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Stock-Structured Distribution of Western Alaska and Yukon Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) from United States BASIS Surveys, 2002–2007

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0XUSK\-0PSLQDUOHDQ-(6WRNVWUXFWXUHGGLVWULEXWLRQRIZHVWHUQ$ODVND
and Yukon juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from United States BASIS surveys, 2002–
13DIQGU)LVK&RPP%XOO±

Abstract: We describe migratory patterns of western Alaska and Yukon Chinook salmon (*Oncorhynchus tshawytscha*) using stock-structured distribution data from United States Bering-Aleutian Salmon International Surveys (BASIS), 2002–2007. Juvenile Chinook salmon were distributed within water depths less than 50 m and their highest densities were found close to river mouths of primary Chinook salmon-producing rivers in the eastern %HULQJ6HD<XNRQ.XVNRNZLPDQG1XVKDJDNULYHUVWKURXJKRXWWKHUVWVXPPHUDWVHD7KLVUHÀHFWVDODWH marine dispersal from freshwater entry points than typically found in Gulf of Alaska stream-type Chinook salmon and resulted in the presence of juvenile Chinook salmon in shallow, non-trawlable habitats during the surveys. Juvenile Chinook salmon stock proportions in the northern shelf region (north of 60°N) were: 44% Upper Yukon, 24% Middle Yukon, 31% Coastal Western Alaska, and 1% other western Alaska stock groups. Juvenile Chinook salmon stock proportions present in the southern shelf region (south of 60°N) were: 95% Coastal Western Alaska, 1% Upper Yukon, and 4% other western Alaska stock groups. It is believed that these stock mixtures do not VXSSRUWVLJQLFDQWQRUWKZDUGPLJUDWLRQRIVWRFNVIURPWKHVRXWKHUQVKHOIDQGUHÀHFWOLPLWHGPL[LQJRIVWRFNV IURPWKHLUSURGXFWLRQUHJLRQGXULQJWKHLUUVWVXPPHUDWVHD6SDWLDOGLVWULEXWLRQSDWWHUQVDQGFRGHGZLUH tag recoveries provide evidence that the distribution of Yukon River Chinook salmon extends northward into the &KXNFKL6HDGXULQJWKHLUUVWVXPPHUDWVHD$OWKRXJKMXYHQLOHVSUHVHQWLQWKH&KXNFKL6HDUHSUHVHQWDPLQRU portion of the total Yukon River juvenile population, continued warming of the Arctic could increase the proportion of Yukon River Chinook salmon migrating north into the Chukchi Sea.

Keywords: Bering Sea, Chinook salmon, distribution, migration, stock structure

INTRODUCTION

Migratory corridors used by Chinook salmon (*Oncorhynchus tshawytscha*) and their distribution within the corridors provide key information on the early marine ecology and life-history strategies of juvenile salmon important to their growth and survival (Brodeur et al. 2000). Juvenile Chinook salmon from western Alaska and Yukon, Canada enter the marine waters of the eastern Bering Sea during the spring and summer and migrate along the coast of western $ODVNDGXULQJWKHLUUVWWLPHLQWKHRFHDQ)DUOH\HWDO An understanding of the underlying migratory patterns of salmon is also required to interpret and apply research survey data to population studies of Chinook salmon (Farley et al. 2005).

Although much of the historical work on salmon migration has relied heavily on tagging and marking (Hartt and Dell 1986; Myers et al. 1996; Morris et al. 2007; Trudel et al. 2007; Tucker et al. 2009) and scale pattern analysis (Hartt and Dell 1986; Myers et al. 1996; Sea-ney et al. 2000), genetic methods have expanded the ability RIUHVHDUFKHUVWRVWXG\PLJUDWRU\EHKDYLRURIPDQ\VDOPRQVWRFNV LQWKHRFHDQ6HHEHWDO+DEHFNHWDO7XFNHUHWDO developments in single nucleotide polymorphism (SNP) PDUNHUVDQGJHQHWLFEDVHOLQHVKDYHSURYLGHGDFFXUDWH assignment of Chinook salmon to freshwater origin (Smith HWDO7HPSOLQHWDO613GDWDFDQEHUHDGLO\VWDQGDUGL]HG and scored very rapidly compared to other genetic markers, WKHUHE\HQKDQFLQJWKHHIILFLHQF\RIVWRFNLGHQWLILFDWLRQDQGIUHVKZDWHU origins.

