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Microsatellite Identification of Sockeye Salmon Rearing in the Bering Sea During 2009-2013

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Abstract

Stock composition of sockeye salmon (*Oncorhynchus nerka*) caught in the southern central Bering Sea during Japanese research cruises in the summers of 2009, 2011, 2012, and 2013 was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for immature sockeye salmon, and a 404-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the stock composition of the fish sampled. Alaskan-origin sockeye salmon were the most abundant in the catch, comprising 86.1% of all sockeye salmon caught (United States total 86.1%), with the catch dominated by sockeye salmon of Bristol Bay origin. Russian-origin salmon accounted for an average of 10.6% of the annual catch, while Canadian-origin sockeye salmon accounted for 3.4% of the annual catch.

Introduction

The application of DNA-based genetic markers to salmon stock identification studies has provided greater resolution of stock composition relative to other biological markers (Beacham et al. 2005) such as scale pattern analysis (Ishida 1989), parasites (Bennett et al. 1998), and otolith characters (Sohn et al. 2005). High resolution stock composition of sockeye salmon mixed-stock samples to lake or river of origin is crucial to our understanding of their population-specific responses to recent climatic regime shifts in the north Pacific Ocean (Welch et al. 2000; Mueter et al. 2002). DNA markers provide a natural tag with which the origin of all individual fish within a sample can be determined if required (Beacham et al. 2005). This is in marked contrast to physical tags, where recovery rate of individually marked juvenile salmon fish is typically well under 1% (Hartt and Dell 1986; Trudel et al. 2009). By employing DNA-based genetic markers for stock identification, larger scale sampling of juvenile salmon in the ocean can be undertaken in order to determine migration routes and areas of marine residence.

The initial application of DNA-based genetic markers to estimation of sockeye salmon stock composition in the Bering Sea was reported by Habicht et al. (2010). By applying a set of 45 single nucleotide polymorphisms (SNPs) to identify population structure in a Pacific Rim distribution of populations, Habicht et al. (2010) defined eight regional stocks of sockeye salmon in the baseline, with a single eastern Gulf of Alaska (EGOA) stock comprised of sockeye salmon from southeast Alaska, British Columbia, and Washington. This EGOA stock, which comprised a mixture of Canadian and American populations, was reported to comprise up to 10% of immature sockeye salmon sampled in the south central Bering Sea during September of 2002 and 2003. Beacham et al. (2011) reported that stock composition of juvenile sockeye salmon captured between 15 July to 9 August 2009 during a research cruise conducted with the Japanese research vessel *Hokko-maru* in the central and northern Bering Sea was 86% Alaskan origin, 10% Russian origin, and 4% Canadian origin. In the current study, we evaluate variation in size and stock composition of immature sockeye salmon caught during Japanese research cruises in the south central Bering Sea in 2009, 2011, 2012, and 2013.

Methods and Materials

Sample collection and analysis

Juvenile sockeye salmon were captured between late July to early August during a research cruises conducted with the Japanese research vessel *Hokko-maru* in the central and southern Bering Sea during 2009, 2011, 2012, and 2013. The cruises were designed to conduct the annual survey of Japanese stocks of chum salmon (*O. keta*) in the southern Bering Sea, with cruise tracks and details of the cruise outlined annually by Japanese investigators (eg. Morita et al. (2011)). Details of the trawl nets and sampling regime were also outlined by Morita et al. (2011). Juvenile sockeye salmon captured were weighed to the nearest 10 g, fork length measured (nearest mm), a tissue sample collected for subsequent analysis of genetic variation. Fish age was determined from scales by staff of the Hokkaido National Research Fisheries Institute, Fisheries Research Agency, Japan. Age reporting followed the method outlined by Koo (1962). An individual designated as x.1 spent 1-3 winters rearing in fresh water (x years), and one winter in the ocean, having been sampled during the summer in their second ocean year. Similarly, individuals identified as x.2 reared for two winters in the ocean, with subsequent capture and sampling during their third summer of ocean rearing. Individuals identified as x.3 were in their fourth summer of ocean rearing. 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 73,000 sockeye salmon from 404 populations from Japan, Russia, Alaska, Canada, and Washington as outlined by Beacham et al. (2014). Baseline populations were organized into 46 reporting groups as outlined by Beacham et al. (2014).

Estimation of stock composition in mixed-stock samples

Stock compositions of mixture samples were estimated with the genetic stock identification software ONCOR (Kalinowski et al. 2007) that incorporated the likelihood model of Rannala and Mountain (1997). Allocations were made to 404 individual populations, and these were summed to provide estimates to 46 regional stock groups (Beacham et al. 2014). Regional stock groups were not listed in Table 1 if estimated stock composition of the reporting group was zero. Precision of the stock composition estimates were calculated through 100 bootstrap simulations of both the baseline and mixture data.

Results

Location, size, and age of catch

The sockeye salmon analyzed were typically captured between 53’ N and 59’ N and 175’ E and 175’ W in the central Bering Sea (Figure 1). Ocean age x.1 individuals were well separated from ocean age x.2 and x.3 individuals in fork length, with a bimodal distribution observed in observed fork length for all four sampling years (Figure 2). Age x.1 individuals were typically less than 400 mm. Mean fork lengths of x.1 individuals were 348 mm (SD=26mm), 349 mm (24mm), 344 mm (33 mm), and 349 mm (24 mm) for individuals caught in 2009, 2011, 2012, and 2013, respectively. Mean length of age x.2 individuals was 476 mm (27 mm), 468 mm (27 mm), 463 mm (32 mm), and 462 mm (49 mm) for individuals caught in 2009, 2011, 2012, and 2013, respectively. Mean fork length of x.3 individuals was 548 mm (40 mm), 540 mm (53 mm), 503 mm (35 mm), and 526 mm (49 mm), respectively. The proportion of x.2 and x.3 individuals in the catch in 2013 was lower than that observed in previous years (Figure 2, 3).

