

# Late-run Sockeye Salmon in the Fraser River, British Columbia, are Experiencing Early Upstream Migration and Unusually High Rates of Mortality—What is Going On?

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[Note: Figures for Lapointe et al are included at the end of this paper.]

## Abstract

Late-run stocks are unique among Fraser River sockeye salmon populations in that they typically delay in Georgia Strait 4 to 6 weeks prior to migrating upstream to spawn. Beginning in 1995, and continuing through 2002, this delay period to 6 weeks earlier than normal. Each year, the early river entry has been associated with high rates of en-route and pre-spawning mortality (>90% in 2000 and 2001). The abnormal behavior and mortality was less extreme in 2002 than the prior two years and results from a radio tagging program indicated that individual late-run sockeye exhibited a range of behaviors from little or no delay to near normal delay. The abnormal behavior and subsequent mortality is already threatening the viability of small populations (e.g. Cultus Lake sockeye). The Pacific Salmon Commission has held workshops and funded several studies to begin investigating the causes of this behavior. Many competing hypotheses have been proposed (e.g. involving physiology, environmental conditions, contaminants, parasites, and predators) regarding the reason(s) for early migration and high mortality. However, the cause of the behavior and mortality remain unknown. Precautionary management actions have resulted in large foregone catches of late-run and summer-run sockeye populations that co-migrate with late-run stocks in the fishing areas (e.g. Adams and Horsefly River sockeye). Similar behavior has been observed in other Fraser River salmon species, but the high mortality rates have not yet been observed.

## Introduction

The Fraser River (Figure 1) is the largest producer of salmon in Canada. Of its five salmon species, sockeye salmon (*Oncorhynchus nerka*) is most commercially valued and the second most numerically abundant. Sockeye spawn in over 150 natal areas throughout the Fraser watershed in locales ranging from 100 to 1200 km upstream from the river mouth. After emergence in natal rivers, fry typically rear for one year in a nursery lake, migrate to the Pacific Ocean as smolts, and return at four years of age to spawn in their natal rivers. About 90% of the total production originates from fewer than 10 nursery lakes. Our knowledge of how Pacific salmon achieve these remarkable migrations is rudimentary (reviewed in McKeown 1984). Maturing sockeye salmon probably find their way from high seas to coastal rivers using a combination of ‘assists’ by ocean currents, environmental cues (e.g. celestial bodies, amount/angle of daylight, magnetic fields; Thomson et al. 1992; Dat et al. 1995, compass-orientation (Quinn 1990; Ogura and Ishida 1995), vision, and olfaction (Ueda et al.1998).

Individual Fraser River sockeye salmon populations have characteristic timings of adult return, and are broadly classified into four groups or ‘runs’ for management (Gable and Cox-Rogers 1993). The early Stuart run consists of populations that spawn in tributaries to Stuart Takla and Trembleur lakes, but the three remaining runs, early summer, summer, and late, are not geographically discrete, and each contains populations from throughout the Fraser River drainage (Figure 1). Abundance of some Fraser River sockeye populations is cyclical, characterized by peak years of large abundance every four years interspersed with years of lower abundance. The summer run is generally the largest, whereas the Late run is abundant in years that are peak years for major constituent populations. The largest Late-run populations occur in peak years (e.g. 1994, 1998, 2002) for the Lower Adams River in the Thompson River drainage (Figure 1). Weaver Creek and the Harrison River in the lower Fraser River and Portage Creek in the Seton-Anderson lake system are the primary contributors on the non-peak years for the Adams stock (Figure 1).

## Migration Timing: Normal and Abnormal

Each of the four management groups arrives sequentially to coastal waters (Johnstone and Juan de Fuca Straits) during the summer months. The peak arrival for early Stuart sockeye typically occurs in early July, followed by the early summer run in late July, the summer-run stocks in early August, and late-run stocks about the third week of August (Gable and Cox Roger 1993). Sockeye salmon take about 1 week to swim from these coastal areas to the Fraser River mouth at which point all but the late-run stocks migrate directly upstream to spawning areas. The progress of upstream migration has been monitored daily since 1974 using a combination of hydroacoustics, test fisheries, and stock identification programs operated by the Pacific Salmon Commission (PSC; Woodey 1987). Historically, Late-run stocks have held in the Strait of Georgia for several weeks before initiating up-river migration. Consequently, their upstream migration has typically peaked in late September (e.g. Adams River sockeye Figure 2a). However, beginning in 1995, the late-run stocks arrived in Georgia Strait at the normal time but commenced their river migration about three weeks earlier than normal (Figure 2b). Since then, late-run sockeye have entered the river progressively earlier each year and in 2000 and 2001, entered the river more than one month earlier than normal (Figure 2c-f). The migration pattern in 2002 was much less extreme than recent years and more similar to patterns observed in the late 1990s (Figure 2g).

The upstream migration pattern for Cultus Lake sockeye has been monitored extensively since the 1940s using a fence at Swelter Creek that is located near the Cultus Lake spawning areas about 100km upstream (4 to 5 days travel) from the estuary. A very stable migration pattern has been observed in each decade from the 1940s through the early 1990s (Figure 3a-f). However, since 1995, the Cultus sockeye have migrated upstream earlier showing a similar pattern to Adams stock (Figure 4b-g). In fact, the same pattern of early river entry in recent years has been observed in all late-run stocks for which monitoring data are available.

A large radio tagging program was conducted in 2002. Sockeye were radio tagged in Johnstone and Juan de Fuca Straits, released and then tracked at 14 receiver sites along the Fraser river. Individual sockeye were identified to stock of origin using DNA methods, and stock assignment was later verified by subsequent tracking to spawning areas. Approximately 230 radio-tagged late-run sockeye passed the radio receivers at Mission (near the PSCs hydroacoustic facility) and they showed a very similar pattern of entry to the overall late-run migration (Figure 5; English et al. 2003). However, individual late-run sockeye released at the same time and location exhibited a range of behaviors from little or no delay to near normal delay (Figure 5).

