Mortality During the Migration of Fraser River Sockeye Salmon (*Oncorhynchus nerka*): A Study of the Effect of Ocean and River Environmental Conditions in 1997

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MORTALITY DURING THE MIGRATION OF FRASER RIVER SOCKEYE SALMON (*ONCORHYNCHUS NERKA*): A STUDY OF THE EFFECT OF OCEAN AND RIVER ENVIRONMENTAL CONDITIONS IN 1997

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In 1997, a record return of 1,671,000 early Stuart sockeye salmon (*Oncorhynchus nerka*) arrived in coastal British Columbia waters to migrate up the Fraser River to reach their spawning grounds north of Stuart Lake, in the most northern portion of the watershed. These fish had faced warmer than average sea surface temperatures associated with a record setting El Niño-Southern Oscillation (ENSO), and were about to face a migration through the Fraser River system during a period when discharge levels were approaching the highest on record. These conditions created fish passage impediments in the lower Fraser canyon and production losses to the run. This report is a collation of papers describing the environmental conditions in the Pacific Ocean and Fraser River during this spawning migration, and will provide behavioural and physiological evidence that strongly suggests that large numbers of early Stuart sockeye salmon were lost due to the accumulated stress. These papers describe the type of information that is necessary in the future to provide in-season decision support to all those involved in the welfare of the Fraser River salmon stocks.

RÉSUMÉ

Macdonald, J.S. 2000. Mortality during the migration of Fraser River sockeye salmon (*Oncorhynchus nerka*): a study of the effect of ocean and river environmental conditions in 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2315: 120 p.

En 1997, un effectif record de 1 671 000 saumons rouges (*Oncorhynchus nerka*) de la remonte précoce de la Stuart sont arrivés dans les eaux côtières de la Colombie-Britannique pour remonter le Fraser jusqu'à leurs frayères au nord du lac Stuart, dans la portion la plus septentrionale du bassin. Ces poissons avaient dû faire face à des températures de surface en mer plus élevées que la normale – associées à une oscillation australe El Niño (ENSO) record – et s'apprêtaient à remonter le Fraser alors que les débits approchaient des niveaux record. Ces conditions contribuèrent à créer des obstacles à la remonte dans le cours inférieur du canyon du Fraser et à infliger de nombreuses pertes aux stocks de géniteurs. Ce rapport rassemble des articles décrivant les conditions environnementales qui prévalaient dans l'océan Pacifique et dans le Fraser au moment de cette migration. Il met en avant des données comportementales et physiologiques qui indiquent qu'un grand nombre de saumons rouge de la remonte précoce de la Stuart sont morts à cause du stress accumulé. Les articles décrivent le type d'information dont toutes les personnes participant à la gestion des stocks de saumons du Fraser auront besoin pour étayer les décisions prises durant la saison.

INTRODUCTION

In 1997, a record return of 1,671,000 early Stuart sockeye salmon (*Oncorhynchus nerka*) arrived in coastal British Columbia waters approximately 7 days later than normal (date of 50% arrival in the lower Fraser River - July 15th vs. normal July 8th). Warmer than average sea surface temperatures associated with an El Niño-Southern Oscillation (ENSO) set records at several recording stations and were believed responsible for the northern diversion of nearly 50% of the run through Johnstone Strait. Lengths of these fish were lower than average and the mean weight of the catches suggested that their condition (length vs. weight relationship) was probably low. Thus, the fish arrived in sub-optimal physical condition for the long and arduous migration to their spawning grounds approximately 1100 km upstream.

During the upstream migration of early Stuart sockeye salmon in July, 1997, a rise in the Fraser River discharge to near-record levels created fish passage impediments in the lower Fraser canyon. These migratory conditions, combined with sub-optimal physical state of the fish, directly led to the largest recorded en-route mortality of a single stock of Fraser River sockeye salmon. Distressed fish were observed in the Fraser Canyon between Hope and Hells Gate, B. C., and in the tributaries of the Fraser River between Hope and the Stuart River, 815 km upstream (Fig. 1). Approximately 681,000 fish of the early Stuart run estimated to have migrated past Mission, were not caught in fisheries nor had they arrived at the spawning grounds in the Stuart River watershed. When this event became apparent, the Fraser Panel of the Pacific Salmon Commission (P.S.C.) alerted Fisheries and Oceans, which initiated a study of the causes and impacts of the en route mortality. This investigation found that a variety of adverse and unusual ocean and river conditions were likely responsible for the en route mortality of the early Stuart sockeye salmon in 1997.

Programs to investigate the effect of environmental conditions in migration habitats occupied by spawning Fraser River salmonids have been in existence for over 30 years. Initiatives have been generated by Fisheries and Oceans Canada and the International Pacific Salmon Fisheries Commission (IPSFC) under a number of titles and as a result of a number of factors. Most recently two 'state of the environment' reviews, the Pearse-Larkin Report and the Fraser Report, have provided the impetus to consider this issue a priority. The theme central to 30 years of investigations, is the belief that a link exists between the health and fitness of spawning stocks of Fraser River salmon and the water temperatures and river discharge experienced by the fish along the migration path. Most vulnerable are the Fraser stocks returning in June, July, and August, including the early Stuart, early summer, and summer stock groups. There have been years in which these fish have entered the Fraser River but have failed to complete their spawning migration. In these years, there is evidence to suggest that fish that do complete their migration have experienced conditions that compromise their ability to produce viable gametes. Stock productivity is threatened, rebuilding initiatives are delayed, and in-season fishery management becomes exceedingly difficult.

This report is a collation of papers describing the environmental conditions in the Pacific Ocean and Fraser River, and the associated biological consequences during the migration of the early Stuart and early summer groups of sockeye salmon. It will provide behavioural and physiological evidence that strongly suggests that large numbers of early Stuart sockeye salmon were lost due to the accumulated stress associated with the 1997 migration. Energetic parameters are described and a model is presented that describes the risk of en route energetic exhaustion associated with the early Stuart spawning migration. Issues pertaining to egg viability and egg-to-fry survival are also considered. This report concludes with suggestions for future work and describes the importance of this research to the management of the early stocks of sockeye salmon. These papers describe the type of information that is necessary in the future to provide in-season decision support to all those involved in the welfare of the Fraser River salmon stocks.

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The editor expresses appreciation to Merrs. Al Lill, Wayne Saito, and other members of the Fraser Bilateral Panel who have the difficult task of monitoring, allocating, and conserving returning stocks of Fraser River salmon in the face of changing societal, political, and environmental conditions. The authors wish to thank Ms. Ann Thompson for her superb editorial efforts during the production of this report.

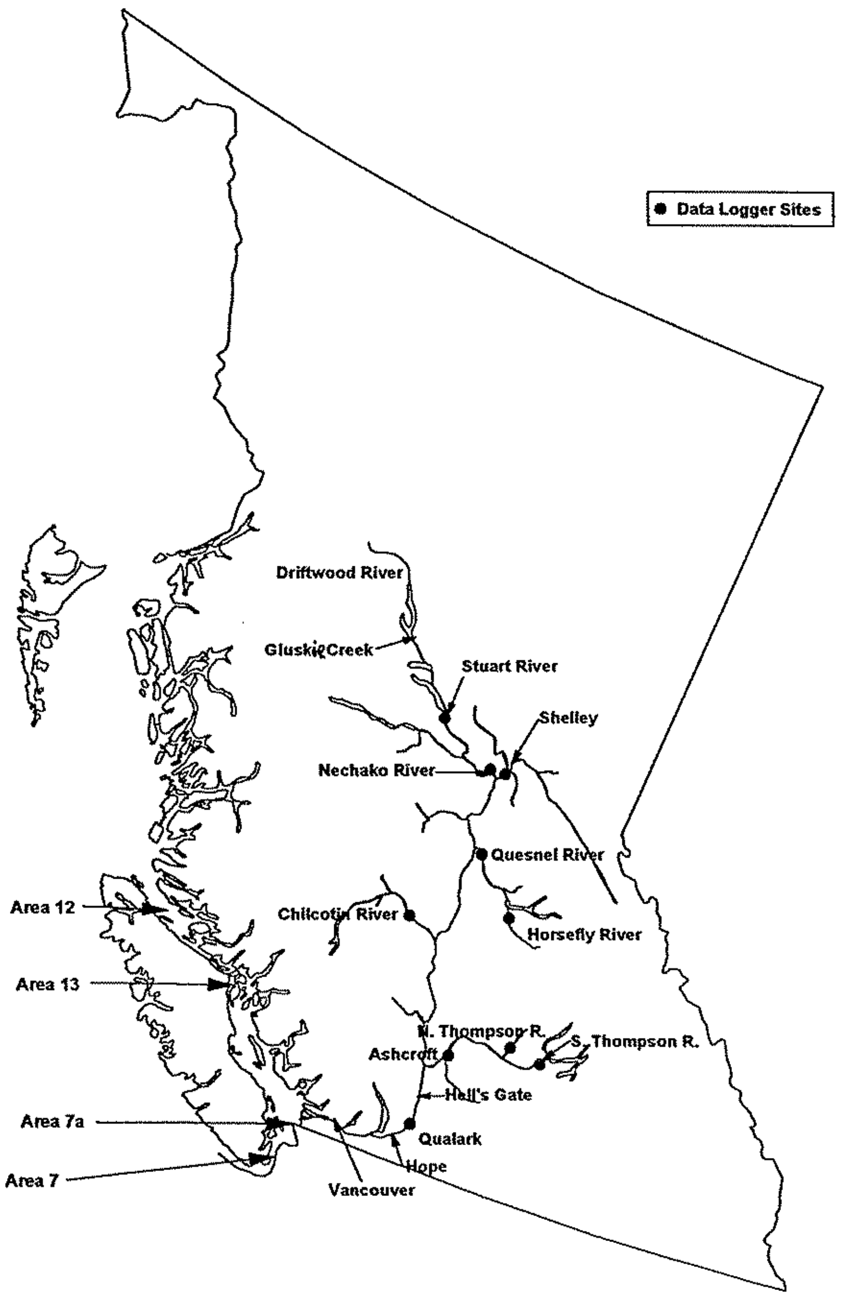

Fig. 1. The Fraser River watershed showing locations where water temperature and discharge acquisition equipment was installed. Geographical locations and pertinent fisheries management areas that are referred to in the text are also indicated.

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AN UNUSUAL OCEAN CLIMATE IN THE GULF OF ALASKA DURING THE SPRING OF 1997 AND ITS EFFECT ON COASTAL MIGRATION OF FRASER RIVER SOCKEYE SALMON (*ONCORHYNCHUS NERKA)*

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INTRODUCTION

The migratory behaviour of Fraser River sockeye salmon (*Oncorhynchus nerka*) on their return from the Gulf of Alaska has been predictable (McKinnell et al. 1999). Fisheries and Oceans Canada provides annual pre-season forecasts of the Fraser River sockeye migration route. Prior to 1977, the forecast was based largely on sea level and the magnitude of the discharge from the Fraser River (Wickett 1977). However, since 1976, the sea surface temperature (SST) at the Kains Island light station at the mouth of Quatsino Sound on northwestern Vancouver Island has provided one of the most reliable predictors, even though the mechanism has not been determined. During warm springs (May and June), the sockeye tend to go north. In cool springs, the sockeye go south. In most years, producing the forecast involves waiting until the temperature data are available to determine which state of nature appears in any given year. This paper describes some unusual events in the migration of sockeye that coincided with an atypical ocean climate in 1997.

DATA AND METHODS

Kains Island sea surface temperature has been recorded daily by the lightkeeper at the Kains Island light station since 1934. The database is maintained at the Institute of Ocean Sciences in Sidney, BC. The Pacific Salmon Commission produces annual northern diversion estimates. Fraser River sockeye northern diversion forecasts are normally issued during the first week of June and updated during the first week of July. Occasionally, interim forecasts are produced mid-month if updates are requested more frequently. The model currently in use is a General Additive Model (D. Welch, unpublished method). May sea surface temperatures are used for the June forecast and mean May + June is used for the July forecast. Only years after 1976 are included in this model.

Sea surface temperatures in the Gulf of Alaska (Reynolds and Smith 1994) for the months of May and June 1982 to 1997, were used with the geographic information system COMPUGRID to develop isothermal contours at 8.9, 9.4, and 10.4°C. COMPUGRID (Geospatial Systems, Inc.) was used to compute the area (km^2) in the Gulf of Alaska that was less than or equal to these isotherms. The areal computations excluded the coastal waters of B. C. and Southeast Alaska (waters shoreward of the islands) and they excluded Prince William Sound and Cook Inlet. The western boundary was 180° longitude. The northern boundary (west of the Alaskan Peninsula) was the Aleutian archipelago.

The mean weight, by year, of Fraser River sockeye caught in seine gear in Areas 12 and 13 (Johnstone Strait) (Fig. 1, Introduction) was extracted from the Fisheries and Oceans Canada catch statistics database (Wong 1983). The total catches of sockeye, by week, for 1952-1996 was obtained from the same database. Preliminary 1997 total sockeye catch data, by week, for Areas 12 and 13 were obtained from Operations Branch, South Coast Division, Fisheries and Oceans Canada.

RESULTS AND DISCUSSION

In early May, 1997, SSTs at Kains Island were below 10°C. Normally, this would have resulted in a low mean monthly SST and a southern migration pattern by the sockeye salmon. After 9 May, 1997, the SST began to rise, reaching ~12.5°C within 2 weeks. SSTs this high in late May had not been observed in the period of record (since 1934). The SST continued to rise throughout June and the mean monthly SST for June (13.6°C) was also the highest observed in the historical record. Sea levels recorded at Tofino had similar anomalies that summer. The extreme SST anomaly observed at the Kains Island light station in 1997 was also observed in the Gulf of Alaska. The area (km^2) of the Gulf of Alaska with SSTs ≤8.9°C in May and June, 1997, was smaller than previously observed. Interestingly, the area of the Gulf of Alaska ≤8.9°C in 1996 was the second smallest in the record. The area ≤8.9°C in June, 1997, was 34.7% of that present in the coolest year in the series, 1987. There has been a significant decreasing trend in the area of the Gulf of Alaska ≤8.9°C since 1981. Bootstrap estimates of the slope and confidence intervals from a linear model suggest that the area of the Gulf of Alaska ≤8.9°C has been decreasing at an average rate of 67,085 and 83,437 km^2 per year in May and June, respectively, since 1981. The 95% confidence intervals are (-40,241 to -101,702) and (-10,742 to -160,094) for May and June, respectively. Note that the 95% confidence intervals do not include 0.0.

The migration of sockeye salmon to the Fraser River in 1997 was one of the most protracted in history. Sockeye were caught in unusually high abundance in pink and chum fisheries during the last two weeks of September. Anecdotal information suggests that high proportions of the sockeye caught in these fisheries were in advancing stages of sexual maturation. The mean weight of sockeye salmon caught in the Area 12 seine fishery was one of the lowest on record in 1997.

The mean size of Fraser River sockeye was near the smallest on record, with a very protracted migration through coastal waters. The migration was so protracted that some Fraser River sockeye appear to have stopped before completing the marine portion of their migration, and entered streams and rivers along the migration route (McKinnell et al. 1999). In Johnstone Strait and on the west coast of Vancouver Island, sockeye salmon have been reported in unusual abundance in rivers and streams where they are not normally found or not normally found in any abundance. U.S. biologists have reported similar findings in Washington State, Oregon, Idaho, and California (K. Kostow, personal communication). Some have speculated that these are Fraser River sockeye that have strayed many hundreds of kilometres from their natal systems. Equally plausible hypotheses consider the possibility that these may be local river-type populations that have experienced very good recruitment. The latter hypothesis cannot apply to those rivers and streams that normally lack sockeye. As these extremes in climate and sockeye biology occurred within the same calendar year, it is natural to look for plausible hypotheses linking them. For the most part, the biological data are preliminary and have not been fully analyzed so any linkages are hypothetical. The abundance of Fraser River sockeye in 1997, combined with their small size, lead naturally to hypotheses concerning density-dependent growth (Peterman 1984; McKinnell 1995). Sexual maturation before the arriving at the Fraser River is a new phenomenon, perhaps suggesting an inadequate swimming speed or a link between maturation rate and elevated temperatures. Late run timing observations lead to hypotheses concerning increased migration distance to the Fraser River if warm ocean temperatures restrict sockeye to northern portions of the Gulf of Alaska (Blackbourn 1987; Welch et al. 1995).

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AN ANALYSIS OF FLOW AND TEMPERATURE CONDITIONS AND PREDICTIONS FOR THE FRASER AND THOMPSON RIVERS IN 1997

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INTRODUCTION

Elevated water temperatures have been linked to pre-spawning mortalities for many sockeye salmon (*Oncorhynchus nerka*) stocks returning to their natal streams in the Fraser River watershed (Gilhousen 1990) (Fig. 1). When the water is too warm, the metabolic rate of the salmon increases, their energy reserves deplete rapidly (Rand and Hinch 1998), and stress and possible mortality can occur. Temperatures above 24°C can cause acute thermal shock (Bouke et al.1975) leading to death in only a few hours, whereas sustained exposure to temperatures between 22°C and 24°C for several days can also be lethal (Servizi and Jensen 1977). Long-term exposure to lesser temperatures such as would be encountered during migration can have equally dramatic consequences. Gilhousen (1990) has shown significant correlation between high river temperatures at Hell's Gate and females that reached their spawning grounds but died before spawning.

Since 1995, an extensive observational and modelling program has been carried out by Fisheries and Oceans Canada in order to provide fisheries managers with an advance warning of potential temperature- and flow-induced stress problems as the fish migrate through the Fraser and Thompson rivers. This report presents both an evaluation of the models predictive performance and a description of the river conditions during the 1997 sockeye migration season.

THE PREDICTIVE MODEL

Ten-day flow and temperature forecasts were issued for the mainstem Fraser and Thompson rivers during the period of July 3 to September 11, 1997. These forecasts were made twice a week (generally every Monday and Thursday) using flow and temperature models run at the Institute of Ocean Sciences (I.O.S.) and described in Foreman et al. (1997). Model coverage extends from Shelley to Hope on the Fraser River (Fig. 1), and Chase to Lytton on the Thompson River. Daily weather forecasts of the solar radiation, maximum and minimum air temperature, dew point temperature, cloud cover, precipitation, and wind speed were provided for Kamloops and Prince George on each prediction day by the Kelowna office of Atmospheric Environment Services (A.E.S.). Also included with these forecasts were observed values of the same parameters over the last 5 days, as well as the precipitation and maximum and minimum air temperatures at Blue River. This meant that each of the model runs covered a period of 15 days; the five days immediately preceding the forecast followed by a 10 day forecast.

Prior to the calculation of 10-day forecast, hourly river temperatures measured by real-time access data-loggers were retrieved for the previous 5 days from the following locations: Shelley (on the Fraser River), Chase (on the South Thompson River), Prince George (on the Nechako River), Alexis Creek (on the Chilcotin River), Quesnel (on the Quesnel River), Rayleigh (on the North Thompson River), Ashcroft (on the Thompson River), and Qualark (on the Fraser River) (Fig. 1). These, together with realtime river discharges obtained from Water Survey of Canada (W.S.C.) for the South Thompson River at Chase, the North Thompson River at McLure, the Thompson River at Spences Bridge, the Nechako River at Vanderhoof and Prince George, and the Fraser River at South Fort George, Marguerite, and Hope permitted an accurate snapshot of recent river conditions.

In addition to weather, the other main inputs required by the temperature model are river flows, and headwater and tributary temperatures. The flows are calculated in two steps. In the first step, the U.B.C. Watershed Model (Quick 1995; Quick and Pipes 1976) uses both the forecasted and recent weather conditions and the eight sets of recent flow measurements, to calculate tributary and headwater flows for the mainstem Fraser and Thompson rivers. The U.B.C. Flow Model (Mountain Hydrology Group 1994) is then used to compute transports and velocities every 10 km along both rivers for the following 15-day period.

Headwater and tributary temperatures are computed using the 15 days of weather and flow conditions, and regression coefficients that were calculated from historical flow and atmospheric measurements. Once all these inputs have been assembled, the river temperature model then computes 15 days of hourly temperatures at the same 10-km locations used by the flow model. These hourly temperatures are then condensed to daily averages, and forwarded to I. V. Williams for input to a biological model that estimates the accumulated stress felt by migrating sockeye salmon (Macdonald et al., this report).

THE FLOW MEASUREMENTS

Hourly river elevations are traditionally measured by the W.S.C. at numerous locations throughout the Fraser River watershed and then converted to flows, using previously calibrated stage-discharge relationships. Some of these observations go back as far as 1912, and this long history has been useful in establishing the relative importance of various tributaries and the relative strength of the 1997 flows.

According to Robin Wyman (personal communication, B.C. Ministry of the Environment), the unusually high discharge rates in the Fraser and Thompson rivers in 1997 arose from a combination of low elevation snow, particularly in the Nechako Watershed, and heavy rains in mid-July (Fig. 2). Unfortunately, the July rain occurred during the early Stuart sockeye run and meant that fish near Hope and South Fort George experienced respective flows that were as much as 60% and 100% larger than normal for that time of year. As discussed in Macdonald et al. (this report) and Hinch and Rand (this report), these strong flows had a major impact on the number of sockeye that were able to reach their spawning grounds.

THE TEMPERATURE MEASUREMENTS

Apart from a few technical and vandalism problems, hourly river temperatures were measured between May and October, 1997, at eight stations in the Fraser watershed (Fig. 1). Observations from sites denoted with a solid circle were available in real-time, while observations at the other sites were recorded and recovered two or three times during the season.

With the exception of a brief period in early July, the 1997 Qualark (lower Fraser River) temperatures were below a 4-year average through July and early August (Fig. 3). In particular, at the time of the peak Hope discharge on July 15 (Fig. 2), the temperature was approximately 2°C below average. A similar pattern occurred at Prince George. The 1997 temperatures were less than average until early August and close to average thereafter. Notice that the daily temperature oscillations arising from solar radiation and air temperature heat transfers are much larger in the shallower Nechako River than in the Fraser River.

Based on the values shown in Fig. 3, it appears that river temperature should not have been a problem for the early Stuart run in July. Similarly, the near average temperatures in August should not have caused any unusual problems for the later sockeye runs.

ANALYSES OF PREDICTION PERFORMANCE

The atmospheric, river flow, and river temperature measurements taken during the period of July 3 to September 11 permitted extensive analyses of model prediction performance. The first analysis was simply to compare the predicted and observed temperatures at all data-logger sites in the model domain. The average difference and the root mean square (rms) of all twenty-one temperature forecasts were calculated after the differences for all 10 days of each forecast were combined (Table 1). Forecasted temperatures for Ashcroft, Qualark, FR610, and FR290 were computed with the river temperature model (Foreman et al. 1997) while those at the other (tributary and headwater) sites were computed via regression on the predicted flows and meteorological conditions.

Table 1. Average and root mean square differences between the 1997 temperature (°C) predictions and observations. (Difference=observed-modelled).

Site	Average	RMS
Shelley	−0.63	1.75
Prince George	−0.02	0.97
FR610	−0.09	1.20
Quesnel	0.23	1.36
Alexis Creek	0.05	1.01
Chase	0.30	1.35
Rayleigh	0.16	0.69
Ashcroft	0.49	0.88
FR290	0.55	0.99
Qualark	0.59	0.88

Systematic biases are evident at several sites. In the Thompson River watershed, the model predictions for the South Thompson River at Chase, the North Thompson River at Rayleigh, and the Thompson River at Ashcroft were on average, too cool by approximately 0.3°C, 0.2°C, and 0.5°C, respectively. Although the Nechako and Chilcotin rivers displayed virtually no systematic biases, there was a bias of about 0.2°C in the Quesnel River and larger biases along the mainstem Fraser River. In particular, the predictions at Shelley were, on average, too warm by 0.6°C while at FR290 and Qualark they were too cool by 0.6°C. Root mean square discrepancies of 1.8°C, 1.4°C, and 1.4°C at Shelley, Chase, and Quesnel, respectively, suggest the need for a closer examination of the regression formulae applied at these sites. Elsewhere the rms values were approximately 1.0°C and, with the exception of Rayleigh, were the smallest at the most downstream locations of Ashcroft (on the Thompson) and Qualark (on the Fraser).

The largest temperature discrepancies at Qualark and Ashcroft occurred in the forecasts issued in late July when the air temperature at Kamloops reached a high of 37°C (Table 2). Although the Environment Canada forecast was reasonably accurate, it appears that the heat transfer term in our model may require some modification for such high values. This will be investigated further.

Table 2. Variations in the root mean square difference between predicted and observed river temperatures at Qualark and Ashcroft over the 1997 migration season. (Difference=observed-modelled).

	Qualark		Ashcroft	
Date	Average	RMS	Average	RMS
July 3	0.93	1.11	0.13	0.60
July 7	0.16	0.75	−0.25	0.55
July 10	−0.03	0.58	−0.43	0.55
July 14	0.44	0.75	0.58	1.06
July 17	0.70	1.17	0.66	0.86
July 21	0.72	0.77	0.73	0.92
July 24	0.92	1.00	0.59	0.81
July 28	1.43	1.56	1.13	1.30
July 31	1.07	1.10	0.95	1.17
August 4	0.44	0.53	0.45	0.69
August 7	0.00	0.42	0.23	0.67
August 11	0.54	0.63	0.88	1.12
August 14	0.98	1.01	1.68	1.86
August 18	0.60	0.76	0.99	1.02
August 21	0.50	0.55	0.85	0.99
August 25	0.83	0.96	0.23	0.39
August 28	1.22	1.25	0.64	0.79
September 1	0.89	0.91	0.34	0.51
September 4	0.43	0.51	0.27	0.59
September 8	−0.22	0.59	0.08	0.42
September 11	−0.13	0.53	−0.34	0.48

Errors (rms) in the prediction of temperature generally increase as the day of prediction moves further into the future (Table 3). A similar trend is evident when an accuracy analysis of the A.E.S. data is performed. In fact, the most important factor affecting the accuracy of the river temperature predictions is the accuracy of the weather forecasts. The weather not only influences river temperatures directly through air-water heat transfers (Foreman et al. 1997), but it also indirectly affects the headwater and tributary temperatures, and the magnitude of the flows (via rainfall, snow, and glacial melt) throughout the entire Fraser Watershed.

Table 3. Root mean square differences between predicted and observed river temperatures at Qualark and Ashcroft as functions of the predictive day.

Day	Qualark	Ashcroft
1	0.81	0.77
2	0.80	0.63
3	0.78	0.72
4	0.84	0.74
5	0.90	0.87
6	0.81	0.95
7	0.88	1.04
8	1.00	1.08
9	1.00	1.00
10	0.93	1.02

The average and the root mean square (rms) of the percentage discrepancy between the 21 observed and predicted flow forecasts at 10 W.S.C. sites in the Fraser watershed were calculated (Table 4). Discrepancies during each of the 10 days in the forecast were combined to produce a single discrepancy for each forecast in preparation for the calculation. The largest systematic biases are on the Nechako and Chilcotin rivers. Flows in the Nechako are partially controlled by releases from the Kenney Dam (Fig. 1) and thus their predictability is not solely dependent on the accuracy of the weather information. The Chilcotin River is handled differently from the other major tributaries in the U.B.C. Fraser Watershed Model. It is not included as a separate river but rather its flows are a combination of several ungauged tributaries, each assumed to be the same temperature as the Chilcotin by the I.O.S. temperature model. The large percentage differences between the modelled and observed flows in Table 4 reflect the difficulty of predicting Chilcotin flows when, on average, the ungauged tributaries were 3.5 times larger than the Chilcotin itself.

Table 4. Average and root mean square percentage differences between the 1997 flow (m^3 s^{-1}) predictions and observations. (Percentage difference=100 X (observed-modelled/ observed).

Site	Average	RMS
Shelley	–3.87	26.40
Nechako River	38.76	45.71
South Fort George	9.66	21.01
Quesnel River	–11.49	22.05
Chilcotin River	–257.31	264.96
Chase	17.33	20.53
N. Thompson River	–4.27	17.76
Marguerite	–4.27	17.76
Hope	10.36	15.78
Spences Bridge	10.06	12.78

SUMMARY AND DISCUSSION

A post-season analysis of the 1997 flow and temperature predictions for the lower Fraser and lower Thompson rivers (Qualark and Ashcroft) show reasonable accuracy, both having rms values of less than 1°C. Predicted flows in the lower portions of these rivers (Spences Bridge and Hope) were between 13 and 16% of the observed values.