Body weight distributions were similarly well defined between age x.1 and x.2 individuals, with x.1 individuals typically less than 800 g in weight, reflective of the bimodal distribution of body weight (Figure 3). Mean weight of age x.1 individuals was 490 g (104 g), 510 g (114 g), 491 g (143 g), and 496 g (111 g) for individuals caught in 2009, 2011, 2012, and 2013, respectively. Mean weight of age x.2 individuals was 1300 g (221 g), 1270 g (230 g), 1251 g (251 g), and 1272 g (367 g) for individuals caught in 2009, 2011, 2012, and 2013, respectively. Mean weight of age x.3 individuals was 2140 g (573 g), 2060 g (730 g), 1530 g (303 g), and 1933 g (589 g), respectively.

Stock composition of Bering Sea samples

Alaskan-origin sockeye salmon were the most abundant in the annual catch of immature individuals in the central Bering Sea. Bristol Bay origin immature sockeye salmon comprised 87.0% of all sockeye salmon caught during the 2009 cruise, 77.1% during the 2011 cruise, 77.3% during the 2012 cruise, and 81.3% during the 2013 cruise (Table 1). Russian-origin salmon accounted for 8.0%, 12.1%, 18.1%, and 4.4% of the catch during 2009, 2011, 2012, and 2013 cruises, respectively. Canadian-origin sockeye salmon accounted for 4.2%, 1.2%, 1.4%, and 6.9% of the catch during 2009, 2011, 2012, and 2013 cruises, respectively. One immature sockeye salmon from Washington State was observed in the catch in 2011. Sockeye salmon from Bristol Bay dominated the catch of Alaskan-origin salmon, with those from the Kvichak River drainage the largest contributor to the catch on average, with an average annual contribution of 20.5% of individuals estimated to be of Kvichak River origin (Table 1). Sockeye salmon from the Naknek River drainage were estimated to be the next most important contributor to the catch, comprising an average of 17.4% of the salmon sampled. Sockeye salmon from the Egegik River drainage were estimated to comprise an average of 13.1% of annual samples. Sockeye salmon from the Wood River drainage were estimated to comprise an average of 10.0% of immature sockeye salmon sampled during the cruises, and those from the Nushagak River 8.1% of the individuals sampled (Table 1).

Russian-origin sockeye salmon caught in the central Bering Sea during 2009, 2011, 2012, and 2013 were estimated to originate primarily, on average, from Karaginsky Bay (3.4%), Kuril Lake (2.8%), and Kamchatka River (1.9%) (Table 1). Russian-origin sockeye salmon comprised 7.2%, 7.5%, 12.8%, and 4.2% of the age x.1 immature sockeye salmon sampled in 2009, 2011, 2012, and 2013, respectively, for an average of 7.9% of the age class (Table 2). However, Russian-origin age x.2 immature sockeye salmon comprised 9.4%, 18.7%, 24.5%, and 12.5% of the age x.2 sockeye salmon, respectively, during the cruises, for an average of 16.3% of the age class (Table 3).

Canadian-origin salmon were estimated to originate primarily from the Skeena River and river drainages to the north (Table 1).

Discussion

Bering Sea analysis

Size distributions of the immature sockeye salmon sampled during the research cruise in all four years were quite similar. For example, the mean fork length of ocean age x.1 individuals differed only by 5 mm across all four years of sampling. Mean fork length of ocean age x.2 individuals differed by 14 mm across across all four years of sampling. Mean weight of ocean age x.1 individuals was differed by 20 g across all four years of sampling, while that of the x.2 individuals differed by 50 g across all four sampling years.

Analysis of stock composition indicated that the catch was dominated by stocks of Bristol Bay origin, similar to results of tagging experiments (Myers et al. 1996), scale pattern analysis (Bugaev and Myers 2009), and previous analyses of genetic stock composition (Habicht et al. 2010; Beacham et al. 2011). Juvenile sockeye salmon catches in the eastern Bering Sea were also reported to be dominated by salmon of Bristol Bay origin (Seeb et al. 2011). Based upon geography and relative abundance, sockeye salmon of Bristol Bay origin should be expected to dominate catches of immature sockeye salmon rearing in the Bering Sea, with sockeye salmon originating from Russia the next most abundant stock. These were precisely the results observed from our analysis of immature sockeye salmon rearing in the central Bering Sea in July and August of 2009, 2011, 2012, and 2013. Our analysis, along with the results of Habicht et al. (2010) and Beacham et al. (2011), indicated that some small portion of Canadian sockeye salmon rear in the Bering Sea during summer, with perhaps some trace contribution by sockeye salmon from Washington State. Recent genetic and otolith mark analyses indicated that Canadian chum salmon (*O. keta*) were also distributed in the Bering Sea (Urawa et al. 2009). As outlined by Habicht et al. (2010), it is uncertain whether rearing of Canadian-origin salmon in the Bering Sea is something new, perhaps brought on by changes in climate, or is in fact typical of a normal rearing pattern of summer movement in the Bering Sea and winter rearing in the Gulf of Alaska.

Improved information of location and timing of specific stocks of sockeye salmon in the Bering Sea and North Pacific Ocean can be obtained through the application of DNA technology to salmon stock identification problems. The major limitation at the present time to refine knowledge on stock-specific areas of ocean residence and timing of migration movement is the difficulty and cost associated with obtaining the appropriate samples from ocean rearing areas and migration routes.

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Table 1. Mean catch per unit effort (CPUE 17 stations (Fig. 1)) and estimated stock compositions (%, 95% confidence limits in parentheses) of mixed-stock samples of sockeye salmon from the central Bering Sea, 2009-2013. Estimated stock compositions were derived from applying a 404-population baseline for each sample, with a Pacific Rim distribution of the baseline ranging from Japan, Russia, Alaska, British Columbia, and Washington State as outlined by Beacham et al. (in press). Reporting regions with no estimated stock composition are not listed. N is sample size