## High Mortality Associated with Abnormal Migration Timing

Associated with this abnormal behavior has been an extraordinarily high mortality rate prior to spawning that has steadily increased since 1996. The mortality has two components: (1) fish that die en-route to the spawning grounds or *en route mortality*, and (2) fish that die unspawned on the spawning grounds or *pre-spawning mortality*. By 2001, the en-route

mortality was as high as 90% in some stocks and pre-spawning mortality ranged from 10 to 30% (Lapointe 2002). In contrast, prior to 1995, *total* freshwater mortality for late-run stocks rarely exceeded 20%. The levels of total mortality prior to spawning increased with earlier upstream migration (e.g. Adams River; Figure 6). Based on the results of the 2002 radio tagging, en-route mortality is highest for the earliest river entrants, and mortality declines for later groups (English et al. 2003). The rate of en-route loss for late run sockeye passing Mission prior to August 17 was 87% ( $\pm 9\%$ ), and 37% ( $\pm 9\%$ ) for fish entering August 17-31, 20% ( $\pm 6\%$ ) for fish entering September 1 through 10, and only 8% ( $\pm 2\%$ ) for fish entering after September 10<sup>th</sup> (overall rate for all timing groups was 19% $\pm 3\%$ ; English et al. 2003). This compares to a relatively consistent and low mortality rate of co-migrating summer run sockeye (overall 8% $\pm 3\%$ ; English et al. 2003). A disk tagging study in the lower Thompson River on Adams River sockeye found a similar pattern for the pre-spawning mortality rate, with the earliest river migrants experiencing 71% pre-spawning mortality rates and the latest migrants having <1% pre-spawn mortality (T. Whitehouse, personal communication). This temporal pattern of pre-spawn mortality is not unusual for Fraser River sockeye. However, it can be a problem when a significant portion of the run migrates into freshwater early as has occurred in recent years with late-run stocks because the high pre-spawn mortality in incremental (applies to the survivors) to the already high en route mortality. For example, the combined effects of 87% en route mortality and 71% pre-spawn mortality mean that the earliest river migrants experienced a total mortality prior to spawning of 96% in 2002.

The high levels of mortality prior to spawning have already threatened the viability of small late-run populations. For example, the recent spawning populations at Cultus Lake have declined dramatically compared to historical averages (Table 1) and no successful spawners were observed in the Cultus Lake sockeye population between 1999 and 2001 (Schubert et al. 2002; a few fish must have spawned successfully as either fry or smolts were found following each of these years). Although the Cultus Lake stock has been declining in abundance for more than 20 years, the recent increase in mortality and reduction in spawning success coincident with the early migration phenomenon has served to push this stock to critical levels, despite the fact that exploitation rates have been held to less than 20% in recent years (Schubert et al. 2002). Projections for the next three generations under different rates of mortality prior to spawning and exploitation rates suggests that if mortality exceeds 90%, then the effective spawning population will decline by more than 75% with no exploitation, and by over 80% if exploitation rate exceeds 10% (Schubert et al. 2002). The Committee for the Status of Endangered Wildlife in Canada (COSEWIC) emergency listed the Cultus Lake Stock as endangered on October 25, 2002, representing only the second time in the past decade that COSEWIC has made an emergency designation (COSEWIC 2002). Emergency listings are reserved for instances when the risk of extinction is imminent and COSEWIC determines that there is insufficient time for the normal assessment process. The plight of the Cultus Lake sockeye exemplifies the additional risk imparted by the recent phenomenon of early migration in addition to other sources of mortality such as harvest.

**Table 1.** Most recent year total escapements and pre-spawning mortality rates compared with historical averages for each of the 4-year cycles of Cultus Lake sockeye. Data from Schubert et al. 2002.

Cycle line Escapement data				
	1998	1999	2000	2001
Avg. 1996-2001	8,767	20,154	5,456	1,434
Most recent year	2,166	12,403	1,227	656
Pre-spawn mortality rate	38%	100%*	100%*	100%*

Notes: \* A few fish that must have successfully spawned as fry or smolts were found in the following year. 2002 Escapement was 4,882 and pre-spawn mortality rate was 14%

### Early Upstream Migration of Other Species

It appears that earlier upstream migration is occurring in other Fraser river salmon species including pink (*O. gorbuscha*), chum (*O. keta*) and chinook salmon (*O. tshawytscha*) (Figure 7). This observation may provide clues to potential causal factors as these species have different marine and freshwater life histories than sockeye, yet they appear to be exhibiting somewhat coincident behavior changes at the adult life stage (except chum which appear to be showing a long term trend towards earlier upstream migration; Figure 7). However, it is possible that the pattern in the other species is simply a coincidence, perhaps due to temporally varying stock abundance within the species (e.g. increasing relative abundance of earlier timed stock components in recent years). Furthermore, it is not known whether mortality rates were elevated in these other species.

## **Possible Causes of Early Migration/High Mortality Phenomenon**

Neither fisheries managers nor scientists understand why these fish are entering rivers early and experiencing such high levels of mortality. The Pacific Salmon Commission has held workshops and funded several studies to begin examining potential causes of the abnormal behavior and mortality. Hypotheses related to physiology (e.g., energetics, osmoregulation, endocrine), environmental factors, contaminants, parasites and diseases, and predators have been proposed. Below we briefly explore possible causes responsible for early migration and mortality. Some factors may only affect timing or mortality, so both are not discussed in all cases.

### **Physiological Issues**

Pacific salmon use a number of biological clocks and cues to time the initial departure from open ocean, onset of gonad development, switch from hypo-osmotic to hyper-osmotic regulation, metering out energy reserves, final gonadal ripening, behaviors of river migration and mating, and senescence. Behavioral and physiological aspects of the first two points, are 'high-seas' issues where as the last five points are more pertinent to the early migration phenomenon, which is related to early entry *into* the river and not early arrival *at* the river (Lapointe 2002). Late-run sockeye are arriving to the river at the same time as they always have historically, but are not "holding" as they used to do. For this reason, our current discussion of possible physiological causes will not include 'high-seas' issues and will instead focus on (1) energy status and (2) osmoregulatory and endocrine issues.