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Farley et al. (2005) initially described migratory pathways of juvenile Chinook salmon in the eastern Bering Sea XOLQ RPDWLRQ XQHPRPOHLWWULEXWLRQH - constructing migration corridors from size data capitalizes on the fact that much of the variability in juvenile size reÀWWKHWLPHRIRFHDQWU\SHDOODWWHUQMXYH - nile salmon from points of ocean entry are apparent in the spatial distribution of size, with the largest juvenile salmon (earliest out-migrants) distributed the greatest distance from their point of ocean entry. In the following analysis, migratory patterns of juvenile western Alaska and Yukon Chinook salmon are described using information on ocean distributions and freshwater origin from coded-wire tags and genetic VWRNLGHQWLÀFDWLRQPHWKRGV

METHODS

Juvenile Chinook salmon were collected with surface rope trawls during the U.S. Bering-Aleutian Salmon International Survey (BASIS) on the eastern Bering Sea shelf from PLGWDUWGDWHWKHVXUYH\DQJHIUR SXVWWRVWHQGGDWHUDQJHIURPHSWHPEH WRFWREHUDULDWLRQLQVWDUWDQGHQGGDWH HFKHUUÀWHFKDQJHLQYHVVHODYDLODELOLW\DQGVXUYH FRYHUDJHDQGGHVLJQFKDQJHQLWLDOVXUYH\GHVLJQ 2003) used transect-based sampling along latitude and longitude lines (Farley et al. 2005). A grid-based sampling design with stations at each degree of longitude and 30 minutes of ODWLWXGHZDVXVHGIURPWR

-XYHQLOH VDOPRQ ZHUH VDPSOHG ZLWK D 1RUGLF WUDZO FROOHFWHGZLWKWKHVXUIDFHURSHWUDZOZDVWUDQVSDFLÀF LPLWHG5LFKPRQG%ULWLVK&ROXPELD5HIHUHQFHWRWUDGH names does not imply endorsement by the National Marine)LVKHULHV6HUYLFH1$$WUDZOLVPORQJDQGKDG KHDGURSHOHQJWKLQJOHQJWKVDQGGLDPRQGFXUHDFP PHVKLQWKHFRGHQG0RVWWUDZOVZHUH towed at the surface at an average speed of 4.3 knots, reVXOWLQJLQDQDYHUDJHYHUWLFDORSHQLQJRIPDQG KRUL]RQWDORSHQLQJRIP6DPSOLQJGHSWKZDVH slightly deeper than the vertical opening as the center of the trawl often was just below the surface during the trawl deployment. Water depths shallower than 20 m were considered non-trawlable and were not sampled. Nor'eastern WUDZOGRRUV POODWKHGRYDOZLWKPEULGOHVZLWKV ZHLJKWRQWKHWRSRIHDFKWUDZOGRRUZHUHXVHG were secured to the wing-tips and center of the headrope to help keep the trawl at the surface and wingtip buoy wakes were monitored to ensure the headrope was maintained at WKHVXUIDFHGXULQJWKHWRZ7UDZOVSHHGDQGZDUSZHUHDGMXVWHGWR keep the trawl at the surface and trawl doors in the water. A 6LPUDG)6VRQDUZDVDWWDFKHGWRWKHKHDGURSHWRPRQLWRUQHW dimensions and trawl geometry during each tow. All trawls were towed astern of the vessel for 30 min at each station. 8QLWFDWFKSHUXQLWHIIRUWRIMXYHQLOHVDOPRQZDVXVHGWRGHVFULEH PHDQDQGVSDWLDOGLVWULEXWLRQZLWKVWDQGDUGL]HGXQLWVRIÀVK - ing effort was effort during a 30-min trawl set. Average area swept by the trawl at each station was 0.25 km².

