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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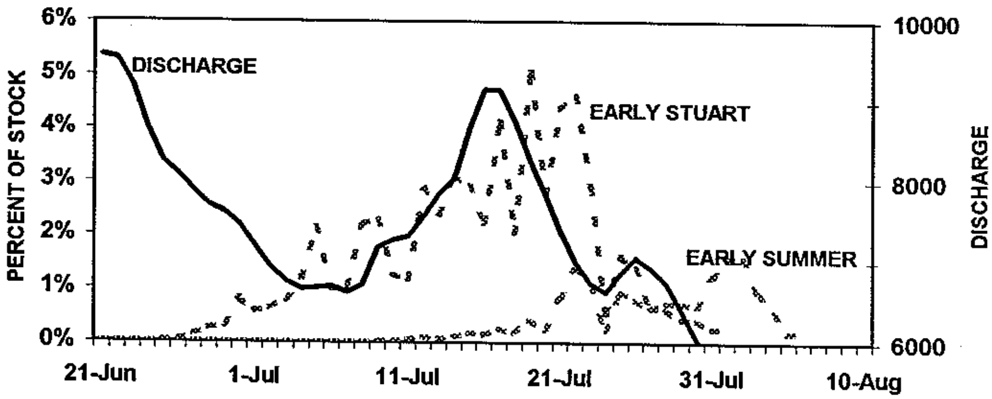

Fig. 1. During 1997 the Early Stuart sockeye salmon migration coincided with a high discharge event in the lower Fraser River. Water levels exceeded 8000 cms for nearly a week as 100,000 to 200,000 fish a day entered the Fraser River.

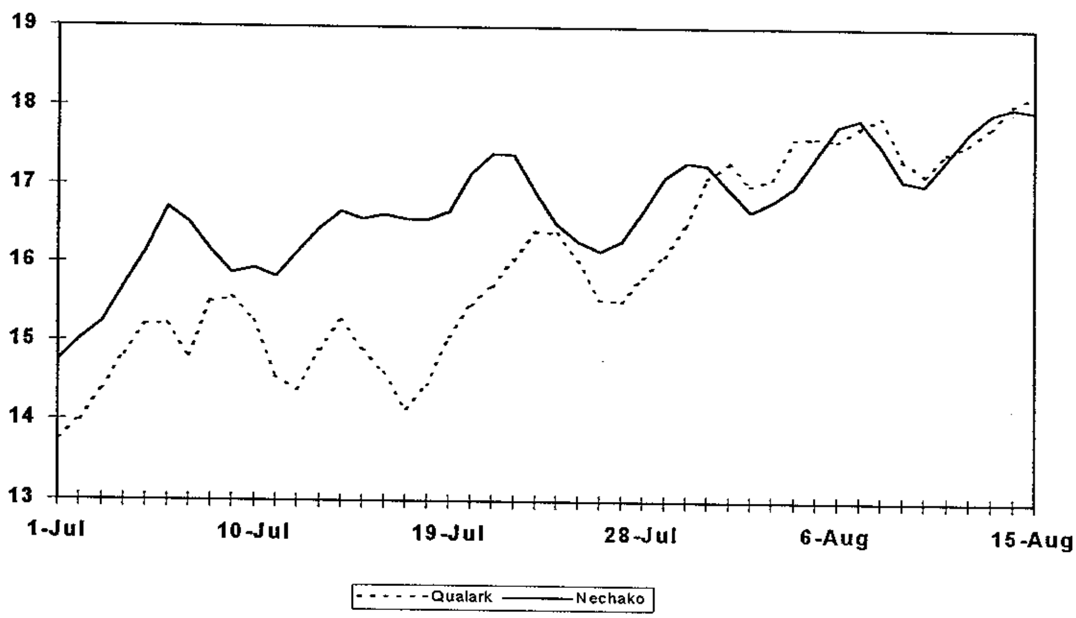

Fig. 2. Water temperatures during the summer of 1997 in the Fraser River watershed. Temperatures in the Fraser River canyon were collected from Qualark Creek, downstream of Hells Gate. Nechako River temperatures were collected near Prince George, upstream of the confluence with the Fraser River.