Although river temperatures were generally below average during the 1997 sockeye migration season, river discharges were generally well above average. At one point during the early Stuart run in mid-July, the flows at Hope and South Fort George were, respectively, 60% and 100% larger than normal for that time of the year. As reported Macdonald et al. (this report) and Hinch and Rand (this report), these strong flows had a major impact on the number of sockeye that were able to reach their spawning grounds.

The most important factor affecting the accuracy of the river temperature predictions is the accuracy of the weather forecasts. The weather not only influences mainstem temperatures directly through air-water heat transfers (e.g. solar radiation, conduction and convection), but also indirectly by controlling headwater and tributary temperatures and hydrology (via rainfall, snow, and glacial melt) which also have an influence on the mainstem. Although it is unlikely that A.E.S will be able to substantially improve the accuracy of their forecasts in the near future, our river forecasts can be improved with addition spatial coverage.

There are two improvements that could be made. The first relates to observational coverage. A.E.S. presently provides daily precipitation and maximum and minimum air temperatures for Blue River, and daily solar radiation, maximum and minimum air temperatures, dew point temperature, cloud cover, precipitation, and wind speed information from Kamloops and Prince George. The U.B.C. Watershed Model must interpolate and extrapolate among these locations to obtain rainfall and air temperature values for the entire watershed. As the present spot measurements may not be representative of large regions, it is clear that observations and forecasts at a few more strategic locations would be beneficial.

Although A.E.S. does have observations and could presumably provide predictions at other locations, this would be at an additional cost to our present contract. An alternative strategy would be to take our own observations by adding air temperature and rainfall instruments to our existing real-time data-logger sites.

The second improvement relates to model coverage. The 1997 flow and temperature predictions were issued for only the mainstem Fraser and Thompson rivers. Given the importance of the Stuart and Horsefly runs, we have recently extended our model coverage to include the Stuart/Nechako and Horsefly/Quesnel rivers. However, in order to provide reasonably accurate predictions for these systems in 1998, we require a real-time observational support system similar to what exists for the Fraser and Thompson rivers. In particular, we would like to augment the information from our real-time temperature data loggers at Prince George and Quesnel by installing new loggers further upstream at Fort St. James and Horsefly. Data from these additional locations would provide sufficient snowcast information to permit forecasting for the complete sub-watersheds.

ACKNOWLEDGMENTS

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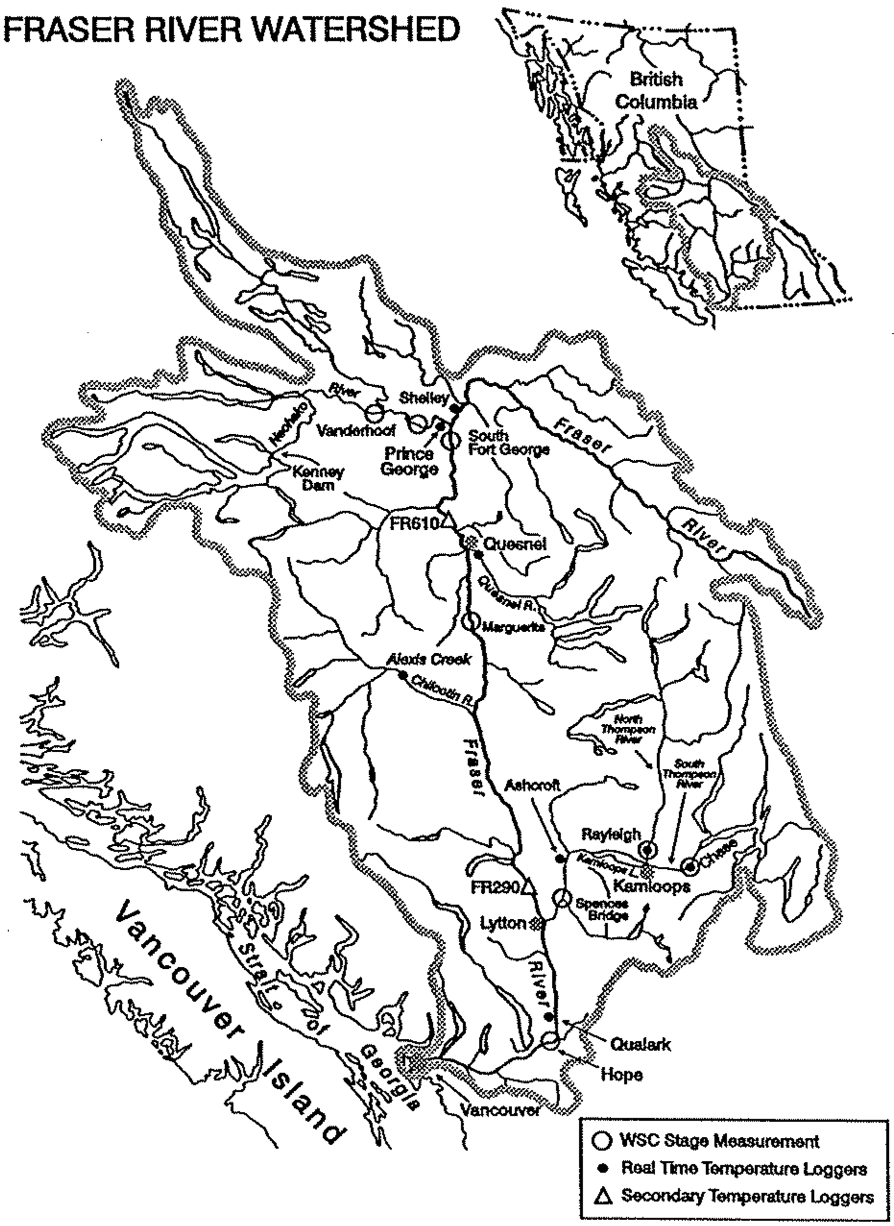

Figure 1. Fraser River watershed showing locations of the Fisheries and Oceans data loggers and the W.S.C. stage measurements.

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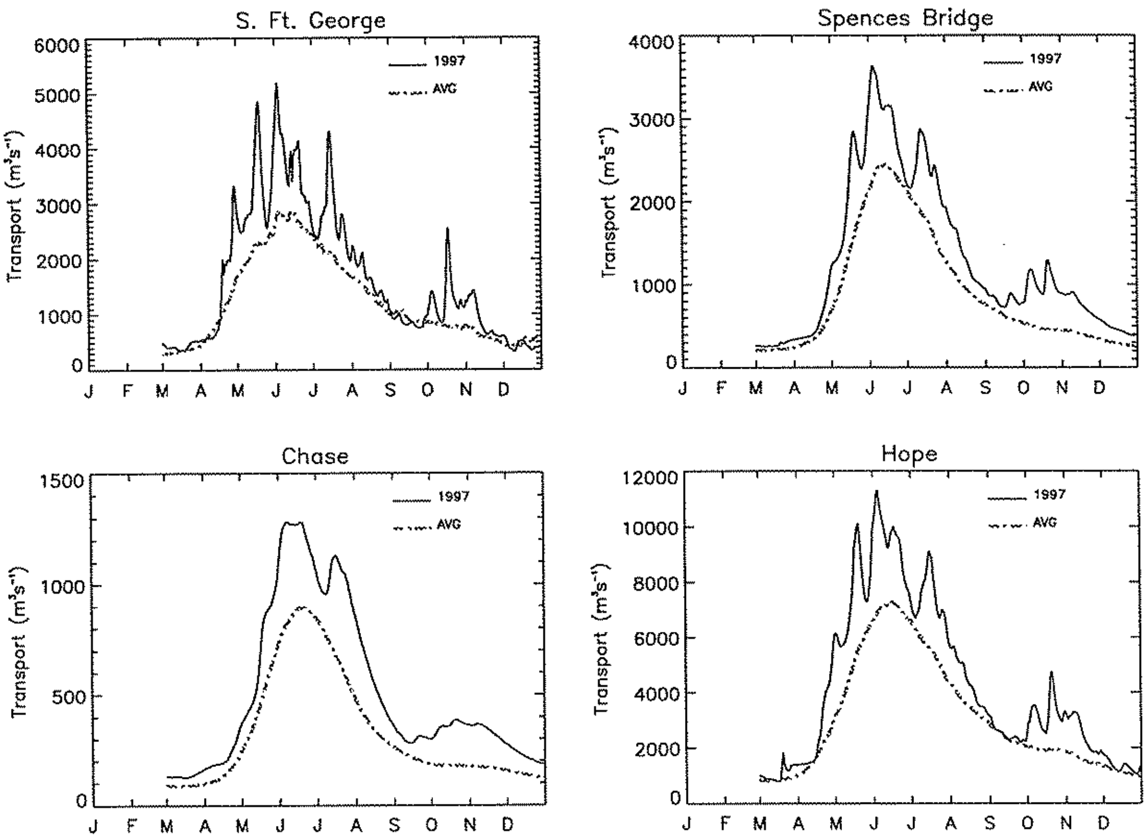

Figure 2. Average and 1997 discharges (m^3/s) at Hope, South Fort George, Chase, and Spences Bridge.

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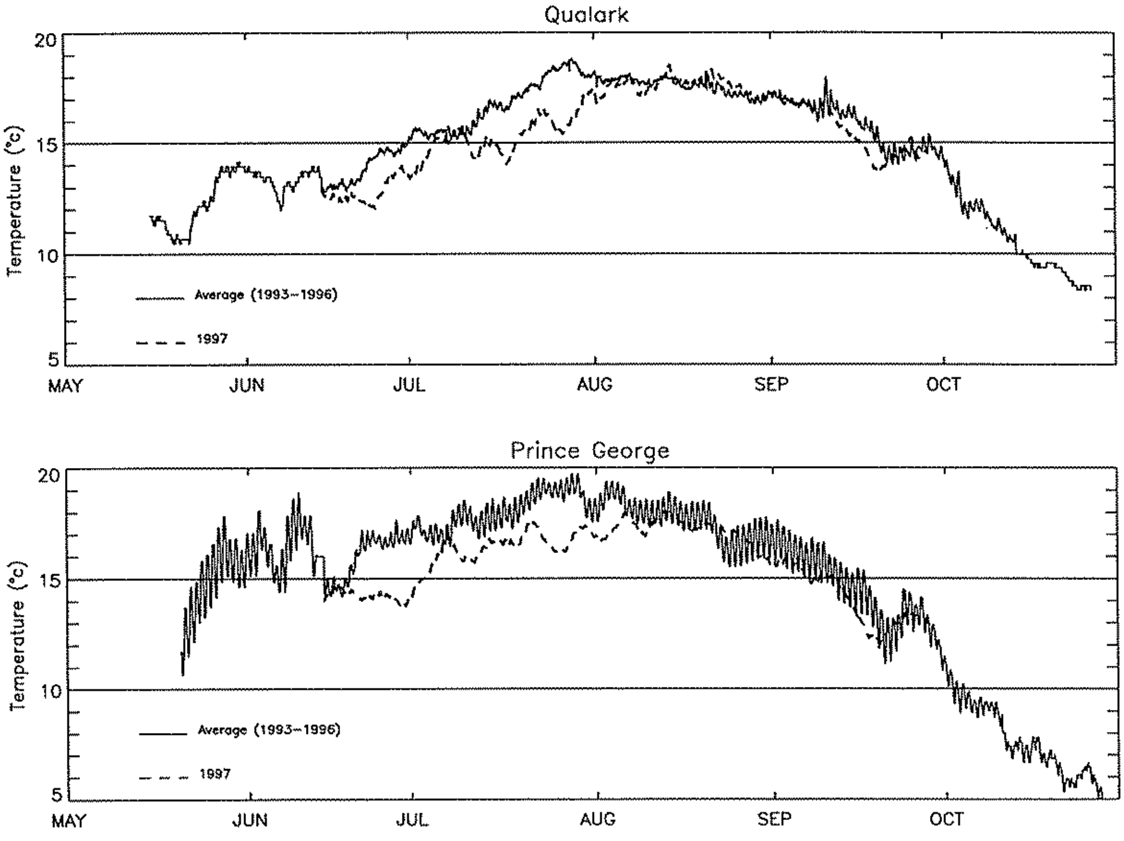

Figure 3. Average (1993-96) and 1997 observed temperatures at Qualark on the lower Fraser River, and Prince George on the Nechako River.

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ESTIMATION OF THE 1997 EARLY RUN SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) ESCAPEMENT TO THE STUART RIVER SYSTEM

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INTRODUCTION

The Stuart River system originates in north central British Columbia northwest of Fort St. James and constitutes the most northern portion of the Fraser River watershed. The system includes the Driftwood, Middle, Tachie, and Stuart rivers, which are separated by Takla, Trembleur, and Stuart lakes, respectively, and over 40 smaller streams (Fig. 1). The Stuart supports two temporally and spatially distinct sockeye salmon (*Oncorhynchus nerka*) populations, the Early and Summer runs. The former, commonly referred to as the Early Stuart, is the focus of this report. Early Stuart sockeye typically arrive in the system from late July to mid-August and spawn in streams tributary to the Middle River and Takla and Trembleur lakes and, on the dominant cycle, in the Driftwood River. Like many Fraser River stocks, Early Stuart sockeye exhibit a pronounced quadrennial escapement cycle, with a strong dominant year and three weaker years. Between 1970 and 1996, escapements averaged 310,000 on the 1993 dominant cycle, 40,000 on the 1994 cycle, 99,000 on the 1995 cycle, and 60,000 on the 1996 cycle. A record of 688,000 sockeye spawned in 1993, the brood year for the 1997 return.

Fisheries and Oceans Canada estimates the stock-specific annual abundance of Fraser River sockeye spawners using a two-tiered system originally developed by the International Pacific Salmon Fisheries Commission. Stocks with large expected escapements (25,000+) are assessed using enumeration fences or mark-recapture studies. Stocks with small escapements (less than 25,000) are assessed using visual techniques. While the Early Stuart complex regularly exceeds 25,000 spawners, the typically small escapements to a large number of streams are more suited to assessment using visual techniques. Early Stuart escapements are estimated from counts of live and dead spawners which are multiplied by an expansion factor to account for observer efficiency and spawner turnover (Andrew and Webb 1987 (unpublished)). Historically, the expansion factor was calibrated by a comparison of spawner counts with escapements estimated from independent studies (enumeration fence or mark-recapture) which were periodically conducted in the Stuart or other systems (Woodey 1984). In 1988, the need for more precise escapement estimates for the large Stuart stock complex led to more intensive annual calibration procedures. In 1995, the calibration process was further augmented by additional fences in response to Fraser River Sockeye Public Review Board (1995) instructions to investigate the role of survey frequency, methods and stream conditions (geographic location, stream size, and population size).

This report summarizes the study design, field methods, analytic techniques, and results of the 1997 Early Stuart sockeye escapement estimation study. Included are estimates of run timing and female spawning success, and preliminary estimates of the escapement of adult males, females, and jacks for each of the constituent stocks. A later report will provide more detailed data and final escapement estimates.

METHODS

The 1997 escapement estimation plan was developed from the abundance forecast (A. Cass, personal communication) and the pre-season management plan (A. Macdonald, Fishery Management biologist, personal communication). Based on a pre-season expectation of at least 500,000 Early Stuart spawners, a plan was developed which had four components. First, the majority (35) of the Early Stuart stocks which spawn in relatively small streams which are densely overgrown by streamside shrubs and trees, were accessed by boat and inspected on foot. Aerial surveys of these streams would not provide reliable results. The entire accessible spawning area in each of these streams was surveyed every 3-5 days. Live sockeye and carcasses were enumerated and date, location, sex, and female carcass spawning success was recorded. After enumeration, the carcasses were removed from the study area by pitching them beyond the stream's high water mark. Second, to calibrate the visual observations, enumeration fences were constructed on three Middle River area streams: Gluskie, Forfar, and Kynoch (O'Ne-ell) creeks (Fig. 1). The fences were installed near the creek outlets; the daily immigration was enumerated through a counting box in the fence. A comparison of these counts with observations from foot surveys conducted above the fences permitted the calibration of visual observations and the calculation of escapement. A representative sample of the spawners was also marked with disk tags to permit the estimation of escapement should the fences wash out. Third, because the Driftwood River system escapement was expected to total at least 300,000 spawners, a mark-recapture study was planned for this system. A base camp was established and tags were applied to migrating sockeye below the lower limit of spawning. Carcass surveys were conducted on foot or by boat, with the upper river spawning areas accessed by helicopter. Daily index counts were conducted from a bridge located in the lower Driftwood River. Fourth, because the brood-year escapement to Dust Creek was almost 50,000 sockeye, an enumeration fence was installed across the creek 500 m above the lake. A base camp was established at the head of the Takla Lake (NW Arm) to house the staff responsible for the fence operation and the survey of the local streams.

The escapement to streams assessed, using visual surveys, was estimated using the procedures described by Schubert (1997). Total escapement was the product of the maximum count of live spawners plus the cumulative recovery of all carcasses (males, females, and jacks) through the date of the peak live count, and an average index expansion factor measured at enumeration fences on Gluskie, Forfar, and Kynoch creeks. The total escapement was partitioned to adult males, females, and jacks based on the ratios from the stream-specific carcass recoveries. Female spawning success was similarly estimated from the stream-specific recovery of female carcasses. The escapement to the fenced streams was the sum of the below fence escapement, estimated using the above procedures, and the fence counts. The mark-recapture estimates were generated using the analytic procedures described by Schubert and Fanos (1997).

RESULTS AND DISCUSSION

The 1997 Early Stuart escapement estimation study began with the construction of enumeration fences in Forfar, Gluskie, and Kynoch creeks on July 19, and in Dust Creek on July 26. Observers were deployed to the Driftwood River in late July, and beach seining began in the lower river on July 29. The first sockeye spawner was reported in Gluskie Creek on July 25. This triggered the start of cyclic foot surveys in all streams; the surveys continued until the completion of spawning in late August. The study design was implemented as planned, except the Driftwood mark-recapture project was cancelled and Kynoch Creek was removed from the index calibration system. The former occurred because, by August 15, beach seining results, bridge counts, helicopter overflights, and foot surveys all showed poor sockeye abundance in the Driftwood River. The latter occurred after a previously undetected hole was discovered under the Kynoch Creek fence. Consequently, the preliminary escapement estimate for Kynoch Creek was based on visual data; the final estimate will be calculated from mark-recapture data and will be used to recalculate the calibration index.

TIMING OF ARRIVAL AND SPAWNING

The timing of sockeye arrival on the Early Stuart spawning grounds was late and protracted. The historic (1941-1996) dates of first arrival, peak migration, and the completion of migration at Middle River area enumeration fences averaged July 24 (range July 17 to July 28), August 1 (range July 22 to August 6), and August 18 (range August 14 to August 22), respectively. In 1997, the date of first arrival (July 25) was near the long- term average. However, peak arrival (August 11) was 10 days later than average, and the completion of the migration in Dust Creek was 11 days later than average and a full week later than previously observed in the Stuart system. The unusual 1997 arrival pattern is shown relative to 1993-1996 for Forfar Creek in Fig. 2. Similar patterns were also recorded in other streams for which historic data are available.

The 1997 daily sockeye counts from the enumeration fences (Forfar, Gluskie, Kynoch, and Dust) show a bimodal arrival pattern that was similar among many Stuart stocks (Fig. 3). In contrast, the daily beach seine catches in the lower Driftwood River showed very few sockeye until August 10, when abundance increased coincident with the second of the two peaks observed in the fenced streams (Fig. 3). This may have reflected disproportionate en route mortality on the Driftwood component of the Early Stuart run, or a slightly later arrival timing. The latter has been observed in the past (Tables 1-2) and would have been undetected in the 1997 data because of the termination of beach seining on August 15. Two subsequent over-flights later in August however, did not record a substantial change in spawner abundance in the Driftwood River.

The period of peak spawning was estimated to be August 9 to August 16 for the aggregate Early Stuart run (Table 1), with a slightly later peak of August 13 to August 20 in the Driftwood River (Table 2). Both were approximately one week later than the cycle average.

ESCAPEMENT ESTIMATES

With the exception of 1997, all previous 1997-cycle escapement estimates for the Early Stuart and Driftwood stocks are verified and confirmed (Tables 1 and 2). The 1997 escapement estimates are preliminary and are based on data that have not been fully verified.

In the case of the 1997 mark-recapture data, bias tests have not been performed. Changes are expected when the final estimates are released later. The 1997 escapement source data and the stock-specific escapement estimates are provided in Table 3.

Our interest in the1997 Early Stuart run can be summarized into four notable findings: 1) total escapement was poor relative to the brood year, the escapement goal, and the in-season abundance estimate; 2) an unusually low proportion of the escapement spawned in the Driftwood River; 3) the sex ratio was skewed toward males; and 4) female spawning success was poor. All of these factors will impact subsequent production and present a challenge for the future management of the dominant cycle Early Stuart run.

The 1997 Early Stuart sockeye escapement was estimated at 265,703 (Table 1). The escapement was dramatically impacted by en route migratory conditions. Of the 802,000 expected by fishery managers to arrive on the spawning grounds (Pacific Salmon Commission 1997), 536,000 failed to reach the Takla/Trembleur system. The resulting escapement was 61% below the 1993 brood year and, more significantly, was only 53% of the escapement target of 500,000 adults.

The spatial distribution of the escapement differed markedly from the 1993 brood year. The percentages of the total 1997 (1993) escapement which spawned in each geographic sub-area were: 11% (63%) Driftwood System; 7% (5%) Takla Lake, NE Arm; 34% (9%) Takla Lake, NW Arm; 15% (7%) Takla Lake, Main Arm; 19% (7%) Middle River; and 13% (9%) Trembleur Lake. In comparison to 1993, escapements declined by over 400,000 spawners in the Driftwood System, remained approximately the same in the Takla Lake and Middle River systems, and declined by over 26,000 in the Trembleur Lake system. The disproportionate decline in the Driftwood River sockeye escapement is notable because the Driftwood has been the backbone of the dominant cycle over the last 30 years. The 1997 escapement was the lowest reported for this brood year since 1965 (Table 2) despite an escapement for the Early Stuart aggregate, which was the fifth largest on record (Table 1). The rebuilding of the Driftwood stock to historic levels on this cycle will be a challenge to fishery managers.

The 1997 sex ratio was highly skewed toward males. Females comprised only 34% of the spawners; the lowest proportion ever observed on this cycle and well below the average of 55% reported since 1941. Spawning success for those females was also relatively poor, averaging 81.2% (range 64.3% to 100%). Typically, spawning success on this cycle averages over 90% (Table 1). Spawning success in the Driftwood River was especially poor (66.7% - Table 2), a result which was consistent with in-season reports that these fish were lethargic and susceptible to stress. The combination of a skewed sex ratio toward males, poor spawning success among those females that did reach the spawning grounds and the poor overall escapement, has obvious implications for subsequent production on this cycle.

ACKNOWLEDGMENTS

The 1997 Early Stuart escapement estimation study was conducted cooperatively by staff from the Fisheries and Oceans Canada and the Carrier-Sekani Tribal Council's Fisheries Program. The study was conducted under the overall supervision of Lanny Kalnin and Garry Zwack, with the field crews directly supervised by Ian Barnes, Rob Bemister, Dennis Classen, Colin Nettles, and Greg Schuler. Tracy Cone supervised the computer entry and analysis of the study data.

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Table 1. Estimated arrival and spawning timing, escapement by sex, and spawning success of the Early Run Stuart River system sockeye on the 1941-1997 cycle.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1941	23-Jul	30-Jul to 09-Aug	6,505	71	2,956	3,478	81.2%	2,825
1945	22-Jul	04-Aug to 10-Aug	31,913	2	16,249	15,662	84.6%	13,246
1949	20-Jul	03-Aug to 09-Aug	582,228	0	306,091	276,137	61.0%	168,458
1953	16-Jul	31-Jul to 08-Aug	154,312	276	66,131	87,905	89.1%	78,336
1957	20-Jul	02-Aug to 18-Aug	235,033	183	114,245	120,605	98.9%	119,273
1961	19-Jul	31-Jul to 13-Aug	199,136	215	90,112	108,809	80.7%	87,182
1965	21-Jul	02-Aug to 12-Aug	23,045	0	9,075	13,970	80.5%	11,241
1969	19-Jul	28-Jul to 05-Aug	109,818	163	50,034	59,621	81.7%	48,688
1973	25-Jul	31-Jul to 09-Aug	300,653	761	143,948	155,944	98.7%	153,876
1977	21-Jul	01-Aug to 12-Aug	118,017	572	45,034	72,411	73.7%	53,380
1981	-	29-Jul to 10-Aug	129,498	41	54,192	75,265	89.3%	67,225
1985	-	30-Jul to 11-Aug	234,231	12	106,090	128,129	91.0%	116,616
1989	17-Jul	27-Jul to 05-Aug	384,819	20	162,699	222,100	95.0%	211,040
1993	22-Jul	01-Aug to 10-Aug	687,969	2	297,292	390,675	98.7%	385,440
1997	25-Jul	09-Aug to 16-Aug	265,703	6	175,741	89,956	81.2%	73,053

Table 2. Estimated arrival and spawning timing, escapement by sex, and spawning success of Driftwood River sockeye on the 1941-1997 cycle.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1941	01-Aug	-	25	0	12	13	81.3%	11
1945	-	-	0	0	0	0	-	0
1949	03-Aug	-	407	0	203	204	89.3%	182
1953	01-Aug	05-Aug to 14-Aug	8,656	0	3,635	5,021	90.5%	4,545
1957	01-Aug	10-Aug to 18-Aug	45,567	2	26,519	19,046	99.7%	18,993
1961	20-Jul	11-Aug to 13-Aug	79,087	87	35,795	43,205	92.2%	39,852
1965	01-Aug	08-Aug to 12-Aug	4,221	0	1,850	2,371	98.8%	2,343
1969	-	-	37,028	41	16,885	20,102	84.7%	17,022
1973	-	01-Aug to 04-Aug	131,172	301	62,962	67,909	99.6%	67,665
1977	-	03-Aug to 09-Aug	54,568	0	19,519	35,049	75.5%	26,451
1981	-	01-Aug to 10-Aug	47,298	0	20,337	26,961	88.3%	23,793
1985	-	09-Aug to 12-Aug	93,959	0	42,427	51,532	91.2%	46,987
1989	-	05-Aug to 10-Aug	234,135	8	97,163	136,964	93.6%	128,253
1993	-	01-Aug to 10-Aug	408,355	0	177,412	230,943	99.0%	228,518
1997	29-Jul	13-Aug to 20-Aug	19,934	0	12,961	6,973	66.7%	4,654

Table 3. Number of surveys, peak live counts, cumulative dead counts, expansion factors, spawning success, and escapement of sockeye adults (by sex) and jacks, by stock, for Early Stuart sockeye salmon, 1997.