6WDWLRQVZHUHVDPSOHGWKURXJKRXW WKH VXUYH\ZLWK DURXQG VWDQGDUG LPHQVLRQVWW\SLFDOO\ VWDWLRQV ZHUH sampled each day. Stations were sampled during daylight ZLWKWKHH[FHSWLRQRIWKHODVWVWDWLRQRIHDFKGD\7KHÀUVW station of the day was sampled just after sunrise, and occasionally sampling would occur during sunrise depending on the schedule set for vessel operations by the chief scientist. Salmon catch rates from the crepuscular time-period were QRWVLJQLÀFDQWO\GLIIHUHQWIURPWKRVHGXULQJGD\OLJKWVDPSOHVDU - ley et al. in press). Sample dates differed by location due to the order in which stations were sampled during the survey. Average sample dates were estimated with a weighted average date with weights provided by the catch at each station.

Standard research trawl protocols were used to process the trawl catch. All salmon were sorted and counted by spe-

Table 1. Number of surface trawl stations sampled during U.S. BASIS surveys on the eastern Bering Sea shelf by year and vessel, 2002–2007.

Year	9HVVHO	Start Date	(QG'DWH	Number of 7UDZO6WDWLRQV
2002	)9 *Sea Storm*	20-Aug-02	07-Oct-02	152
	)9 *Northwest Explorer*	08-Sep-02	06-Oct-02	44
2003	)9 *Sea Storm*	21-Aug-03	08-Oct-03	151
2004	)9 *Sea Storm*	14-Aug-04	30-Sep-04	143
2005	)9 *Sea Storm*	14-Aug-05	06-Oct-05	127
2006	)9 *Sea Storm*	14-Aug-06	20-Sep-06	105
	)9 *Northwest Explorer*	21-Aug-06	04-Sep-06	53
2007	)9 *Sea Storm*	15-Aug-07	08-Oct-07	136
	NOAA Ship *Oscar Dyson*	05-Sep-07	26-Sep-07	50

EHQOLIKHLWRUWDJHOOMXHQO&KLQRRNVDORQZH]LEHIRUDEVLQDGLSRVHIQRXWVZHUHRYH IURPMXHQO&KLQRRNVDORQWKDEVLQDGLSRVHQ examined for the presence of a coded wire tag at the Auke Bay Laboratories in Juneau, Alaska. Individual lengths and weights were collected from a subsample of up to 50 Chinook salmon and genetic samples were collected from these K

Kriging models implemented in ArcGIS software package (6,ZHUHWRQVWUXFWWKHSDWLDOGLVWULEX - tion map of juvenile Chinook salmon on the eastern Bering 6KHOKHSDWLDPHDQVPRGHZWKDRRDSR - QLDOUHJUHVVRULRIWRVWLQWKHULJLQPRGH and the spatial covariance of juvenile Chinook salmon was PRGHZWK D VSKHULFDOYDULRJUDP&UHKH spatial model was used to estimate the distribution of juvenile Chinook salmon in non-trawlable habitats with the addition of boundary conditions. Boundary conditions were created by adding with zero catch points on land at spatial scales matching the survey sampling grid.

