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Nonrandom Distribution of Canadian Sockeye Salmon Rearing in the Bering Sea and Coastal Gulf of Alaska

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Abstract

Individual identification of sockeye salmon (*Oncorhynchus nerka*) caught in coastal Gulf of Alaska and central Bering Sea sampling sites was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for 2,255 juvenile sockeye salmon obtained from coastal surveys in the Gulf of Alaska, and 627 immature individuals from surveys in the Bering Sea. A 387-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the individual identification of the fish sampled, with emphasis on Canadian-origin salmon. Not all Fraser River stocks displayed the same trends in relative abundance with respect to coastal Gulf of Alaska sampling groups, perhaps indicative of differential initial rearing environments. Immature sockeye salmon from some Canadian stocks rear in the Bering Sea at levels that are not commensurate with subsequent abundance as measured by escapement, indicative of a nonrandom distribution of rearing areas by stock. Immature Harrison River sockeye salmon from the lower Fraser River have only been identified in samples originating from waters in British Columbia. The marine rearing areas subsequent to the first year of marine residence are unknown for this population.

Introduction

The use of DNA-based genetic markers for salmon stock identification can be undertaken in order to determine migration routes and areas of marine residence for immature salmon. For Canadian sockeye salmon (*Oncorhynchus nerka*), migration routes of juveniles upon ocean entry were described by Tucker et al. (2009), where the general pattern of a northward and westward movement of juvenile sockeye was outlined. By the fall of first year of ocean residence, Canadian-origin sockeye salmon were widely distributed in coastal regions of the Gulf of Alaska. After spending the first winter in the Gulf of Alaska, some portion of immature Canadian-origin sockeye salmon move into the Bering Sea by the following summer for rearing (Habicht et al. 2010; Beacham et al. 2011, 2012), with the rest of the immature sockeye salmon presumably remaining in the North Pacific Ocean or Gulf of Alaska for rearing. Rearing either in the Bering Sea, North Pacific Ocean, or the Gulf of Alaska would likely differentially influence growth and survival of resident populations, as ocean productivity and salmonid rearing density likely differs between these environments. It would thus be important to determine if Canadian-origin sockeye salmon are distributed nonrandomly with respect to rearing in the Bering Sea and Gulf of Alaska, as rearing locations may influence subsequent survival. In the current study, we evaluate the stock-specific relative abundance of juvenile Canadian-origin sockeye salmon in the Gulf of Alaska and immature salmon in central Bering Sea.

Methods

Samples were obtained from juvenile and immature sockeye salmon captured during research cruises conducted in the Gulf of Alaska and Bering Sea during 1996-2011. Gulf of Alaska sample collections were summarized by Tucker et al. (2009) and Trudel et al. (2011), with Bering Sea sample collections summarized by Beacham et al. (2011, 2012). Coastal samples from all months of the year were grouped together in each of five areas (British Columbia adjacent to border with Alaska, southeast Alaska, Prince

William Sound, Kodiak Island, and Alaska Peninsula) to evaluate relative abundance of specific stocks of salmon. Sampling centered on juveniles in their first complete year of ocean residence. Samples were obtained from immature sockeye salmon collected in the central Bering Sea in late July and early August in 2009 and 2011. Sampling centered on individuals which had spent either one or two years of ocean residence. Tissue samples were preserved in 95% ethanol, and sent to the Molecular Genetics Laboratory at the Pacific Biological Station of Fisheries and Oceans Canada in Nanaimo. Fourteen microsatellites (Beacham et al. 2005) were surveyed with an ABI 3730 capillary DNA sequencer, and genotypes were scored by GeneMapper software 3.0 (Applied Biosystems, Foster City, CA) using an internal lane sizing standard as outlined by Beacham et al. (2005).

Baseline populations

The baseline used for estimation of stock composition consisted of a survey of about 67,000 sockeye salmon from 387 populations from Japan, Russia, Alaska, Canada, and Washington as outlined by Beacham et al. (2011). Baseline populations were organized into 46 reporting groups as outlined by Beacham et al. (2011).

Estimation of stock composition in mixed-stock samples

Stock compositions of mixture samples were estimated with the genetic stock identification software cBayes (Neaves et al. 2005) or ONCOR (Kalinowski et al. 2007) that incorporated the likelihood model of Rannala and Mountain (1997). Allocations were made to 387 individual populations, and estimated stock of origin of each individual in the sample was determined by the probability of assignment to a specific stock or population. Any individuals with a probability of assignment of < 0.50 were excluded from the analysis.