Stock Group	Stock	Number of surveys	Peak live	Cumulative dead	Expansion factor[A]	Weighted percent spawning success	Source of sex ratio[B]	Escapement estimate: Male	Escapement estimate: Female	Escapement estimate: Jack
Driftwood River	Blackwater Creek	7	424	155	1.7	88.4%	-	599	385	0
	Driftwood River	12	8,074	3,652	1.7	66.7%	-[C]	12,961	6,973	0
	Kastberg Creek	2	146	7	1.7	90.6% [C]	-[C]	169	91	0
	Kotsine River	3	566	37	1.7	90.6%	-[C]	666	359	0
	Lion Creek	7	1,149	229	1.7	86.3%	-	1,389	954	0
	Porter Creek	8	1,645	1,351	1.7	93.6%	-	3,480	1,613	0
Takla Lake N.E. Arm	Ankwill Creek	10	1,399	232	1.7	90.9%	-	1,804	969	0
	Bates Creek	7	268	65	1.7	91.1%	-	386	180	0
	Blanchette Creek	9	138	4	1.7	64.3%	-[D]	159	82	0
	Five Mile Creek	9	1,526	1,001	1.7	78.2%	-	2,667	1,629	0
	Ten Mile Creek	7	38	8	1.7	75.0%	-	57	21	0
	Fifteen Mile Creek	9	404	39	1.7	100.0%	-	377	377	0
	Forsythe Creek	9	541	121	1.7	83.2%	-	814	311	0
	French Creek	8	350	174	1.7	92.1%	-	536	355	0
	Frypan Creek	10	1,275	422	1.7	83.3%	-	1,816	1,069	0
	Hudson's Bay Cr.	10	1,122	540	1.7	73.2%	-	2,051	774	0
	Shale Creek	10	583	65	1.7	90.7%	-	563	539	0
	Tliti Creek	1	2	2	1.7	80.1% [D]	-[D]	5	2	0
	Twenty-five Mile Cr.	10	900	193	1.7	82.8%	-	1,136	722	0
Takla Lake N.W. Arm	Crow Creek	9	1,468	1,130	1.7	92.7%	-	2,887	1,530	0
	Dust Creek	n/a	n/a	n/a	n/a	87.4%	-	50,133	24,114	0
	Hooker Creek	9	272	47	1.7	89.1%	-	330	212	0
	McDougall Creek	10	894	1,331	1.7	81.9%	-	2,716	1,067	0
	Point Creek	10	1,422	861	1.7	91.6%	-	1,430	862	0
	Sinta Creek	9	1,357	1,718	1.7	90.9%	-	3,743	1,485	0
Takla Lake Main Arm	Bivouac Creek	9	1,184	824	1.7	82.3%	-	2,146	1,268	0
	Gluskie Cr., above	8	3,793	3,305	1.6	76.7%	-	7,723	3,859	0
	Gluskie Cr., below	8	586	1,193	1.6	76.7%	-	1,689	1,157	0
	Leo Creek	9	502	98	1.7	68.6%	-	639	381	0
	Narrows Creek	10	4,183	3,303	1.7	76.7%	-	8,267	4,459	0
	Sakeniche River	7	979	806	1.7	80.9%	-	1,873	1,160	2
	Sandpoint Creek	7	1,874	1,880	1.7	85.9%	-	4,138	2,244	0
Middle River	Forfar Cr., above	8	3,581	1,749	1.9	74.2%	-	7,132	2,960	0
	Forfar Cr., below	8	593	1,367	1.9	73.8%	-	2,094	1,611	0
	Kazchek Creek	1	675	86	1.7	80.1% [D]	-[D]	853	441	0
	Kynoch Cr., above	9	7,036	2,473	1.7	76.9%	-	10,848	5,316	4
	Kynoch Cr., below	9	687	2,229	1.7	76.9%	-	2,698	2,283	0
	Middle River	4	550	0	1.7	76.7% [E]	-[E]	568	367	0
	Rossette Creek	9	3,164	4,405	1.7	76.7%	-	7,819	5,048	0
Trembleur Lake	Felix Creek	11	6,259	3,743	1.7	79.8%	-	12,223	4,780	0
	Fleming Creek	1	1,200	400	1.7	81.4% [F]	-[F]	1,826	894	0
	Paula Creek	11	3,382	4,118	1.7	81.4%	-	8,562	4,188	0
	Tildesley Creek	1	1,300	0	1.7	81.4% [F]	-[F]	1,769	866	0
Total (average)		(8)	-	-	-	(81.2%)	-	175,741	89,956	6

[A] Forfar and Gluskie expansions are stock-specific; all others are Forfar/Gluskie average.
[B] Noted only when insufficient data were available for that stock.
[C] Composite Driftwood data.
[D] Composite Takla Lake data.
[E] Rossette Creek data.
[F] Paula Creek data.

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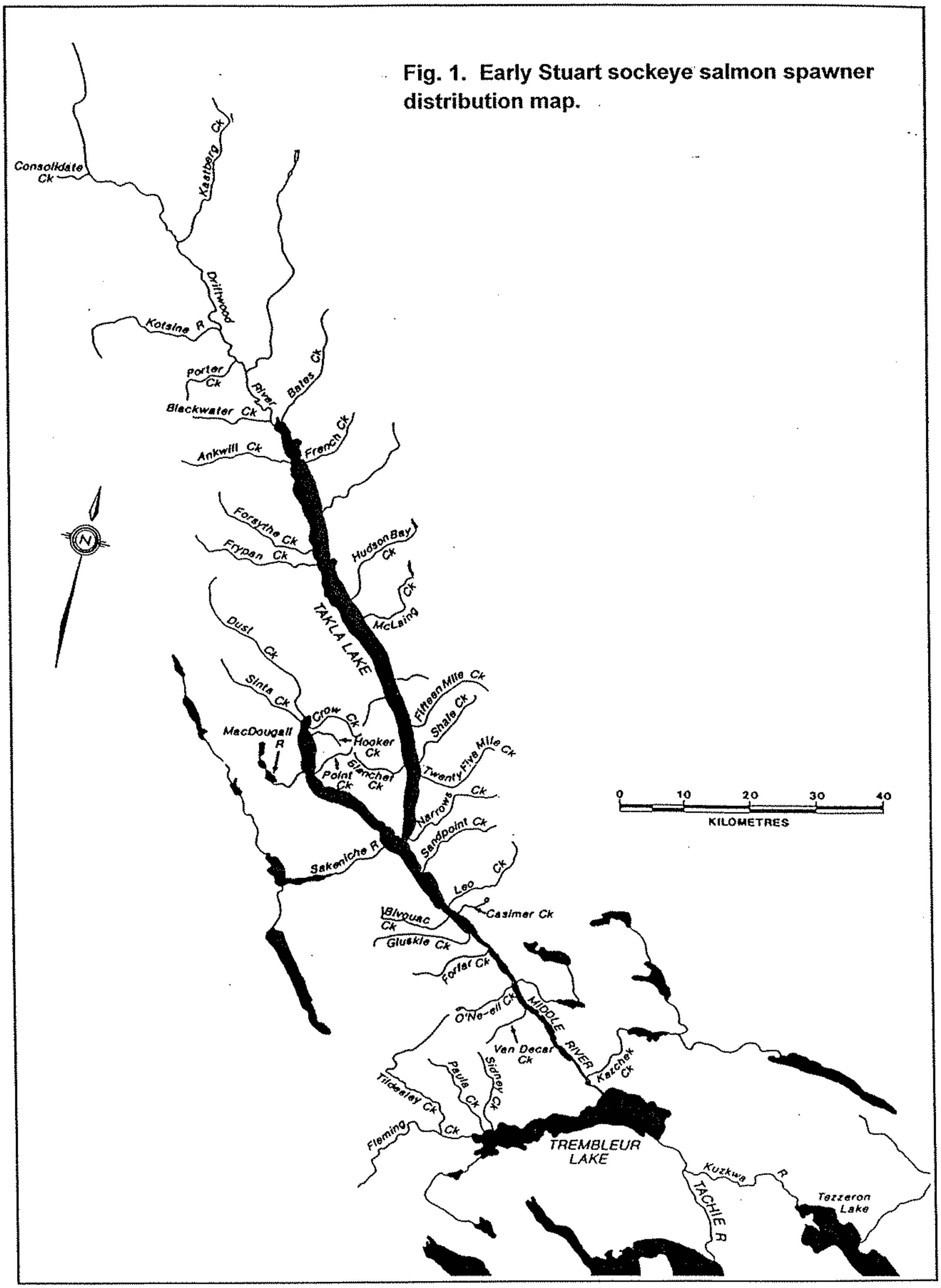

Fig. 1. Early Stuart sockeye salmon spawner distribution map.

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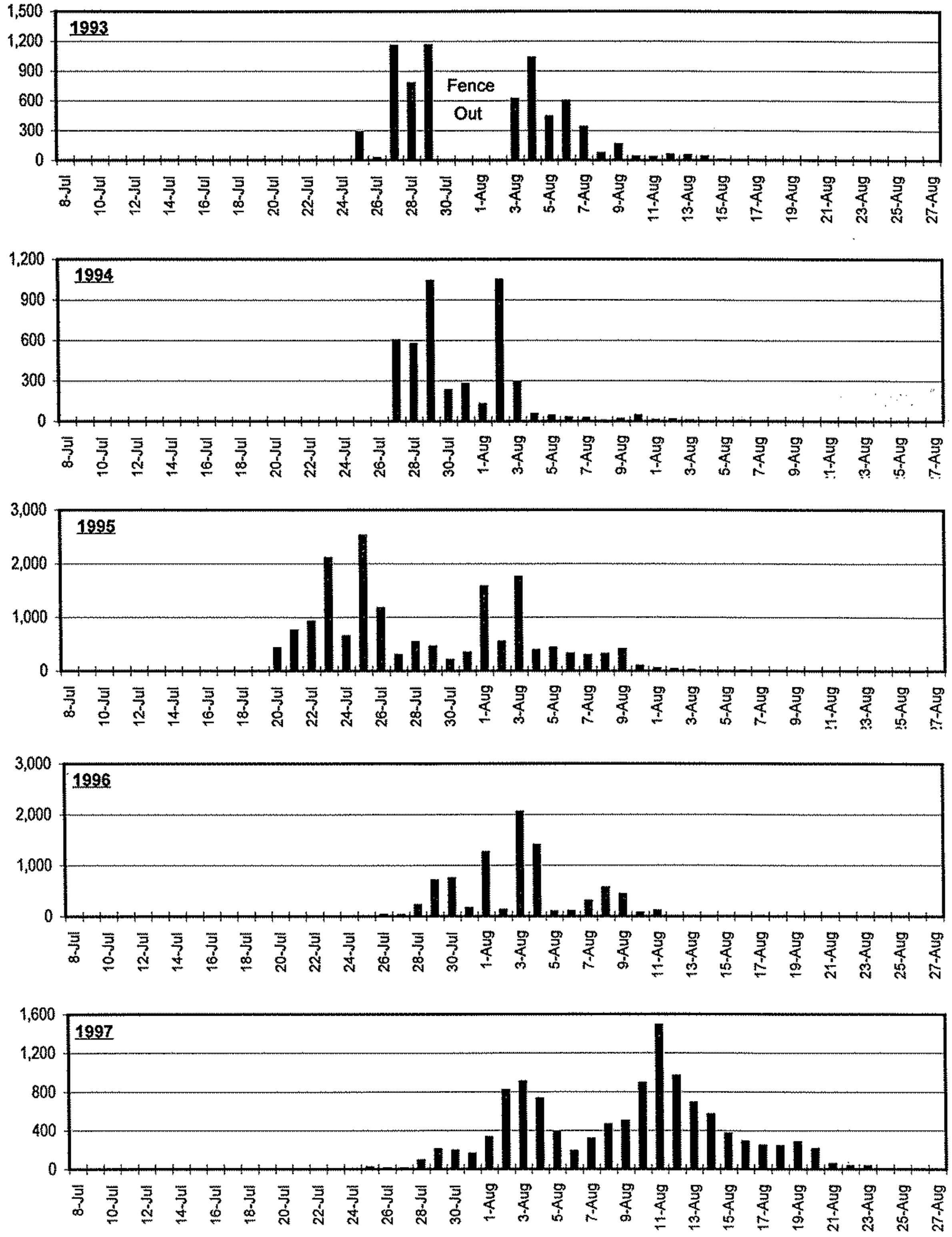

Fig. 2. Daily immigration of sockeye salmon past the Forfar Creek enumeration fence, 1993-1997.

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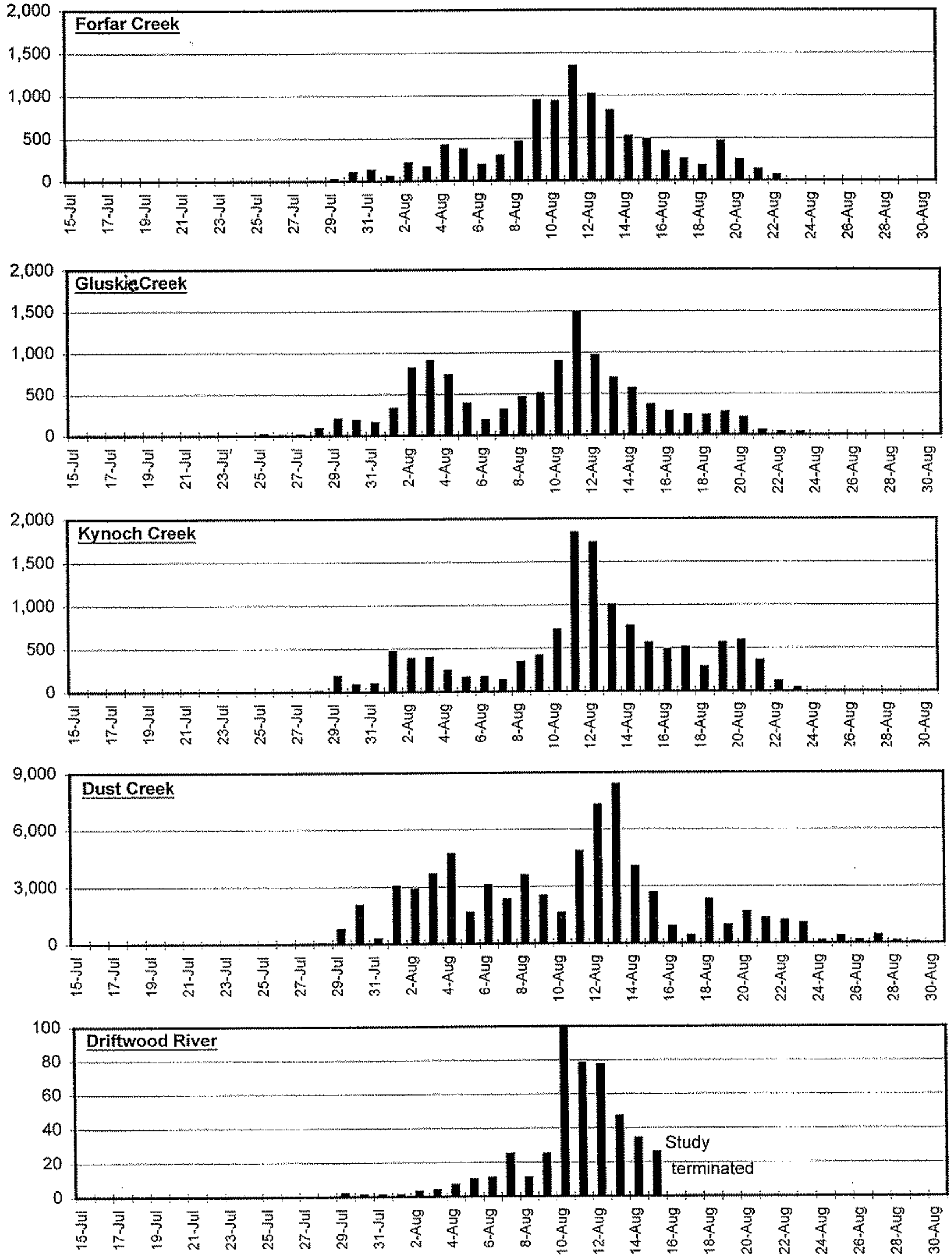

Fig. 3. Daily sockeye immigration at enumeration fences in Forfar, Gluskie, Kynoch, and Dust creeks, and daily beach seine catches of sockeye in the lower Driftwood River, 1997.

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THE EFFECTS OF IN-RIVER CONDITIONS ON MIGRATING SOCKEYE SALMON (*ONCORHYNCHUS NERKA*)

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INTRODUCTION

Spawning migration records of Early Stuart sockeye salmon (*Oncorhynchus nerka*) dating back to 1949 document a number of years during which in-river passage problems occurred. A desire to relate in-season run strength to physical and biological conditions in the river during the migration has led to the development of a variety of models and decision support systems (Foreman et al. 1997; Hinch and Rand 2000; Williams et al. 1996, Williams et al 1999). In 1997, a coincidence of higher than average water and temperature levels in the Fraser River, and large densities of fish, provided an opportunity to utilize these models and observe migration behaviour in the face of adverse conditions. This paper will document behavioural observations made during the Early Stuart sockeye salmon spawning migration in the Fraser River system and comment on the utility of the decision support system approach.

Historical accounts from the Hudson's Bay Company records indicate that Early Stuart sockeye salmon suffered run failures at Fort St. James in 1899 and 1900 (Cooper and Henry 1962). Reports of migratory losses for this stock in recent years have been correlated to high river discharge and/or water temperature. Passage problems have been associated with high water levels in the lower river (IPSFC Annual Reports 1955, 1960, 1964, 1982; Table 1), high water temperatures in the upper river (1992, 1994, 1998; Fraser River Sockeye Public Review Board (Canada) 1995; Macdonald et al. in press), and possibly years in which high fish density coincides with high water levels (Macdonald and Williams 1998). While other Fraser River sockeye salmon stocks may be negatively impacted by high discharges and/or temperatures, the Early Stuart run are the most vulnerable. Early Stuart sockeye are the first sockeye salmon to enter the Fraser River, their timing coinciding closely with the annual spring freshet which peaks in late May-early June and rising water temperatures.

Table 1. Population estimates of Early Stuart sockeye migrating past Mission and arriving at the spawning grounds during years of water velocity blockage (IPSFC Annual Reports). Maximum water velocities (cms) are at Hells Gate between July 10th and 25th (Environment Canada Database).

YEAR	MAX. WATER VELOCITIES	POPULATION at MISSION	ESCAPEMENT
1955	8920	30,000	2,200
1960	8160	30,000	14,600
1964	9340	32,000	2,400
1982	7780	90,000	4,600

METHODS

During July and August, 1997, the salmon migration in the Fraser River watershed was watched closely by staff of the Fisheries and Oceans Canada and the Pacific Salmon Commission (P.S.C.). Observations of fish behaviour and condition were reported by a number of people from locations at the mouth of the Fraser River to the Early Stuart sockeye salmon spawning grounds located at the northern extent of the Fraser River watershed (Fig. 1; see Introduction). Bioassay samples were taken from fish at some locations along the migration route, to estimate stress levels or reproductive condition. The results of these observations are summarized in this paper and bioassay results are presented in detail in other papers in these proceedings. Operators at adult enumeration fences on the mouths of three of the Early Stuart stock's natal tributaries provided spawning behaviour observations, as well as estimates of arrival timing and spawning stock strength (Schubert 2000, this report). Temperature and discharge records were collected from several locations in the river (Fig. 1; see Introduction; Foreman et al. 2000, this report), and water samples were collected from Qualark Creek on July 18th and 21st when river discharge was 8000-9000 cms, to measure suspended sediment loads (n=2 on each date).

RESULTS AND DISCUSSION

Observations of migrating salmon made by employees of the Department of Fisheries and Oceans (fisheries officers, habitat managers, and scientists) and the P.S.C., documented many unusual behavioural events at many locations along the migration route (Table 2). During a period of high water discharge in the lower river (July 17th-20th, > 8000 cms, Foreman and Quick, this report) as the majority of the Early Stuart sockeye salmon run was entering the Fraser River, migration passage problems were observed at Hells Gate and other locations where water velocity was high (Fig. 1). Whether their migration was completely blocked, or simply impeded is uncertain. However, the discharge levels caused large shoals of fish to accumulate in back-eddies and along the river margins. According to information collected from salmon enumeration activities at Qualark Creek (H. Enzenhofer, personal communication), at least 100,000 fish/day were entering the lower river from the Strait of Georgia between July 19th and 24th, adding further to existing concentrations of fish. Migration corridors on the margins of the river, particularly in constricted locations, have fish passage capacity limitations that vary with water level and streambank topography. Fish were restricted to an area <2 m in width at Hells Gate on August 1st after the flow had declined considerably (Table 2). While little is known about the effects of fish density on their migration rate, it seems probable that the combination of high fish density and migration impediments associated with high river flow rates created a further delay to the migration and additional stress (Macdonald and Williams 1998).

Initially, fish remained along the margins of the Fraser River but as migration delays continued, stress levels rose and energy reserves declined (see Donaldson et al. 2000; Higgs et al. 2000; Hinch and Rand 2000; this report). Many fish entered non-natal Fraser River tributaries; initially, in the lower river (first report July 17th as flow exceeded 8000 cms) but during the first week of August, reports were also received of fish in tributaries in the Prince George and Fort St. James area (Table 2). Most of these fish were Early Stuart sockeye as determined from scale analysis (Pacific Salmon Commission data). Some fish attempted to spawn in these non-natal systems (e.g. Ford Creek); others may have delayed their migration to seek temporary refuge from the currents and/or turbidity in the mainstem of the Fraser River. For instance, many of the Stuart sockeye observed in the Bridge River on August 6th were gone a week later. The number of these fish that continued with their upstream migration is not known.

Suspended sediment concentrations in the lower river were approximately 200 mg/l on July 18th and 125 mg/l on July 21st. These levels are comparable to observations made during spring freshet on previous years at Hells Gate, and while not considered to be stressful or lethal to migrating salmonids, they may cause greater susceptibility to in-river gillnet fisheries (Servizi and Gordon 1989). Sediment loads above 800 mg/l may be lethal, particularly during extended duration (Newcombe and MacDonald 1991). Levels of 1000 mg/l in the Chilcotin River in 1964 delayed salmon spawning migration for 6 days and caused injuries to the nose and head regions (IPSFC 1965). Many Early Stuart sockeye that had strayed into non-natal tributaries in 1997 had experienced mechanical erosion to the skin on their heads (Table 2). This damage may have been associated with high turbidity and, while not lethal, could possibly have led to disorientation during the migration.

The milling activity in the Fraser River and its tributaries was gradually replaced by reports of lethargic fish moving downstream, swimming actively, or being swept passively (first reported on July 24th, Table 2). Many of these fish were in a moribund state and clearly visible on the surface despite extremely turbid water. Migration losses in 1992 and 1994 when stress associated with high water temperature was cited as the cause, were not accompanied with observations of dead or dying fish. Fish were simply reported as "missing" and believed to have sunk after death or sought deeper water as a response to the stress associated with high temperature (Clarke et al. 1994). In-river migration losses in 1992 and 1994 were less than losses in 1997, and migration problems in the lower river in 1997 were related to high water levels and not to temperature.

Water temperatures may have reached levels sufficient to cause stress in the upper portions of the Fraser watershed in 1997. Daily mean temperatures exceeding 18°C were recorded at upper Fraser River locations and in the Nechako River in early August (Fig. 1; see Introduction, and Fig. 2). River temperatures increased during late July and early August to levels that were above average, which created additional stress on the fish that had already endured extreme ocean temperatures and river flow. Studies from 1969 to the mid-1980's record pre-spawning mortalities of sockeye in the Fraser system associated with pathogenic bacteria and parasites that flourish in elevated water temperatures (Williams 1973, 1977; Williams et al. 1977; Wood 1965).

Reports of downstream displacement continued through August, with peak displacement occurring in the second week as evidenced by large counts at the Mission hydroacoustic facility (Fig. 1, see Introduction; Table 2). These were fish that likely entered the river in mid-July and were impeded by flows in the lower river between July 17th and 20th. Their die-off coincided with the time that they would normally have exhausted their energy reserves upon completion of spawning in their natal creeks north of Fort St. James (peak spawning August 5th, 1949-1987; Gilhousen 1990). The success of the Early Stuart sockeye run is thought to be limited by available energy reserves (Hinch and Rand 1998), and has been modelled accordingly (see Hinch and Rand 2000, this report). In-river migration losses have been recorded during years in which migration duration was prolonged due to high water levels (Table 1; Gilhousen 1990). A delay of 4 to 7 days can lead to high en route mortality (Cooper and Henry 1962). In 1997, migration problems were compounded by the smaller and poorer condition of the Early Stuart fish that arrived at the mouth of the Fraser River (see McKinnell 2000, this report). Larger fish can achieve higher swimming velocities and are less likely to succumb to pre-spawning mortality than smaller fish in years when water levels are high. In 1997, the successful spawners were several centimetres larger than fish that were not successful (Fig. 3a and b).

The Integrated Fraser Salmon Model was used in 1997 to estimate the potential impact of discharge and temperature on Early Stuart sockeye (Williams et al. 1999). The model is based on a spatially explicit, seamless migration path built from 1:20,000 Terrain Resource Information Management (TRIM) maps. The model imports the daily water levels and temperature from the Qualark real-time data logger. Water levels are converted to discharge and these daily values are used to modify the impedance of the migration path from Hope BC, to the spawning grounds. Key sites such as Hells Gate are treated separately and are an additive factor to impedance. The migration path in the mainstem Fraser River is divided into sixty-seven 10-km segments from Hope to Shelley to conform to the Foreman temperature prediction model. A 10-day water temperature predicted from predicted environmental conditions plus estimated temperatures from the previous 5 days based on actual temperatures were received from I.O.S. as a grid where the y axis = 67 (distance), x axis = 15 (days), and each cell of the grid contained the predicted water temperature. A data set was received twice weekly and imported into the model database. Temperatures from the previous estimates based on actual temperatures were retained and the new 10-day prediction was added, so that the database grew as the season progressed. This grid is attached to the migration path. The model records the temperatures the fish are exposed to as they swim up the migration path. Daily estimates of early Stuart passage at Mission were received from the Pacific Salmon Commission's hydroacoustic data at Mission. These data were converted to percentages and these were used to estimate temperature and discharge effects. Forfar Creek, a tributary to Middle River, was used as a surrogate for the total early Stuart run as the migration network was still under construction at this time.

This model predicted the impact of environmental conditions for the Middle River stock group with good results. The timing of arrival at the spawning grounds was predicted with reasonable accuracy (Fig. 4). The model predicted that over 50 % of this group would not arrive at the spawning grounds, based on the Middle River stock group as a surrogate for the total run (Fig. 5a). No attempt was made during the season to break out the Driftwood stock group from the Early Stuart in using this model, as the network did not extend to this area at the time. However, in retrospect, if we add 2 days' migration, the model estimates that virtually all fish in this group were at serious risk (Fig 5b). The model network for the early Stuart was completed in 1998.

During their spawning migration of 1997, the Early Stuart sockeye salmon run was met with four extreme but natural environmental events along the migration corridor. Fish in the northeastern Pacific Ocean were forced further north than in previous years due to warm sea surface temperatures. Having further to return to the mouth of the Fraser River, they arrived several days late where they were faced with above average water discharges. A large run size in 1997 resulted in there being high fish densities in the lower portion of the Fraser River, which in coincidence with the high water velocities, led to migration impediments and blockages. As water levels receded, water temperature rose to stressful levels resulting in epizootic outbreaks and additional stress. Nearly half of the fish that were expected to return failed to make it to the spawning grounds; many diverted to non-natal Fraser River tributaries or languished and died in the margins of the mainstem. Despite this ominous message, the 1997 Early Stuart sockeye salmon run was the fifth largest on record.

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Table 2. A collation of observations of sockeye salmon migration behaviour in the Fraser River watershed during the summer of 1997. Date, location, and source of observations are also presented.

DATE	OBSERVER	LOCATION	OBSERVATIONS
July 17/97	D. Pretula (PSC staff)	Hells Gate	Cessation of migration, milling behaviour along stream margins, high discharge and turbidity.
July 17/97	H. Enzenhofer (DFO)	Emory Creek	Many sockeye holding in Emory Creek.
July 18/97	A. Lill (DFO)	Hope to Hells Gate	Helicopter over-flight - milling and unusual behaviour by sockeye in the lower river.
July 18/97	D. Barnes, D. Martens, B. Gordon (DFO)	Qualark Creek	Sockeye in mainstem deeply coloured, lethargic and appear to be in poor condition and stressed.
July 19/97	D. Pretrula, D. Barnes	Hells Gate	Migration resumed in small numbers.
July 19/97	D. Barnes	Emory Creek	Approx. 500 sockeye in Emory Creek.
July 21/97	D. Pretula	Hells Gate	Strong migration behaviour observed.
July 21/97	D. Barnes	Qualark Creek	Many sockeye seen milling in mainstem.
July 22/97	G. Kostiuk (DFO)	Hope to 2 miles above Hells G.	Helicopter over-flight - sockeye impeded, vulnerable to poaching activity
July 24/97	S. Hinch (UBC)	Yale Gravel Bar	Shoals of darkly coloured sockeye milling and drifting downstream.
July 25/97	J. Davis (DFO)	Qualark Creek	Small numbers of sockeye are migrating along margins of mainstem, coloured, in poor shape.

Table 2 (continued).