### **Energy Status and Use**

Sockeye salmon do not actively feed during upriver migrations and Late-run sockeye do not generally feed during their "holding" pattern in the Strait of Georgia. Because salmon have limited energy and time to complete their migration and spawn, unusually low energy reserves could be a trigger that prompts late run sockeye to initiate freshwater migrations earlier than usual. The spawning ground lengths of mature Late-run sockeye have been increasing during the period of early upstream migration which suggests that low energy reserves may not be an issue (Lapointe 2002). However, in some recent years, body energy density in Fraser River sockeye stocks has been significantly lower (Crossin 2003) than that observed during the only other time that it was measured (the 1950s; Gilhousen 1980). Thus lengths may not be accurate measures of overall body energy.

The prevalence of energetically costly swimming behaviors has been directly linked to migration mortality in other populations of Fraser sockeye (Hinch and Bratty 2000). Following the spring freshet, the Fraser River discharge declines throughout the summer and into the fall. As river discharge declines, river temperatures increase through the summer and then begin to decrease in the fall with declining air temperatures. Thus, late-run salmon that enter the river earlier than normal encounter temperature and flow conditions to which they may not be properly adapted. Elevated temperatures accelerate energy depletion by speeding up routine metabolism, but the largest energy drain is caused by fast water flows that elevate active metabolism. The combination of increased flows and temperatures associated with early entry could lead to increased en-route and or pre-spawn mortality. However, since 1995, summer discharge or water temperatures have not consistently generated difficult migratory conditions so it is unlikely that environmental conditions, alone, are causal factors.

### **Osmoregulation and Endocrinology**

Salmon must adjust their osmoregulatory (and ionoregulatory) systems before moving from the sea to freshwater. In seawater, fish constantly gain ions and lose water across the gills, but remain in osmotic and ionic balance by drinking seawater and excreting excess ions (Clarke and Hirano 1995). In freshwater, fish face the opposite problem since they gain water and lose ions across the gills, but remain in balance by producing dilute urine and actively taking ions up at the gills. Osmoregulatory dysfunction clearly represents an additional possible cause since this would adversely affect swimming ability, and thus lead to premature mortality.

Endocrine factors such as thyroid hormone, cortisol, prolactin and growth hormone control the osmoregulatory transition from seawater to freshwater. An uncoupling of the endocrine signals that prepare adults to migrate upstream may cause early freshwater entry. Reproductive hormones are critical to other behaviors since plasma levels of sex hormones show distinct patterns that correlate well with egg maturation and spawning behaviors during salmon migration (McKeown 1984). However, there has been little research on the role of reproductive hormones in relation to migration behaviors. One hypothesis suggests that changing levels of reproductive hormones initiate homing migration, as well as the onset of gonadal growth (Ueda et al. 1998). A preliminary study on the 2001 late-run sockeye found that some of the maturation hormones were at levels below those expected (Farrell and Van Der Kraak unpublished data). Possibly, the normal delay in river entry by late-run sockeye is controlled by timed variation in reproductive hormones.

## Oceanic and In-river Environmental Conditions

Environmental conditions in the region of the Pacific where Fraser sockeye salmon grow are dynamic, responding to large-scale changes in climate. Climate changes occur on different time scales and are caused by different phenomena. Changes to the Aleutian low pressure gradient drive ocean productivity on 10 to 20 year cycles (termed regimes; Beamish et al. 1997). Abrupt changes in productivity (termed regime shifts) occurred in 1998/1999 and have been hypothesized as a factor causing the change in sockeye salmon migratory behavior (Beamish et al. 2002). This most recent regime (1998-2001) is regarded as being exceptionally warm with poor growth and abundance of euphasids, a primary food source for sockeye. However, the early migration phenomenon occurred during other regimes too (1996-1997 and 2002). Thompson (2002) and Blackbourn (2001) summarized oceanographic variables (e.g., physio-chemical water properties, upwelling indices, current patterns, climate indices) for the coastal straits, continental margin, and northeast Pacific. No definitive links were established by preliminary analyses between the abnormal migration behavior and conditions in the Strait of Georgia (coastal strait) or the Juan de Fuca Strait (continental margin; Figure 1).

At present, there is little evidence to suggest that earlier than normal migration in Fraser sockeye is related to inter-annual changes in Fraser River discharge or temperature (Blackbourn 2001; Thomson 2002; Lapointe 2002). It is possible that these environmental features could affect migration success and mortality through effects on energy, as discussed above and through interactions with parasites as discussed below.

## Parasites and Disease

There are many examples of altered behavior of fish (hosts) that attempt to either avoid zones of infection or alter their behavior as a result of infection. For example, in Ireland, sea lice (*Lepeophtheirus salmonis*) infestations were associated with premature river migrations of sea trout (*Salmo trutta*; Tully et al. 1993). Though there is no compelling evidence that sea lice are responsible for early migration in sockeye salmon, it is possible that a kidney parasite (*Parvicapsula minibicornis*) may be. The parasite has been rarely detected in Fraser sockeye sampled in marine areas and is undetectable when sockeye first enter the river, but by the time salmon reach spawning grounds, the parasitic infection is typically severe (Jones et al. 2003). It has been identified in virtually all of the major spawning populations of Fraser River sockeye including stocks from all four run-timing management groups (Jones et al. 2003). The parasite is believed to be acquired in the lower Fraser River and experiments have shown that juvenile salmon can be infected by the parasite when held in cages near the estuary (Jones, unpublished data). Parasitic and bacterial diseases cause stress, aberrant swimming behaviors and premature mortality in migrating wild salmon (Gilhausen 1990). In this case, the parasite causes the development of lesions within the glomeruli of the kidney (St. Hilaire et al. 2002) and would likely decrease osmoregulatory ability and increases the opportunity for en-route mortality.

It is hypothesized that the traditional “holding” behavior by late-run sockeye was a tactic for avoiding the contraction of this parasite (J. Woodey, Personal Communication). A temperature holding study conducted in 2002 found that warmer water temperatures lead to more rapid development of parasite infestations (Jones, Unpublished Data). Delaying migration until water temperatures cool in the fall may delay the lethality of the disease until after spawning. A change in the “zone of contraction” or in parasite development rates may be a contributor to mortality. However, because the parasite appears to be contracted primarily in freshwater and its effect on kidney would likely impair osmoregulation in freshwater, it seems unlikely that the parasite is causing early migration.