Results and Discussion

Coastal Gulf of Alaska captures of juvenile sockeye salmon ranged from sites off the Alaska Peninsula, Kodiak Island, Prince William Sound, Kayak Island, southeast Alaska, and British Columbia (BC) border locations primarily from May through November (Fig. 1) (Tucker et al. 2009). Individuals from the most southern stocks (Columbia River, Lake Washington) were observed only in the BC border and southeast Alaska sampling regions (Table 1). Stocks from the Fraser River drainage were evaluated in some detail. Individuals from the Early Stuart stock in the Fraser River drainage were observed in all five coastal regions, as well as in the Bering Sea (Table 2), even though escapement in this stock is typically modest when compared with other Fraser River stocks. The Stellako River stock in the Fraser River, although at greater abundance than the Early Stuart stock in the BC border, southeast Alaska, and Prince William Sound sampling regions, was not observed in the Alaska Peninsula and Kodiak Island sampling regions. The Gates Creek stock was at a similar abundance to the Early Stuart stock in BC border and southeast Alaska sampling regions, but was not detected subsequently in the other regions. The North Thompson River, Birkenhead River, Cultus Lake stocks, all detected in either BC border or southeast Alaska regions, and subsequently observed in Bering Sea samples (Table 2), were not observed in more northern and western sampling regions during their first year of ocean residence (Table

1). The level of sampling in the more northern and western regions was less than that of the BC border and southeast Alaska regions, and this may account for the lack of detection of specific stocks to some degree. However, not all Fraser River stocks displayed the same trends in relative abundance with respect to sampling groups, perhaps indicative of differential initial rearing environments.

Individuals from the Owikeno Lake stock in central coastal British Columbia were observed in the BC border, southeast Alaska, and Prince William Sound sampling regions (Table 1), as well as subsequently in the Bering Sea (Table 2). Individuals from the Skeena River and Nass River were common in the BC border and southeast Alaska. Individuals from stocks on Haida Gwaii (formerly known as the Queen Charlotte Islands), were only detected in the BC border and southeast Alaska regions. Some juveniles from southeast Alaska populations initially migrated south and through Dixon Entrance to gain access of the eastern Gulf of Alaska (Table 1). Individuals from transboundary river stocks (Stikine River, Taku River, Alsek River) were not detected in British Columbia waters, which is reasonable considering the geographic locations of the rivers. Individuals from the most northern transboundary river, the Alsek River, were comparatively less frequent in the southeast Alaska sampling region compared with the Taku River and Stikine River, a result expected based solely upon the sampling locations in the region (Fig. 1), and the geographic location of the river mouth. Unsurprisingly, Cook Inlet sockeye salmon juveniles were detected only in the Prince William Sound, Kodiak Island, and Alaska Peninsula sampling regions (Table 1).

No Bristol Bay-origin sockeye salmon were detected at any of the sampling locations from June through to the following March (Table 1), which suggests that Bristol Bay sockeye salmon rear in the Bering Sea, further south in the North Pacific Ocean, or more offshore locations in the Gulf of Alaska during their first summer, fall, and winter in the ocean. Sampling of immature sockeye salmon south of the Aleutian Islands in the North Pacific Ocean during February-March 2009 indicated that some Bristol Bay ocean age 1 sockeye salmon (55% of sample) were present in this region, along with eastern Gulf of Alaska (largely Canadian) (10% of sample)(Farley et al. 2011).

In 2009, 3.8% of immature sockeye salmon rearing in the central Bering Sea were estimated to be of Canadian origin (Beacham et al. 2011). These individuals would have matured mainly in 2010, with perhaps some maturing in 2011 as age 5 year individuals. Of the 17 individuals identified as Canadian origin in the 450-individual sample from the Bering Sea in 2009, seven individuals were estimated to be of Fraser River origin. None of these seven individuals originated from stocks that dominated the 2010 return, with no individuals estimated to have originated from either early or late South Thompson River drainage stocks, Chilko Lake, or Harrison River. These four stocks accounted for approximately 93% of the drainage escapement in 2010. Instead, all individuals were estimated to have originated from less productive, less abundant stocks within the Fraser River drainage (Table 2). For example, the Early Stuart stock is comprised of a number of early-returning populations to the Stuart River drainage in the upper Fraser River drainage (Fig. 2). There is no current commercial exploitation of this stock, as the level of abundance is not sufficient to support a commercial fishery. Similarly, the Cultus Lake population in the lower Fraser River drainage (Fig. 2) is currently of conservation concern, and fisheries are managed with the objective of reducing exploitation on this population. No Fraser River-origin individuals were identified in the 2011 sample of 177

