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Depth distribution of 1SW Chinook salmon in Quatsino Sound, British Columbia, during winter

by

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ABSTRACT

We conducted a trawl survey in Quatsino Sound, British Columbia, to determine the vertical distribution of Chinook salmon during their first winter at sea (1SW) and to test the hypothesis that 1SW Chinook salmon migrate to deeper waters as they get larger. Fifteen-minute tows were performed at 0m, 15m, 30m, and 45 m at seven locations within Quatsino Sound and associated Inlets. We also performed a 15-minute tow at 60 m in four of these locations. Catches peaked at 30-45 m at three locations and were low but stable at all other sites, indicating that the vertical distribution of 1SW Chinook salmon varied among sites within Quatsino Sound. Overall, the size of 1SW Chinook salmon increased with depth, though a bimodal size-frequency distribution was observed at 60 m. Further research will thus be required to understand the processes affecting the distribution of Chinook salmon in the marine environment

INTRODUCTION

Winter is generally considered a critical period for Pacific salmon during their first year in the ocean (Beamish and Manhken 2001; Beamish et al. 2004). Due to low temperature and productivity, salmon may face an extended period of food shortage during winter and have to rely on the energy reserves accumulated in the previous summer and fall to fuel their metabolism. Mortality occurs once energy reserves are depleted. As smaller salmon tend to have lower energy reserves and higher weight-specific metabolic rates, they may also experience higher mortality rates than larger conspecifics (Farley et al. 2011).

Very few studies have attempted to estimate mortality for juvenile salmon during the winter months, possibly due to the difficulty of estimating the abundance of highly migratory fish and to logistical difficulties associated with sampling fish in the rough sea conditions that typically prevail during that time. Trudel et al. (2012) recently estimated mortality rates of juvenile Marble River Chinook salmon in Quatsino Sound, British Columbia, by comparing fall and winter catch-per-unit-effort obtained in trawl surveys. Based on extensive sampling in coastal waters and DNA stock identification techniques, this population is known to reside within Quatsino Sound until the second summer of ocean residence. Their analysis suggested that 60-90% of the juvenile Marble River Chinook salmon died over the winter months. In their study, Trudel et al. (2012) attempted to account for seasonal changes in the depth distribution of juvenile Marble River Chinook salmon. However, little is known on the vertical distribution of juvenile Chinook salmon in this area during winter as sampling focused on near surface waters. In the straits of Southeast Alaska, Chinook salmon are observed in deeper waters during winter and as they attain larger sizes (Orsi and Wertheimer 1995). A similar study has not been carried yet in British Columbia waters.

The objective of this study was to investigate the depth distribution of Chinook salmon in Quatsino Sound during their first winter at sea (1SW). We also compared the size of these fish among depth strata to test the hypothesis that 1SW Chinook salmon migrate to deeper waters as they get larger. This then has implications for mortality assessment.

METHODS

Study area

This study focused on 1SW Chinook salmon in Quatsino Sound, British Columbia (Figure 1). The Quatsino Sound system is composed of three interconnected inlets and one sound, which opens onto the continental shelf off west coast Vancouver Island. At the eastern end of the system, Rupert Inlet and Holberg Inlet are separated from Neurotsos Inlet and Quatsino Sound by the Quatsino Narrows. The combined length of these inlets measures approximately 133 km. Quatsino Sound is a nursery area for Marble River Chinook salmon, a local stock that initially disperse throughout Rupert Inlet and Holberg Inlet, and then to Neurotsos Inlet and Quatsino Sound where they remain for a year before venturing into continental shelf waters (Trudel et al. 2012). Other stocks originating from distant watersheds such as southern Vancouver Island, Puget Sound, and the Columbia River also utilize this area during winter (S. Tucker, unpublished data).

Sampling

Trawl surveys were conducted in Quatsino Sound on March 10-12, 2013 (Table 1). A rope trawl originally manufactured by Cantrawl Nets Ltd., Richmond, British Columbia, and later modified to a model 240 trawl by the fishing crew, was towed at 15 minutes (Trudel et al. 2012). The trawl has a heavy-duty front end of hexagonal web made from 3/8 in. (9.5 mm) and 5/16 in. (7.9 mm) Tenex rope, and a tapered body made-up of 64 in. (163 cm), 32 in. (81.3 cm), 16 in. (40.6 cm), 8 in. (20.3 cm) and 4 in. (10.2 cm) polypropylene sections, an intermediate section of 3 in. (7.6 cm) polypropylene, and a codend of 1.5 in. (3.8 cm) knotted nylon lined with 0.25 in. mesh (64 mm). It has three 40 m bridles of 5/8 in. (1.6 cm) wire rope per side that are attached with a single hook-up to 5 m Jet doors. Typically, 100-150 m of 1.25 in. (3.2 cm) warp was paid out to tow the trawl at the surface. The trawl was towed at 5 knots (2.6 m s^{-1}); this typically achieved a mouth opening that was approximately 28 m wide by 16 m deep as measured acoustically by a Scanmar trawl eye mounted on the headrope.