Freshwater stock origins of juvenile Chinook salmon ZHGHWHUPLQHIURFRGHZUHWDJ-HUHWWDO UHFRYHULHDQ IURJHWLF WRN LGHWLFDWLRQQDOVV Coded-wire tags were assigned to freshwater origin using WKHFRWZLGHPDUN GDWDEDPDLQWDLQH EWKH3DFLI 6WDWHDULQ)LVKHULHRPLVVLRQWWSZPSFRUJ and by coded-wire tag release information provided by the KLWKRUHPDSLGV)LVKDWFKHU5-&

A coast-wide baseline of 42 SNP genetic markers for

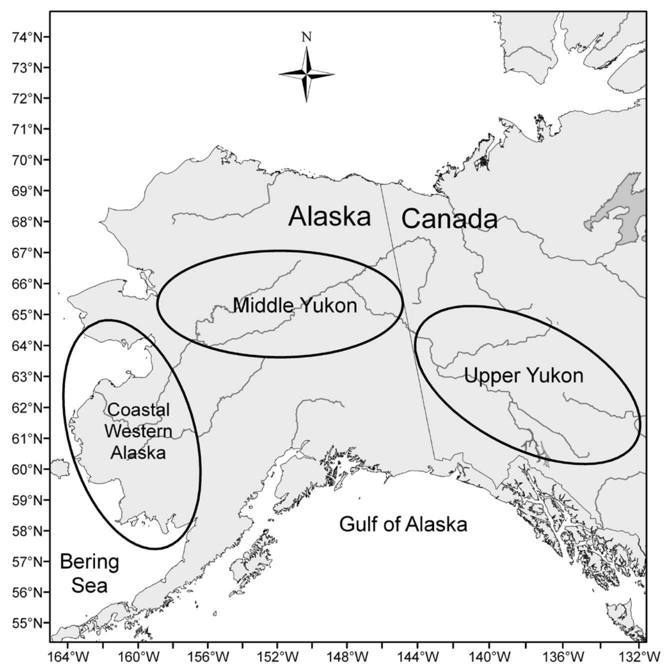

Fig. 1. Approximate locations of regional genetic stock groups of juvenile Chinook salmon (Coastal Western Alaska, Middle Yukon, and Upper Yukon) captured during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf.

&KLQRRNVDPRQGDWDHIURPSLQWDOV used to assign freshwater origin of juvenile Chinook salmon GDWDZHUHDLQHIURMXHQO&KLQR VDPRQWHGXLQJRQWKHPHWKRGV FRWDOQWRNPL[WXUHVWLPDWHGIR three locations on the eastern Bering Sea shelf. Mixed stock proportions at each location were estimated using conditional maximum likelihood models implemented in the SPAM PL[HWRN RWDUHSURJUDP HEHW DO Accuracy of mixed stock assignment to freshwater origins FRQGHUHLQWKLVDQDOVLVUHWHWKDQRQWKH 6EDPSOHWDO

Chinook salmon outside of the eastern Bering Sea were not assumed to be present in the area sampled by the U.S. %\YHXLQWKHUWWRPHDWHMXHQOH KLWRUWDJHWKHUHRQLQRRNVDPRQWRNVIUR eastern Bering Sea river systems were considered in the mixed stock analysis. Stock groups included in the analysis ZHWKHSSHUXNRQLYHWRNJURXWKHLGGOHXNRQ 5LYHUWRNJURXWKRDVWDOHVWHUQDWRNJURX DQDQGWKHVWRNJURX)LJ KRDVWDOHVWHUQ Alaska stock group included the Lower Yukon Chinook salmon stocks and all other western Alaska stock groups DVLGHRWKHNRQLYHUHSWWKHSHU.XVNRNZLP 5LYHUDQRWKHDND3HQXQWRNJURXRUVLP - plicity, these two stock groups were combined into a single 2WKHUWRNJURXSKHLGGOHXNRQWRNJURXLQFOXGHH 6DQDQWULEXWDUWUHDPVGUDLQLQJWKHXUHDQDIWHDQ .DQWDJ0DQDLQWKHLGGOHXNRQWRNJURXLQFOXGHH 6DQDQWULEXWDUWUHDPVLQWKHSSHU.XNRQ5LYHUDQ DQQ5LYHUEDVLQWKHSSHUXNRQWRNJURXLQFOXGHH Canadian tributary streams draining the Pelly and Big Salmon basins and Nordenskiold rivers, and Yukon mainstem Canadian headwaters.