## Contaminants

A risk assessment conducted by Johannessen and Ross (2002) indicated that there are clearly a number of toxicants that sockeye encounter during some phase of their life that could effect their neural, olfactory, endocrine, osmoregulatory, immunocompetence, or development. Additionally, some toxicants could act to attract or repel fish (e.g. into the Fraser River, or out of the Strait of Georgia). The type of contaminant that would likely be responsible for change in migration timing would be one that acted as an attractant. Although the researchers identified several recent trends in contaminant use in B.C. that provide support to the supposition that contaminants may play a role in abnormal migration timing, the lack of knowledge on the response of fish to many of these contaminants, or their synergistic effects are too poorly understood to support or refute a causal relationship between early migration and contaminants. Johannessen and Ross (2002) identified several associations between the pattern of mortality and application/use of different contaminants. There are contaminants that could be harmful to fish such as pesticides, wood preservatives and persistent organic pollutants in addition to more recently developed contaminants that pose unknown risk. Collectively, although there has been increased application and/or use of some contaminants, at present there is no direct evidence that any of these substances are causal agents or cofactors. Addison (2002) concluded that it was unlikely that changes in the operation of, and discharges from the Annacis Island Waste Water Treatment Plant over the last decade, have directly affected the sockeye migration. However, he noted that no monitoring data are available for some chemicals (e.g. therapeutic drugs)

which could be candidates to cause subtle adverse effects on the fish. Furthermore, some chemicals known to cause adverse effects have not been analyzed reliably, or often enough to allow assessment of their significant in effluent from the plant.

### **Marine Predation Threat**

It is possible that increases in abundance or changes of behavior in marine mammals, and in particular killer whales and harbor seals may affect timing of river entry by leading to alterations in maturing salmon. Sockeye may enter freshwater prematurely in an attempt to avoid marine predators. Adult salmon are thought to comprise only 4% of the annual diet of some marine mammals, but may be an important seasonal food resource (Olesiuk et al. 1990). Recent research by Keple (2002) determined that abundance of marine mammals in the Strait of Georgia was highest in the Autumn and spring, not in the summer when sockeye are holding. There is evidence of both declines and increases in population size for different species of marine mammals in the Strait of Georgia (Keple 2002), but there have not been any obvious trends since 1995 that appear to explain the early migration. Another possible mechanism proposed for marine predators was a change in their functional response (preferentially targeting on sockeye salmon relative to alternative prey items). However no data are available to test this possibility.

### **Summary and Prognosis**

One of the major factors limiting progress toward determining causal mechanisms has been the lack of knowledge of the physiological cues that salmon use to initiate upstream migration. Thus, most of the studies attempting to explain early migration have been correlative in nature. Not surprisingly, these studies have found reasonable associations between either the abnormal migration timing or the high mortality and various environmental and other factors in some years but not in others. What is clear from this summary of possible causes is that the mechanisms responsible for these patterns are complex, likely representing the synergistic action of numerous stressors. We know relatively little about physiological and environmental cues used by adult salmon during their migration, and even less about how these cues interact. The consequences of factors such as low energy, parasite infection, and dysfunctional osmoregulatory system on the reproductive fitness of salmon that survive to spawn are unknown. Intergeneration effects add another unknown dimension to the issue of early migration and mortality.

The costs to the fishery of this abnormal behavior and ensuing mortality have been substantial. Not only have present day catches and future production of late-run stocks been reduced, catches of summer-run sockeye, which co-migrate with the late-run stocks, have also been restricted to minimize incidental by-catch of late-run stocks (Lapointe 2002). We estimate the cost in lost fish production/harvest was approximately 7.2 million fish in 2002. Using a very conservative estimate of the ex-vessel price of \$10 per fish, the losses just to fishermen associated with this problem likely exceeded \$72 million dollars last year. And this figure does not include added losses to processors and others involved in the salmon industry. The Pacific Fisheries Resource Conservation Council (Anon 2001) warns that the exceptionally high mortality rates constitutes a severe conservation risk and puts the sustainability of Fraser sockeye fisheries in doubt. Biological extirpation is also an imminent possibility for some stocks, impacting both fisheries and biodiversity. Indeed, the Cultus Lake sockeye are now listed under Canada's new Species at Risk Act as "endangered." Currently, there is little basis for predicting the behavior or the long-term sustainability of the affected Fraser River sockeye salmon stocks. A better understanding of the causal mechanisms might enable researchers to predict the behavior and permit fisheries managers to develop more adaptive in-season harvest tactics. Improved knowledge of the immediate and intergenerational fitness consequences would provide valuable information for developing models to predict stock sizes for fisheries management purposes, and mitigation measures to prevent stock collapse.

The next several years will provide an opportunity to closely monitor the patterns of run timing and mortality, and to explore the relationships between these phenomena. Baseline studies that contrast early, normal, and late run individuals will facilitate the generation of testable hypotheses. The research group involved in this paper are spear-heading an interdisciplinary, multi-agency research program to explore differences between abnormal and normal migrants and examine the intergenerational consequences of abnormal migration timing. In addition, as hypotheses are developed, refined, accepted, and rejected, intervention studies can be used to alter parameters of interest (e.g., artificially supplementing or depleting energy stores, enhancing or decreasing parasite loads) to further define links between timing, mortality, and fitness.

### **We'd like your ideas!!**

If this paper has stimulated you to think about this problem or if you have experience with a similar problem, we'd like to hear your ideas. Please send your ideas to either Mike Lapointe ([Lapointe@psc.org](mailto:Lapointe@psc.org)) or Scott Hinch ([shinch@interchange.ubc.ca](mailto:shinch@interchange.ubc.ca)). To keep informed of the progress on this issue, visit the Pacific Salmon Commission website at [www.psc.org](http://www.psc.org).