July 25/97	J. Davis	Hells Gate	Dark coloured fish migrating through fish-way, larger fish appear to be more successful. Approx. 1000 fish at lower mouth of fish-way.
July 26/97	G. Kostiuk	Hope to Hells Gate	Vessel patrol - fish dark, lethargic, passage problems, many in creek mouths and off-channel.
July 28/97	N. Schubert (DFO)	Forfar Creek	First report of sockeye at spawning ground fences. Fish are in good shape.
July 29/97	L. Boursema (DFO)	Hope to Hells Gate	Vessel patrol - many black, lethargic fish on surface susceptible to damage by prop and river upwelling.
Aug. 1/97	S. Macdonald (DFO)	Hells Gate	Water down. 40' from peak, fish coloured, migrating through ladder, remaining <2 m from shore in a dense pack.
Aug. 1/97	H. Enzenhofer, D. Barnes	Qualark Creek.	Sockeye drifting downstream along margins and thalweg of mainstem. Fish marked, damaged.
Aug. 1/97	H. Enzenhofer	Qualark Creek.	Sockeye spawning in lower mainstem tributaries
Aug. 4/97	S. Roxburgh (DFO)	China Bar to Alexandra Bridge	Coloured sockeye milling in back eddies frequently washed downstream by current. Flesh samples soft.
Aug. 4/97	S. Roxburgh	Unnamed Crk. in lower river	70 sockeye migrating up a creek too shallow to immerse them. Eggs loose and fungal growth on fish.
Aug. 4/97	N. Schubert	Forfar Creek	Date of past years peak spawning but few fish have arrived. Fish in poor shape. They spawn immediately on arrival.

Table 2 (continued).

Aug. 5/97	L. Boresma	Ford and Annis Creek	Sockeye paired to spawn but sampled fish not ripe. Some mortalities.
Aug. 5/97	D. Aurel (DFO)	Lower river	Many fish dead and dying , floating downstream.
Aug. 6/97	PSC staff	Coquihalla River, Emory Creek	Many sockeye observed, 97% were early Stuart stock. Most immature and fit except for erosion to skin on head.
Aug. 6-10/97	T. Mulligan (DFO)	Mission	Recordings from a split-beam sounder indicate large numbers of targets moving downstream in the Fraser water column. Commercial gillnets at this time and approx. location, capture up to 100 moribund sockeye/set on the upstream side of the nets.
Aug. 7/97	H. Stalberg (DFO)	Seton River and Cayoose Creek	11,000 sockeye counted in Seton, 5600 in Cayoose systems - far more than normal. Fish lethargic, dark, 1000 mortalities. Approx. 25% with fungus. Scale analysis indicates them to be Stuart stock.
Aug. 7/97	H. Stalberg	Bridge River	10,000 sockeye counted - far more than normal. 1000 dead sockeye counted.
Aug. 1-8/97	D. Girodat, G. Lario (DFO)	Chilcotin to Nechako	Fish seen in Stone, San Jose, Williams Lake, Hawks, Mackin, Churn systems. No sign of mortality in the tributaries or on margins of Fraser mainstem.
Aug. 8/97	B. Rosenberger (DFO)	Lower tribs.	Sockeye reported in Kwoiek, Stein, Texas, Spuzzum systems as well as in the mainstem.
Aug. 8/97	R. Elson, R. Argue (DFO)	Nechako River	Sockeye reported in Bednesti, Nancut, Nahounlie systems, in poor condition, extensive fungal growth.

Table 2 (continued).

Aug. 9/97	D. Barnes	Stuart Lake	Sockeye in poor condition, more males than females
Aug. 11-12/97	N. Schubert	Forfar Creek	Peak spawning, approx. 1000/D arriving at Forfar and Gluskie creeks.
Aug 12/97	D. Barnes	Nechako River	Many lethargic fish in poor condition. 4:1 M/F sex ratio.
Aug. 13/97	H. Stalberg	Seton River and Cayoose Creek	Decline in sockeye numbers (< 5000) in the systems, few dead fish seen. Gates Creek run has arrived on spawning grounds.
Aug. 13/97	N. Schubert	Stuart River	Large numbers counted at Ft. St. James, good condition.
Aug. 14/97	N. Schubert	Stuart tributaries	Driftwood return very poor, 1000/D at Forfar and Gluskie creeks.
Aug. 25/97	B. Andersen (DFO)	Gluskie Creek	Sockeye continue to arrive at spawning grounds. Fish in good shape but lethargic. Little spawning activity (e.g. digging, pairing), egg viability questions. More males than females.
Aug. 29/97	B. Andersen	Gluskie and Forfar	'as above'

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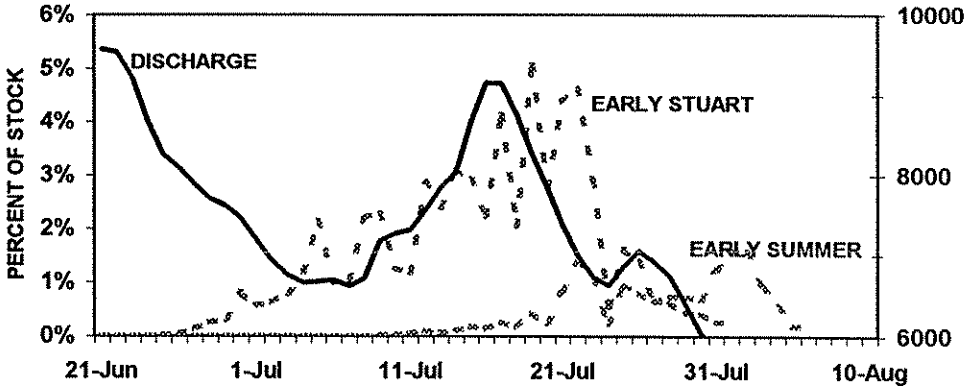

Fig. 1. During 1997 the Early Stuart sockeye salmon migration coincided with a high discharge event in the lower Fraser River. Water levels exceeded 8000 cms for nearly a week as 100,000 to 200,000 fish a day entered the Fraser River.

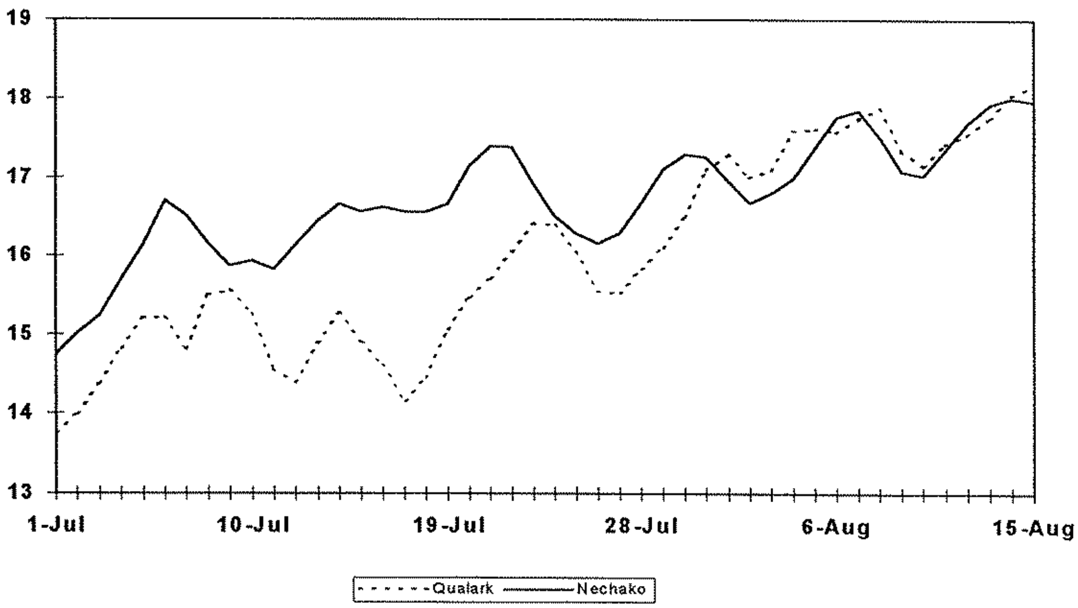

Fig. 2. Water temperatures during the summer of 1997 in the Fraser River watershed. Temperatures in the Fraser River canyon were collected from Qualark Creek, downstream of Hells Gate. Nechako River temperatures were collected near Prince George, upstream of the confluence with the Fraser River.

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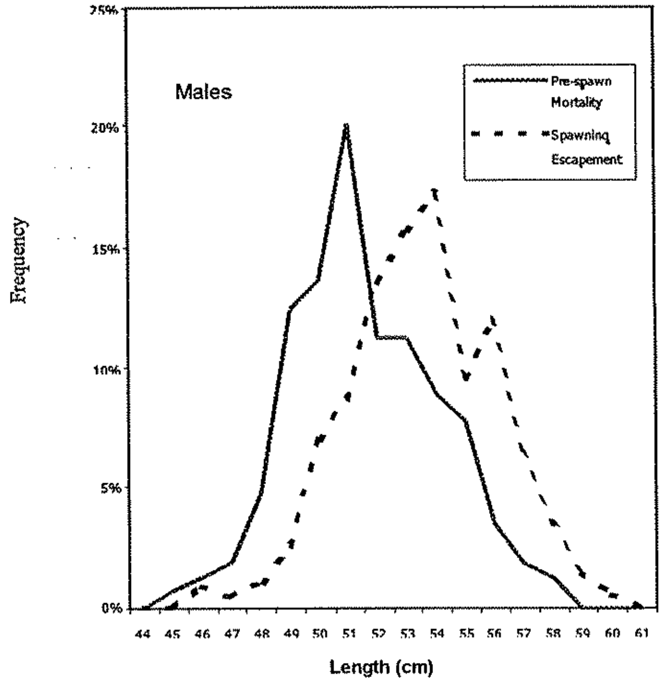
(a)



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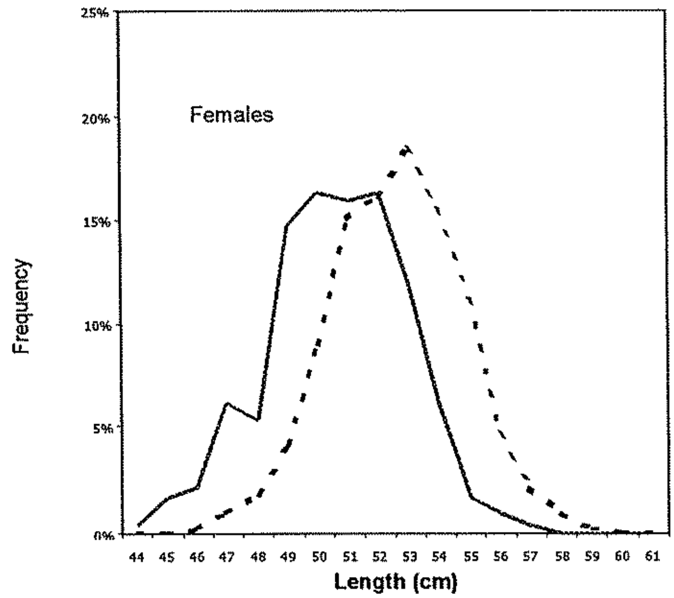

Fig. 3. Lengths of Early Stuart sockeye that spawned successfully compared with sockeye that arrived at the spawning grounds but died before spawning in 1997. Males (a) and females (b) are plotted separately.

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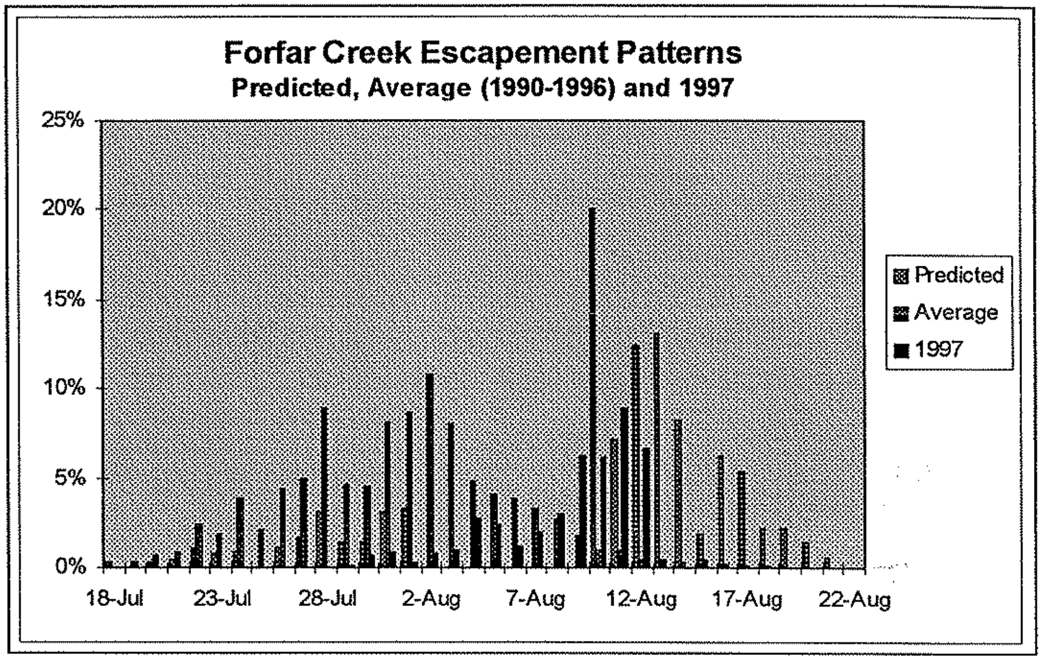

Fig. 4. Comparisons of actual arrival timing with timing predicted by the integrated Fraser salmon model. Average arrival timing during the last 7 years is also presented to demonstrate the 1997 delay in arrival.

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(a)

(b)

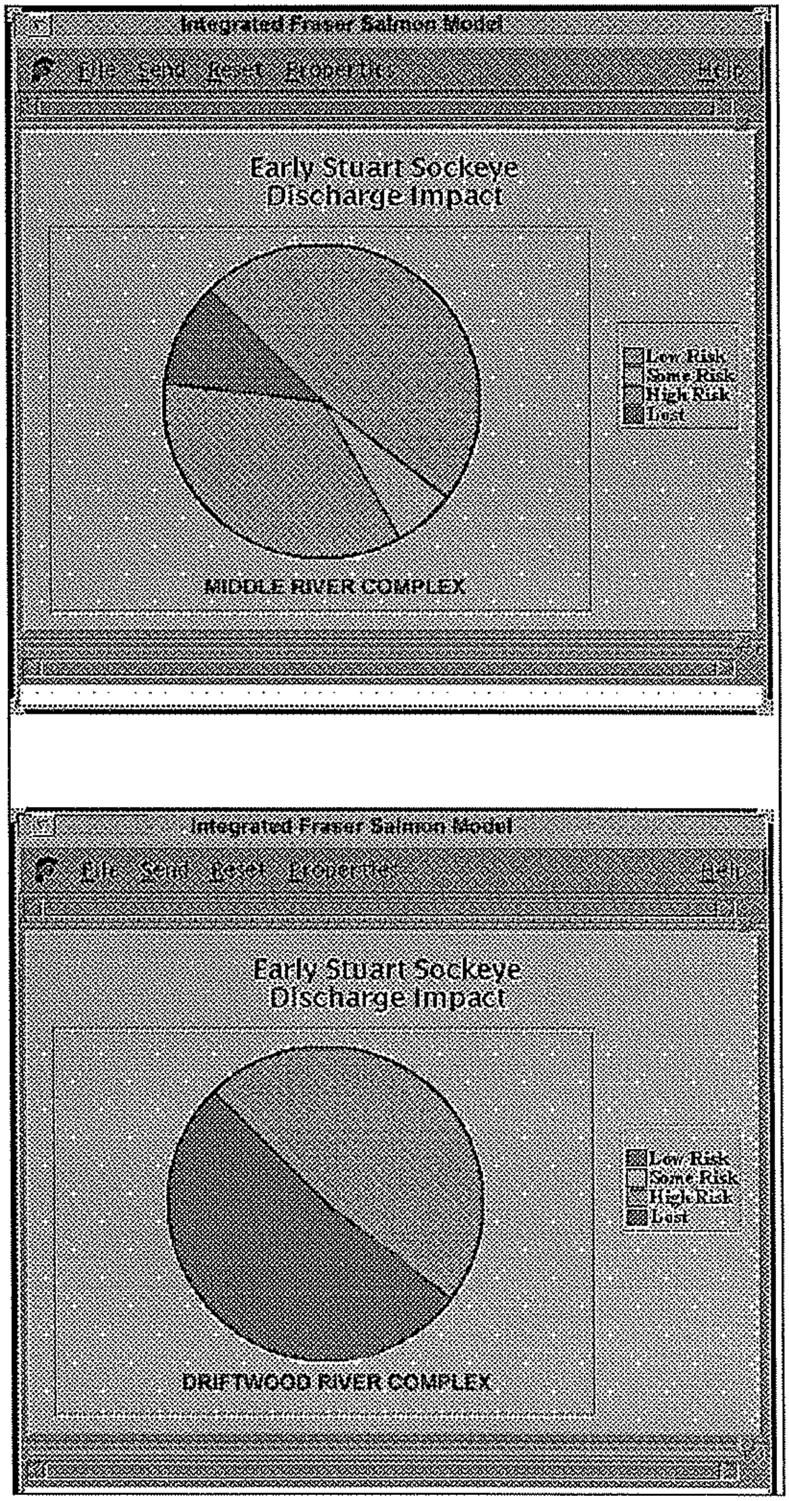

Fig. 5. Results of the integrated Fraser salmon model based on conditions faced by (a) the Middle River stock group, and (b) the Driftwood River stock group which assumes an additional 2 days' swimming time. Risk of loss is presented in four categories.

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ENERGY USE AND RISK OF EN ROUTE ENERGY EXHAUSTION IN ADULT EARLY STUART SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) DURING 1997

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INTRODUCTION

The up-river spawning migration of adult Pacific salmon can be energetically expensive. Many stocks travel extremely long distances (i.e. over 1000 km) and, because feeding stops prior to migration, all must rely on stored energy. Based on analyses of body composition before and after spawning migrations, swimming activity by long distance migrants usually depletes 75 to 95% of body fat (reviewed in Brett 1995). Despite a fairly good understanding of the total energetic costs of spawning migration for several stocks of Pacific salmon, we know relatively little about how specific environmental features are responsible for the depletion of body energy associated with migration. High levels of discharge and/or temperature can cause migrational delays and high-energy use (Hinch et al. 1996; Hinch and Rand 1998, and references within), but at what levels and combinations do these impose risk of en route mortality? If particular levels of environmental features predispose migrating salmon to risk of en route mortality, fisheries managers would benefit from predictive, mechanistic models that could warn them, either before or during the migration, of the likelihood of this risk. In this note, we provide a brief overview of a bioenergetics model that predicts energy use for up-river migrating Early Stuart sockeye salmon (*Oncorhynchus nerka*), and demonstrate how it can be used, after the fact, to "hindcast" energy use and risk of energy exhaustion for the 1997 migration. Our future goal is to make this approach truly predictive such that risk could be assessed prior to or during the migration.

APPROACH

The following is a summary of the components and validation of the bioenergetics model; details are provided in Rand and Hinch (1998). We partitioned the 1200-km river migration route into five contiguous segments, each characterized by differences in flow and temperature conditions (Fig. 1). The model tracks energy use through all five river segments for the average individual in the population. Energy use was a function of body size, swim speeds, water temperature, and travel time. Swim speed estimates derive from fish that were tracked using electromyogram (EMG) telemetry through sites that were representative of the specific flow conditions of each segment along the migration route of Early Stuart sockeye, including the lower Fraser River, Fraser Canyon, Hell's Gate, and Nechako River, from 1993 to 1995. The procedures for implanting EMG transmitters and estimating swim speeds from EMG data are given in Hinch et al. (1996) and Hinch and Rand (1998). Swim speeds were sampled by the model at each time step from a log-normal distribution based on all recorded swim speeds that were appropriate for that segment. Both aerobic and anaerobic metabolism was taken into consideration in the model. We assumed that anaerobiosis was invoked when swim speeds met or exceeded 80% of critical swim speed (Webb 1971), and then imposed a 15% anaerobic "tax" on metabolism during these periods. The time step for the model was set at 5 seconds, which approximates the time scale at which the EMG data were recorded. We made simple assumptions about the amount of energy that was diverted into gonad production (Rand and Hinch 1998).

To test the validity of the model, we input temperature, body size, and travel time information that applied to Early Stuart sockeye in 1956 (Gilhousen 1990), along with our recent estimates of swimming speeds (Hinch and Rand 1998), and compared model predictions to actual measures of body energy content reported in Idler and Clemens (1959) at sequential locations along the migration. The year 1956 was one of the few in which total body energy was measured at locations along the migration. We simulated 1997 energetics by inputting the same types of environmental and fish data appropriate for Early Stuart sockeye migration in that year.

RESULTS AND DISCUSSION

The river migration bioenergetics model predicted energy use for Early Stuart sockeye in 1956, a year of typical river migration conditions, that closely matched measures of body energy depletion in that same year at sequential migration locations (Fig. 2). There was a general linear decline in body energy, with the exception of energy use during the end of the first week of migration in which a sharp decline was apparent in our model predictions and empirically by Idler and Clemens (1959). This time period corresponded to passage through the lower Fraser River Canyon (e.g. model segment-2; Fig. 1). The reasonably good similarity between predicted and observed energy use in 1956, especially at the end of the migration, suggests that the energetics model may be appropriate for predicting total energy use in other years.

Predicted energy expenditure in 1997 showed a sharp decline at the start of the second week (Fig. 2) corresponding to passage through the lower Fraser Canyon (e.g. model segment-2; Fig. 1). This happened several days later in 1997, relative to 1956, due to higher discharge in 1997 slowing forward progress. This was followed by five days of less energetically expensive migration (Fig. 2) through the middle portions of the Fraser Canyon (e.g. model segment-2; Fig. 1), and a one-to-two-day passage through the Hell's Gate Fishway area (e.g. model segment-3; Fig.1) which was moderately energetically expensive. The bioenergetics model does not currently deal with the issue of "blockage" whereby migrants may be totally stopped for several days at one location, as was observed for a few days in July, 1997, at Hell's Gate. Instead, it assumes migrants continue to make forward progress but with very low travel rates. Energy use for the remainder of the Fraser River route (e.g. model segment-4; Fig. 1) was at a lower rate, relative to 1956 values, because modelled swim speeds tended to slow during periods of higher discharge. This swim speed-discharge compensation relationship, which was used in the energetics model, was empirically determined (Rand and Hinch 1998). This phenomenon may occur as a behavioural means for migrants to conserve energy. By day 30 (Fig. 2), energy use became elevated due to the relatively warmer water experienced in the Nechako and Stuart river systems (e.g. model segment-5; Fig. 1). However, energy use was again lowered by day 35-36 (Fig. 2) owing to the cooler waters experienced by migrating through Stuart Lake, Tachie River, Trembleur Lake, and Middle River systems (e.g. model segment-6; Fig. 1). Predictions of total migration energy use were much higher in 1997 compared to 1956 because of the relatively high discharge in the Fraser River in 1997 (Fig. 2). Discharge is positively correlated with travel time in the model, an empirical relationship that is reported in Rand and Hinch (1998).

The migration energetics model predicted that an average individual fish reached the spawning ground after 22 days of river migration in 1956, and after 37 days in 1997 (Fig. 2). Rand and Hinch (1998) suggest that an energy exhaustion "risk threshold," for an average migrant, may exist at a state of 80% depletion of the initial energy reserve prior to river entry. This threshold was selected because this is the maximum level of energy depletion that has been measured for Early Stuart sockeye that have reached spawning grounds (Idler and Clemens 1959). This value was derived from years when passage conditions were "average." Thus, this is probably an overly conservative threshold, and does not consider that energy-exhaustion-related mortality probably occurs at lower levels of energy depletion in years of particularly high discharge and/or temperature because of additional stresses (e.g. disease). Nonetheless, our risk threshold was reached in 1997 by day 35, which is equivalent to passage out of the Stuart River and into Stuart Lake (Fig. 1). Interestingly, interrenal nuclear diameter analyses on Early Stuart sockeye salmon collected in 1997 along their migration route revealed that this particular location was the first where migrants displayed significant amounts of stress (see Donaldson et al. 2000, this report). Our risk threshold does not consider how extremely low energy states, as would have been experienced by migrants that survived to reach spawning grounds, could lead to reduced reproductive success by impairing reproductive behaviours or by reducing the viability of gametes.

FUTURE MODEL DEVELOPMENT AND MANAGEMENT IMPLICATIONS

By integrating the migration bioenergetics model with current Fraser River flow and temperature models (Foreman et al. 1997), and future Fraser watershed flow and temperature models, it should be possible to predict, days and potentially weeks in advance, the risk to an average Early Stuart sockeye of reaching critically low energy states. Managers could use these types of model predictions to help them meet spawning ground escapement goals by adjusting fishing mortality to compensate for potential natural en route mortality that could occur when risk of energy exhaustion is high.

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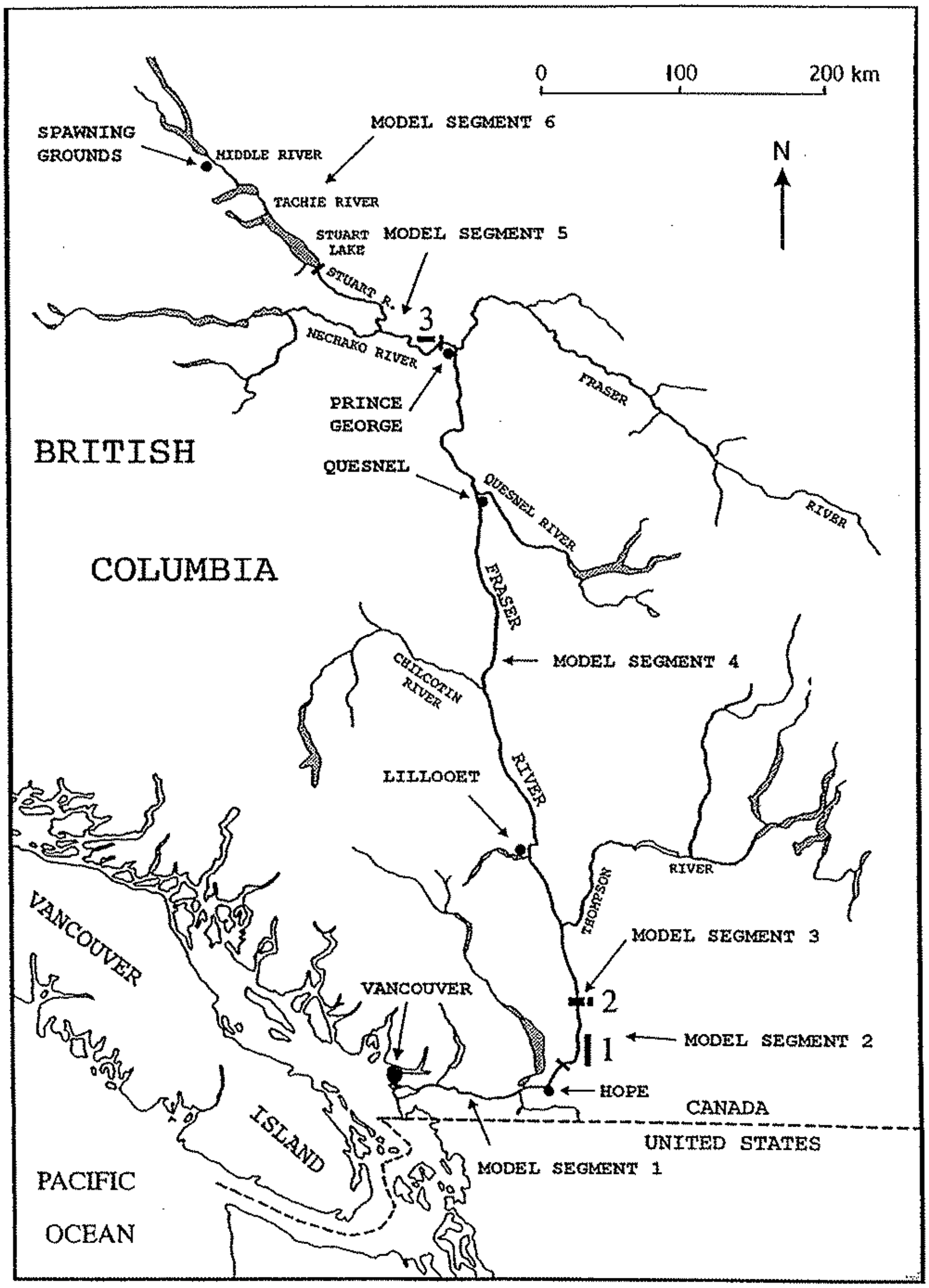

Fig. 1. Map of the Fraser River, its main tributaries, and the main juvenile sockeye salmon rearing lakes in the Fraser watershed. Our study population migrates north in the Fraser River, then west in the Nechako and Stuart rivers. They spawn throughout the region north of Stuart Lake, but primarily in tributaries of the Middle River. The three river sections through which fish were radio-tracked with EMG telemetry are indicated with numbers and solid bars next to the rivers. Bioenergetic model segments are delineated by bars that bisect the migration route.