Major region	Stock	Estimate			
Year		2009	2011	2012	2013
CPUE		27.9	10.5	9.4	18.0
N		446	177	159	313
Washington State	Washington		0.6 (0.0, 1.7)		
British Columbia	Fraser River	1.9 (0.0, 2.9)		0.2 (0.0, 1.2)	0.3 (0.0, 0.6)
	Vancouver Island	0.2 (0.0, 0.8)			0.3 (0.0, 1.0)
	Central Coast				0.3 (0.0, 0.8)
	Haida Gwaii				0.3 (0.0, 1.0)
	Skeena River	0.2 (0.0, 0.7)	0.6 (0.0, 2.2)	0.6 (0.0, 1.9)	2.9 (1.0, 4.2)
	Nass River				0.3 (0.0, 1.0)
	Stikine River	0.4 (0.0, 1.8)	0.6 (0.0, 3.2)	0.6 (0.0, 2.6)	1.2 (0.0, 2.6)
	Taku River				0.9 (0.0, 3.7)
	Alsek River	1.5 (0.0, 2.8)			0.4 (0.0, 3.6)
Southeast Alaska	SE Alaska		1.8 (0.0, 3.9)		
Central Alaska	Cook Inlet	0.9 (0.3, 3.1)	3.5 (1.1, 7.9)	2.3 (0.0, 4.1)	4.4 (1.4, 7.1)
	Kodiak Island	0.8 (0.0, 2.2)	3.7 (0.0, 5.6)	1.6 (0.0, 5.3)	3.1 (0.7, 6.1)
Bristol Bay	Ugashik River	5.7 (0.5, 6.5)	8.9 (0.0, 11.3)	2.0 (0.0, 5.8)	0.9 (0.0, 5.8)
	Egegik River	10.5 (7.4, 16.5)	4.1 (1.1, 15.9)	17.7 (6.4, 24.9)	20.1 (11.0, 29.0)
	Naknek River	11.7 (8.3, 18.1)	23.5 (10.0, 26.5)	18.5 (4.4, 22.9)	15.9 (7.7, 21.1)
	Alagnak River	3.5 (1.6, 5.3)	7.3 (3.3, 12.0)		3.9 (1.2, 6.0)
	Kvichak River	31.0 (20.7, 34.4)	13.7 (5.0, 22.9)	14.5 (7.9, 28.7)	22.7 (14.4, 28.1)

	Nushagak River	5.5 (2.0, 9.6)	10.4 (2.8, 14.7)	11.2 (6.1, 21.0)	5.1 (1.5, 10.7)
	Wood River	14.7 (10.6, 18.3)	6.3 (2.6, 12.8)	11.8 (3.8, 18.0)	7.2 (3.6, 10.9)
	Igushik River	1.3 (0.0, 4.0)	2.9 (0.0,6.9)		1.8 (0.0, 3.4)
	King Salmon River	3.1 (0.0, 5.5)		1.6 (0.0, 4.6)	3.7 (0.0, 5.9)
Russia	Chukotka	1.0 (0.0, 2.2)	1.3 (0.0, 4.3)	0.5 (0.0, 3.7)	0.2 (0.0, 1.2)
	Karaginsky Bay	2.6 (0.0, 4.1)	2.2 (0.0, 6.8)	7.9 (0.3, 12.5)	0.7 (0.0, 4.6)
	Olutorsky Bay	0.4 (0.0, 1.9)		0.6 (0.0, 1.9)	1.3 (0.0, 2.6)
	Kamchatka River	2.0 (0.0, 3.5)	2.0 (0.0, 3.0)	2.7 (0.0, 5.5)	0.8 (0.0, 2.2)
	Northwestern Kamchatka	0.3 (0.0, 1.0)			
	Southeastern Kamchatka			0.5 (0.0, 1.8)	
	Kuril Lake	0.5 (0.2, 3.3)	5.3 (1.0, 8.2)	4.0 (1.1, 9.2)	1.4 (0.3, 4.3)
	Bolshaya River	0.6 (0.0, 1.4)	1.3 (0.0, 4.7)	1.3 (0.0, 3.4)	

Table 2. Mean catch per unit effort (CPUE 17 stations (Fig. 1)) and estimated stock compositions (%, 95% confidence limits in parentheses) of mixed-stock samples of age x.1 sockeye salmon from the central Bering Sea, 2009-2013. Estimated stock compositions were derived from applying a 404-population baseline for each sample, with a Pacific Rim distribution of the baseline ranging from Japan, Russia, Alaska, British Columbia, and Washington State as outlined by Beacham et al. (in press). Reporting regions with no estimated stock composition are not listed. N is sample size

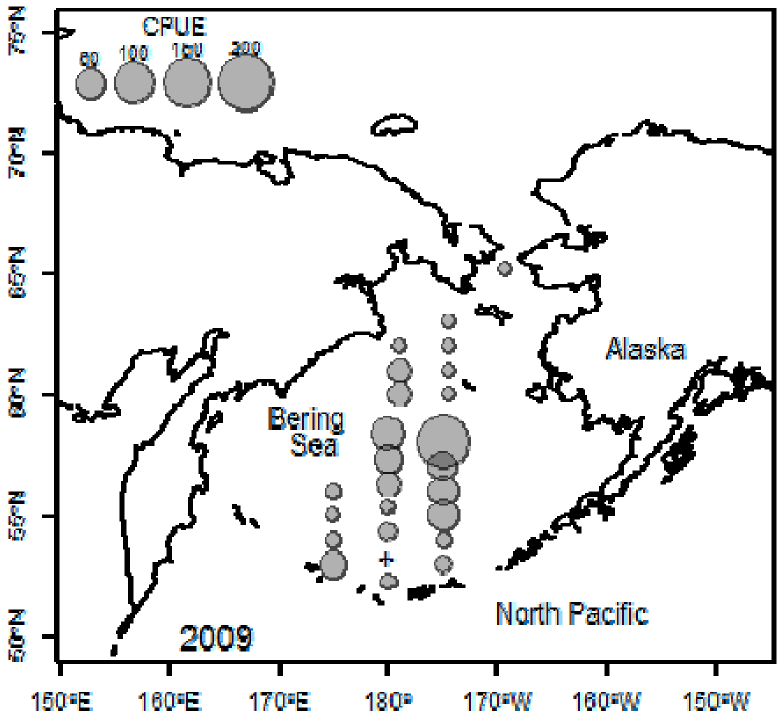
Major region	Stock	Estimate			
Year		2009	2011	2012	2013
CPUE (age x.1)		21.2	4.5	5.3	13.7
N		339	76	89	238
Washington State	Washington				
British Columbia	Fraser River	1.6 (0.0, 3.2)			0.4 (0.0, 0.8)
	Vancouver Island				
	Central Coast				0.3 (0.0, 1.3)
	Haida Gwaii				0.4 (0.0, 1.3)
	Skeena River	0.3 (0.0, 0.9)	1.7 (0.0, 3.9)	1.1 (0.0, 3.4)	3.8 (1.7, 5.9)
	Nass River				0.4 (0.0, 1.3)
	Stikine River	0.2 (0.0, 2.3)	1.4 (0.0, 7.5)	1.1 (0.0, 4.5)	0.7 (0.0, 2.6)
	Taku River	0.8 (0.0, 1.8)			0.7 (0.0, 3.0)
	Alsek River	0.9 (0.0, 6.6)		0.7 (0.0, 3.3)	0.6 (0.0, 3.5)
Southeast Alaska	SE Alaska				
Central Alaska	Cook Inlet	1.5 (0.2, 3.4)	7.9 (2.6, 15.9)		5.2 (2.1, 8.1)
	Kodiak Island	0.6 (0.0, 3.4)	5.0 (0.0, 9.1)	1.7 (0.0, 7.0)	3.9 (0.9, 6.9)
Bristol Bay	Ugashik River	4.3 (0.0, 6.2)	12.5 (0.0, 16.4)	4.8 (0.0, 10.1)	0.2 (0.0, 5.0)
	Egegik River	10.9 (4.8, 19.6)	5.1 (0.6, 24.0)	22.1 (8.2, 34.7)	18.0 (10.2, 26.6)
	Naknek River	12.3 (6.4, 19.1)	28.0 (5.7, 33.4)	21.1 (4.6, 29.8)	15.9 (7.7, 21.1)
	Alagnak River	2.9 (0.8, 5.3)	4.9 (0.0, 9.6)	0.6 (0.0, 5.2)	3.6 (0.0, 5.0)
	Kvichak River	32.9 (19.6, 35.0)	14.0 (3.2, 28.9)	9.7 (2.7, 28.2)	24.9 (12.9, 33.3)