To determine the depth distribution of 1SW Chinook salmon, we performed 15-minute tows at the surface, 15 m, 30 m, and 45 m in seven locations within Quatsino Sound (Figure 1) and associated Inlets. We also performed a 15-minute tow at 60 m in four of these locations. Fish samples obtained from the trawl were sorted by species, enumerated, and measured to the nearest millimetre on board the ship. All the juvenile Chinook salmon were systematically scanned for coded-wire tags, irrespective of adipose fin clips or not, as not all CWT-tagged fish are clipped (Morris et al. 2004). We used a combination of coded-wire tag recoveries of known-age fish and DNA analyses to establish size-classes in order to separate juveniles from adults, and to differentiate life history types (Fisher et al. 2007; Trudel et al. 2007a, 2007b 2012), as there is considerable overlap among size modes that represent the multiple age groups. Up to 30 juvenile Chinook salmon were randomly selected from each tow and measured to the nearest gram. For these fish, we also took a skin sample from the operculum using a hole-punch and preserved in 95% ethanol to determine their stock of origin using microsatellite DNA (Beacham et al. 2006; Tucker et al. 2011, 2012) and removed calcified-structures (i.e. scales and otoliths) for age determination. These fish were then preserved by freezing individually at minus 20ºC for later chemical and calorimetric analyses such as stable isotopes, and stomach contents analyses.

Statistical Analyses

The number of fish caught per 15-minute tows was compared among depth strata using a Friedman rank sum test with unreplicated blocked data (Sokal and Rohlf 1995). For this analysis, we set the sampling site as a block. We limited this comparison to the 0 m, 15 m, 30 m, and 45 m depth strata, as they were all surveyed at the 7 sites. We also performed a chi-squared contingency table tests on this restricted data set to determine whether or not there was a significant interaction between depth and site (Sokal and Rohlf 1995). The p-value for the chi-square test was simulated by Monte Carlo simulations (10,000 simulations) (Manley 2007). Size-frequency distribution was compared among depth strata using a Kruskal-Wallis test (Sokal and Rohlf 1995). All the statistical analyses and figures were performed in R (R Development Core Team. 2012).

RESULTS AND DISCUSSION

A total of 258 1SW Chinook salmon were caught in Quatsino Sound in March 2013. The number of 1SW Chinook salmon caught per 15-minute tow ranged from 0 to 34 (Table 1) and appeared to follow two patterns within Quatsino Sound: 1) catches were uniformly low at the surface and peaked at 30-45 m at three of the sites (site 1, 2, and 6), and 2) catches were relatively low but stable throughout the water column at four sites (site 3, 4, 5, and 7) (Table 1; Figure 2). Friedman's test indicated that catches did not vary significantly by tow depth, though the p-value was borderline non-significant ($\chi^2 = 7$; df = 3; $p = 0.07$). In contrast, a contingency table analysis revealed that there was a significant interaction between site and depth ($\chi^2 = 101.6$; $p < 0.0001$), indicating that, overall, catches of 1SW Chinook salmon varied significantly by depth, but that this pattern was not consistent among sites.

The average size of 1SW increased with sampling depth from 209 mm in surface tows to 254 mm at 60 m tows (Figure 3). Interestingly, the size-frequency distribution appeared to be bimodal at 60 m, with a peak around 210 mm and one around 275 mm (Figure 3), suggesting there was a mixture of stocks or life-history types 1SW Chinook salmon at this depth (i.e. subyearling vs yearling smolts). The collection of DNA samples will help resolve this unknown in the future. Kruskal-Wallis test indicated that the size-frequency distribution varied significantly among depth-strata ($\chi^2 = 42.6$; df = 4; $p < 0.0001$), even when 1SW Chinook salmon caught at 60 m were excluded from the analysis ($\chi^2 = 11.3$; df = 3; $p = 0.01$).