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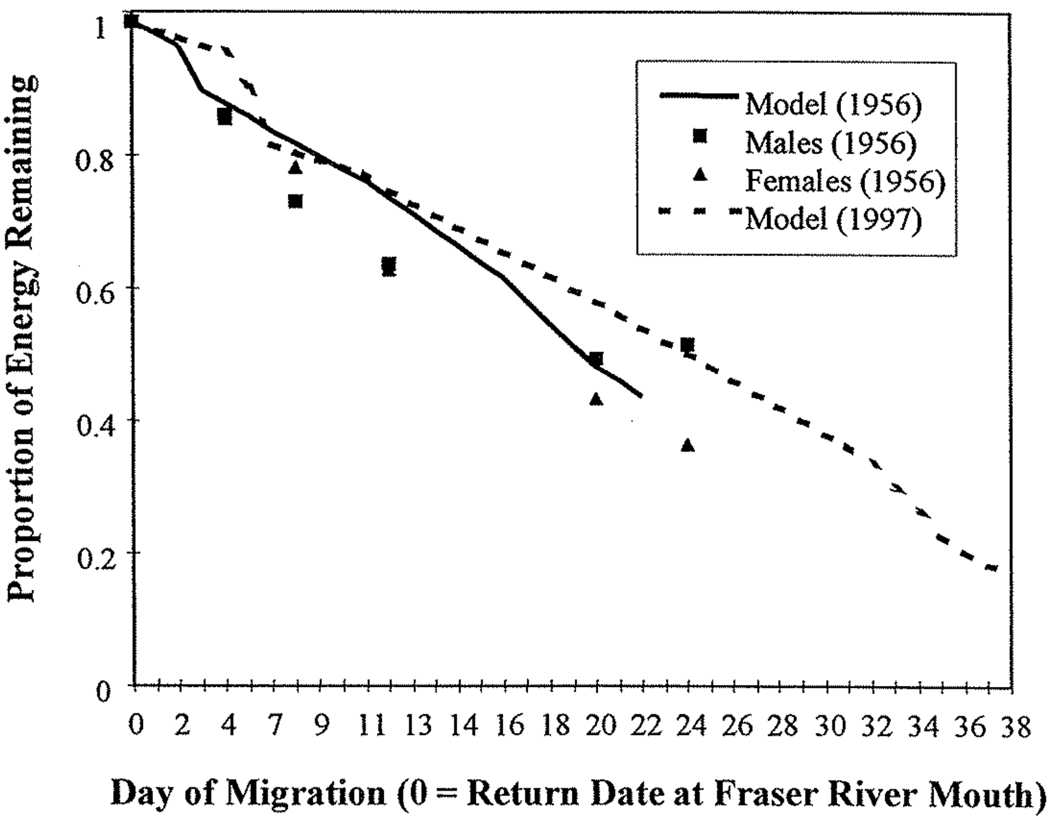

Fig. 2. Proportion of energy remaining, relative to that at the start of migration, for an average Early Stuart sockeye salmon at sequential sites along their upriver migration route. Day zero is the start of the migration at the Fraser River mouth. The lines represent predictions from the bioenergetics model of energy remaining in 1956 (thin line) and 1997 (thick line) Early Stuart migrants. The symbols represent empirical measures, acquired along the migration route, of energy remaining for male (squares) and female (triangles) Early Stuart sockeye salmon in 1956.

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PHYSIOLOGICAL AND ENDOCRINE CHANGES DURING THE ANADROMOUS MIGRATION OF EARLY STUART SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) IN 1997

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INTRODUCTION

The purpose of this study was to investigate stress and reproductive parameters in early Stuart sockeye salmon, which were subject to unusually high flow rates (up to 9000 cubic m/sec) in the region of Hells Gate in July, 1997. Causative factors that contributed to the high flow rate in 1997 included heavy snow pack, high lake water levels, and the cool wet spring (see Macdonald et al. 2000; Foreman et al. 2000, this report). In 1993 and 1995 several stress and reproductive parameters had been quantified during the anadromous migration in order to determine the effects of gillnet injury on migrating salmon and to obtain baseline data for evaluation of the effects of high water temperature in the migrating salmon (Donaldson et al.1997). In the present study, the focus was on the stress response to high water flow in the lower portions of the river. Therefore, samples were analyzed from Hells Gate, from Qualark, a site downstream from Hells Gate, from the Stuart River at Fort St. James as they approached the spawning grounds, and from Gluskie Creek; one of approximately 40 spawning streams (Fig. 1). The following parameters were quantified to estimate stress: plasma glucose, cortisol, and lactate and interrenal nuclear diameter; and for reproduction: gonadosomatic index (GSI), estradiol 17β (estradiol), and 17α, 20β-dihydroxy-4-pregnen-3-one (17,20P).

MATERIALS AND METHODS

FISH SAMPLING SITES

Sockeye salmon (*Oncorhynchus nerka*) of the Early Stuart stock were captured by dipnet during high water conditions at Qualark on July 18th and July 21st, at Hells Gate on July 19th and 20th, by gillnet and dipnet from the Stuart River at Fort St. James on August 9th, and by dipnet at Gluskie Creek on August 10th (Fig. 1).

ASSAYS

Hematocrit: Hematocrit was measured at the collection sites using micro hematocrit tubes and a hematocrit centrifuge.

Glucose: Glucose was assayed using the enzymatic (Trinder), colorimetric method (Sigma Chemical Co.) utilizing 5 μL plasma samples and Sigma glucose standards.

Interrenal nuclear diameters (IND): IND's were determined by processing fixed samples of head kidney for light microscopy. Regions of the head kidney sections containing interrenal cells were identified and marked. These regions were then photographed under oil immersion at 1000x using a Zeiss Axiophot photomicroscope at U.B.C. Negatives were printed and the interrenal nuclear diameters from all in focus interrenal nuclei in a single photograph were directly measured on the photograph, and mean interrenal nuclear diameters were determined by applying a factor based upon photography of a stage micrometer.

Cortisol: Cortisol was quantified by radioimmunoassay (RIA) using an antibody-coated tube I-25 assay (Incstar Corp.) which has been validated for use in salmon (Stratholt et al. 1997). Plasma aliquot size was 10 μL and determinations were in duplicate.

Lactate: Lactate was quantified at the Pacific Biological Station, Nanaimo, utilizing a kit from Sigma Chemical Co. In the assay, lactic acid is converted to pyruvate and hydrogen peroxide. In the presence of hydrogen peroxide, peroxidase catalyses the conversion of chromogen precursors to produce a colored dye with absorption maximum at 540 ηm.

Estradiol 17 beta: Estradiol was quantified by RIA according to the method of Van Der Kraak et al. (1994). Initially, 100 μL of plasma was heat extracted 1:20 in phosphate buffer. The assay was performed, in duplicate, utilizing two 200 μL aliquots, each equivalent to 10% of the extract.

17α, 20β dihydroxy-4-pregnen-3-one (17,20P): 17,20P was quantified by RIA according to the method of Van Der Kraak et al. (1994). The assay was performed, in duplicate, utilizing two 100 μL aliquots of the heat-extracted plasma referred to above.

Gonadosomatic Index (GSI): Gonadosomatic indices were determined by measuring body weight and gonadal weight, and expressing gonadal weight as a percentage of body weight.

RESULTS

Hematocrit: Mean hematocrits values at each collection location were: Qualark - 43.1%; Hells Gate (HG) - 46.2%; Fort St. James (FSJ) - 40.5%; Gluskie Creek (GC) - 44.6%.

Glucose: Fish collected from Qualark and Hells Gate between July 18th and 21st had similar plasma glucose levels and showed little variation between sexes (Fig. 2). Means in females ranged from 70.5 mg/dL on July 20th at HG to 113.5 mg/dL on July 19th at HG, while means in males ranged from 81.7 at HG on July 20th to 95.4 at Qualark on July 21st. Females captured at FSJ on August 9th had glucose levels that were dramatically elevated to 264.2 mg/dL. This increase was sustained in fish sampled at GC on August 10th (females 275.4, males 193.4).

Interrenal Nuclear Diameters: INDs were highest in females from the first sampling at Qualark on July 18th (Fig. 2). They were also elevated in the females sampled at HG on July 19th and 20th, and at GC on August 10th. The lowest values in both males and females were recorded at the second Qualark sampling on July 21st (Fig. 3).

Cortisol: Overall, cortisol levels were higher in females than in males. In females, the lowest mean cortisol values (200 and 211 ηg/mL) were observed in the two samplings at Qualark while the highest mean values (703 and 742 ηg/mL) were observed at HG on July 19th and at FSJ on August 9th (Fig. 4). Some individuals at the latter sampling site had extremely high cortisol levels in the range of 1300-1700 ηg/mL. In males, the lowest cortisol levels were also observed in fish collected at Qualark and the highest level was observed at HG on July 20th (Fig. 4). Males were not captured at FSJ.

Lactate: Lactate levels were low in fish sampled on both dates at Qualark and high in fish sampled at HG (Fig. 5). Levels were also unexpectedly high in approximately half of the females sampled at FSJ. At GC the lactate levels were relatively low with higher values in females than in males.

Estradiol: Estradiol declined with increasing distance from the mouth of the river from a high of 36 ηg/mL at Qualark on July 18th and 59 ηg/mL on July 21st, to a low of 0.55 ηg/mL at FSJ and below detection limits at GC (Fig. 6).

17α, 20β dihydroxy-4-pregnen-3-one: In females, 17,20P was first detected at FSJ at an average concentration of 5.7 ηg/mL (Fig. 7), and had risen to over 400 ηg/mL. In males, 17,20P was only detected at GC where it reached 58 ηg/mL (Fig. 7).

Gonadosomatic Index: Mean GSIs in females were between 6 and 7% at Qualark and Hells Gate while mean GSI at Gluskie was over 16%. Mean testicular size measured as GSI was between 2 and 4% at all locations (Fig. 8).

DISCUSSION

STRESS PARAMETERS

Hematocrit: The lowest hematocrits were seen in sockeye sampled at FSJ. This was probably associated with the poor condition of a number of these fish.

Glucose: The elevation of plasma glucose is a secondary stress response in fish (Mazeaud et al. 1977). Plasma glucose levels at Qualark and HG were within the normal range for salmonids while glucose levels at FSJ and GC were remarkably elevated. Earlier studies on this sockeye stock (French et al. 1983) indicated that glycogen reserves are maintained in the liver and muscle until late in the migration, and that carbohydrate reserves may be the last energy source to be utilized in support of spawning. Our data indicate that glycogen was already being mobilized into glucose at FSJ in fish that were not yet ready to spawn based on their 17,20P plasma concentrations (vide infra). Glucose levels in mature chum salmon in their natal river were shown to be higher than those in sea water (Kakizawa et al. 1995).

Interrenal nuclear diameters: Increases in INDs reflect exposure of fish to chronic stress (Donaldson 1981). Interpretation of the results was hampered by small sample sizes and by the lack of previous IND data from this stock for reference purposes. However, of all fish sampled, it is likely that female salmon collected at Qualark on July 18th had experienced the highest amount of chronic stress. This is consistent with these fish having been exposed to the highest flow rates of the season. They may have experienced migration blockages at Hells Gate in the preceding days, and fallen back to more benign locations.

The IND values from females collected at Hells Gate and on the spawning grounds (Gluskie Creek) indicated that these fish had also been exposed to chronic stress associated with migration delays. The relatively low IND values observed in the males and females collected from Qualark on July 21 suggest that these were fresh fish that had recently arrived in the lower river as water levels were dropping. These fish were visually in better shape than those collected previously and based on their estradiol levels, were probably at an earlier stage of the spawning migration process. They had likely not been exposed to the blockages at Hells Gate.

Cortisol: The release of cortisol into the blood plasma is a primary stress response in fish (Mazeaud et al. 1977). Cortisol reflects exposure to acute stress but can also be chronically elevated in fish that have been infected by *Saprolegnia* or are suffering from other diseases or chronic stressors (Donaldson 1981; Fagerlund et al. 1995). The finding of higher cortisol levels in females than in males is consistent with previous findings in migratory sockeye salmon. Thus, at the Gluskie sampling site in 1993, cortisol levels in female sockeye salmon were twice those observed in males (Donaldson et al. 2000 (unpublished manuscript)). On or close to the spawning grounds, high cortisol levels may reflect the presence of 17,20P as this steroid has been shown to increase cortisol levels. *In vitro* studies have shown that 17,20P can form a substrate for cortisol biosynthesis (Barry et al. 1995).

Cortisol levels were elevated at all sampling sites relative to values that have been observed in resting fish and were generally higher than values recorded in Early Stuart sockeye in 1993 and 1995 (Donaldson et al. 2000 (unpublished manuscript)). The differences among sites reflect the proximity of the stressor. Fish at Hells Gate were faced with the immediate challenge of negotiating the fish-way when flows were near record levels and as a result had very high cortisol levels. Fish at Qualark were either yet to have been exposed to stress (e.g. July 21st), or had been exposed to such high stress levels in the past that they had exhausted their ability to produce and release cortisol (e.g. July 18th). Based on estradiol levels, the fish collected on July 21st were probably fresh, less mature fish than those in other collections. *Saprolegnia sp.* infections observed in several females at FSJ, are likely responsible for their extremely high cortisol levels. These fish were visually in poor condition. Pickering and Pottinger (1989) report a linkage between high cortisol levels and fungal infections. It is interesting to note that the salmon (samples #141 and #139) with the highest cortisol levels also had the highest glucose levels, and the highest lactate levels of all fish sampled at FSJ. This indicates the close physiological relationship among these stress parameters.

Lactate: Elevated lactate is associated with severe exercise as demonstrated by Burgetz et al. (1996) with farmed sockeye salmon that were exercised to exhaustion. In 1993 and 1994 (unpublished data), and in this study, sockeye collected immediately after negotiating the Hells Gate fish ladder had high lactate levels. Fish collected from the spawning grounds and at Qualark had lower levels, similar to those measured in resting fish at the Cultus Lake Laboratory (Blackburn and Clarke unpublished manuscript). However, lactate levels may also be elevated as a result of other stressors, including the fungal infections as may have been the case with many of the fish collected at Fort St. James. No data exists to corroborate this finding. At all sites female sockeye were more prone to elevated lactate levels than males.

REPRODUCTIVE PARAMETERS

Estradiol 17 beta: Elevated estradiol concentrations are associated with the process of vitellogenesis. Estradiol from the ovary stimulates the production of the yolk protein, vitellogenin, in the liver. The vitellogenin is then transported to the ovary via the bloodstream where it is incorporated into the developing ova. A significant portion of oocyte growth in salmonids occurs during freshwater migration, but less in sockeye than in spring chinook that spend several months in fresh water before spawning (Slater et al. 1994). The decline in estradiol concentration during the migration signals the end of vitellogenesis and the completion of oocyte growth. The females sampled at Qualark on July 21 had higher estradiol levels than at other locations and during other years (1993 and 1995), which is consistent with them being fresh migrants undergoing active yolk synthesis. The estradiol levels on the other sampling dates in 1997 and at other locations, show a progressive decline over time that is consistent with the completion of egg development. Observations in previous years had indicated that net mark stress could suppress estradiol (Donaldson et al. 2000 (unpublished manuscript)). This may have occurred in 1997 in some individuals, particularly at Fort St. James where fish exhibited lower estradiol levels than previous years. Either vitellogenesis was complete or estrogen synthesis was prematurely suppressed. In addition to low estrogen concentrations, these fish also had low 17,20P values indicating that these fish may have been experiencing problems with estradiol synthesis rather than switching to synthesis of 17,20P. Recent research has demonstrated that administration of the aromatase inhibitor fadrozole to maturing coho salmon (*Oncorhynchus kisutch*) can accelerate the decline in estradiol synthesis and the initiation of 17,20P synthesis (Afonso et al. 1999, 2000).

17α, 20β dihydroxy-4-pregnen-3-one: This hormone is associated with the process of oocyte final maturation in females and spermiation in males. Normally in migrating salmon, 17,20P begins to rise as estradiol falls (e.g. pink salmon, Dye et al. 1986, sockeye salmon, Truscott et al. 1986). Females usually exhibit higher plasma concentrations than males. In either sex, the presence of the hormone indicates that the fish is very close to or in the process of spawning. The low levels of 17,20P in females observed at Fort St. John were similar to observations made in 1995 but lower than those made in 1993 (Donaldson et al. 2000 (unpublished manuscript)). These fish had not begun the final maturation process, possibly as a result of exposure to stressful conditions. On the spawning grounds, in samples from all three years, 17,20P levels had risen in both females and males but were highest in 1993. The 1993 fish were closer to ovulation than those captured in 1997.

Gonadosomatic Index: The GSI in females at Hells Gate was a little higher than that observed in 1993 (Donaldson et al. 2000) suggesting that the 1997 fish were a little more advanced in their development. In 1993, GSI increased from approximately 5% at Hells Gate to approximately 11% at FSJ. GSI was not recorded at FSJ in 1997. However, the GSI of 16% observed at Gluskie in 1997 was higher than that observed in 1993. The maturity in male FSJ between Qualark, Hells Gate, and Gluskie indicates that some of the males at Gluskie had already spawned.

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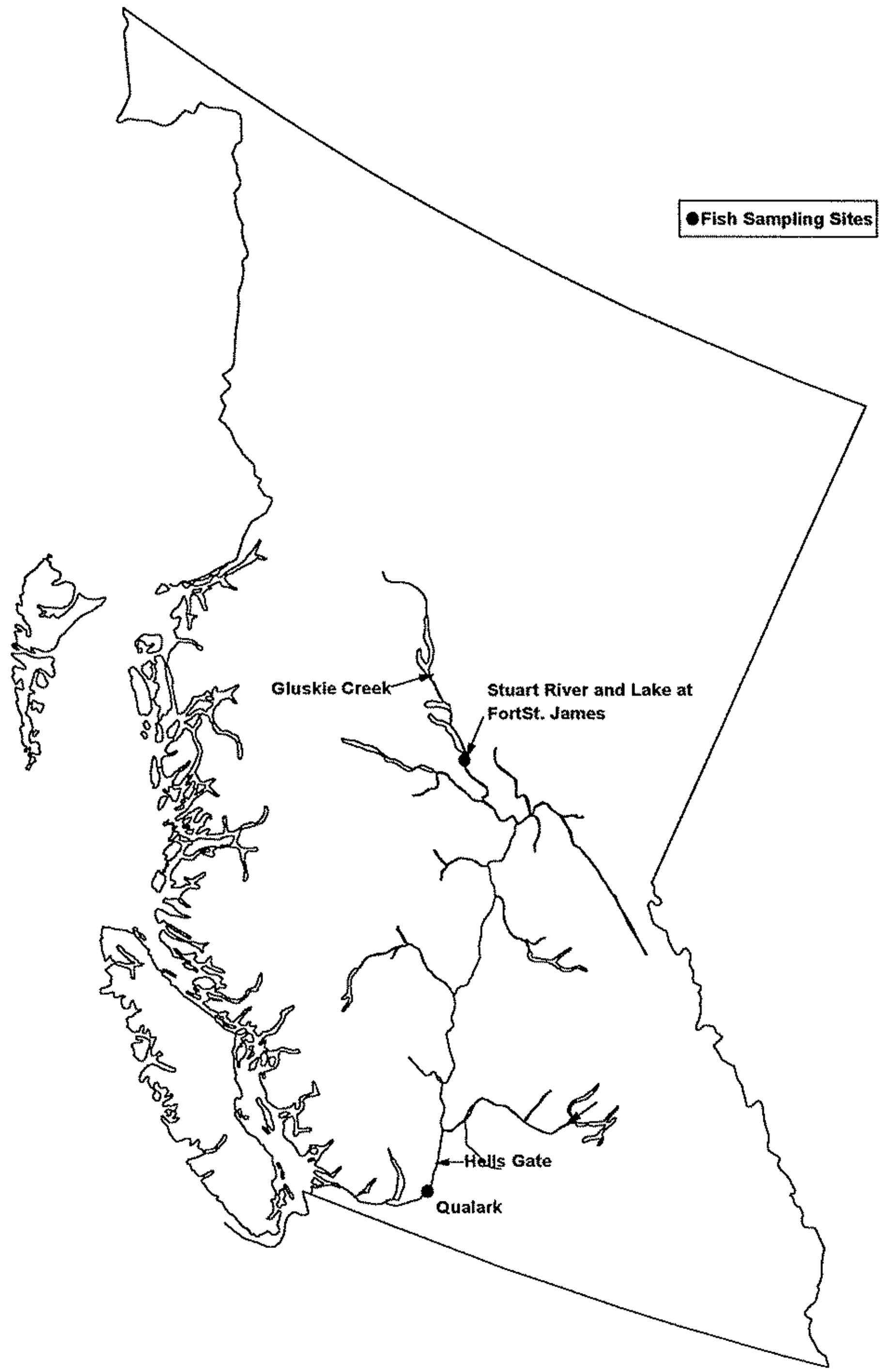

Fig. 1. Map of Fraser River Basin showing blood sampling sites in 1997.

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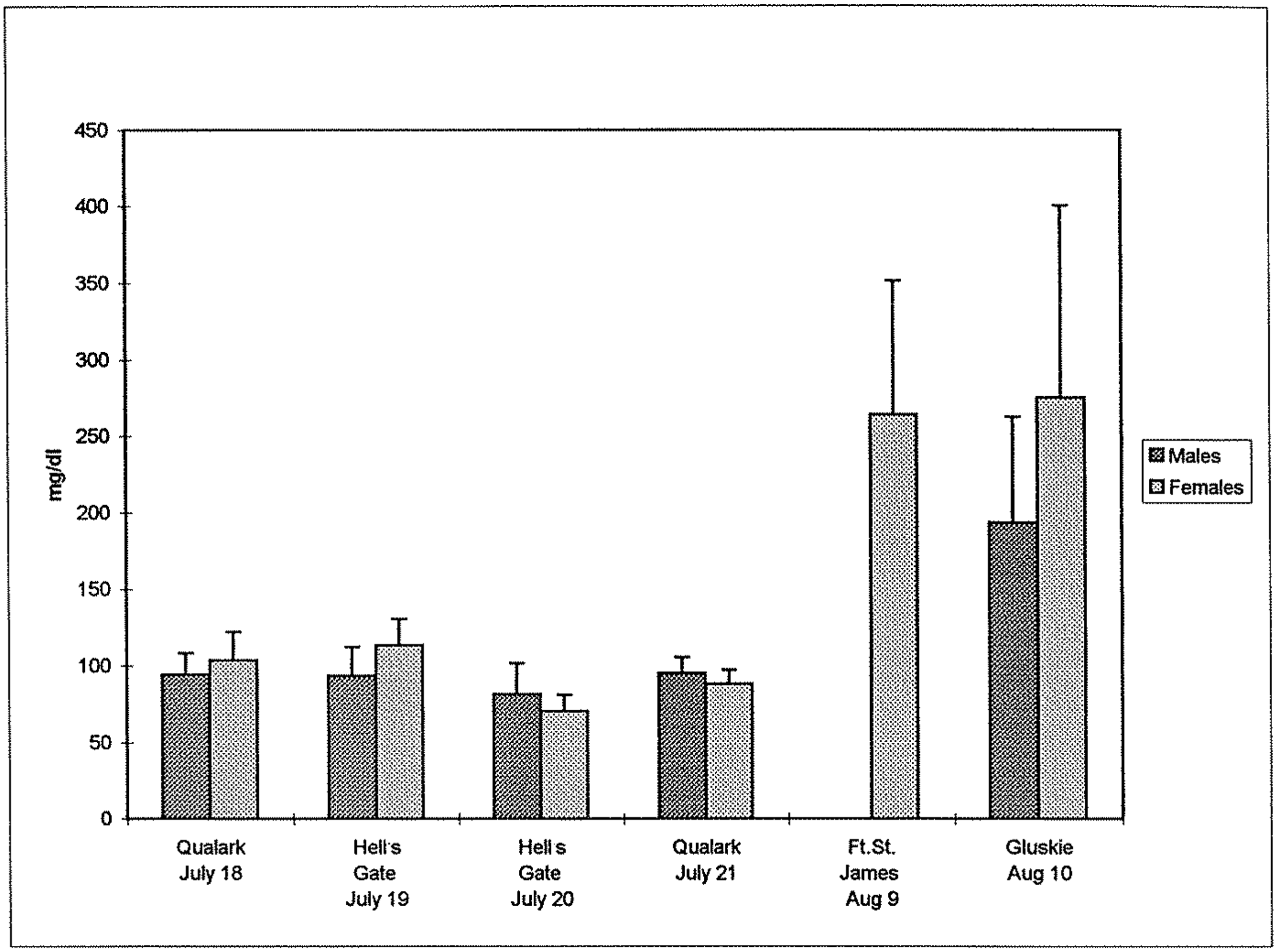

Fig. 2. Plasma glucose (mean and standard deviation) in Early Stuart sockeye, 1997.

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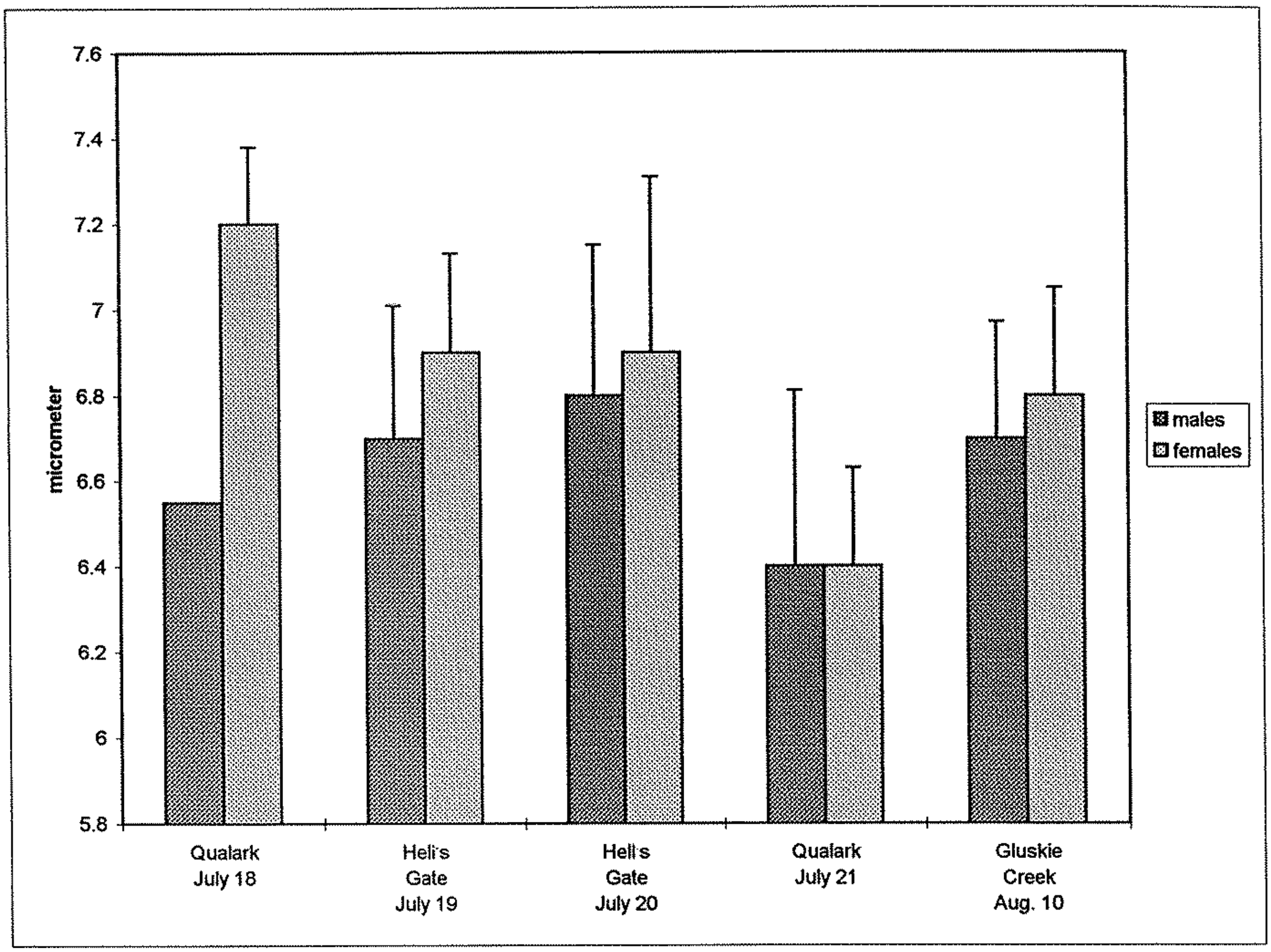

Fig. 3. Interrenal nuclear diameters (mean and standard deviation) in Early Stuart sockeye, 1997.