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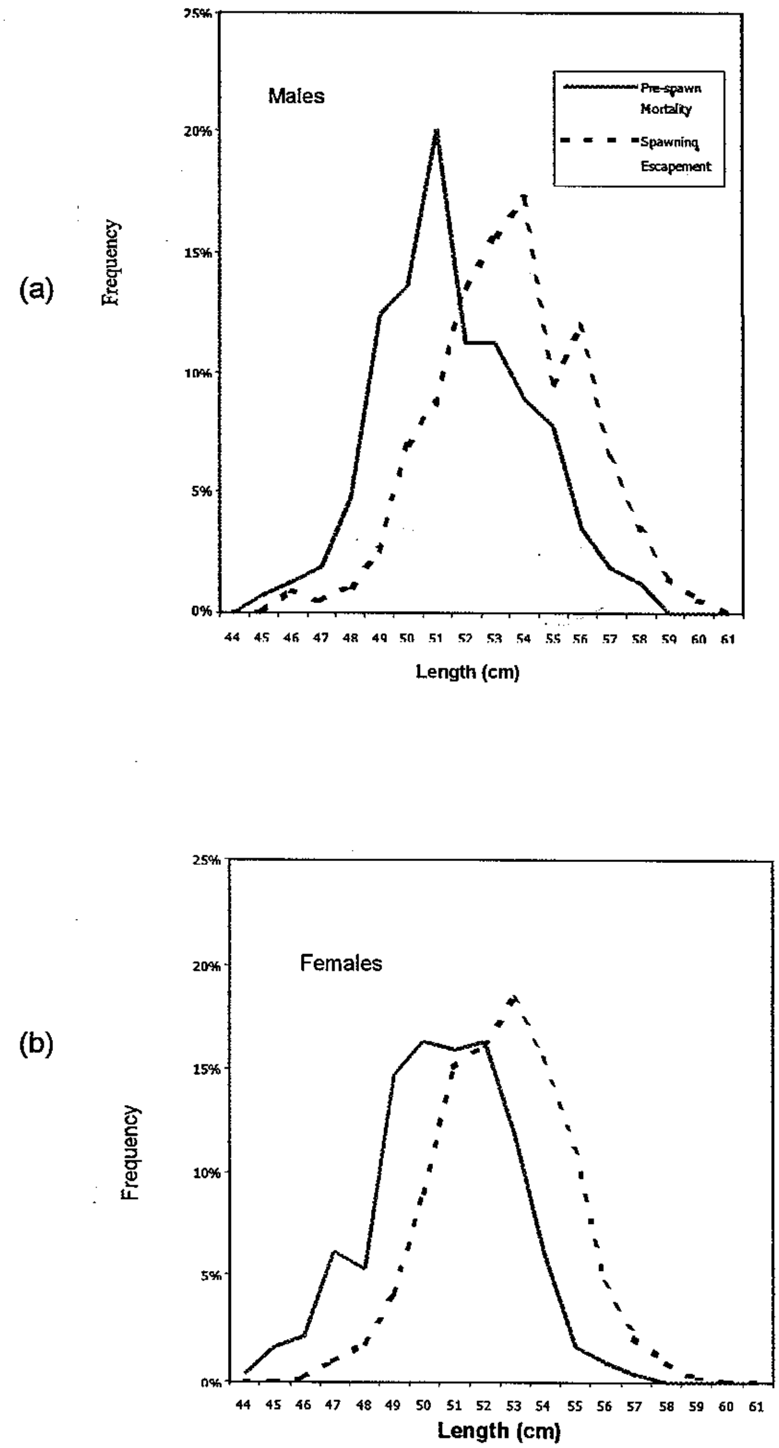

Fig. 3. Lengths of Early Stuart sockeye that spawned successfully compared with sockeye that arrived at the spawning grounds but died before spawning in 1997. Males (a) and females (b) are plotted separately.

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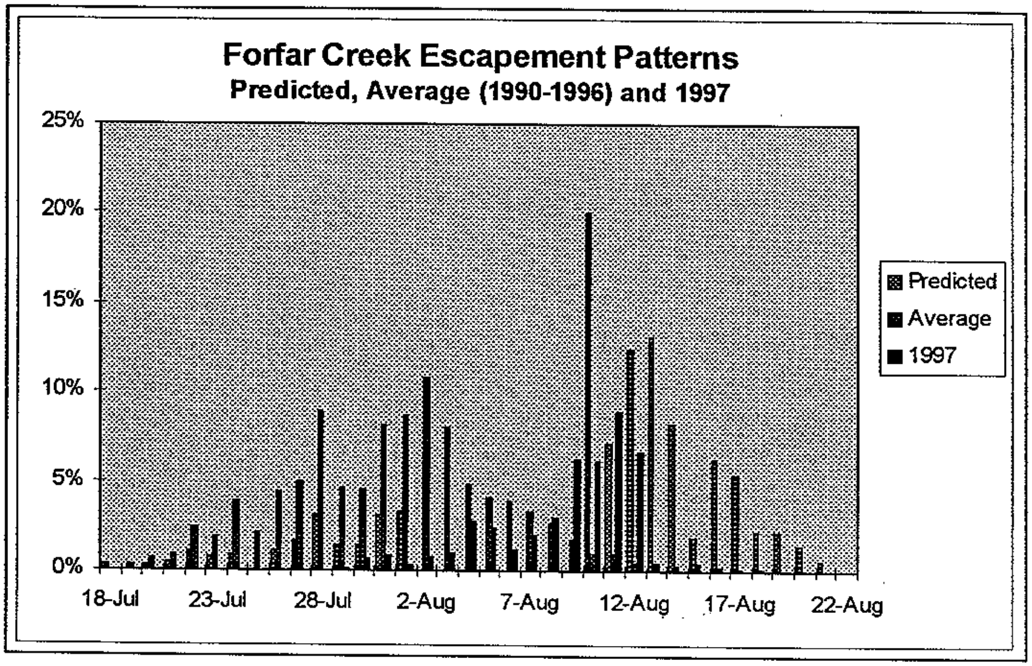

Fig. 4. Comparisons of actual arrival timing with timing predicted by the integrated Fraser salmon model. Average arrival timing during the last 7 years is also presented to demonstrate the 1997 delay in arrival.