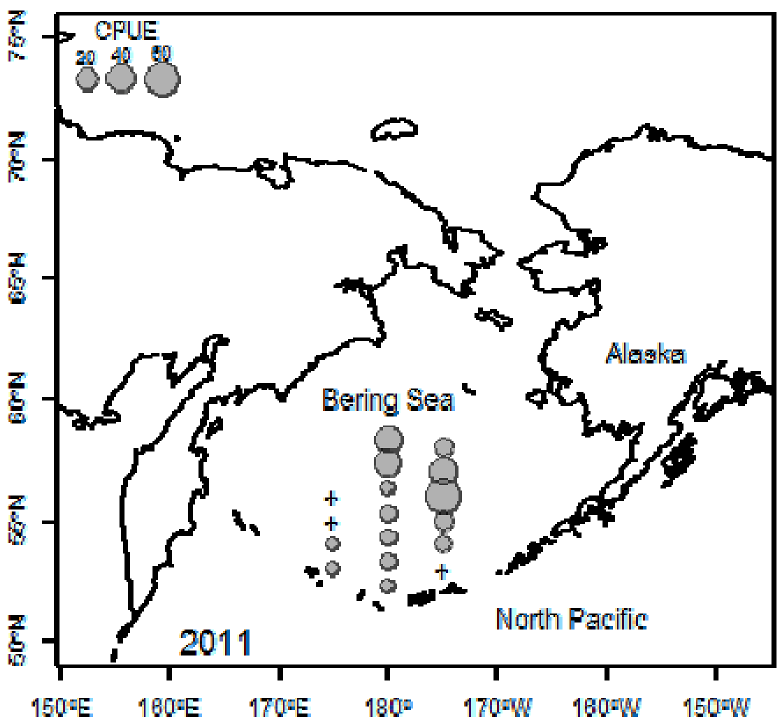
	Nushagak River	4.7 (2.2, 9.2)	5.7 (0.0, 12.8)	8.4 (2.7, 22.1)	5.9 (1.54 12.0)
	Wood River	15.2 (10.0, 19.3)	2.0 (0.0, 8.5)	15.0 (3.5, 20.5)	6.0 (1.5, 9.3)
	Igushik River	1.1 (0.0, 4.9)	4.1 (0.0, 8.2)		0.2 (0.0, 5.0)
	King Salmon River	2.4 (0.0, 5.6)			4.5 (0.0, 8.9)
Russia	Chukotka	1.5 (0.0, 2.5)	1.2 (0.0, 3.9)	0.9 (0.0, 3.5)	0.3 (0.0, 1.3)
	Karaginsky Bay	2.3 (0.0, 5.5)		8.1 (0.0, 13.5)	1.0 (0.0, 4.0)
	Olutorsky Bay	0.5 (0.0, 2.5)		0.6 (0.0, 5.4)	1.1 (0.0, 4.3)
	Kamchatka River	1.4 (0.0, 4.5)	3.6 (0.0, 7.9)	1.2 (0.0, 7.1)	0.4 (0.0, 2.3)
	Northwestern Kamchatka	0.4 (0.0, 1.1)			
	Southeastern Kamchatka				
	Kuril Lake	0.2 (0.0, 2.8)	2.7 (0.0, 5.5)	2.6 (0.0, 3.8)	1.4 (0.3, 4.3)
	Bolshaya River	0.9 (0.0, 2.0)			

Table 3. Mean catch per unit effort (CPUE 17 stations (Fig. 1)) and estimated stock compositions (%, 95% confidence limits in parentheses) of mixed-stock samples of age x.2 sockeye salmon from the central Bering Sea, 2009-2013. Estimated stock compositions were derived from applying a 404-population baseline for each sample, with a Pacific Rim distribution of the baseline ranging from Japan, Russia, Alaska, British Columbia, and Washington State as outlined by Beacham et al. (in press). Reporting regions with no estimated stock composition are not listed. N is sample size