individuals from the central Bering Sea (Beacham et al. 2012), and this may reflect that the 2012 abundance returning to the Fraser River was approximately 15 times less than that observed during 2010.

Outside of the Fraser River, one individual in the 2009 Bering Sea sample was estimated to have originated from Owikeno Lake (Table 2), a stock which until the 1970s supported the largest non-Fraser River origin sockeye salmon fishery in British Columbia. The abundance of this stock declined dramatically owing to low marine survival that was unrelated to fishery exploitation in British Columbia (McKinnell et al. 2001), and has remained at a relatively low level of abundance. Relative to the escapement of Skeena River sockeye salmon (one individual observed), sockeye salmon from the Alsek and Stikine Rivers were over-represented in the 2009 sample of immature sockeye salmon in the central Bering Sea (Table 2). Single individuals from the Stikine River and Skeena River were present in the 2011 sample from the Bering Sea (Beacham et al. 2012), indicating that some portion of immature salmon from these two stocks rear in the central Bering Sea. Immature Canadian sockeye salmon rear in the Bering Sea at levels that are not commensurate with subsequent abundance as measured by escapement, indicative of a nonrandom distribution of rearing areas by stock.

Within the Fraser River drainage in southern British Columbia, most juveniles spend one year rearing in fresh water before migrating to the ocean as smolts. However, Harrison River sockeye salmon, located within the lower portion of the drainage (Fig. 2), migrate to the ocean directly after fry emergence and rear for a period of time in the Fraser River delta (Birtwell et al. 1987) or nearby Howe Sound (Beamish et al. 2010). Unlike many other Fraser River populations, previous surveys have suggested that they usually leave the Strait of Georgia through the southern route via the Strait of Juan de Fuca (Fig. 2), and rear off the west coast of Vancouver Island during their first winter in the ocean (Tucker et al. 2009). Juvenile Harrison River sockeye salmon have also been caught in the northern part of the Strait of Georgia in February 2004, suggesting that, in addition to Juan de Fuca Strait some may be leaving the strait through Johnstone Strait (Beamish et al. 2010). Unlike many other Fraser River populations, Harrison River sockeye salmon have been markedly increasing in abundance during the last 10 years (Fig. 3). Juvenile sockeye salmon in British Columbia typically migrate northwards after entry into the marine environment (Tucker et al. 2009; Welch et al. 2009). We have analyzed 2,255 juvenile sockeye salmon obtained from surveys in the Gulf of Alaska, and 627 immature individuals from surveys in the Bering Sea, and have never sampled an individual estimated to have originated from the Harrison River. Juvenile Harrison River sockeye salmon have only been identified in samples originating from waters in British Columbia. Individuals have been sampled in the Gulf of Alaska and Bering Sea from other Fraser River populations of lower abundance than the Harrison River (Table 2), so the absolute abundance of Harrison River sockeye salmon should not have limited detection of this population. The marine rearing areas subsequent to the first year of marine residence are unknown for this population.

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Table 1. Number of juvenile sockeye salmon by stock sampled during surveys in five coastal areas of the Gulf of Alaska, 1996-2010. N is sample size.