Juvenile mixtures in the northern shelf region (north of 60°N) were compared with expected stock mixtures, and the expected stock mixtures were estimated by the average mixtures present in historical and recent commercial and subsistence harvests in the Yukon River and Norton Sound fisheries. Harvest estimates were not corrected for potential stock selective harvest.

RESULTS

Juvenile Chinook salmon were primarily distributed ZWKLQWKHGSWKWKDQWKUHKWKHUWR - PHDWHPLGGOHVWWKUHKWKPLGGOHFWRE FKLJKWGQWLHMXHQKLQRRNVDPRQZHUH close to river mouths of primary Chinook salmon-producing rivers in the eastern Bering Sea (Yukon, Kuskokwim, and Nushagak rivers) (Fig. 2). Juvenile Chinook salmon were distributed as far north as the Chukchi Sea and the southern extent of their distribution was along the north shore of Bristol Bay. The migration of juvenile Chinook salmon was also in the north the shorter than the

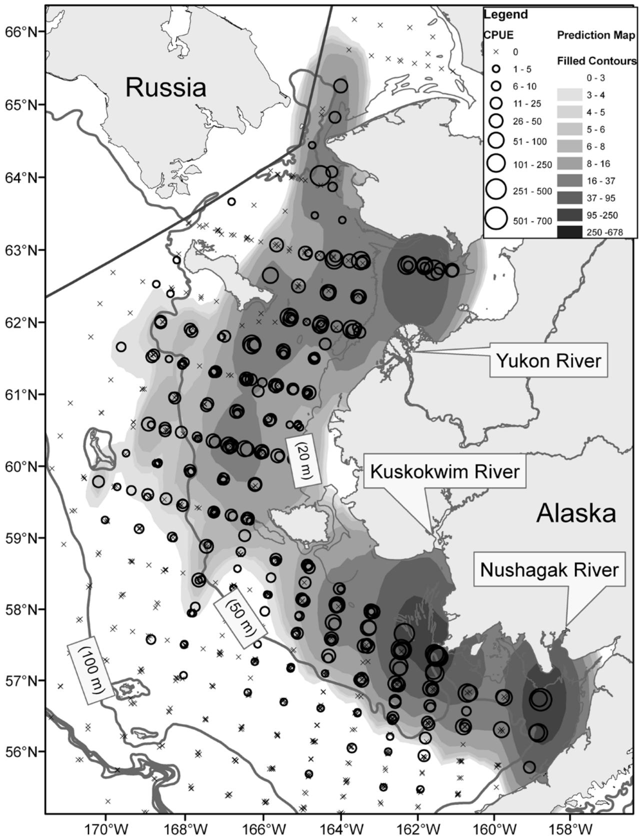

Fig. 2. Distribution of juvenile Chinook salmon during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf (mid August to early October), 2002–2007. Distribution is based on catch per unit RIHIRUW&38(ZWKDEQWUDZKDXOVDWKWDQDUGQW RIHIRUW,QLYLGXOWUDZODWKFHUR YHUODLGRQWKH&38(SUHGLF-tion surface from a Kriging spatial model. Contours are shaded at geometric intervals of the prediction surface.

