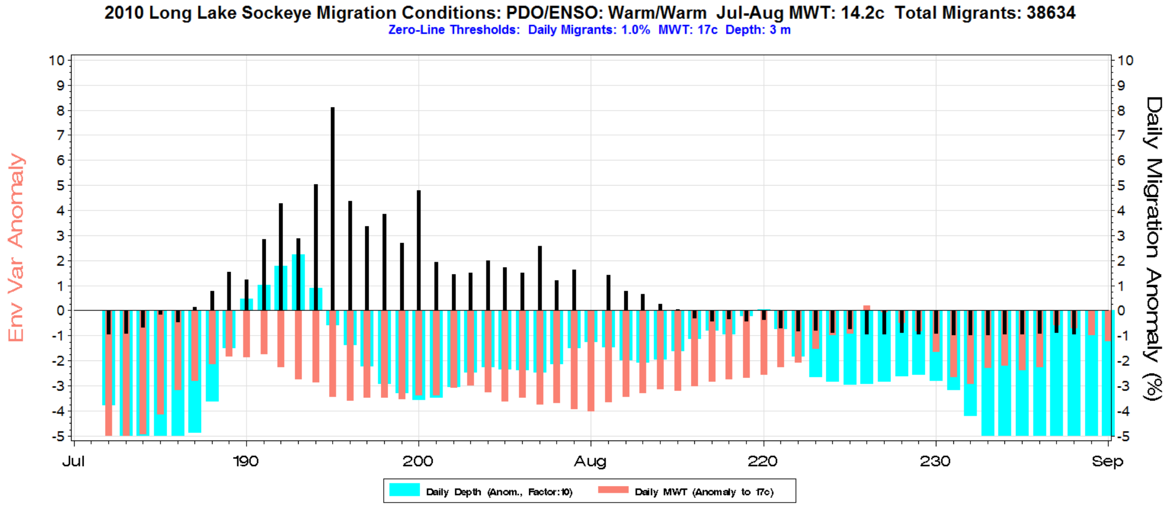
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m

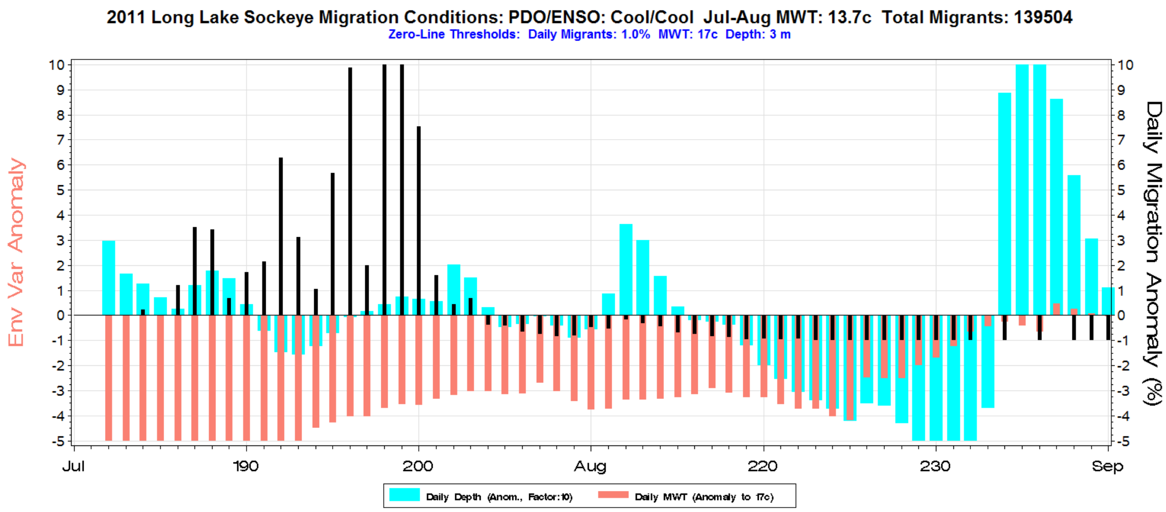


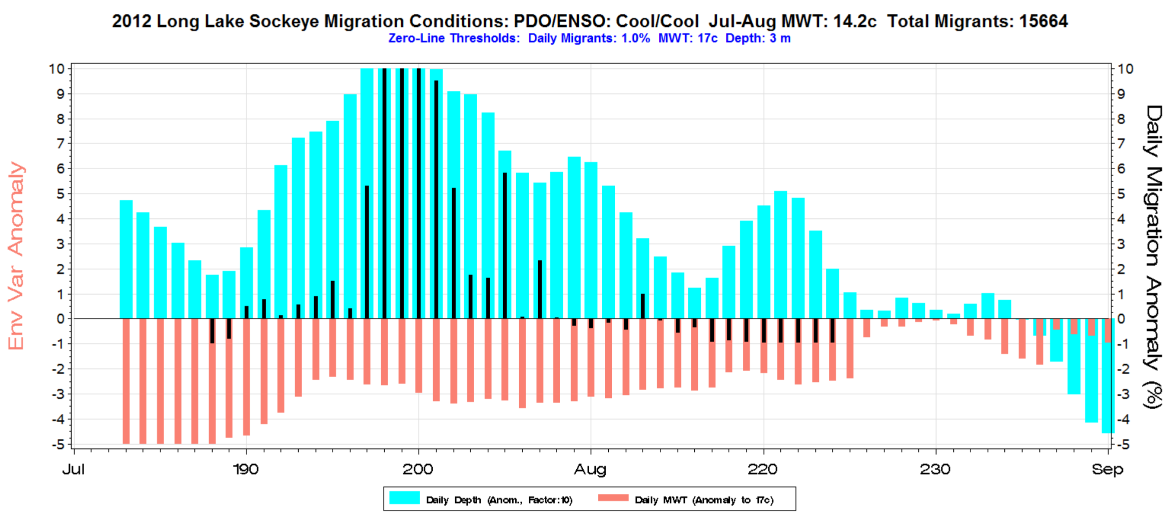

2007 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Jul-Aug MWT: 14.9c Total Migrants: 19102
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


2008 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 13.9c Total Migrants: 16389
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


2009 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Jul-Aug MWT: 14.4c Total Migrants: 18446
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


2010 Long Lake Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Jul-Aug MWT: 14.2c Total Migrants: 38634
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


2011 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 13.7c Total Migrants: 139504
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)


2012 Long Lake Sockeye Migration Conditions: PDO/ENSO: Cool/Cool Jul-Aug MWT: 14.2c Total Migrants: 15664
Zero-Line Thresholds: Daily Migrants: 1.0% MWT: 17c Depth: 3 m
Env Var Anomaly
Daily Migration Anomaly (%)
Jul
190
200
Aug
220
230
Sep
Daily Depth (Anom., Factor:10)
Daily MWT (Anomaly to 17c)