Stock of origin	BC Border	Southeast Alaska	Prince William Sound	Kodiak Island	Alaska Peninsula
Sampling years	1998-2010	1996-2010	1996-1997	1996-1997	1997
N	595	1355	151	133	21
Columbia River	2	13			
Lake Washington	12	21			
Fraser River stocks					
Early Stuart	2	18	7	7	2
Bowron	1	1			
Nadina				1	
Pitt	4	6	1		
Chilliwack		3			
North Thompson	3	17			
Portage		8			
Cultus	6				
Birkenhead	4	13			
Gates	2	11			
Big Silver	1	3			
Chilko	39	84	8	25	
Quesnel	15	59	7	15	
Nahatlatch		1	1		
Stellako	12	30	15		
Early South Thompson	3	46	1		
Late South Thompson	35	178	17	15	1
Late Stuart	33	129	1		
Weaver	15	23	5		
BC South Coast		5			
Nimpkish	1	8			
WCVI	49	73	18	6	
Owikeno	19	37	2		
BC Central Coast	40	74	5	2	
Skeena	188	150	11	6	6
Nass	72	87	7	5	1
Haida Gwaii	22	13			
Stikine		154	13		
Taku		12			
Alsek		1	1	17	5
Southern southeast Alaska	15	72	16	14	2
Northern southeast Alaska		5	12	11	2
Cook Inlet			3	9	2

Table 2. Number of Canadian-origin individuals by stock estimated to be present in a sample of immature sockeye salmon obtained from the central Bering Sea, July 15 – August 9, 2009. Probability of assignment of individual assignment to stock is indicated, as well as 2010 escapement (thousands) and an index of relative abundance in the sample. The index of relative abundance was estimated as the number of individuals from the stock in the 2009 sample/2010 escapement abundance times 10^6. For example, for the Early Stuart stock, the index was (1/60,000) x 1,000,000 = 17.

Stock	2009 Bering Sea research catch (N=450)	Probability of individual assignment	2010 Escapement x 1,000	Bering Sea abundance/2010 escapement x 1,000,000
Late South Thompson R	0		7,519	0
Chilko Lake	0		2,463	0
Early South Thompson R	0		1,429	0
Harrison River	0		762	0
Early Stuart	1	0.99	60	17
Late Stuart	2	0.95-0.98	75	27
North Thompson	2	0.87-0.98	24	83
Birkenhead River	1	0.78	128	8
Cultus Lake	1	1.00	10	100
Owikeno Lake	1	0.98	130	8
Skeena River	1	1.00	686	1
Stikine River	4	0.54-0.99	64	63
Alsek River	4	0.54-0.81	82	49