Previous studies have reported that juvenile Chinook salmon are dispersed throughout the water column, and that they are primarily distributed in the top 30 m during summer and fall, but migrate further down in the winter, and that larger Chinook salmon migrated to deeper waters (Orsi and Wertheimer 1995; Beamish et al. 2007). Results obtained from this study are consistent with previous studies, though our analyses indicate that the winter depth distribution of 1SW Chinook salmon also varies spatially. The systematic sampling design used in this study made it possible to examine changes in the vertical distribution of 1SW Chinook salmon on a finer spatial scale and the consistency of their vertical distribution in the water column. Conductivity-temperature-depth (CTD) cast conducted at these sites did not show any consistent physical (i.e. temperature) or chemical (i.e. salinity and oxygen) depth profiles that could explain these results. None of the 1SW Chinook salmon caught in this study has been genotyped yet. Hence the origin and life-history type of these fish is currently unknown. Further research will thus be required to understand the processes affecting the distribution of Chinook salmon in the marine environment.

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Table 1. Number of juvenile Chinook salmon caught in 15-minute tows at different depths at seven different sites in Quatsino Sound, British Columbia.

Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Total
0	0	1	3	5	1	1	2	13
15	1	6	4	9	1	1	2	24
30	11	34	8	2	2	32	10	99
45	33	32	2	9	1	5	0	82
60	14	18	8	0	--	--	--	40
Total	59	91	25	25	5	39	14	258