Major region	Stock	Estimate			
Year		2009	2011	2012	2013
CPUE (age x.2)		6.4	5.6	3.7	3.3
N		102	94	63	57
Washington State	Washington		1.1 (0.0, 2.1)		
British Columbia	Fraser River	2.0 (0.0, 4.9)			
	Vancouver Island				
	Central Coast				
	Haida Gwaii				
	Skeena River				
	Nass River				
	Stikine River				2.0 (0.0, 8.8)
	Taku River				3.1 (0.0, 10.0)
	Alsek River	1.1 (0.0, 4.4)			1.6 (0.0, 6.4)
Southeast Alaska	SE Alaska		2.3 (0.0, 5.3)		
Central Alaska	Cook Inlet			2.9 (0.0, 6.6)	
	Kodiak Island	1.8 (0.0, 7.3)	1.1 (0.0, 4.9)	1.4 (0.0, 7.2)	1.6 (0.0, 5.4)
Bristol Bay	Ugashik River	12.2 (0.0, 17.2)	4.6 (0.0, 8.1)		
	Egegik River	10.4 (2.5, 23.4)	6.1 (0.0, 12.6)	9.4 (0.0, 26.4)	25.9 (9.6, 36.0)
	Naknek River	8.6 (1.8, 18.1)	21.9 (5.2, 26.5)	14.5 (0.8, 23.3)	8.9 (0.0, 19.7)
	Alagnak River	5.6 (0.0, 10.3)	9.1 (2.4, 16.6)		4.4 (0.0, 10.0)
	Kvichak River	23.6 (8.7, 32.9)	14.7 (6.1, 29.6)	17.3 (4.3, 34.2)	23.8 (2.3, 29.3)

	Nushagak River	8.8 (0.3, 16.1)	11.0 (0.7, 20.3)	15.8 (3.3, 31.9)	4.9 (0.0, 18.7)
	Wood River	13.9 (5.1, 22.0)	9.3 (1.4, 17.1)	11.9 (1.2, 20.4)	11.3 (0.4, 18.6)
	Igushik River	1.6 (0.0, 6.1)			
	King Salmon River	1.0 (0.0, 5.5)		2.5 (0.0, 7.5)	
Russia	Chukotka	0.3 (0.0, 3.8)	1.4 (0.0, 6.0)	0.5 (0.0, 3.7)	
	Karaginsky Bay	3.2 (0.0, 6.7)	3.6 (0.0, 12.6)	4.8 (0.3, 14.0)	0.4 (0.0, 11.1)
	Olutorsky Bay			1.3 (0.0, 6.4)	3.7 (0.0, 7.5)
	Kamchatka River	2.3 (0.0, 5.7)	1.2 (0.0, 6.0)	5.0 (0.0, 11.0)	2.6 (0.0, 9.1)
	Northwestern Kamchatka				
	Southeastern Kamchatka			1.5 (0.0, 4.7)	
	Kuril Lake	2.5 (0.0, 7.4)	7.5 (1.2, 12.8)	8.7 (0.9, 17.7)	5.8 (0.0, 16.3)
	Bolshaya River	1.1 (0.0, 4.5)	5.0 (0.0, 8.1)	2.7 (0.0, 5.8)	


CPUE
100
200
Alaska
Bering
Sea
North Pacific
2009
75°N
70°N
65°N
60°N
55°N
50°N
150°E
160°E
170°E
180°
170°W
160°W
150°W


CPUE
20
40
60
Alaska
Bering Sea
North Pacific
2011
75°N
70°N
65°N
60°N
55°N
50°N
150°E
160°E
170°E
180°
170°W
160°W
150°W