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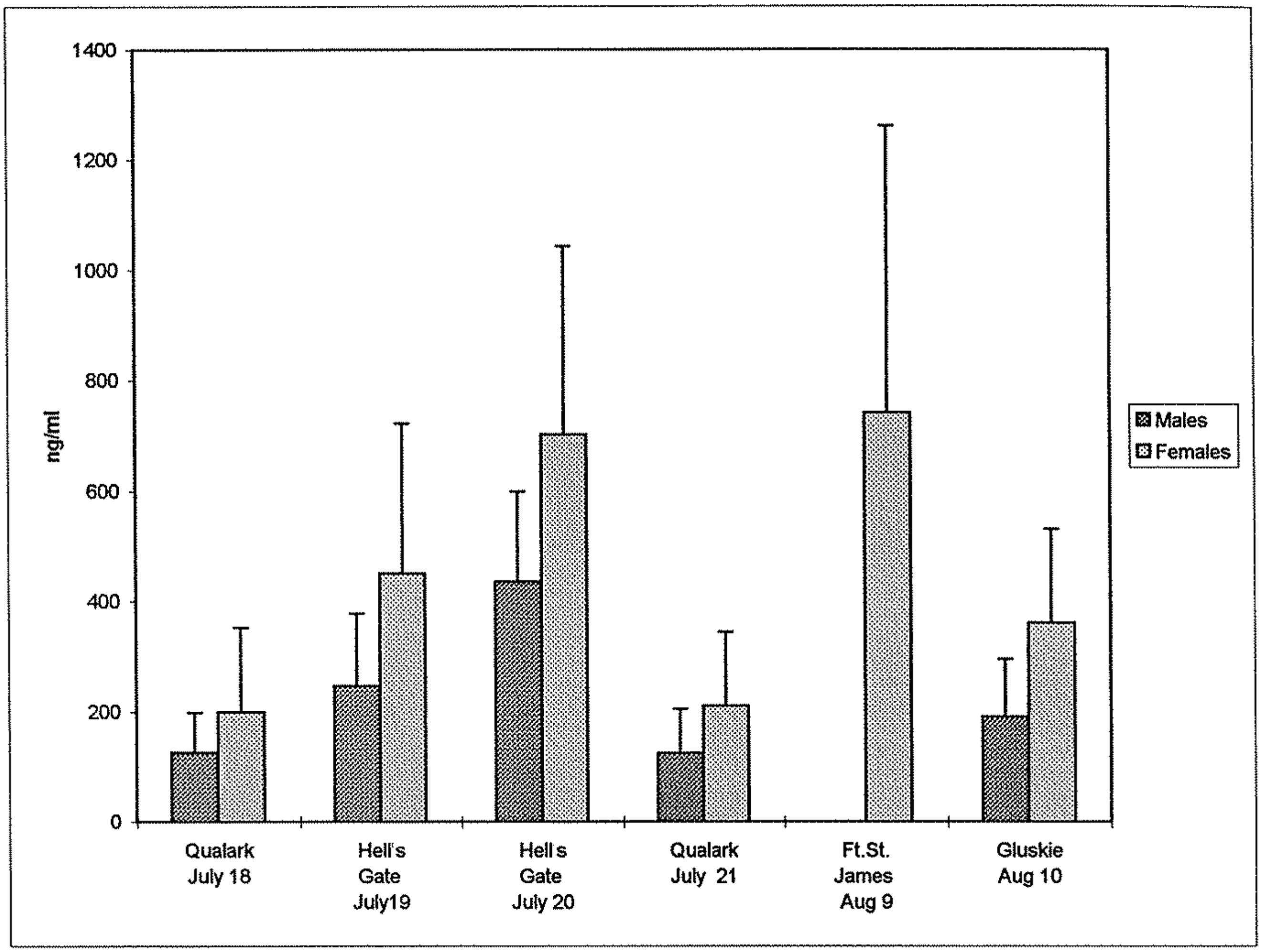

Fig. 4. Plasma cortisol (mean and standard deviation) in Early Stuart sockeye. 1997.

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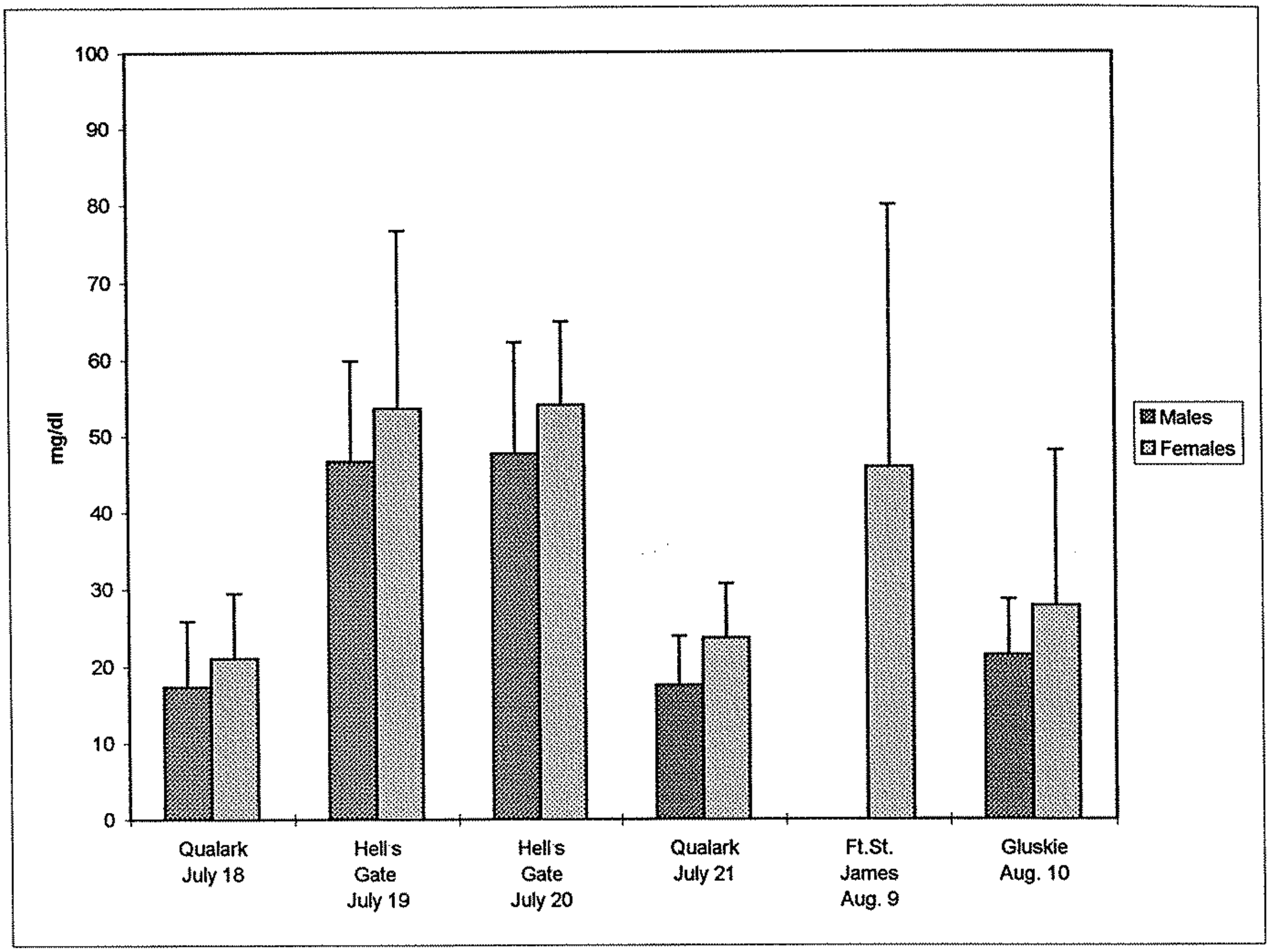

Fig. 5. Plasma lactate (mean and standard deviation) in Early Stuart sockeye, 1997.

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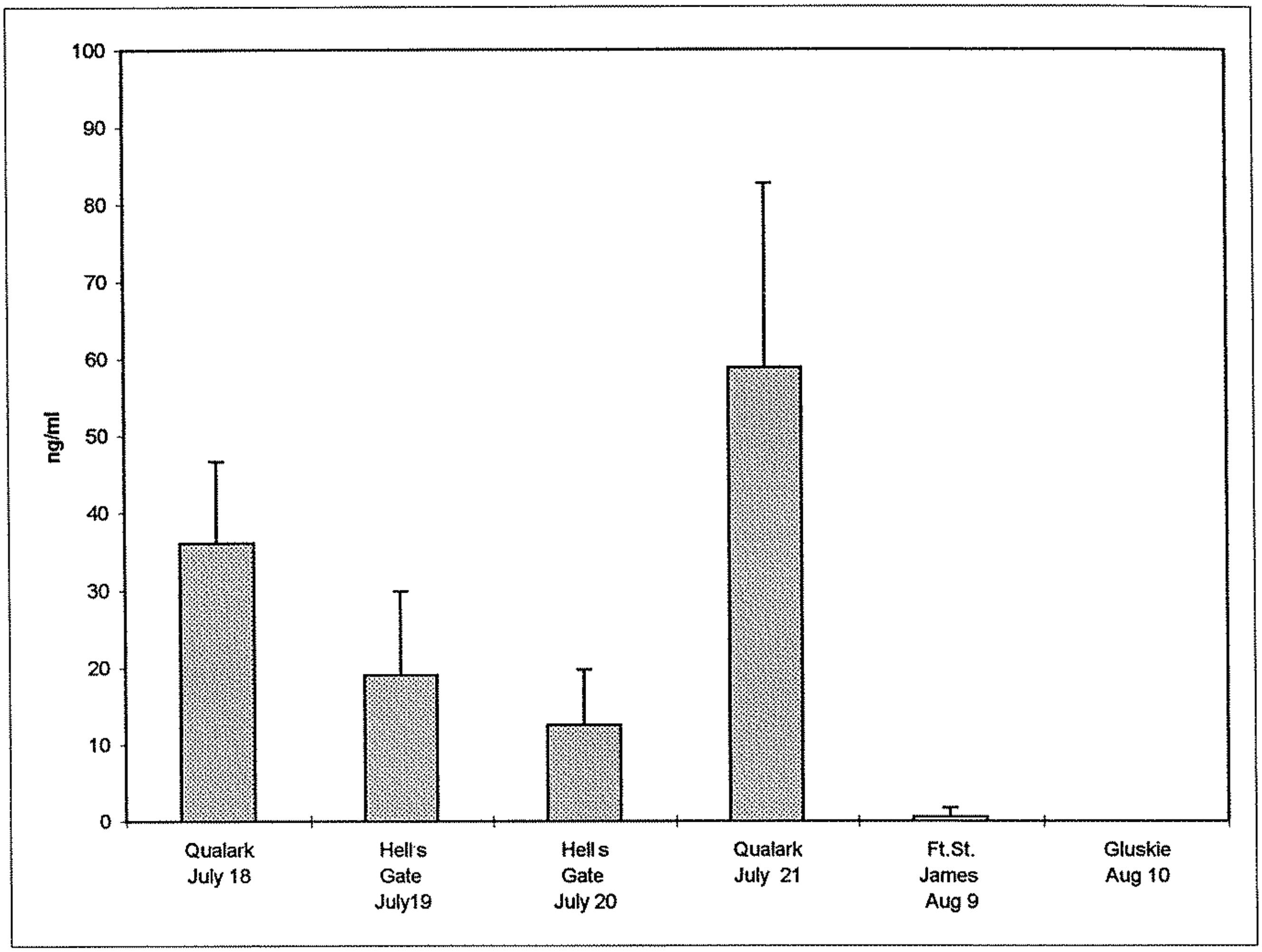

Fig. 6. Plasma estradiol-17beta (mean and standard deviation) in Early Stuart sockeye, 1997.

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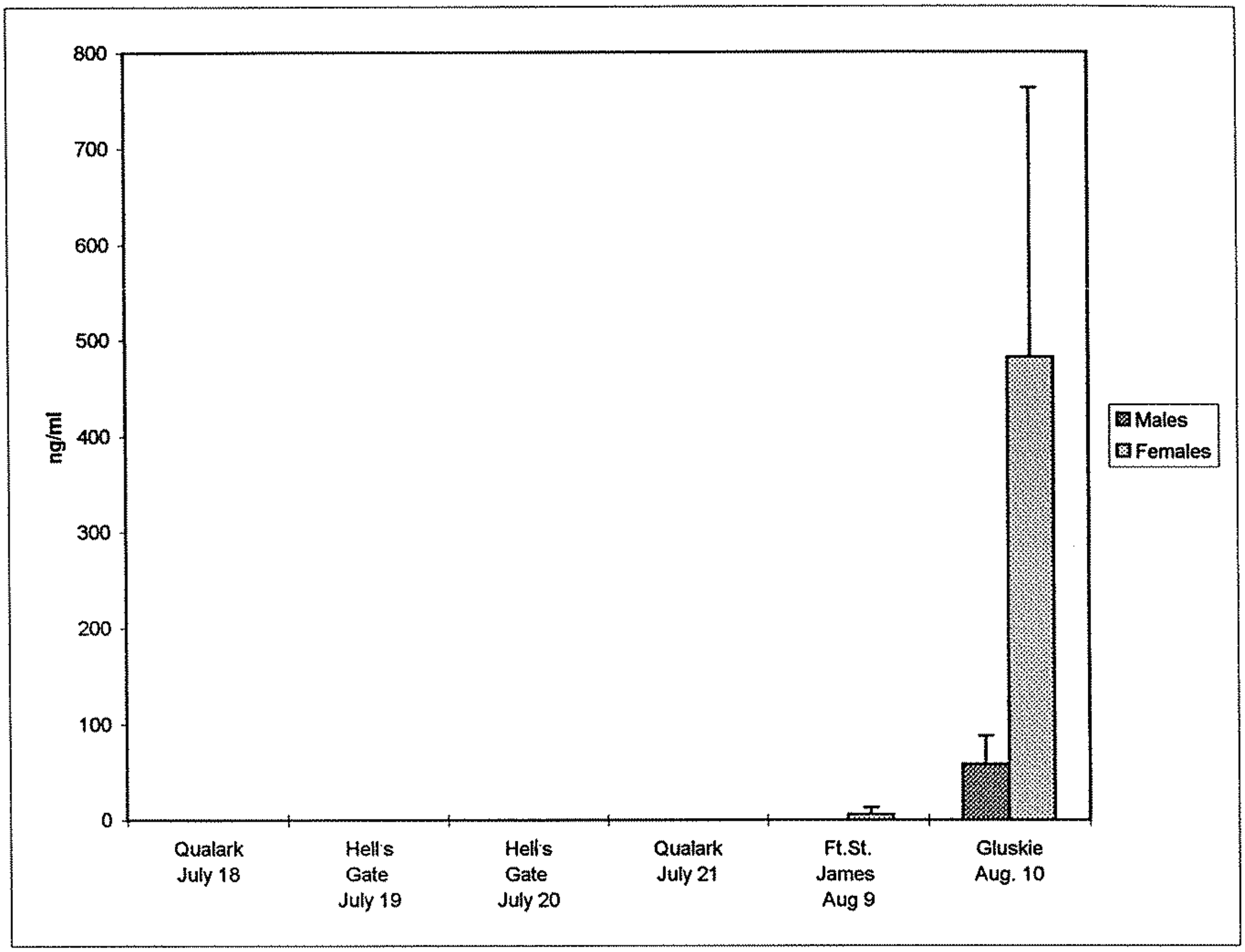

Fig. 7. Plasma 17-alpha, 20-beta dihydroxy-4-pregen-3-one (mean and standard deviation) in Early Stuart sockeye, 1997.

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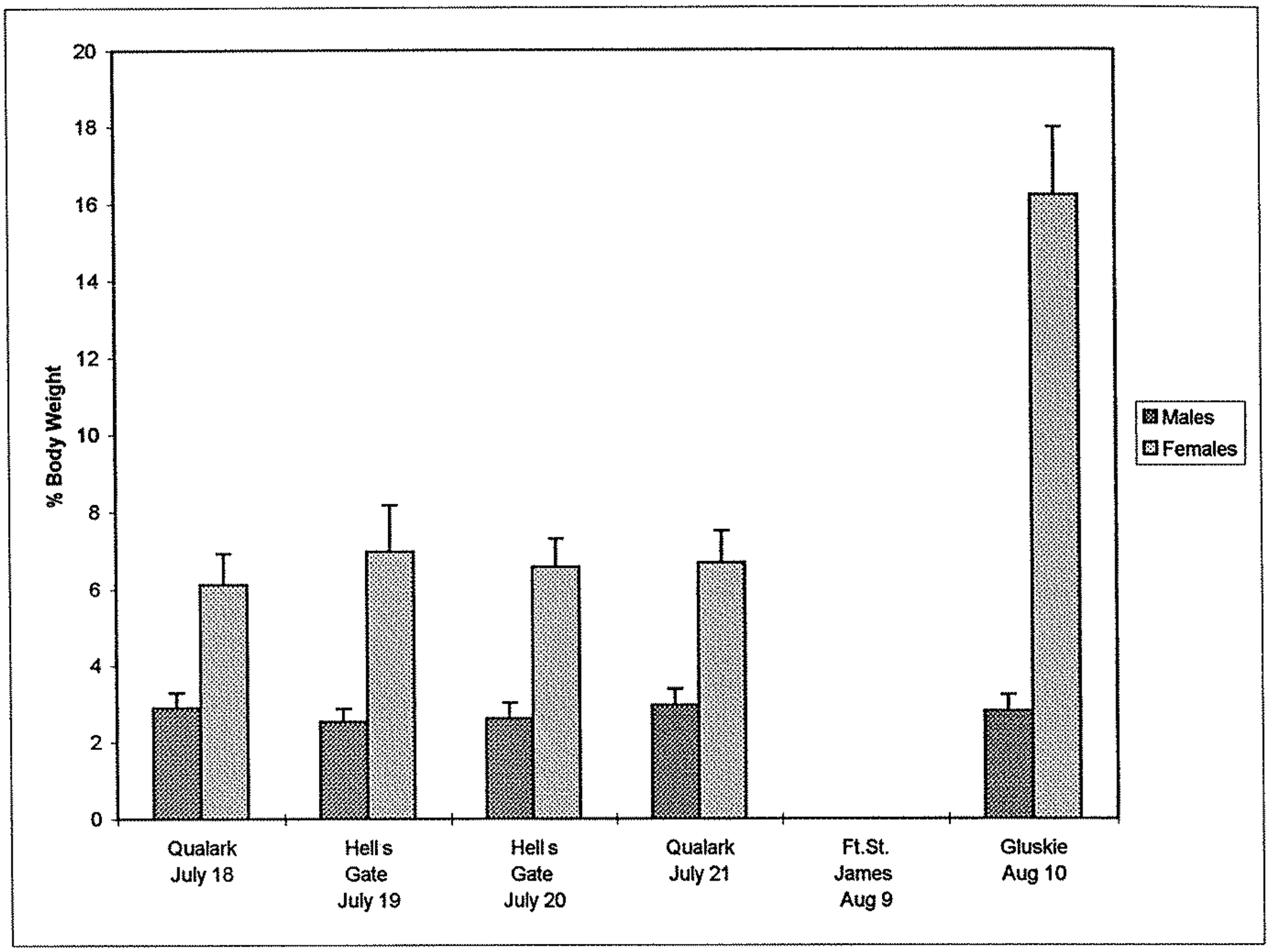

Fig. 8.Gonadosomatic index (GSI) (mean and standard deviation) in Early Stuart sockeye, 1997.

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CHANGES IN THE LEVELS OF PROXIMATE CONSTITUENTS AND GROSS ENERGY IN THE MUSCLE (FILLET) OF 4-YEAR-OLD EARLY STUART SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) DURING THE 1997 UPSTREAM FRASER RIVER SPAWNING MIGRATION

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INTRODUCTION

During July and the first three weeks of August, 1997, water flow rates in the Fraser River at Hope, B.C., exceeded the average values that had been recorded for the previous 52 years (see Macdonald et al. 2000), while the range for water temperatures measured in the river at two sites was normal (varied between 14 and 18 °C). The excessively high Fraser River discharge coincided with the upstream migration of 4-year-old Early Stuart sockeye salmon and many of the returning sockeye salmon (>0.5 million) failed to complete their 1100-km migration to their natal streams.

The adequacy of the energy reserves in the sockeye at the time of entry into the river when the fish had ceased feeding was postulated as one of the major factors that played a role in the high 1997 pre-spawning mortality. This is because a previous study conducted over 40 years ago found that this race of sockeye salmon had just enough energy in their bodies in the form of lipid and protein to complete their arduous upstream journey (Idler and Clemens 1959; Gilhousen 1980). However, since this time it has been observed that the size of this race of sockeye salmon at the time of maturity has declined, especially during the last decade, probably because of warmer ocean conditions. Ocean conditions may have also altered the distributions of the fish along with the amounts and distributions of their food supply during the last few months of ocean residency (Hinch et al. 1995; Cox and Hinch 1997; Welch et al. 1999). The reduced size of the fish at the time of river entry likely has decreased their whole body stores of lipid, and possibly protein, since it is known that the levels of both proximate constituents are directly related to fish size during the juvenile to adult stage of life history (Shearer 1994). With fewer energy reserves, the smaller fish would have increased difficulty successfully complete their spawning migration because they would have had to increase their energy expenditures due to the exceptionally high river discharge rates in 1997, particularly at some locations in the river such as Hell's Gate and the Yale gravel bar (Hinch et al. 1996).

Accordingly, this investigation was undertaken to determine whether the temporal changes found for muscle (fillet) levels of lipid, protein, and gross energy during the 1997 upstream Fraser River spawning migration of 4-year-old Early Stuart sockeye salmon mirrored those found previously for the fish that returned in 1957 and 1958 (Gilhousen 1980), the only other times when this has been investigated. The levels of proximate constituents and gross energy in the fillets were examined since previous studies on sockeye, and other salmon undergoing spawning migration, have shown that catabolism of lipid and protein in the muscle of the fish provides most of the required amount of energy for migration and gonadal maturation (Gilhousen 1980; Mommsen et al. 1980; Ando et al. 1985). The latter is especially true in female salmon, which enter the river at a less advanced state of sexual maturity than the males.

MATERIALS AND METHODS

A total of 164 adult (4-year-old) male and female sockeye salmon was collected either by dipnet (Qualark, Hell's Gate, and Gluskie Creek) or by a combination of dipnet and gill net (Nechako River at Prince George and Stuart River at Fort St. James). An effort was made to collect at least 10 male and female fish at each of the five locations along the Fraser River during the migration period (Table 1). At each sampling location, each fish was weighed (to the nearest gram), measured (fork length, to nearest 0.1cm), and sexed. The gonads were also removed and weighed. Thereafter, the fish were stored on ice until they were filleted (included belly flap in each case). Subsequently, each fillet was placed into a plastic bag that was sealed after removal of as much air as possible, and then the fillets were stored frozen at -20°C pending analysis.

Before analysis, the fillets were allowed to completely thaw in a cold room (4 °C). Each fillet was homogenized thoroughly using a Braun food processor. The weighed portions of the homogenate were analyzed, in duplicate, according to the procedures described by Higgs et al. (1979) in order to determine concentrations ($g \bullet kg^{-1}$) of moisture, ash, protein, and lipid. The gross energy contents ($MJ \bullet kg^{-1}$) of the fillets were estimated later by using the energy equivalents of 23.64 $kJ \bullet g^{-1}$ of protein and 36.4 $kJ \bullet g^{-1}$ of lipid (Higgs et al. 1995).

RESULTS AND DISCUSSION

The mean weight of sockeye sampled in 1997 at Qualark, B.C., which is located about 165 km from the mouth of the Fraser River, was less than sockeye sampled at Albion, B.C (~ 129 km from the mouth of the Fraser) in 1957 and 1958 (Gilhousen 1980). The difference was especially evident in females. A two-way analysis of variance revealed that males were larger than females in 1997 (weight and length), and size varied with sampling location ($p<0.01$) (Table 1). There was significant interaction with size between sex and sampling location ($p<0.05$). Fish size may be an important variable influencing the proximate composition of whole fish and fish muscle (especially concentrations of lipid, moisture and protein in whole fish, Shearer, 1994, and Johansen and Jobling, 1998). Accordingly, a two-factor (sex, location, sex by location interaction) analysis of covariance was performed with length as the covariate to correct for the effect of fish size on each parameter in the fish fillets (i.e. moisture, ash, protein, lipid, and gross energy, Table 1). The results of these tests showed that fish length had the same influence on each parameter regardless of sampling location (parallel slope values). With the exception of lipid and ash contents, fish size had a positive influence on the values of each parameter (significant covariate effect, $p \leq 0.01$). After adjustment for fish length (grand mean length used as reference), there was no effect of sex of fish ($p<0.05$), but sample location had highly significant effects on the value of each parameter ($p<0.001$), with no significant interactions between the factors (Table 2).

A sequentially modified Bonferroni t-test ($p=0.05$) was performed on all possible pair-wise comparisons of mean parameter values (corrected for length) between locations with equal weight given to the values for each sex. Mean weights of the fish did not decline significantly until after they had travelled beyond Hells Gate and then there was no further decrease (Table 2). Mean levels for moisture, ash, lipid, and gross energy in the flesh also remained unchanged until the fish had passed Hells Gate. By contrast, protein concentration began to decline earlier in the migration as values at Hells Gate were lower than those at Qualark Creek and continued to decline in samples from up-river locations. The fish began to utilize muscle protein as an energy source in the lower river and continued to use it through the Nechako and Stuart river systems.

The utilization of the main organic constituents during the 1997 Early Stuart migration differed from the observations made by Gilhousen (1980) for the same race of sockeye salmon in the 1950's. In the 1950's muscle lipid catabolism furnished the majority of energy for migration and gonadal development during the early portion of the journey (Figs. 1-3). Protein catabolism then began extensively during the latter part of the journey. In 1997, however, (uncorrected) mean concentrations of lipid in the flesh of the male and female salmon were generally below those found for the fish in 1957 and 1958 at the first two sampling points closest to the mouth of the Fraser River (Fig. 2). This trend was especially noticeable in the female salmon. Moreover, the corrected data (Table 2) and the uncorrected data (Fig. 2) show a similar trend at subsequent sampling points, and they reveal that the 1997 fish were extensively utilizing muscle lipid as a source of energy between Hells Gate and the Nechako River. Thereafter, there was no significant decline in muscle lipid stores. Owing to the reduced initial stores of muscle lipid and consequently energy (Fig. 4), and the possibly higher utilization of lipid as a source of energy in the 1997 versus 1957 and 1958, it appears that the 1997 fish were forced to utilize protein as an energy source at an earlier time (distance) than those observed in the late 1950s.