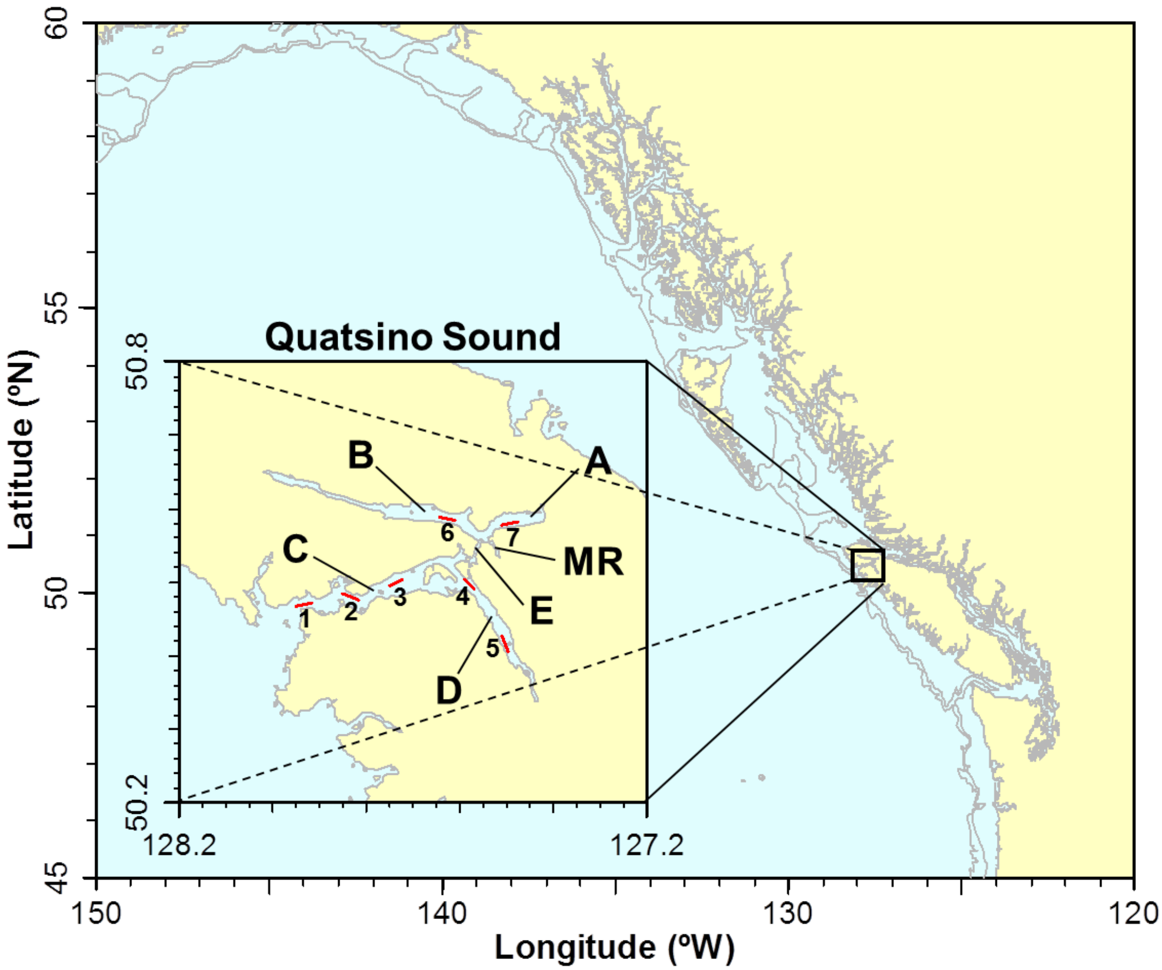

Figure 1. Location of the Quatsino Sound System and Marble River (MR) in British Columbia, Canada. A: Rupert Inlet; B: Holberg Inlet; C: Quatsino Sound; D: Neurotsos Inlet; E: Quatsino Narrows. The numbers represent the sites where 15-minute tows were conducted. Sampling was conducted at the surface, 15 m, 30 m, and 45 m at all sites, and at 60 m at sites 1-4.

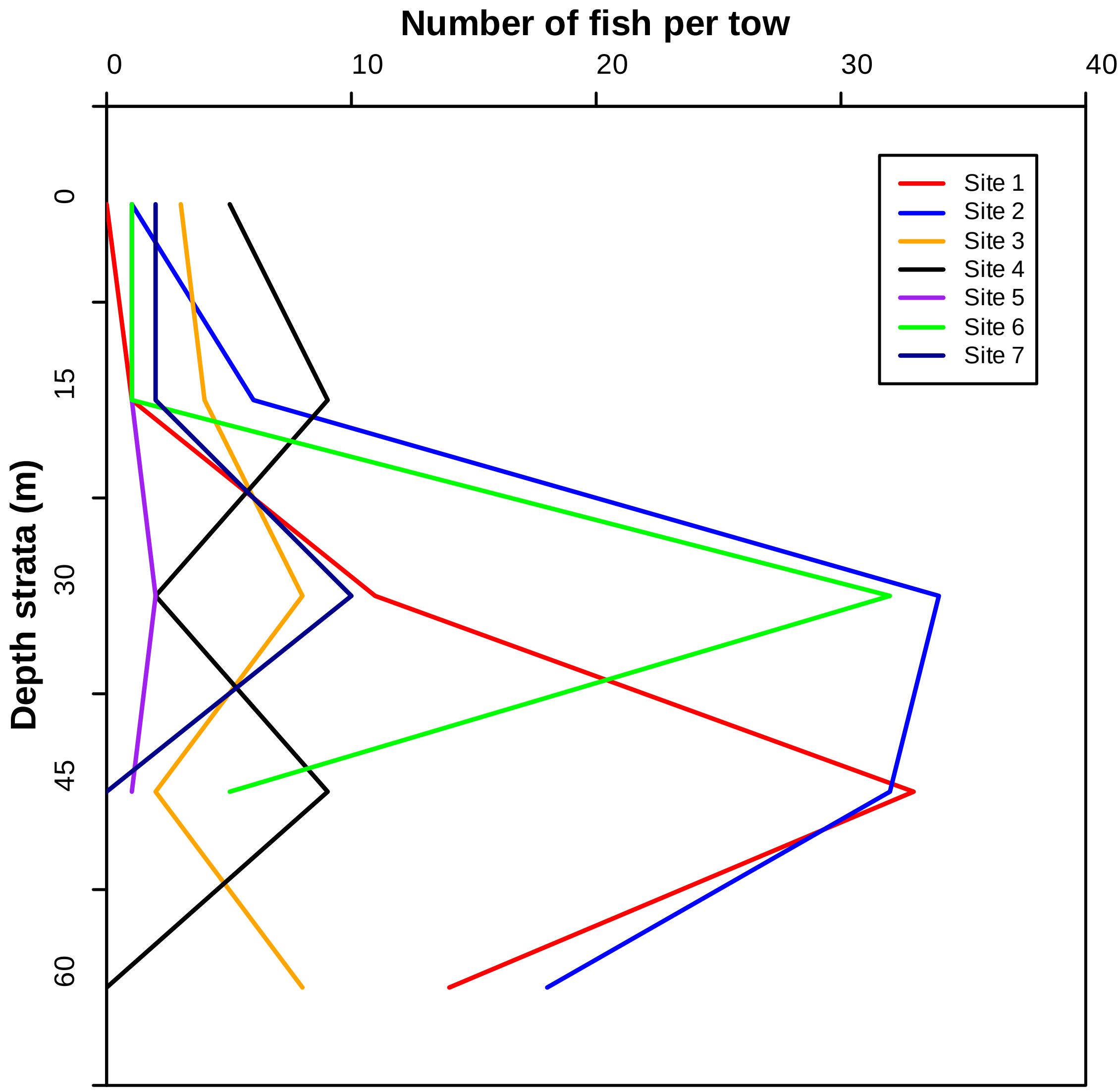

Figure 2. Depth distribution of juvenile in Quatsino Sound, British Columbia, in March 2013.