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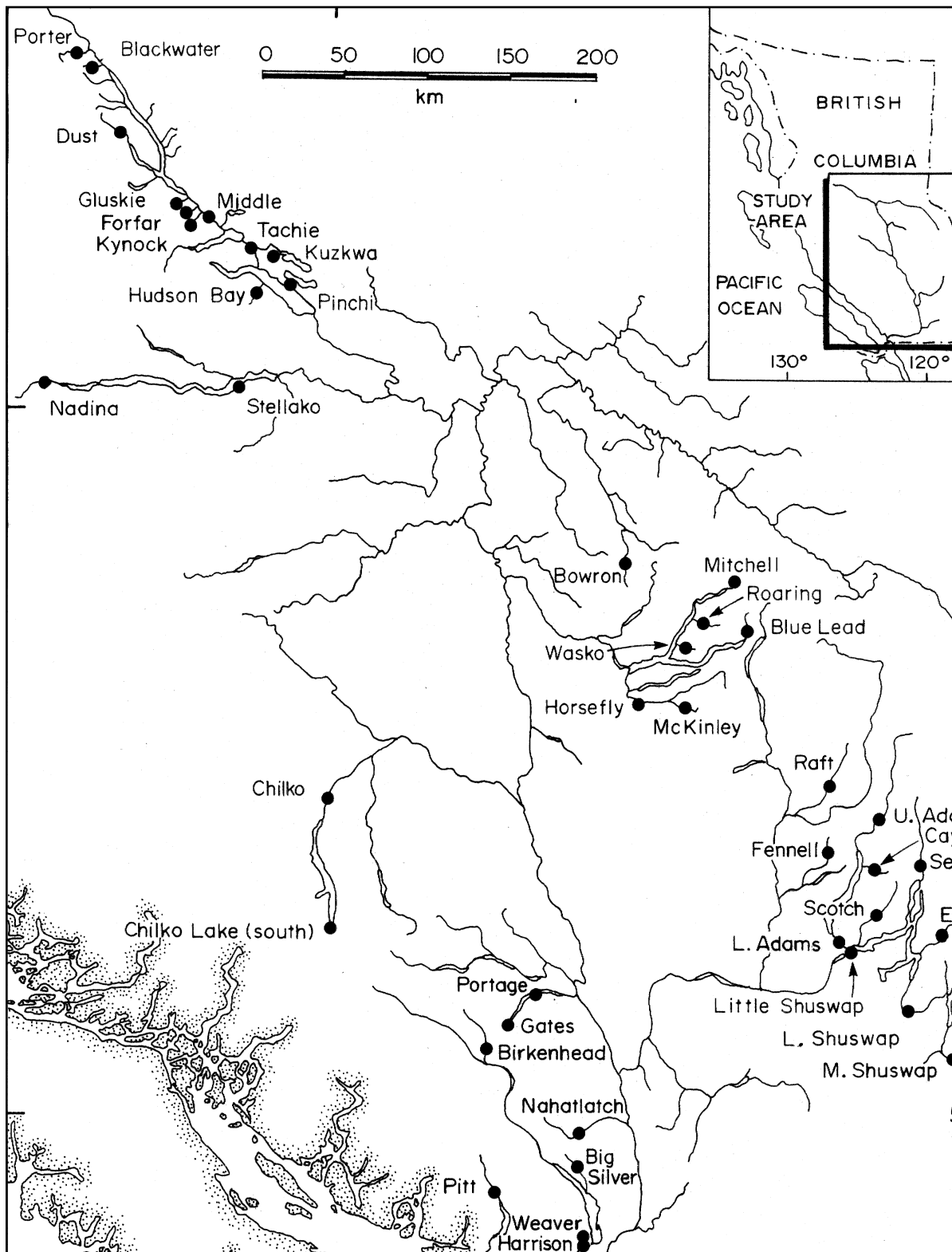
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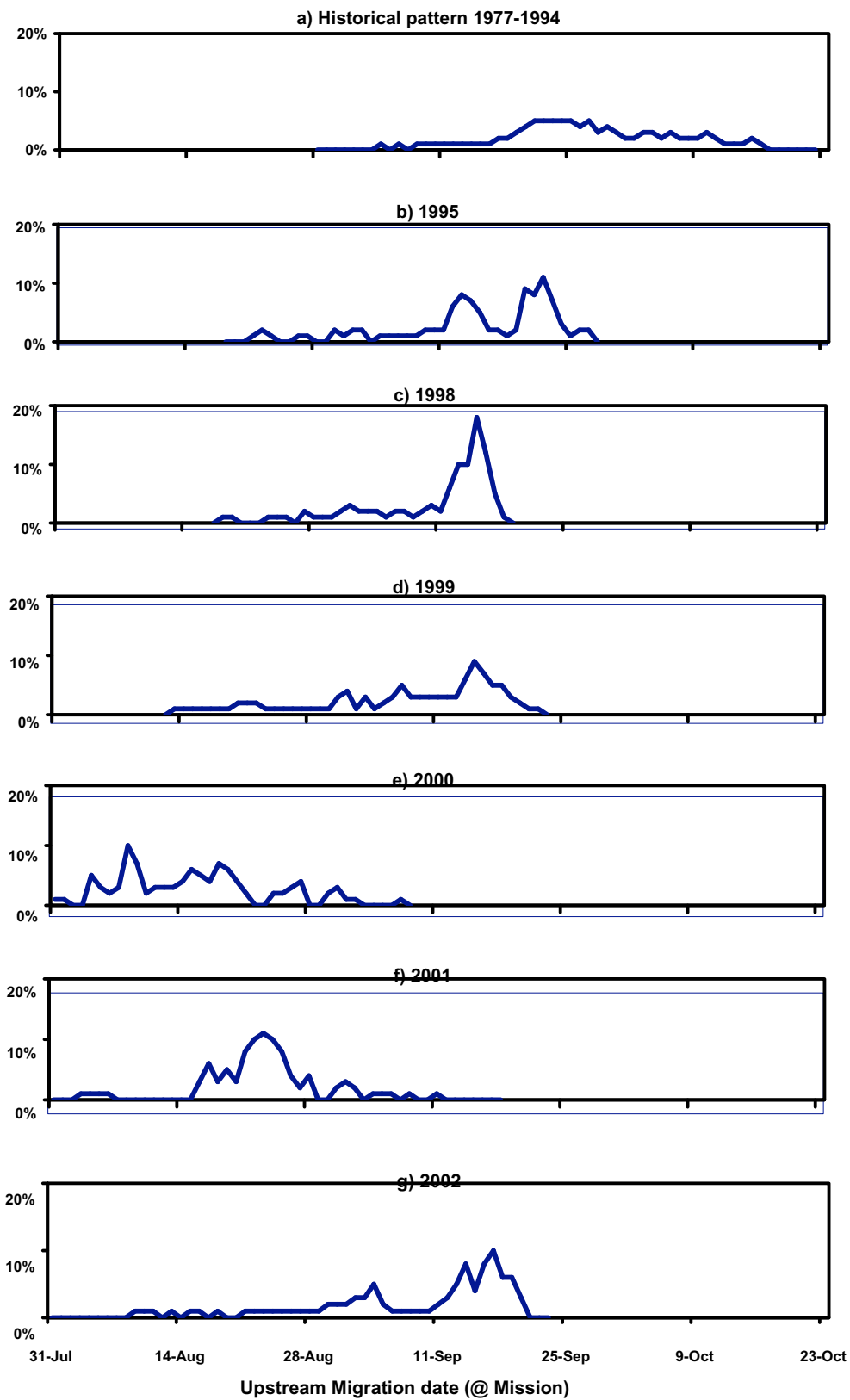
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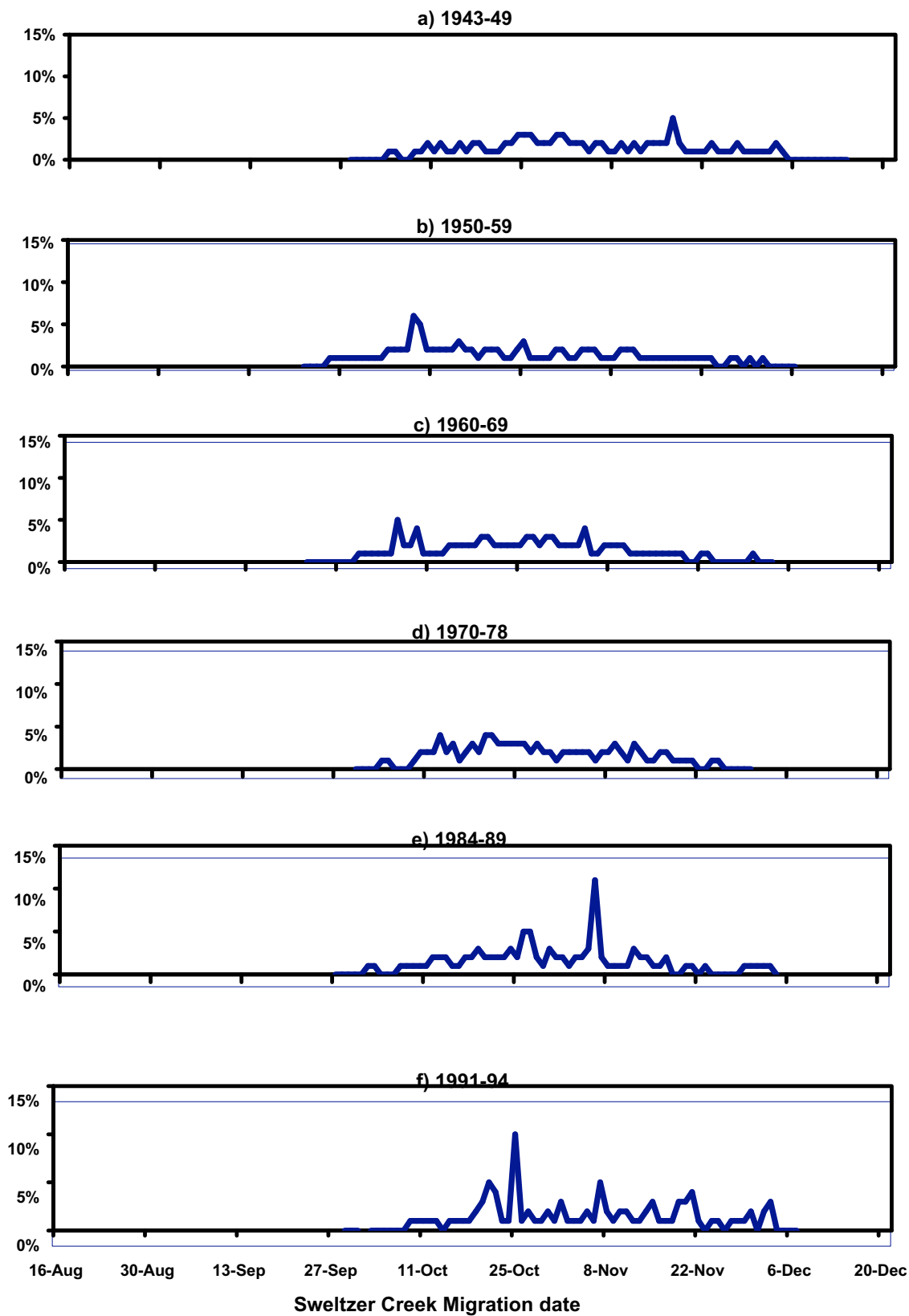
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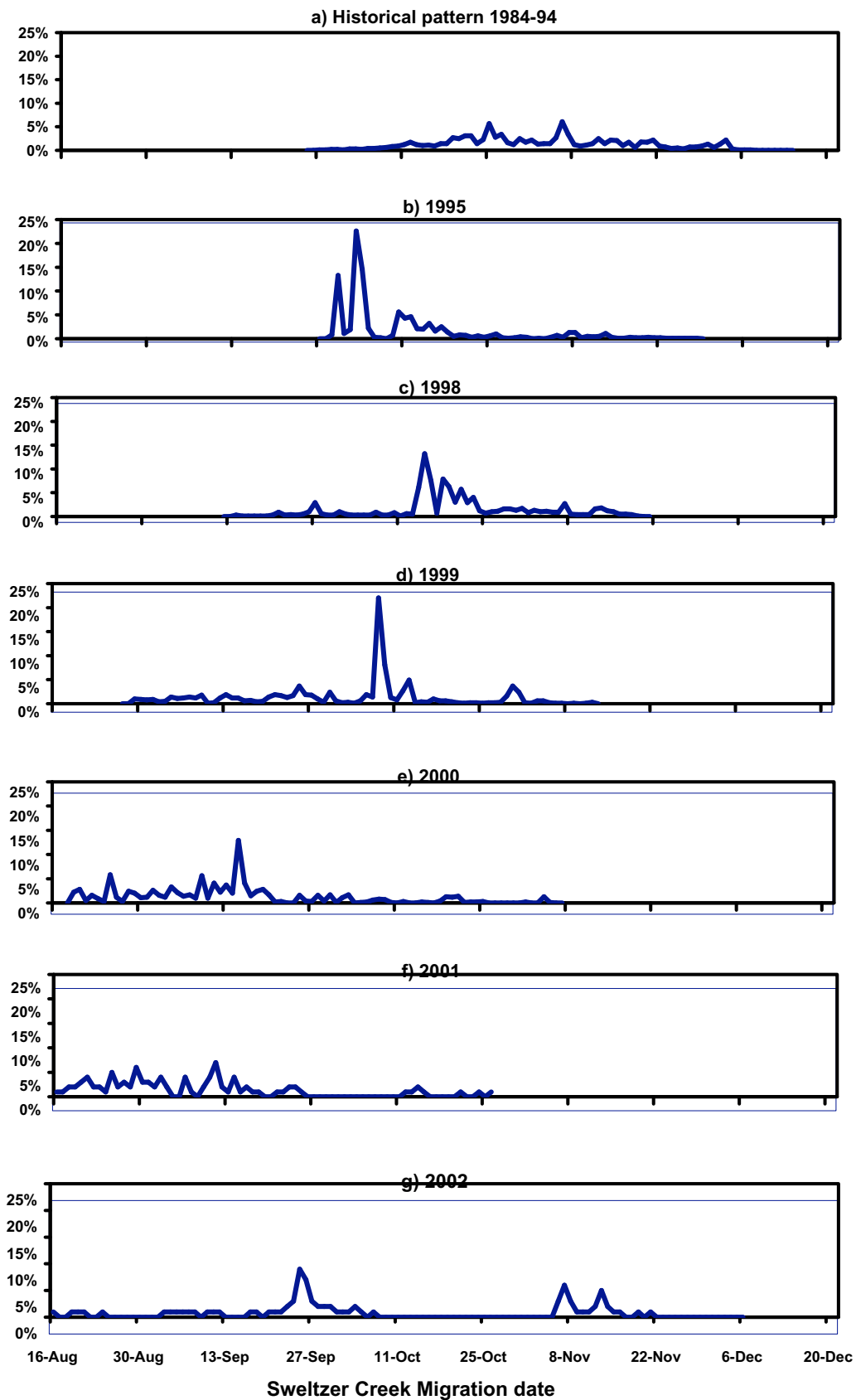
**Figure 1.** Map of the Fraser River watershed indicating locations of relevant spawning grounds. The inset shows the location of map within British Columbia. Principal late-run spawning populations include Cultus Lake, Harrison River and Weaver Creek sockeye in the Lower Fraser area, Portage Creek in the Seton-Anderson (mid-Fraser Area), and Lower Adams, Little River, Lower and Middle Shuswap Rivers, in the Thompson drainage (Mid-Fraser Area).