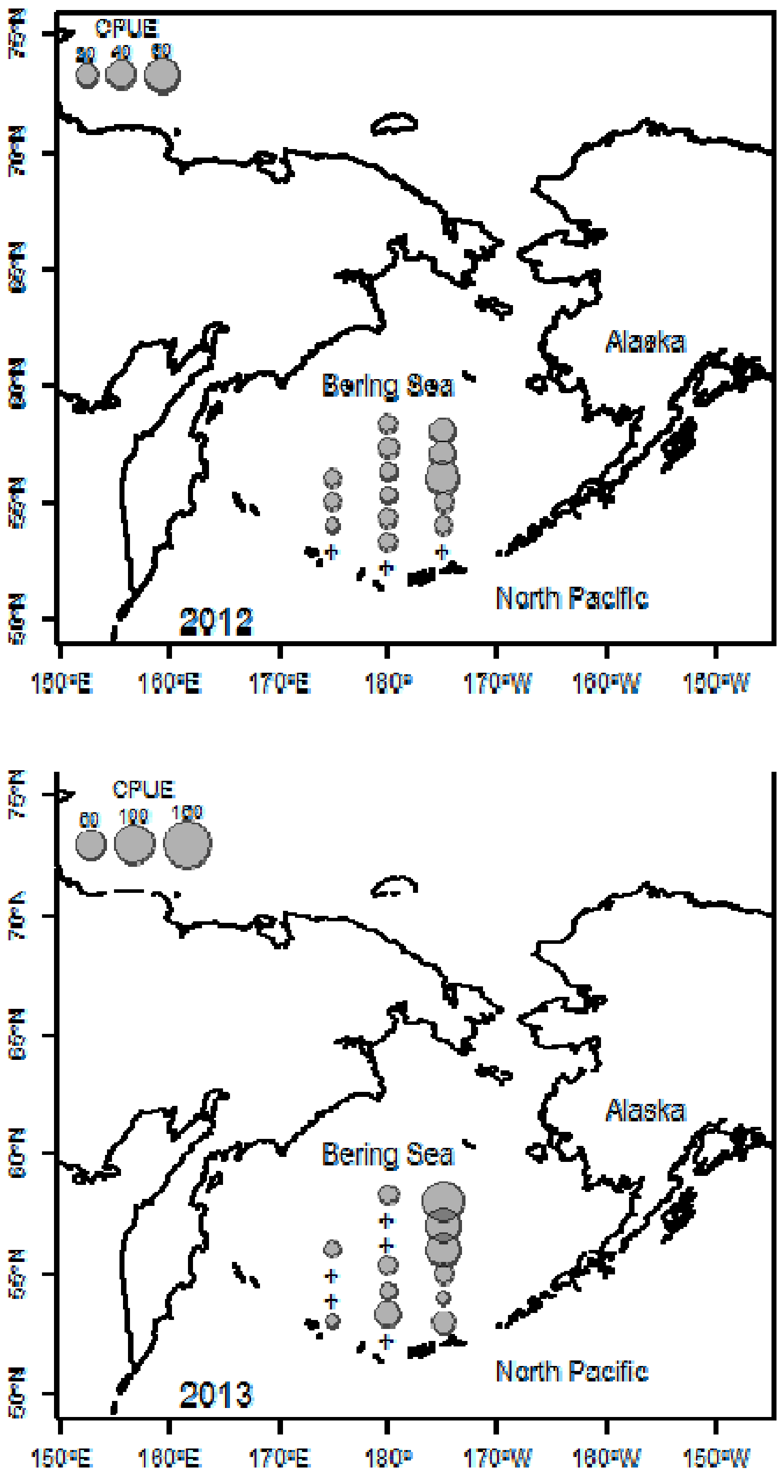
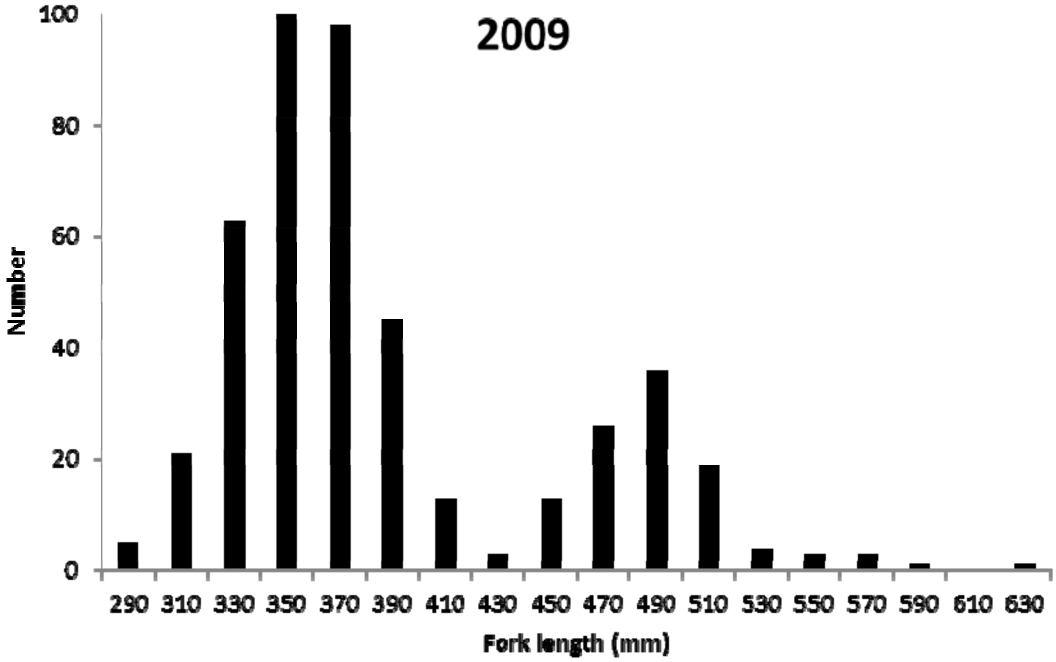
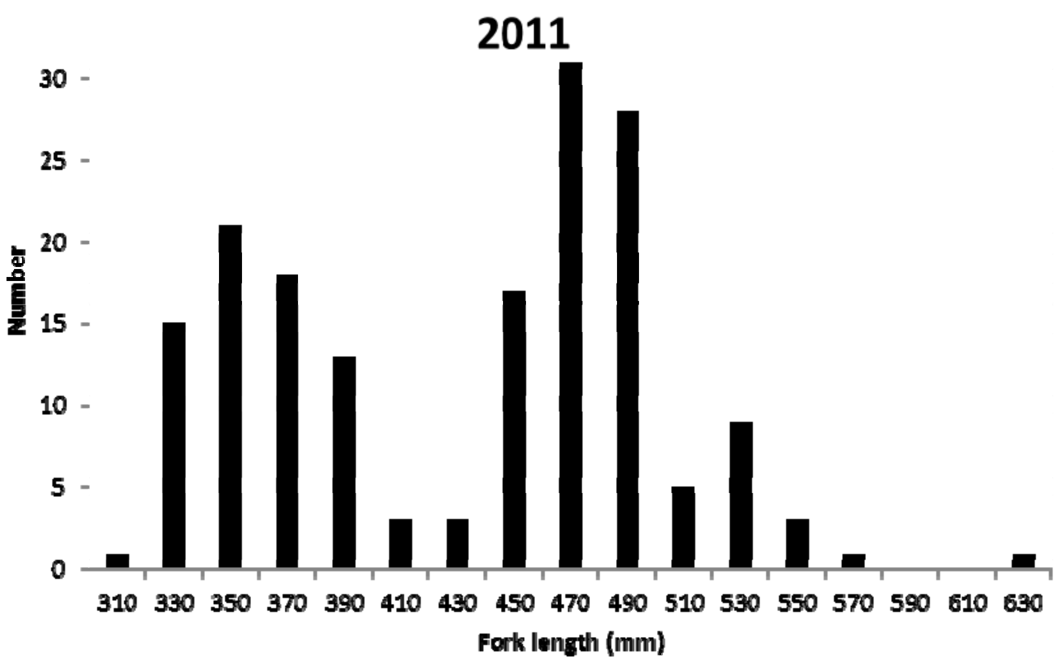


Figure 1. Catch locations of immature sockeye salmon during the 2009, 2011, 2012, and 2013 research cruises of the *Hokko-maru* in the central Bering Sea, with catch abundance outlined by size of the symbol.