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(a)

(b)

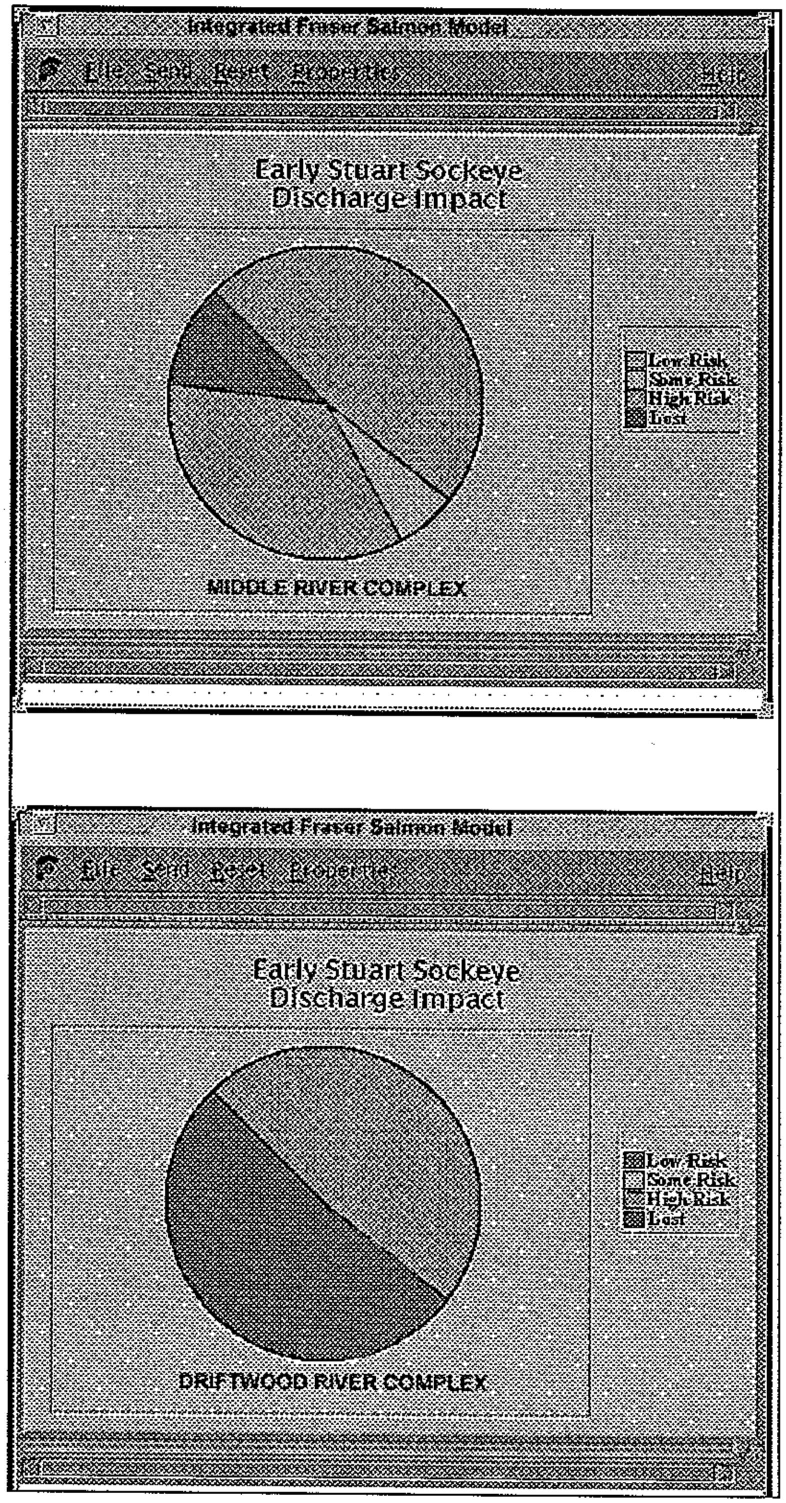

Fig. 5. Results of the integrated Fraser salmon model based on conditions faced by (a) the Middle River stock group, and (b) the Driftwood River stock group which assumes an additional 2 days' swimming time. Risk of loss is presented in four categories.

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