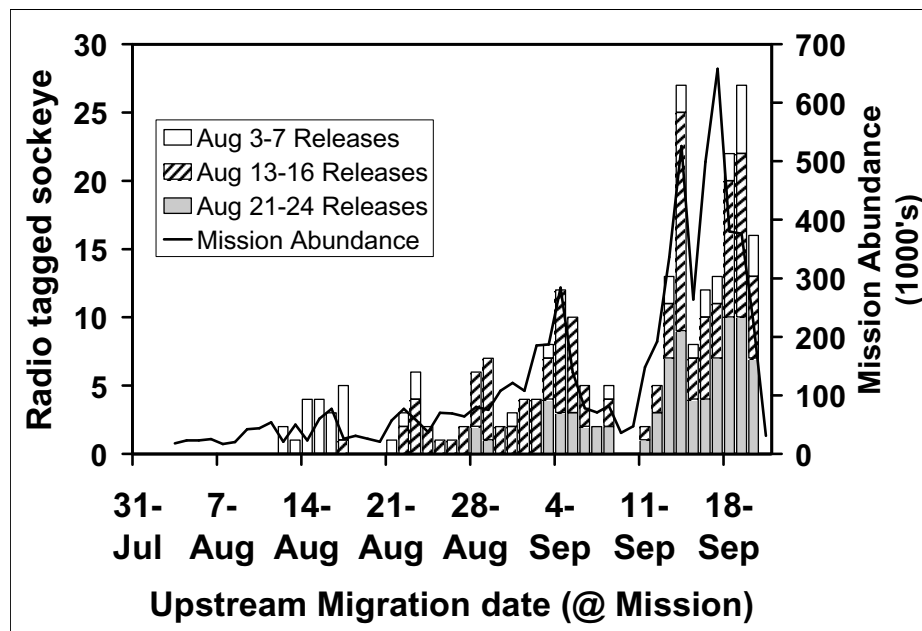
**Figure 2.** Annual migration timing for Lower Adams River sockeye salmon (daily % of annual totals) for the period of 1977-1994 (a) as mean values for the individual years from 1995 (b) through 2002 (g). The passage of fish past a hydroacoustic counting facility at Mission, B.C. was used to assess timing.