2009
100
80
60
40
20
0
Number
290 310 330 350 370 390 410 430 450 470 490 510 530 550 570 590 610 630
Fork length (mm)


2011
30
25
20
15
10
5
0
Number
310 330 350 370 390 410 430 450 470 490 510 530 550 570 590 610 630
Fork length (mm)

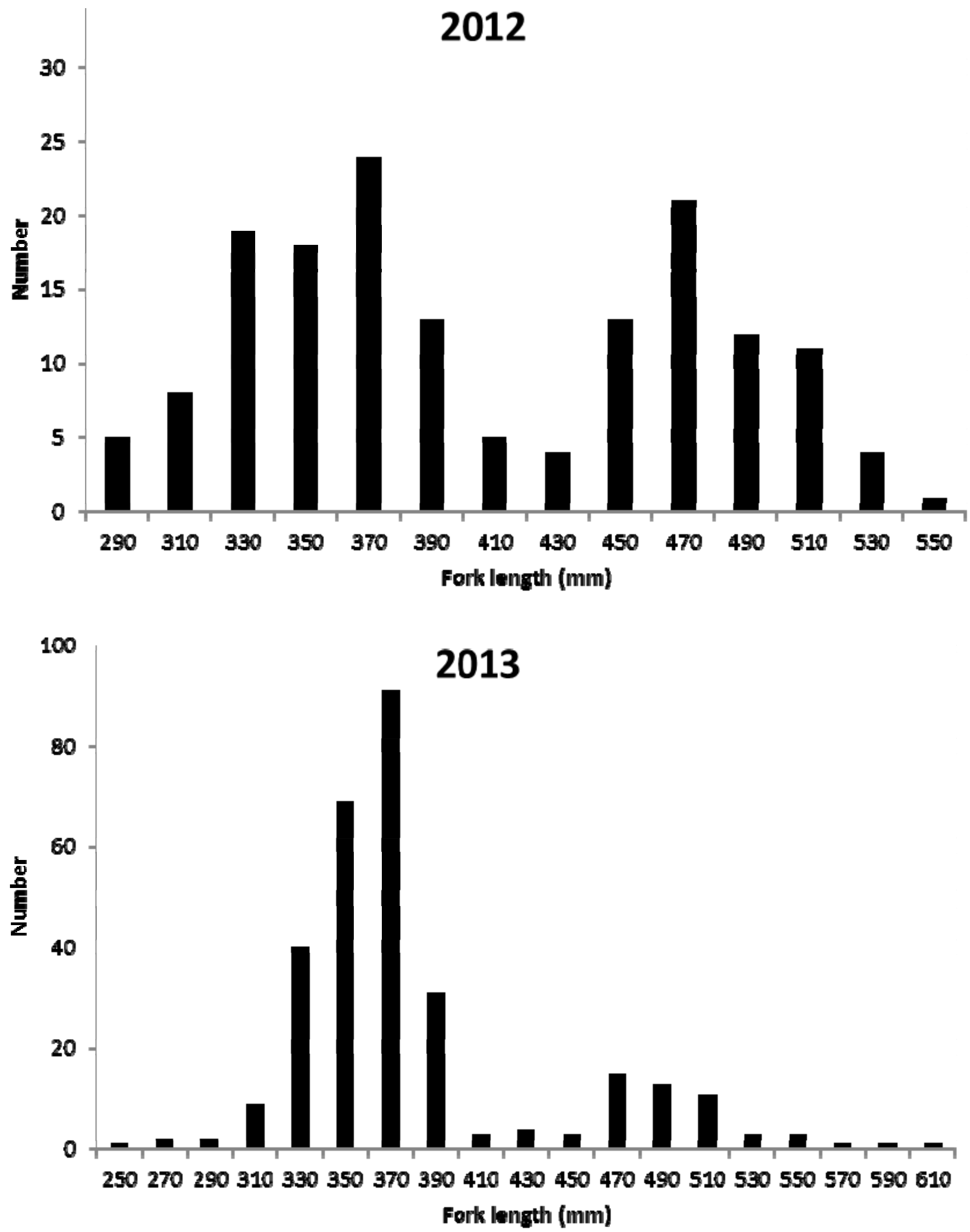
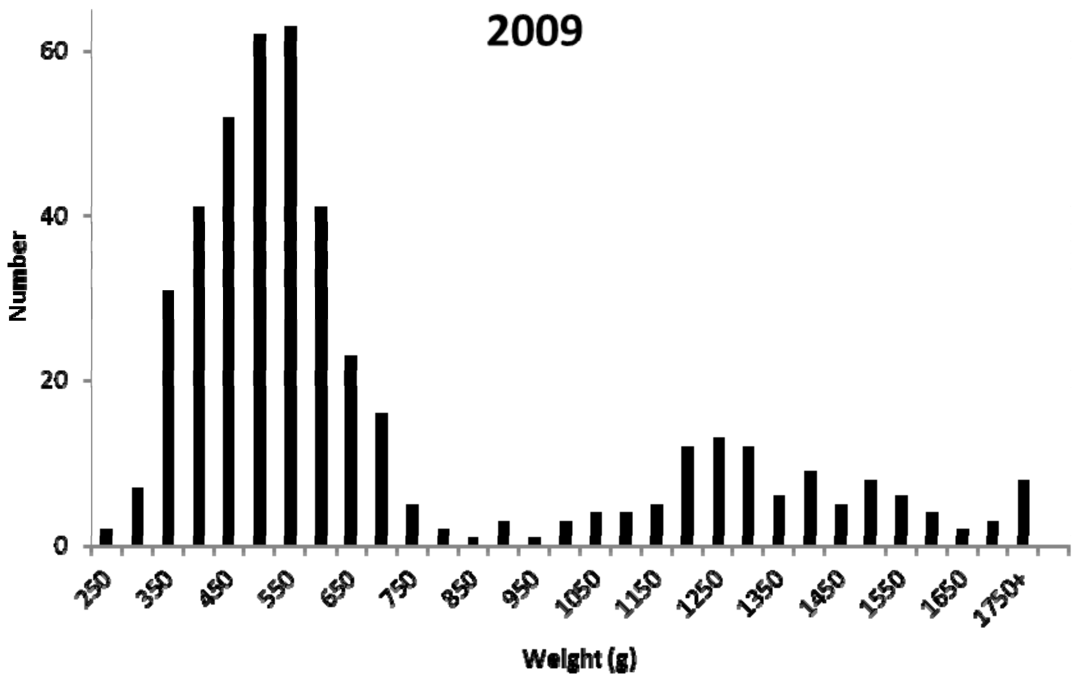
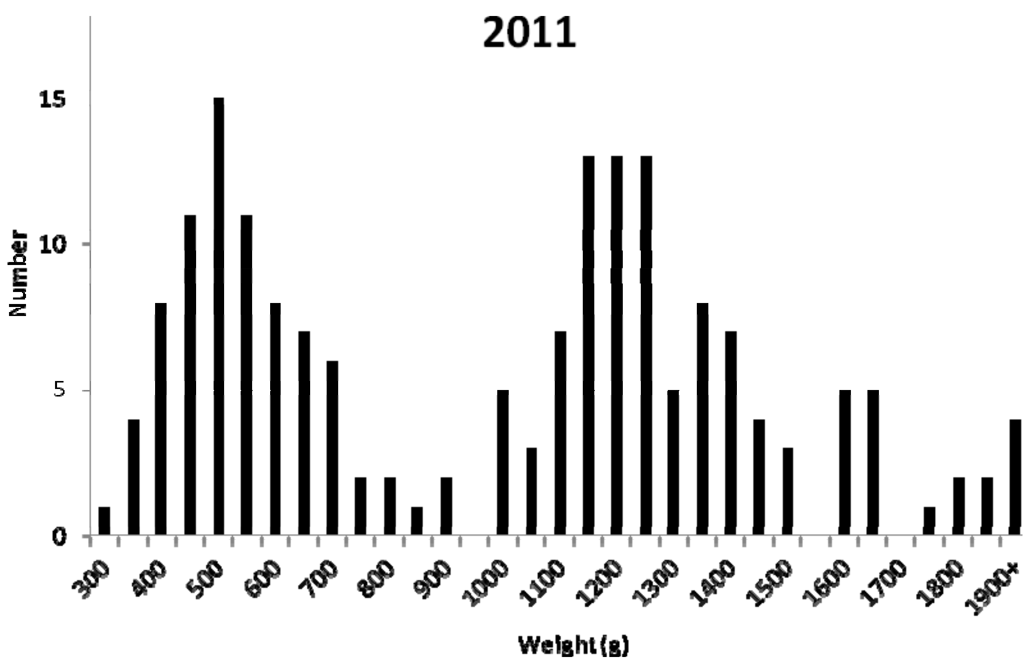