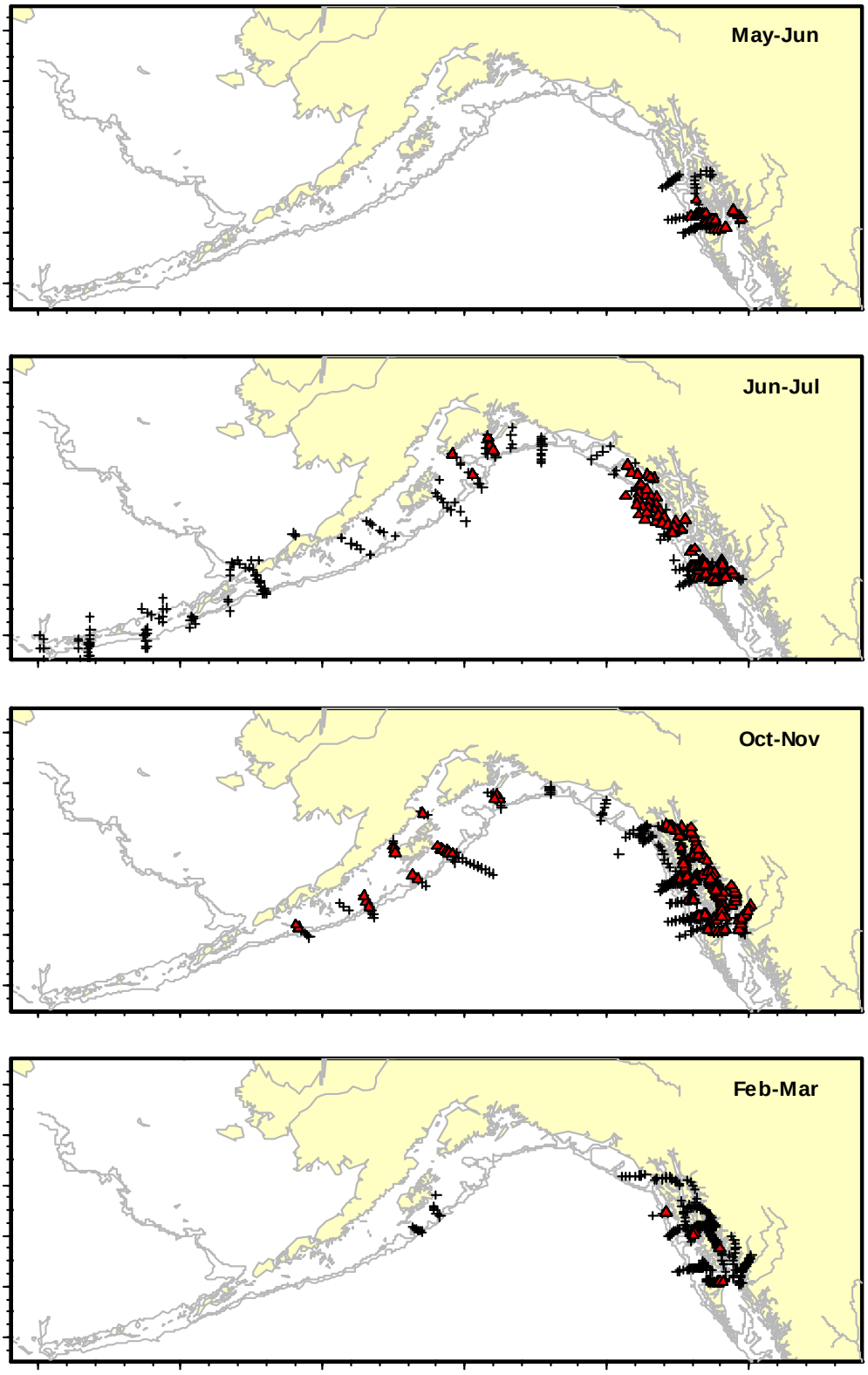

Figure 1. Sampling locations (crosses indicate individual tows) and relative catch of juvenile sockeye salmon in coastal Gulf of Alaska surveys 1996-2010.