The depletion of the muscle protein reserves in the 1997 fish began when the muscle lipid concentrations had fallen to approximately 35-40 $g \bullet kg^{-1}$(Fig. 5). In this regard, it is noteworthy that 10% of the fish (males and females combined) sampled at Qualark, B.C., had muscle lipid concentrations that were near or within this range and by the time the fish reached the Nechako River, 100% of the fish were well below this range. Using the data depicted in Figs. 2 and 5, we estimated that on the average, the 1997 sockeye began to utilize their muscle protein stores as a major source of energy when they had completed about 50% (550 km) of their upstream migration. By contrast, this did not occur in the fish sampled in the latter 1950's until about 68% (748 km) of the journey had been completed.

The determined and corrected mean levels of moisture in the flesh were found to be inversely related to the levels of lipid, protein, and ash, with lipid and protein exerting the most influence (Tables 1 and 2). This relationship was also observed for this race of sockeye salmon in the 1950s by Idler and Clemens (1959) and Gilhousen (1980). The corrected mean levels of ash and gross energy in the flesh (Table 2) followed the same trend as we described above for protein, except significant differences were not observed for either parameter between fish sampled at Qualark and Hells Gate.

CONCLUSIONS AND RECOMMENDATIONS

Our findings indicate that there are major differences between the Early Stuart sockeye salmon examined in the 1950's and in 1997 with respect to their temporal changes in muscle (fillet) stores of lipid, protein, and energy during their upstream spawning migrations. In 1997 the fish had lower initial lipid and energy reserves, perhaps because of their smaller size at the time of river entry and less feed (energy) intake during the last few months of ocean residency. The high Fraser River discharge in 1997 likely forced the fish to utilize muscle lipid as a source of energy more rapidly than previous years. These factors necessitated the earlier utilization of muscle protein stores than occurred in the fish sampled in 1957 and 1958. It is unknown whether the reduced concentrations of lipid and energy in the 1997 fish contributed to high en route and pre-spawning mortality, but 10% of the live fish sampled at Qualark Creek had muscle lipid concentrations that required them to begin to draw upon protein as a source of energy. This percentage may have been higher in the overall population since we selected survivors at each sampling location, avoiding moribund fish.

In the future, we recommend that the proximate compositions of whole fish minus gonads and of the gonads themselves be followed as was done by Williams et al. (1986) in their study of early run Fraser and Thompson river pink salmon. Also, we recommend that appropriate numbers of male and female early Stuart sockeye salmon be sampled not only at strategic locations along the Fraser River spawning migration route, but also before the fish enter the Fraser River to gain improved insights about their initial nutritional status. Ideally, this type of study should be conducted for several consecutive years. This will allow collection of sufficient data that will help resource managers to more accurately predict the future spawning success of runs of this race of salmon, particularly, in years when the fish face similar or even more difficult challenges than those encountered by the 1997 fish due to varying ocean and river conditions. Moreover, the compilation of this information may enable the development of mitigative approaches that will assist the fish during these difficult periods.

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Table 1. Mean levels ± 1 standard deviation of proximate constituents and gross energy in the fillets of 4-year-old early Stuart sockeye salmon during the 1997 upstream Fraser River spawning migration in relation to the time and location of sampling and the sex and size of the fish.

Sampling date in 1997	Sampling location	Distance from Steveston, B.C. (km)	Sex [1]	Number of fish	Weight (g) [2]	Fork Length (cm) [2]	Proximate constituents ($g \bullet kg^{-1}$ fillet): Moisture	Ash	Protein	Lipid	Energy [3] ($MJ \bullet kg^{-1}$)
July 18-21	Qualark	165	M	17	2325 ± 313	59.3 ± 2.43	716.2 ± 18.4	20.6 ± 2.45	210.3 ± 6.52	62.2 ± 15.7	7.22 ± 0.55
	Qualark	165	F	23	1890 ± 290	56.0 ± 2.23	714.6 ± 13.5	20.0 ± 2.14	208.2 ± 6.75	62.0 ± 14.9	7.18 ± 0.49
July 19-20	Hells Gate	200	M	17	2405 ± 313	60.5 ± 2.34	709.4 ± 9.75	21.9 ±2.78	204.3 ± 8.43	68.7 ± 7.14	7.33 ± 0.31
	Hells Gate	200	F	13	2202 ± 305	58.6 ± 2.32	719.7 ± 13.6	20.6 ± 1.53	204.4 ± 8.00	62.7 ± 13.8	7.11 ± 0.59
August 6	Nechako River	773	M	19	2004 ± 308	57.9 ± 2.33	792.7 ± 17.2	15.1 ± 1.79	180.0 ± 11.8	19.6 ± 6.49	4.97 ± 0.48
	Nechako River	773	F	11	1933 ± 378	57.6 ± 2.40	797.4 ± 16.1	15.8 ± 2.47	174.8 ± 13.2	18.1 ± 4.05	4.79 ± 0.40
August 7-9	Stuart River	967	M	23	2267 ± 308	59.7 ± 2.51	810.6 ± 15.9	12.0 ± 1.31	165.2 ± 11.7	16.1 ± 5.72	4.49 ± 0.45
	Stuart River	967	F	11	1670 ± 238	55.4 ± 2.18	822.8 ± 19.8	12.1 ± 1.06	153.0 ± 13.9	14.3 ± 5.50	4.14 ± 0.45
August 10	Gluskie Creek	1086	M	15	2180 ± 319	59.3 ± 2.73	809.8 ± 11.3	11.8 ± 0.60	163.9 ± 17.8	15.4 ± 2.21	4.43 ± 0.44
	Gluskie Creek	1086	F	15	1861 ± 194	56.7 ± 1.45	811.3 ± 11.6	13.0 ± 1.23	162.7 ± 9.46	14.5 ± 3.07	4.37 ± 0.22

[1] M = male; F = female.
[2] Two-Way Analysis of Variance indicated $P<0.01$ for sex of the fish and location of sampling and $P<0.05$ for the interaction of these factors.
[3] The gross energy content of the fillets was estimated by ascribing 23.64 $kJ \bullet g^{-1}$ protein and 36.4 $kJ \bullet g^{-1}$ lipid.

Table 2. Corrected means (adjusted to account for differences between groups in fish length) for fish weights, and levels of proximate constituents and gross energy in the fillets of 4-year-old early Stuart sockeye salmon during the 1997 upstream Fraser River spawning migration in relation to the time and location of sampling and the sex of the fish.[1]

						Proximate constituents ($g \bullet kg^{-1}$ fillet)				
Sampling date in 1997	Sampling location	Distance from Steveston, BC (km)	Sex [2]	Number of fish	Weight (g)	Moisture	Ash	Protein	Lipid	Energy ($MJ \bullet kg^{-1}$)
July 18-21	Qualark	165	M	17	2205 A[3]	717.7 C	20.6 A	209.2 A	61.7 A	7.18 A
	Qualark	165	F	23	2139	711.5	20.1	210.4	63.2	7.27
July 19-20	Hells Gate	200	M	17	2139 A	712.6 C	21.8 A	202.0 B	67.6 A	7.24 A
	Hells Gate	200	F	13	2152	720.3	20.6	204.0	62.5	7.10
August 6	Nechako River	773	M	19	2039 B	792.3 B	15.1 B	180.3 C	19.8 B	4.98 B
	Nechako River	773	F	11	2000	796.6	15.8	175.4	18.4	4.82
August 7-9	Stuart River	967	M	23	2093 B	812.7 A	11.9 C	163.7 D	15.3 B	4.43 C
	Stuart River	967	F	11	1989	818.9	12.2	155.7	15.7	4.25
August 10	Gluskie Creek	1086	M	15	2052 B	811.4 A	11.8 C	162.8 D	14.8 B	4.39 C
	Gluskie Creek	1086	F	15	2026	809.2	13.1	164.1	15.2	4.43

[1] Two-Way Analysis of Covariance with length as the covariate indicated that there was no effect of sex ($P>0.05$) on any of the variables. However, there was a highly significant effect of location of sampling on all variables ($P<0.001$). No significant interactions between sex and location were found.

[2] M = male; F = female.

[3] Within a column, a sequentially modified Bonferroni t-test of all location pairwise mean differences (equal weight given to values for each sex) indicated the homogenous groups (common postscripts) ($P=0.05$).

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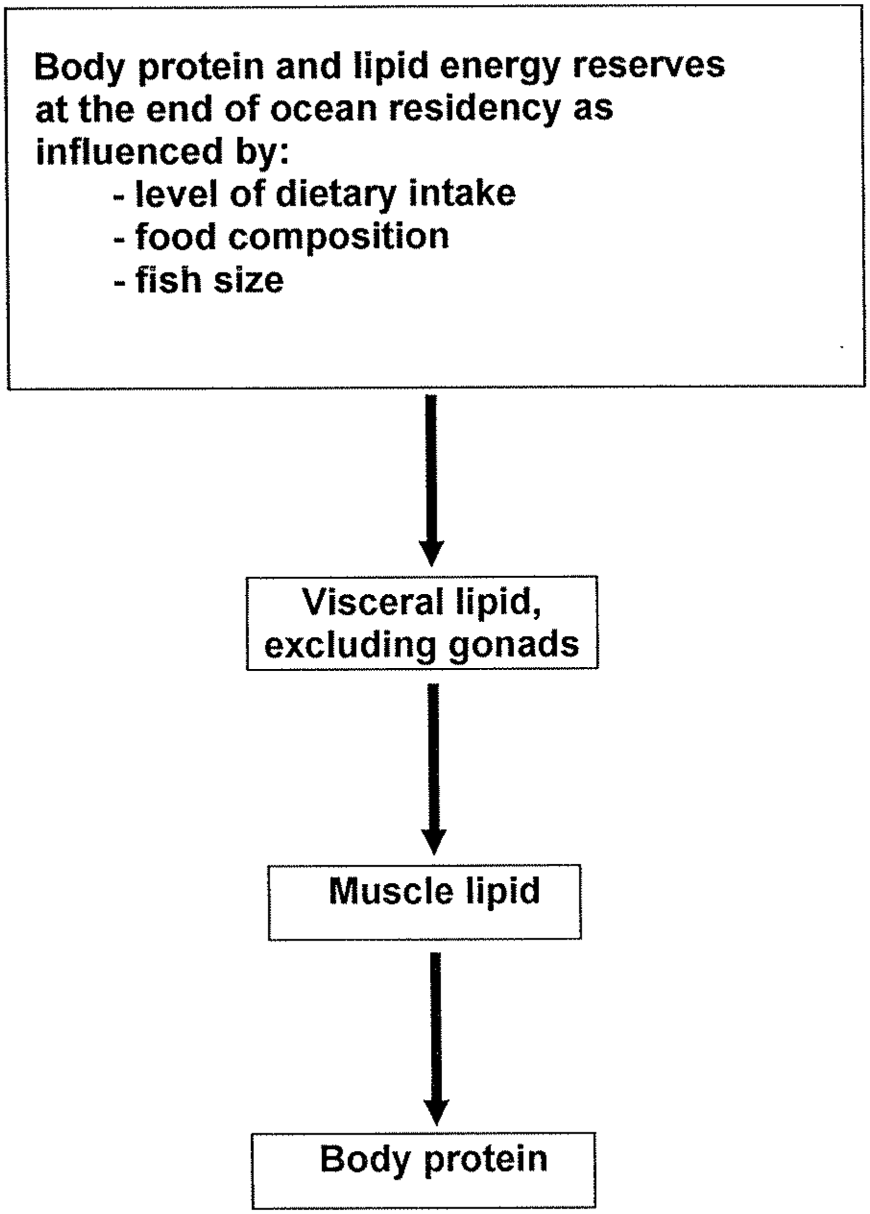


Fig. 1. General sequence observed by Gilhousen (1980) for utilization of the main organic constituents in early Stuart sockeye salmon to furnish energy for gonadal maturation and upstream Fraser river migration (>1100 km). If the fish reach their natal streams, death occurs following spawning. At this time, there is depletion of most of the lipid reserves and a significant portion (~30-60%) of the protein energy reserves that were present in the fish at the end of ocean residency. The latter situation may account for the death of many sockeye salmon if they entered the river with insufficient energy reserves.

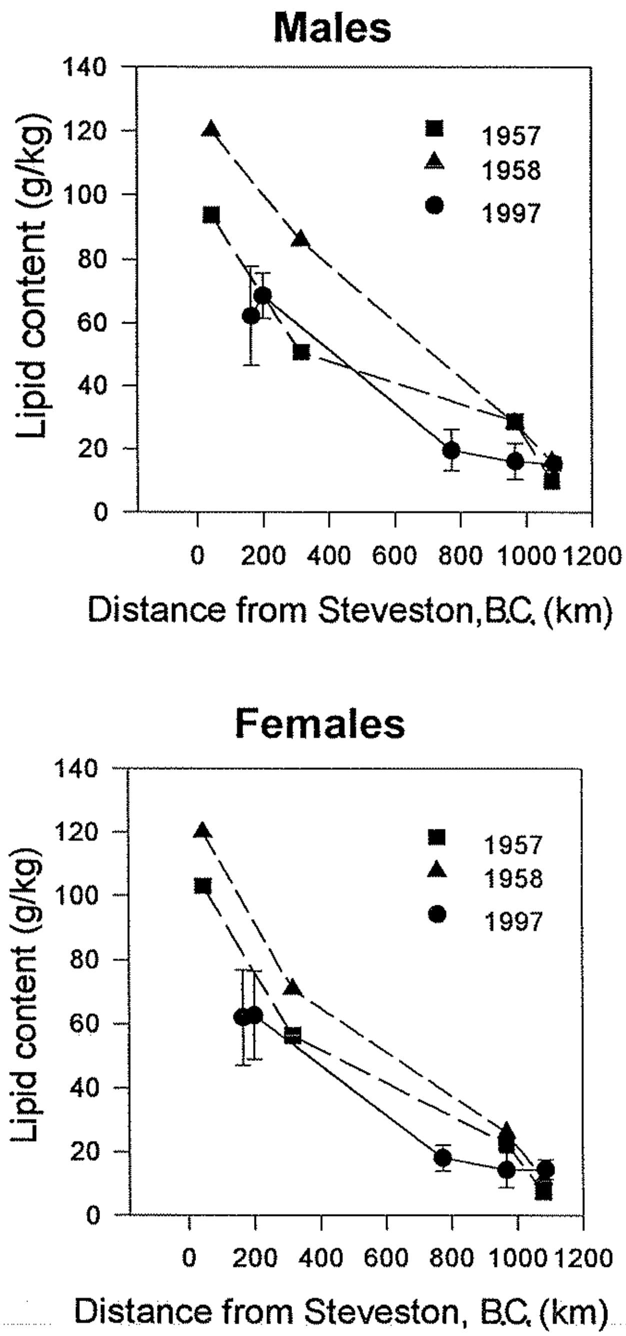


Fig. 2. Temporal changes in the muscle (fillet) lipid contents (mean ± 1SD) of male and female early Stuart sockeye salmon during their upstream Fraser River spawning migration in 1997 in relation to values reported by Gilhousen (1980) for this race of salmon in 1957 and 1958.

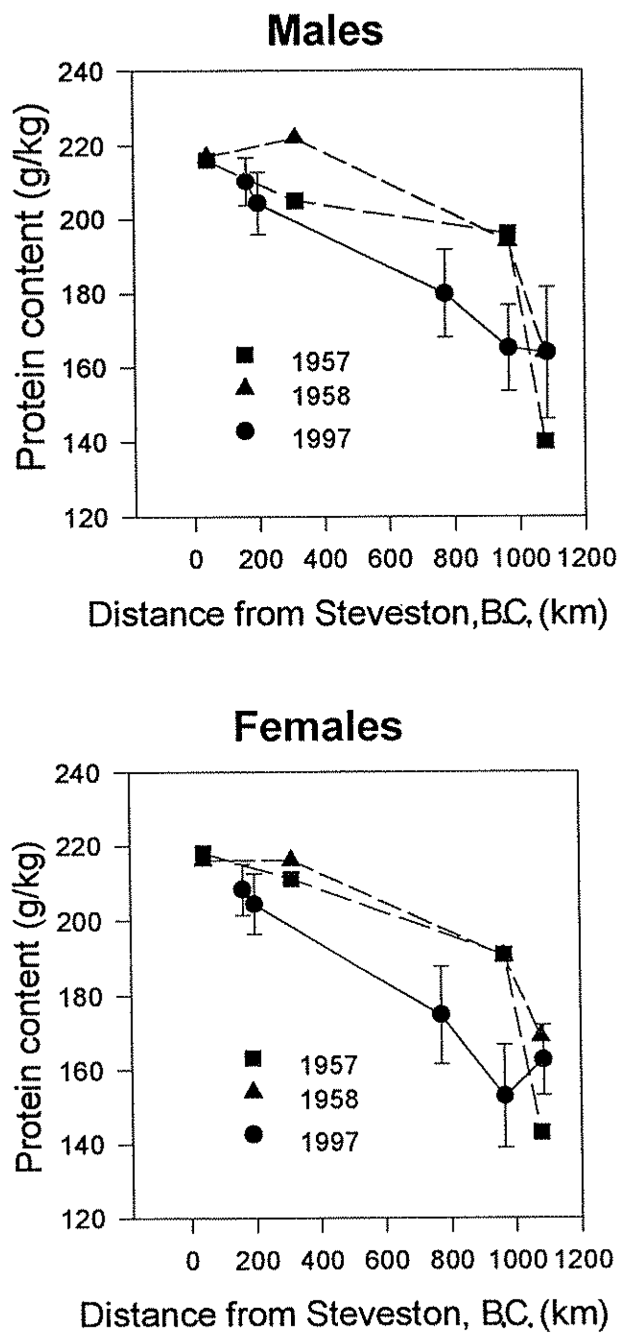
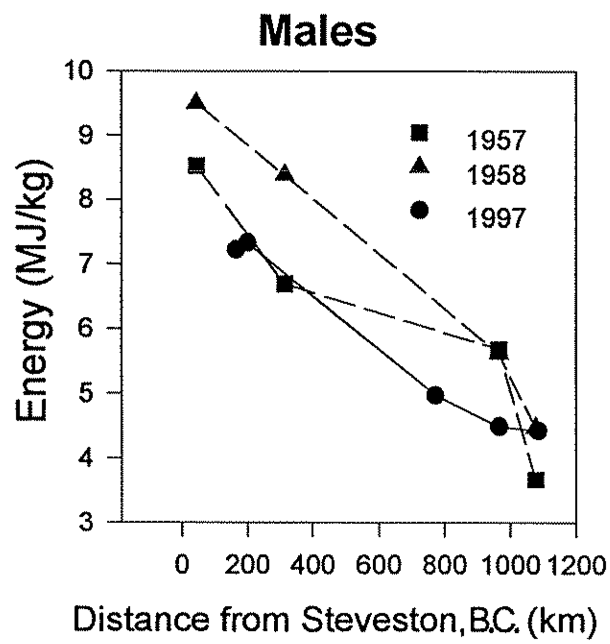


Fig. 3. Temporal changes in the muscle (fillet) protein contents (mean ± 1SD) of male and female early Stuart sockeye salmon during their upstream Fraser River spawning migration in 1997 in relation to values reported by Gilhousen (1980) for this race of salmon in 1957 and 1958.



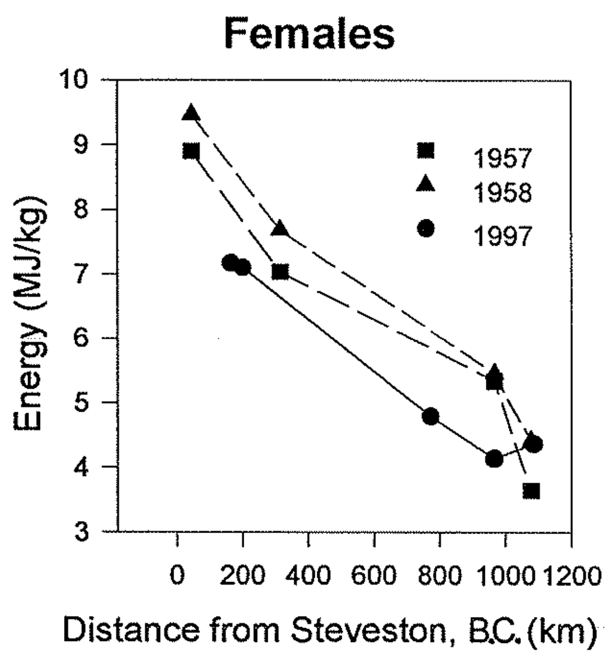


Fig. 4. Temporal changes in the muscle (fillet) gross energy contents (mean ± 1SD) of male and female early Stuart sockeye salmon during their upstream Fraser River spawning migration in 1997 in relation to values reported by Gilhousen (1980) for this race of salmon in 1957 and 1958.

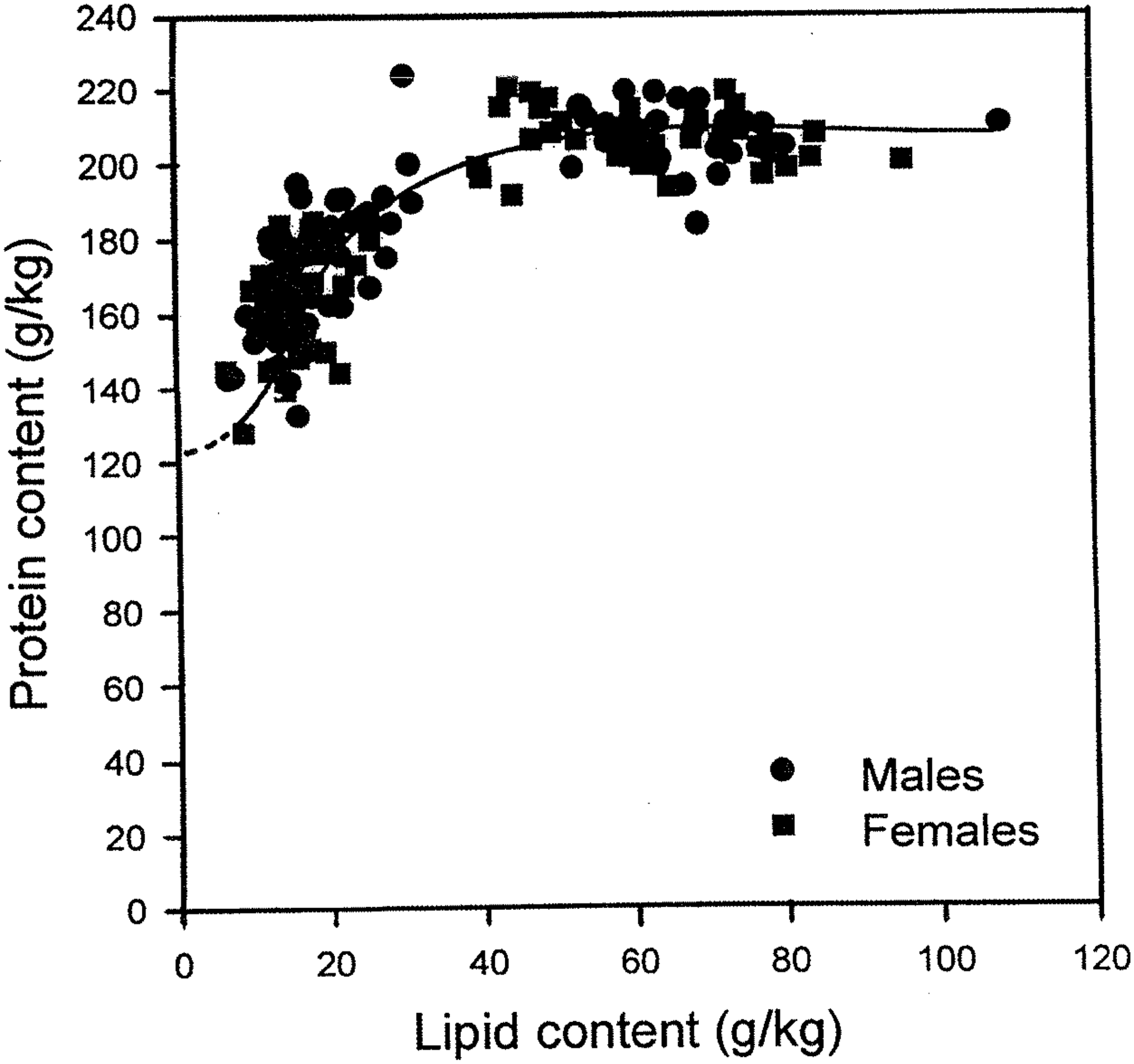


Fig. 5. Graphical representation of the relationship that was observed between protein and lipid concentrations in the flesh (fillets) of male and female early Stuart sockeye salmon during the 1997 Fraser River spawning migration (n=164). Declines in flesh protein concentrations were noted when the lipid concentrations decreased to 35-40 g/kg. The shape of the curve was fitted by eye.

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EARLY STUART SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) EGG QUALITY AND EGG-TO-ALEVIN SURVIVAL FOR THE 1997 ESCAPEMENT

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INTRODUCTION

During the 1997 return migration, portions of the Early Stuart adult sockeye salmon stock encountered high water velocities at Hells Gate in the Fraser River, B.C. The result was high en route mortality and potentially increased stress levels in surviving fish. These sockeye arrive at their natal streams just prior to spawning, and any physiological changes in response to stress might result in reproductive impairment (Donaldson 1990). Thus, there were concerns over egg viability and egg-to-alevin survival of those fish that reached the spawning grounds.

In 1997, an opportunity existed to study Early Stuart sockeye egg viability and alevin survival collaboratively with ongoing research in three sockeye spawning creeks tributary to Takla Lake and Middle River. Researchers from the Takla Fish Forestry Interaction Study (Macdonald et al.1992 and Macdonald 1994) initiated sockeye fertilization success, egg-to-alevin survival, and individual female egg quality/viability experiments in artificial redds in previous years. Incidental hatchery survival data for the Stuart stock were made available by L.J. Albright (Department of Biological Sciences, Simon Fraser University).

Gluskie, Forfar, and Kynoch creeks represent three of 33 spawning streams utilized by the Early Stuart sockeye stock, making up an average of 12%, 15%, and 28%, respectively, of the total estimated early Stuart escapements (Langer et al. 1992). This report summarizes sockeye incubation information collected from these three creeks in the summer, fall, and winter of 1997. The studies provided information on egg fertilization success and egg-to-alevin survival for all three creeks, individual female egg quality/viability from Gluskie and Forfar creeks (Pedersen 1997), and hatchery survival of fertilized eggs from Gluskie Creek (L.J. Albright, unpublished data).

METHODS

Sockeye gametes used for the fertilization success, egg-to-alevin survival, and egg quality/viability experiments were collected from Gluskie Creek (August 13, 1997) and Forfar Creek (August 14, 1997). Gametes for fertilization success and egg-to-alevin survival experiments were collected and fertilized from Kynoch Creek on August 14, 1997. Five sexually mature (gravid) females were captured from each creek. A female was considered gravid when gentle abdominal pressure applied in an anterior to posterior direction along the belly easily extruded eggs. Females appearing to be partially spawned or immature were not used. The females were sacrificed, measured for fork length, weighed, and eggs stripped by abdominal massage. Approximately 250 eggs from each female were taken for egg quality/viability experiments and placed in separate containers, of which 50 eggs were frozen for subsequent egg quality analysis. A further 800 eggs from each of the five females were stripped and pooled into one container for fertilization success and egg-to-alevin survival tests. Milt from five sockeye males was collected by first drying the abdominal area with a paper towel and then applying pressure. Milt from the five fish was pooled and aliquots were added to each egg container (five containers for individual females tests and one container of pooled eggs). Docile, fungus covered, or unhealthy looking males were not sampled.