Figure 2. Frequency histogram based upon fork length of immature sockeye salmon caught during the 2009, 2011, 2012, and 2013 research cruises of the *Hokko-maru* in the central Bering Sea.


2009
Number
0
20
40
60
250
350
450
550
650
750
850
950
1050
1150
1250
1350
1450
1550
1650
1750+
Weight (g)


2011
Number
0
5
10
15
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900+
Weight (g)

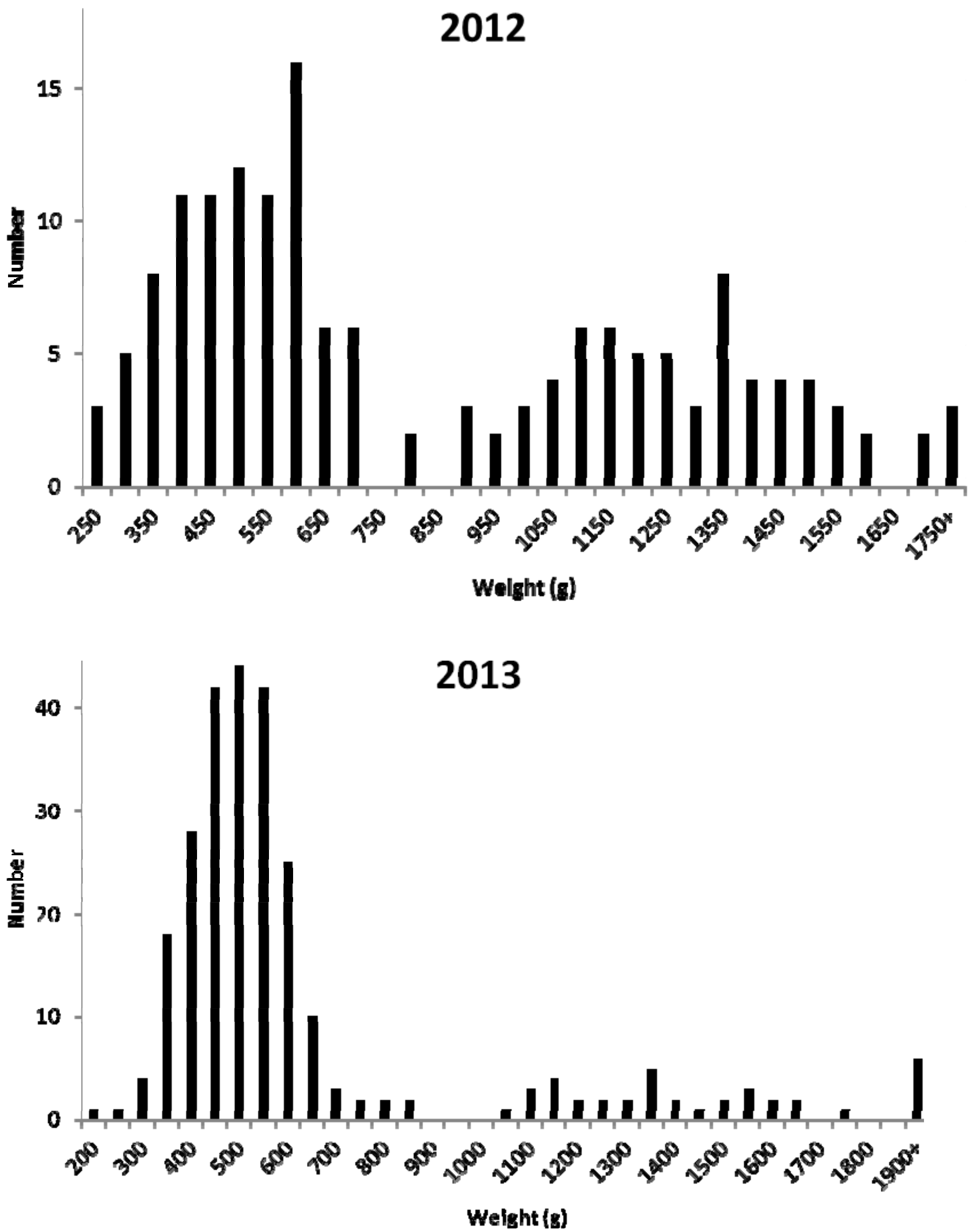


Figure 3. Frequency histogram based upon weight (grams) of immature sockeye salmon caught during the 2009, 2011, 2012, and 2013 research cruises of the *Hokko-maru* in the central Bering Sea.