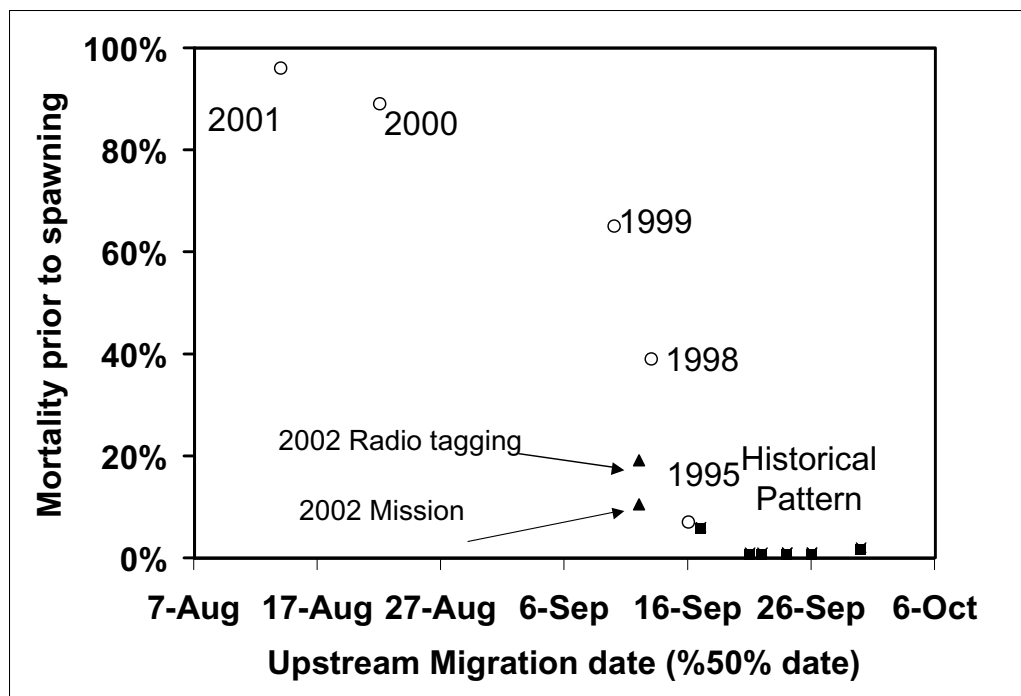
**Figure 3.** Decadal average annual migration timing for Cultus Lake sockeye (daily % of annual totals) past the enumeration fence at Sweltzer Creek for the 1940s (a) through the 1990s (f) (Data from Schubert et al. 2002).