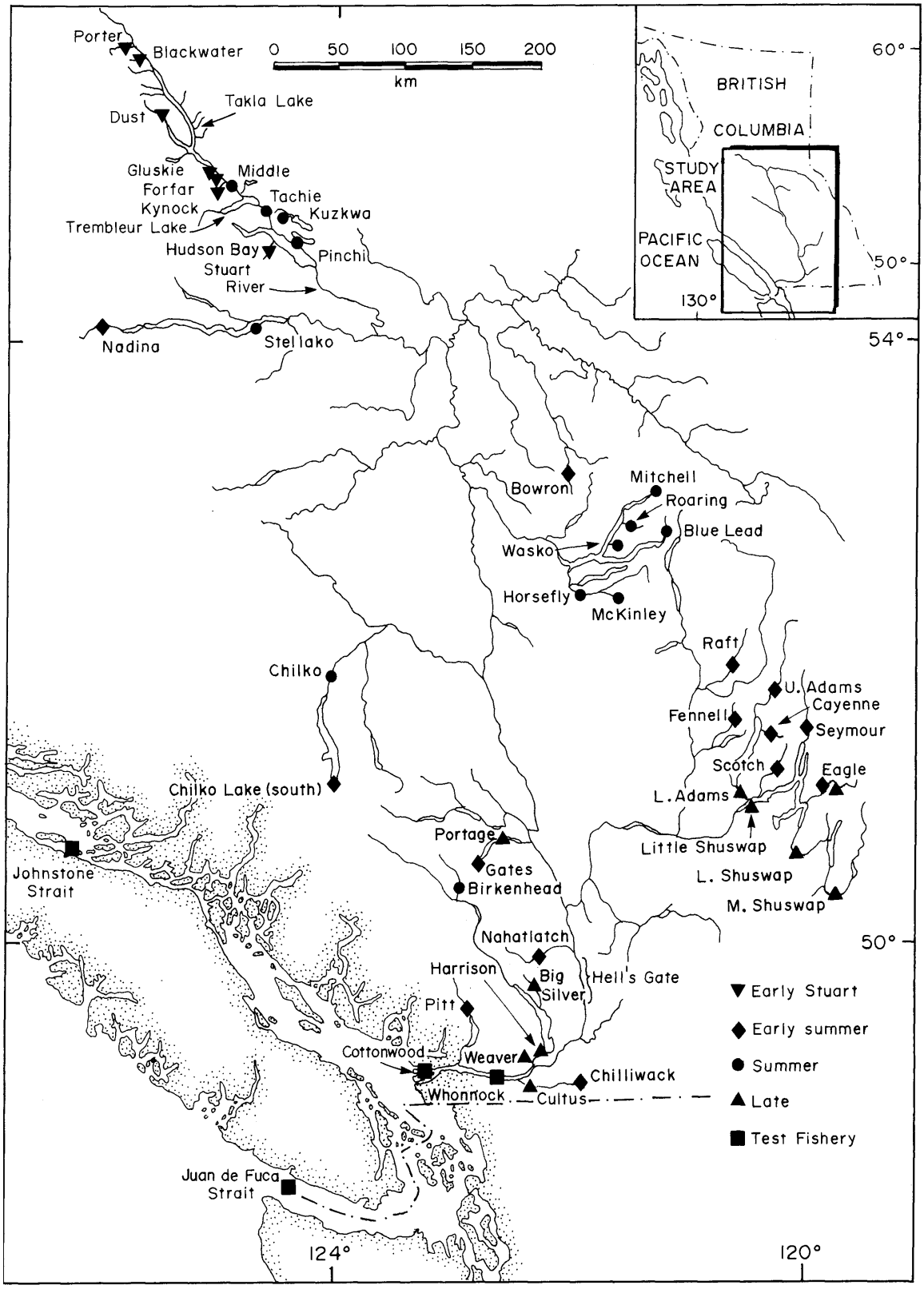

Figure 2. Locations of sockeye salmon spawning populations within the Fraser River drainage.

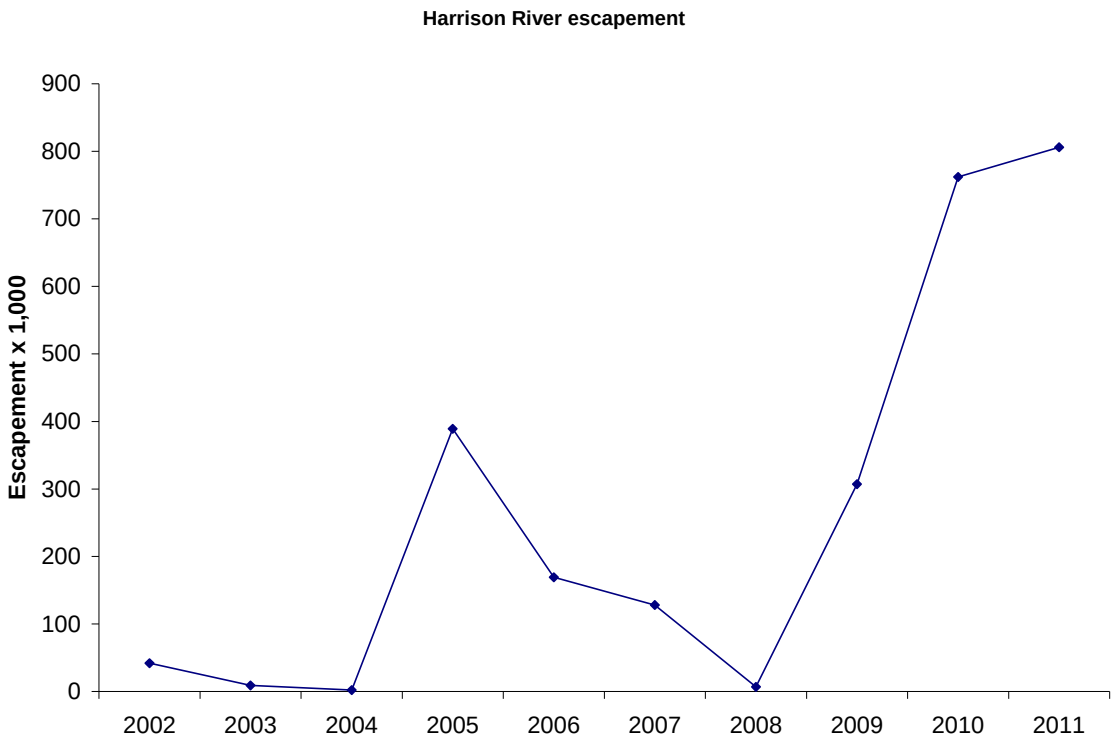

Figure 3. Escapement of Harrison River sockeye salmon, 2002-2011.