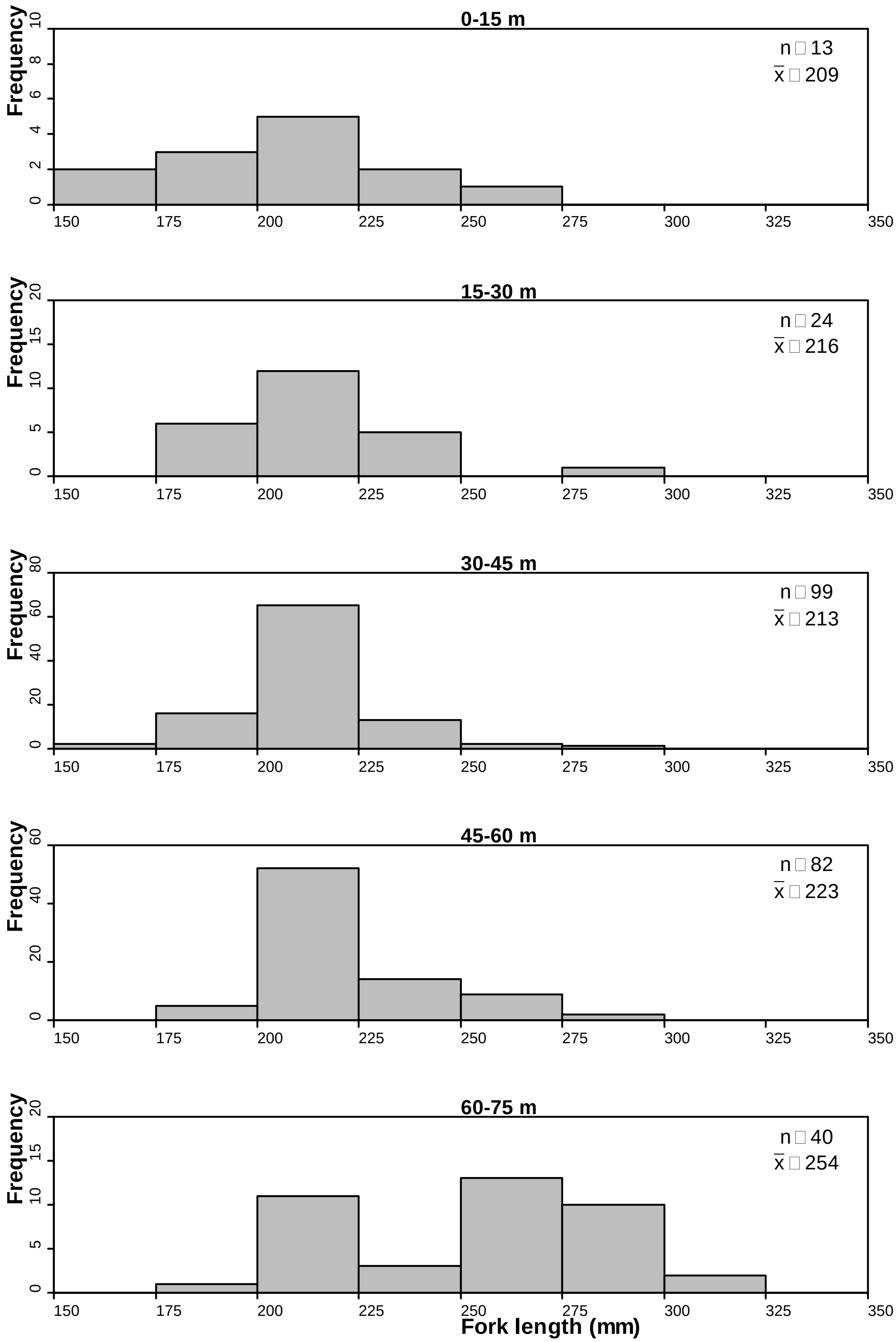

Figure 3. Size-frequency distribution of juvenile Chinook salmon caught in Quatsino Sound, British Columbia, in March 2013, by capture depth.