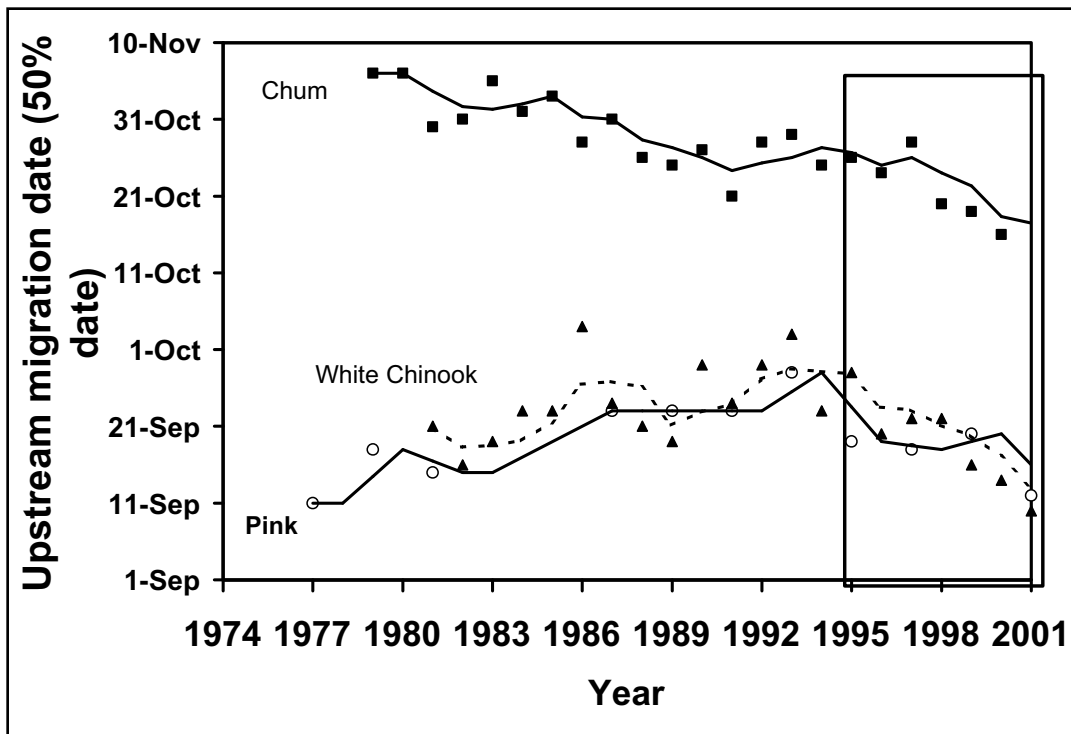
**Figure 4.** Annual migration timing for Cultus Lake sockeye (daily % of annual totals) past the enumeration fence at Sweltzer Creek for the period of 1984-1994 (a) as mean values and for the individual years 1995(b) –2002(g). (Data from Schubert et al. 2002).



**Figure 5.** 2002 Timing of river entry of radio tagged late run sockeye by tag release time (stacked histograms, left hand axis) and Mission daily abundance of late run sockeye (solid line, right hand axis). Clear bars are for the August 3-7 tag releases, bars with slanted markings denote the August 13-16 releases, and gray bars denote the August 21-24 releases. Release locations were approximated 1 week swim from Mission site (if no delay occurred). (Data from English et al. 2003).



**Figure 6.** Relationship between the annual 50% upstream migration date at Mission B.C. and annual mortality levels prior to spawning for Lower Adams river sockeye salmon. Data for the years 1974-1994 are plotted as black squares, 1995-2001 as open circles. Two black triangles are plotted for 2002, one based on the radio tagging results and the other based on comparing Mission hydroacoustic estimates to the upstream estimates. Data are missing for off-peak years for the Lower Adams when Adams sockeye proportions could not be accurately estimated historically using scale patterns. Estimates for the 2000, 2001 years are based on DNA stock composition, but are still uncertain due to small proportions.



**Figure 7.** Timing of upstream migration (Median or 50% dates) for Fraser River chum (black squares with solid line), white Chinook (black triangles with dotted line) and Pink salmon (open circles with solid line) from the 1970s through 2001. Trend lines are 3-year moving averages. Note Fraser River pink salmon only return on odd years, data not yet available for other stocks in 2002. The rectangle at the far right side of the graph denotes the period of early upstream migration for Fraser River sockeye. Pink salmon data are from the Pacific Salmon Commission. Data for Chinook and Chum were provided by Fisheries and Oceans Canada.