Following milt addition, sperm were activated by adding creek water to the containers. After 15 minutes, excess milt was rinsed from the eggs with creek water, and the eggs were then placed in a cooler for transport to the artificial redd site. For incubation of fertilized sockeye eggs, an *in situ* incubation capsule method described by Scrivener (1988) and Cope (1996) was used for both the egg-to-alevin survival and egg quality/viability studies. Capsules were filled with spawning size gravel (1.3-5.1-cm gravel diameter) and approximately 30 fertilized eggs were placed in each. The capsules were placed in three artificial redds dug with shovels and located in glide habitat. Capsules were placed at the mean natural redd depth of 20 cm (Macdonald et al.1992). Gravel was then placed on the redds so that fines were winnowed away by the stream flow. The artificial redds were surrounded with a wide mesh wire fence to prevent spawning sockeye from digging up the capsules while building natural redds.

To ascertain fertilization success, approximately 1200 fertilized eggs from each of the three creeks were placed in capsules (400 eggs/capsule) and kept in their respective stream water for 48 hours. They were then removed and preserved in Stockard's solution, and later examined for blastodisk formation in the laboratory (Velsen 1987).

To determine egg-to-alevin survival in Gluskie, Forfar, and Kynoch creeks, fertilized eggs were placed in 25 incubation capsules in artificial redds (3 redds/creek). In redd #2 of each creek, a Vemco temperature datalogger was buried at 20 cm for hourly intergravel temperature readings. Sediment traps and dissolved oxygen (D.O.) standpipes (20 cm depth) were placed in the redds as well. Physical monitoring at each artificial redd site included creek water temperature, dissolved oxygen, velocity, and water depth measurements. Intergravel water temperature and dissolved oxygen measurements were taken from the standpipes.

Individual female egg viability was tracked for Forfar and Gluskie creeks with five incubation capsules per female (n = 25 capsules in each of Gluskie and Forfar) placed adjacent to each other in artificial redd #2. To quantify potential egg quality parameters that could be linked to viability, frozen unfertilized egg samples were analyzed for weight, size, and lipid content. Wet and dry weights and egg diameter were determined at the Fisheries and Oceans Canada's Cultus Lake Laboratory. Total lipid content (gravimetric) determinations were made in Denmark (Pedersen 1997).

All capsules from the individual egg female quality/viability experiment were sampled September 22, 1997. Egg-to-alevin survival capsules were sampled every 2 to 6 weeks by extracting three capsules from each artificial redd. Numbers of live and dead embryos and development stage were determined in the field and samples were preserved in Stockard's solution or 10% formalin. Live/dead counts and developmental stage data were later corroborated in the laboratory.

Collection of gametes used for survival tests in a hatchery took place on August 8, 1997, from Gluskie Creek. Eggs were stripped from 20 females and milt was pooled from five males. The fish were collected, gametes stripped, and eggs fertilized in the same fashion as described previously. Fertilized eggs were stored in water and transported to a hatchery at Simon Fraser University, Burnaby, B.C. Eggs were incubated in 12 to 14 °C water until they hatched.

RESULTS

FERTILIZATION SUCCESS AND EGG-TO-ALEVIN SURVIVAL

The fertilization success for Gluskie, Kynoch, and Forfar based on three capsules per creek was 89%, 95%, and 95%, respectively. Egg-to-alevin survival was approximately 70% for Kynoch and Forfar broods (Fig. 1). Gluskie survival was considerably lower with less than 10% of eggs surviving to alevins by January 14, 1998. Physical conditions were sub-optimal in the Gluskie artificial redd numbers 1 and 3; data from these test sites were not used in the calculation of egg-to-alevin survival. In artificial redd #1 the D.O. measurements were consistently less than 1.0 mg/L (< 3.0 mg/L is considered sub-optimal for salmonid eggs, McNeil 1969; Cope 1996) and intergravel temperatures were 2.0 °C cooler than Gluskie stream temperatures, indicating a low dissolved oxygen, cool groundwater source. Artificial redd #3 was inundated with large amounts of fine sediments due to ponding created by a salmon counting fence. Both of these redd sites had nearly 100% mortality after 6 weeks. In Gluskie redd #2 there was a sharp decline in survival of eggs between fertilization and stage 15, and a steady decline thereafter. Forfar and Kynoch eggs had an initial decline in egg survival from fertilization to first collection date, followed by a slow decline. We did not find an appreciable difference in development stages between the creeks at the sample collection dates with the exception of hatching. Hatching first occurred in Kynoch Creek.

EGG QUALITY/VIABILITY

Average individual survival rates of eggs ranged between 8% and 65% in Gluskie Creek and between 63% and 92% in Forfar Creek (Table 1). Intergravel conditions were marginal in the Gluskie artificial redd (redd #2), with intergravel dissolved oxygen ranging from 3.0 to 9.5 mg/l. In Forfar Creek the intergravel conditions were optimal with dissolved oxygen ranging between 11.1 and 11.3 mg/l. An egg survival index was calculated as the arcsine of percent egg survival and compared to female fork length, egg dry weight, and egg lipid content (Fig. 2). Female wet weight and egg diameter data were considered too imprecise for comparisons to be made. Of the parameters used for description of egg quality, egg lipid content was positively correlated to egg survival in both creeks (R^2 = 0.21-0.69). The influence of female fork length and egg dry weights on survival were not consistent between creeks. Larger females had fewer eggs survive in Gluskie Creek (R^2 = 0.81) but no relation existed in Forfar Creek. Larger eggs did well in Forfar Creek (R^2 = 0.60) but had poorer survival in Gluskie Creek (R^2 = 0.44).

HATCHERY SURVIVAL

Fertilized eggs from Gluskie Creek and raised in hatchery conditions experienced a survival rate of 48% (estimated by volume) in the first 30 days after fertilization (L. Albright, S.F.U., personal communication). Survival stabilized until 60 days after fertilization when an additional 6% mortality was observed. It is suspected that the latter mortality (6%) was due to malformation or premature breakdown of the chorion. Total egg-to-fry survival was estimated at 42%. The remaining embryos hatched 75 days after fertilization (650 ATUs) and survived to 2-g fry.

DISCUSSION

FERTILIZATION SUCCESS AND EGG-TO-ALEVIN SURVIVAL

Fertilization success in 1997 of 89% to 95% is comparable to Cope's (1996) incubation work in 1993 and 1994 using the same brood stock. Average fertilization success from his study was 95% using techniques similar to ours. The slightly poorer (89%) fertilization success of 1997 Gluskie eggs may be the result of poorer egg quality.

Cope (1996) found mean survival rates 6 weeks post-fertilization in 1993 and 1994 for each creek were 22% and 14% (Gluskie), 26% and 4% (Forfar), and 70% and 61% (Kynoch), respectively. He suggested the cause of high variation between 1993 and 1994 was due to adult thermal stress and late arrival on the spawning grounds in 1994. The mean survival rates to the same developmental stage from our study were 50% (Gluskie), 88% (Forfar), and 89% (Kynoch). The 1997 survival rates are considerably higher, indicating no reduction in egg quality due to adult stress at this developmental stage. Cope (1996) found mean survival rates in late December or post-hatch in 1993 and 1994 for each creek were 26% and 8% (Gluskie), 21% and 2% (Forfar), and 67% and 64 % (Kynoch), respectively. The mean survival rates for newly hatched alevins from this study were below those found in Gluskie in 1993 and 1994, much higher in Forfar, and within the same range in Kynoch. These results highlight the large degree of variability that exists with *in situ* incubation experiments. Other researchers have noted this variability but, in general, the survival values from this experiment are considerably higher than other studies (Scrivener 1988).

The 1997 brood stock peak spawning was approximately 10 days later than the average peak spawn time, raising concerns about optimal hatching and emergence dates with reduced thermal unit accumulation in late summer. The 50% hatching date for alevins was approximated as early December which is later than the hatching range of September 27 to October 29 found by Cope (1996). Hatching did occur prior to the onset of severe 1997/98 winter conditions, which may have allowed the alevins to avoid anchor ice formation through intergravel migration (Cope 1996; Patterson and Herunter, unpublished manuscript).

EGG QUALITY/VIABILITY

Results from this study show a wide range of mean egg survival from five different spawners in Gluskie Creek (8-65%). This difference is likely attributed to variation in egg quality since milt quality, incubation conditions (the incubation capsules were placed immediately adjacent to one another in artificial redd #2), and treatments were identical among the five groups of eggs. The selection of "gravid, healthy" females reduced the possibility that mortality was caused by immature or overmature eggs (Craik and Harvey 1984; Springgate et al. 1984). The high pre-hatching mortality in Gluskie Creek may be due to marginal intergravel conditions at the artificial redd site.

Forfar females exhibited much higher and more consistent egg survival rates (61-93%) than Gluskie females. It is not known when the specific stocks (i.e., Gluskie, Forfar) of fish migrated through Hells Gate or whether they were subjected to similar migrational stresses, but our limited data set suggests that Forfar fish arriving on the spawning grounds had higher egg survival rates than Gluskie fish.

Of the egg quality parameters investigated only egg lipid concentration showed a positive trend in both Forfar and Gluskie creek fish when compared to percent survival. The divergent results (female length and egg dry weight) obtained between Forfar and Gluskie females and eggs may be due to Gluskie fish being more highly stressed or an artifact of small sample size. Our preliminary data suggest that egg lipid concentration may be a useful indicator of egg viability.

HATCHERY SURVIVAL

Hatchery survival of Gluskie eggs (42%) is very low compared to gamete collections from other B.C. sockeye stocks by Fisheries and Oceans Canada staff, where total egg-to-fry survival averaged 95%. All stocks were collected, fertilized, and handled in an identical manner. These data indicate that, in general, the Gluskie Creek gametes were of poor quality. The above natural incubation temperatures of 12 to 14 °C may have been the cause of the 6% loss 2 weeks prior to hatching; however, August ,1997, Gluskie Creek intergravel temperatures ranged from 11.0 to 12.5 °C. Hatchery survival to the 20-day stage was poor (48%); the *in situ* egg-to-alevin experiment found Gluskie survivals at 10 days post-fertilization to be similar at 55%.

SUMMARY

The following points summarize fertilization success, egg-to-alevin survival, egg quality/viability, and hatchery survival for selected 1997 Early Stuart stocks:

1. Fertilization success (for three creeks) of 89-95% was similar to previous studies. Slightly lower 1997 fertilization success was exhibited by Gluskie eggs.

2. Egg-to-alevin survival (for three creeks) was low for Gluskie (10%), average for Kynoch (70%), and above average for Forfar (70%) compared to previous studies.

3. Individual female egg quality/viability appears to be more inconsistent between females and generally lower for Gluskie Creek than Forfar Creek in 1997.

4. Egg lipid concentration showed a positive trend with percent survival in both Forfar and Gluskie creeks.

5. Hatchery egg-to-fry survival of Gluskie stock was poor (42%).

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Table 1. Female spawner size, egg measurements, and egg survival rates for 10 females collected from Gluskie and Forfar creek, August, 1997. Egg diameter, egg wet weight, and egg dry weight were based on a sample size of 20 eggs; standard deviation in parentheses. Lipid content was determined from triplicates of homogeneous dried egg masses. Egg survival was based on samples collected 6 weeks post-fertilization. Egg survival rate is the average percent survival from 2 capsules of 30 eggs for each female. * Values not available.

Female Spawner	Fork Length (cm)	Wet Weight (lbs)	Egg Diameter (mm)	Wet Weight /egg (mg)	Dry Weight /egg (mg)	Lipid /egg (mg)	Egg Survival (%)
Female 1 Gluskie	60.5	5.3	5.30 (0.14)	85.54 (4.09)	32.98 (1.6)	-----*	**10**
Female 2 Gluskie	52.4	3.1	4.83 (0.10)	66.27 (2.71)	24.77 (1.2)	3.70 (0.07)	**42**
Female 3 Gluskie	58.8	5.1	5.17 (0.11)	84.78 (2.77)	32.57 (1.0)	5.05 (0.17)	**30**
Female 4 Gluskie	59.5	4.7	5.03 (0.11)	79.43 (3.76)	30.17 (1.3)	1.72 (0.03)	**8**
Female 5 Gluskie	52.1	3.4	5.02 (0.13)	75.27 (3.49)	27.10 (1.6)	3.76 (0.10)	**65**
Female 1 Forfar	56.8	4.1	5.20 (0.14)	83.48 (3.68)	31.06 (1.1)	4.87 (0.02)	**92**
Female 2 Forfar	57.2	4.2	5.20 (0.11)	89.22 (3.44)	35.77 (1.4)	5.54 (0.09)	**93**
Female 3 Forfar	60.8	5.8	5.29 (0.13)	82.56 (4.27)	33.61 (1.5)	5.31 (0.02)	**80**
Female 4 Forfar	55.2	3.5	5.15 (0.14)	78.94 (3.21)	29.33 (1.1)	4.18 (0.05)	**61**
Female 5 Forfar	59.3	4.8	-----*	75.69 (4.26)	28.24 (1.2)	3.87 (0.01)	**63**

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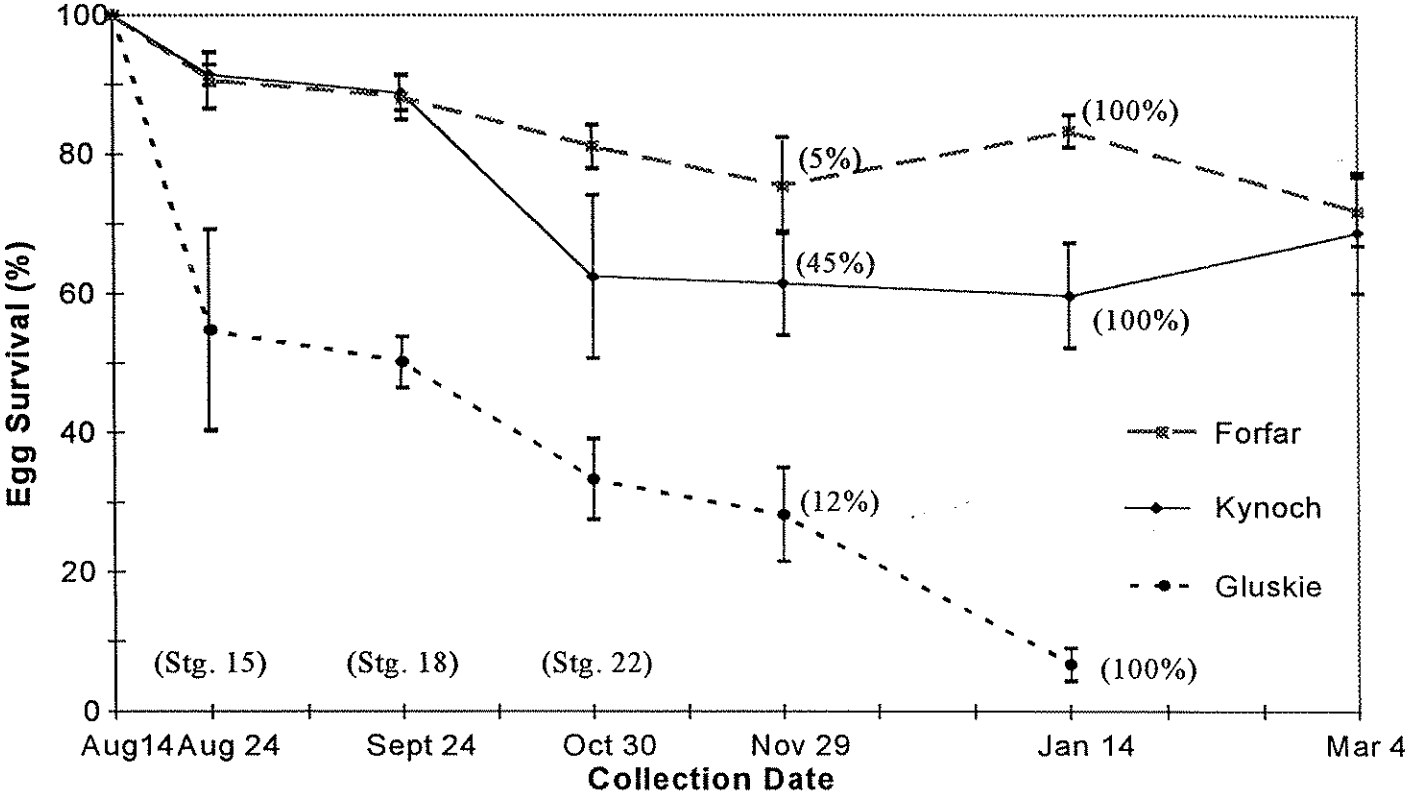

Fig 1. Egg survival from incubation capsules for Kynoch, Gluskie, and Forfar creek sockeye. Kynoch and Forfar survivals at each collection date are the average survival for nine capsules containing thirty eggs each. The Gluskie survivals are based on three egg capsules. Gluskie was not sampled in March. Bracketed values from Aug. 24 to Oct. 29 represent the mean development stage for all three creeks (based on Velsen 1987). The bracketed percentages on Nov. 29 and Jan. 14 represent the percentage of alevins hatched for each creek. Error bars represent +/- 1 standard error.

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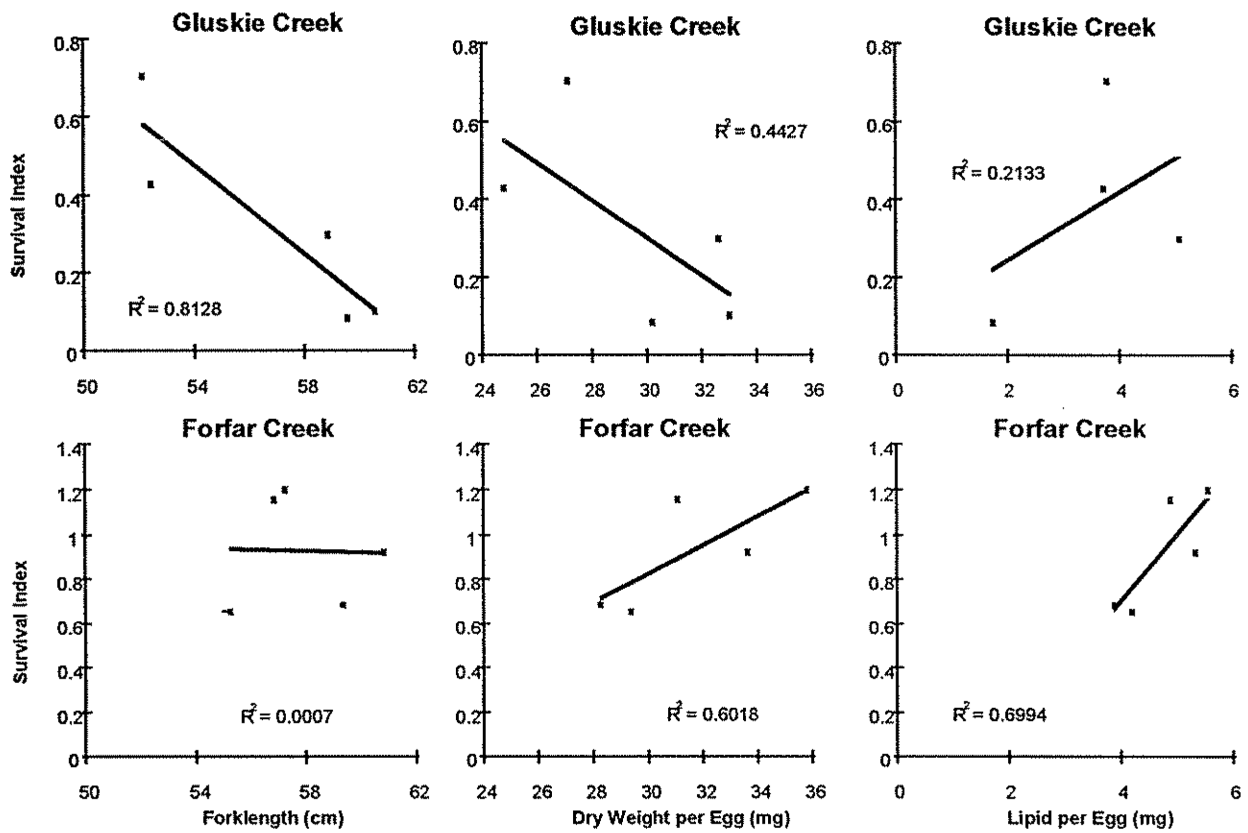

Fig. 2. Egg survival rates 6 weeks post-fertilization from individual females as related to female fork length, pre-fertilization egg dry weight, and pre-fertilization lipid content. Survival index is the arcsine transformation of the egg survival rate.

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MANAGEMENT IMPLICATIONS TO THE 1997 MIGRATION AND FUTURE NEEDS

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The Fraser River Panel was formed in 1985 under the auspices of the Pacific Salmon Treaty to manage commercial fisheries for Fraser River sockeye and pink salmon in Panel Area waters. The Panel is a bilateral body, composed of Canadian and U.S. section members, that regulates fisheries to achieve targets for spawning escapement and catch by First Nations in the Fraser River watershed (gross escapement), and international and domestic catch allocations for commercial fisheries.

Stock assessment information, including in-season sockeye and pink run size and passage at Mission, the up-river boundary for Panel Area commercial fisheries, is provided by the Fisheries Management Division of the Pacific Salmon Commission (P.S.C.). Fisheries and Oceans Canada manages fisheries outside the Panel Area in a complementary manner to Panel regulations with the use of the stock assessment information provided to the Panel. Objectives for gross and spawning escapement and catch of Fraser sockeye are established by grouping the stocks based on migration timing: (1) Early Stuart, (2) Early Summer run stocks, 3) Mid-summer run stocks, and (4) Late run stocks. Pre-season fishing plans are produced from information on forecasts of return size, migration timing, and coastal migration routes, escapement objectives, and international and domestic catch allocations.

Canada and the U.S. did not reach an agreement on catch sharing arrangements for Fraser River sockeye and pink salmon for the 1997 season. Domestic fisheries were regulated by the respective countries through an agreed procedure whereby P.S.C. staff would conduct their planned stock assessment programs to provide Canadian and U.S. Panel chairs with estimates of in-season run size, Panel Area catch, and sockeye and pink passage at Mission. Both countries also agreed to frequently exchange information on fishing plans and the fisheries throughout the season. These procedures were followed throughout the season.

In Canada, Canadian members of the Fraser River Panel, Fisheries and Oceans Canada management committees and First Nations fisheries representatives convened many times a week throughout the season to receive P.S.C. and Fisheries and Oceans Canada information updates and provide advice on development of fisheries regulations for Canadian commercial fisheries. Through this process, all parties involved in fisheries management were kept informed of the environmental influences on salmonid migration in the Fraser River.

Description of the assessment and management of the Early Stuart sockeye salmon return is the focus in this report, a stock that was present and numerically abundant at the time of the migration impedance, and was harvested by fisheries in both Canada and the U.S. The information was obtained from currently unpublished in-season information exchanged between P.S.C. staff, Canadian and U.S. co-chairs of the Fraser River Panel, and Fisheries

Oceans Canada, from P.S.C. news releases issued periodically during the season, and from the Environment Watch web site.

The Early Stuart sockeye forecast return and escapement target in 1997 was 1,044,000 and 500,000 fish, respectively. An allowable catch was anticipated and fisheries were planned if the in-season run size estimate was as forecast. During the initial period of the migration in late June and early July, the size of the return was unknown, and P.S.C. staff indicated in-season assessment would not be possible until a peak in abundance passed through Juan de Fuca Strait. The return appeared to be either late or less than forecast, and fisheries in Canada remained closed below Sawmill Creek (between Hope and Qualark Creek) (see Fig. 1, Introduction).

On June 27th, P.S.C. staff expressed a concern that high water levels in the Fraser River might present migration difficulties for Early Stuart sockeye salmon, but by July 6th the migration concern was reduced when the Fraser River discharge dropped to slightly above average (see Fig. 2, Foreman et al. 2000). Water temperatures were also within the optimal range for efficient swimming according to an Environment Watch update. Beginning in the first week of July, both countries were kept apprised of Fraser River discharge and temperature conditions on a continual basis through the Environmental Watch program.

The U.S. opened their first fishery, by reef nets, on July 5. By July 6, stock assessment indicators suggested that the return would be similar to the pre-season forecast but with a later migration timing than normal. Migration into the river was estimated to be above 100,000 sockeye past Mission. Provided with this information, the U.S. opened Treaty Indian and non-Indian gillnet fisheries in Areas 7 and 7A on July 7-8. Canada opened the following fisheries: commercial gillnet fisheries in Johnstone Strait on July 7-8 and in the Fraser River on July 9, a commercial troll fishery in Johnstone Strait and the Strait of Georgia on July 10-11, and First Nations gillnet fisheries from Steveston to Sawmill Creek within the July 6-8 period.

On July 10, the Early Stuart run size assessment continued to suggest a return similar to the pre-season forecast, although the number of fish entering the lower Fraser River was not keeping track with gross escapement requirements. Although Canadian commercial and aboriginal pilot sales fisheries were anticipated in the pre-season plan for the following week of July 13 to 19, these were not scheduled because fish were required for spawning escapement and upper Fraser aboriginal catch. Fisheries were also not scheduled in the U.S. The Environmental Watch update on July 10 indicated that river discharges were increasing to well above average levels.

Through the week of July 13-19, migration conditions in the Fraser River deteriorated and became a serious concern in Canada as discharge increased to levels that caused sockeye migration impediments in previous years. Fisheries remained closed in Canada below Sawmill Creek and in the U.S.

On July 16, the Early Stuart sockeye run size estimate was increased to 1,200,000 sockeye. The abundance of sockeye entering the Fraser River had also increased substantially, and by July 18, the estimate of Early Stuart sockeye past Mission was approximately 600,000 fish.

On July 17, quantitative estimates of impacts to sockeye migration as a result of the Fraser River conditions were developed using an 'Integrated Fraser Model' and made available publicly in the Environmental Watch updates (Williams et al. 1999; Macdonald et al. 2000).

Fisheries below Sawmill Creek were not scheduled for the following week of July 20-26 in areas of Early Stuart abundance because of the environmental concerns. All parties closely followed the progress of the run.

On July 21, an Environmental Watch update included river discharge levels and estimates of effects of migration impedance from the Integrated Fraser Model. Discharge had dropped significantly to 7,500 CMS on July 21 from a peak of 9,300 on July 16. Concern abated for sockeye that entered the lower river at the lower discharge levels but continued to exist for that part of the population that was exposed during the period of high discharges. The model indicated that of approximately 500,000 sockeye exposed to the high discharge, the mortality estimate was 14% and the proportion seriously at risk to enroute mortality was estimated at 18%, for a total of 32% (range of 27%-37%) affected by the unusually high discharges.

Response to these predictions of enroute mortality became an in-season fisheries management issue since the Early Stuart run was still in progress. Migration into the lower river continued, and on July 21, the in-season estimate of Early Stuart passage at Mission was 773,000 sockeye, and the run size estimated was 1,400,000. The Panel decided to respond to the mortality issue, in addition to the sustained closure of fisheries that had been implemented, by increasing the gross escapement of Early Stuart sockeye to compensate for enroute mortality estimates. The decision to adjust the gross escapement was made because the run size increase identified a potential for additional catch, and the Panel wanted to ensure that measures were taken to adequately address the enroute mortality issue prior to further fisheries.

The gross escapement adjustment was calculated by multiplying the estimated rate of mortality (37%) by the estimated number of Early Stuart sockeye exposed to the high discharge levels (506,000 fish); the product of 187,000 was added to the Early Stuart sockeye gross escapement target. The mortality estimate of 37% was selected from the upper end of the potential mortality range of 27% to 37% following the precautionary principle in an attempt to reduce the risk of underestimating the actual mortality.

During the week of July 20-26, migration conditions improved, the Early Stuart sockeye run size was increased to 1,550,000 sockeye, and the Mission estimate of Early Stuart sockeye increased to a level (greater than 900,000 sockeye) well above the adjusted gross escapement target. Given these circumstances, additional fisheries directed on Early Stuart sockeye were opened in Canada for commercial and First Nations gillnet fisheries in the Fraser River within the period July 23-27. Mission estimates of Early Stuart sockeye subsequently increased to 1,100,000 fish.

After the week of July 20-26, no further adjustments to fisheries or gross escapements were made by the Panel in response to adverse environmental conditions because migration conditions improved and further enroute mortality problems were not identified.

In 1997, observations of environmental conditions and estimation of impacts to salmon migration during the season allowed rapid adjustment to fisheries and management targets of escapement and catch. Annual in-season assessments of migration conditions are required if the strategies followed in 1997 are to be improved and implemented in the future.

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