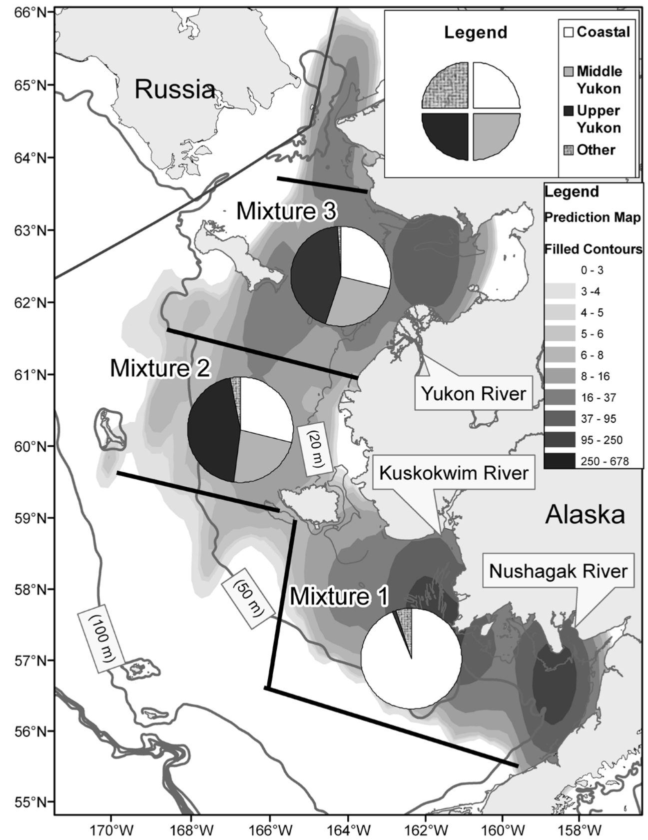

Fig. 3. Genetic stock mixtures of juvenile Chinook salmon (Coastal Western Alaska, Middle Yukon, Upper Yukon, and 'other' stock groups) captured during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf (mid August to early October), 2002–2006. Mixtures are overlaid on a map of juvenile Chinook salmon distribution and black bars identify the spatial extent of samples used for HKPL[WXUHVWLPDWXUHVRYHUODLGRQWKH&38(SUHGLFWLRQ surface from a Kriging spatial model. Contours are shaded at geometric intervals of the prediction surface.

Table 2. (WDWWRFN[WXUHVWKQ FKVHVDPSOHVWDQG IDFHWUDZOVYH on the eastern Bering Sea shelf by region and location, 2002–2006. Average sample dates and DNA sample sizes are included.

Stock Mixture	Region	Location	Average Sample Date	Sample Size	Stock Group			
					Coastal Western Alaska	Middle Yukon	Upper Yukon	Other
1	Southern Bering Shelf	< 167°W	24-Aug	819	0.95 (0.89–0.98)	0.00 (0.00–0.00)	0.01 (0.00–0.01)	0.04 (0.02–0.11)
2	Northern Bering Shelf	60°N<>62°N	24-Sep	238	0.31 (0.23–0.37)	0.23 (0.15–0.30)	0.44 (0.37–0.52)	0.02 (0.00–0.08)
3	Northern Bering Shelf	62°N<>64.5°N	10-Sep	299	0.30 (0.25–0.35)	0.26 (0.20–0.32)	0.43 (0.37–0.50)	0.01 (0.00–0.03)
2 & 3	Northern Bering Shelf	60°N<>64.5°N	14-Sep	537	0.31 (0.26–0.35)	0.24 (0.20–0.29)	0.44 (0.40–0.49)	0.01 (0.00–0.03)

southern shelf region. Peak densities of juvenile Chinook salmon occurred in the shallowest water depths sampled GXULQJWKHVXUYH\LQFDQWRHUMXYHQLOHLQ salmon were estimated to be present in water depths shallower than could be sampled by the trawl gear (20 m).

Average sample dates of the genetic mixtures differed due to the order in which stations were sampled during the VXUYH\DYHUDJHVDPSOHGDWHRIPL[WXUH DQ ZDV 6HSWHPEHU DQG 6HSWHPEHU UHVSHFWLYHO\DYHUDJHVDPSOHGDWHRIPL[WXUHDQ FRPELQHGZDV6HSWHPEHU

6WRFN PL[WXUHVGLIIHUHG E\ UHJLRQ DQG ORFDWLRQ)LJ ,QWKHQRUWKHUQUHJLRQWKHPL[WXUH VWRFN SURSRUWLRQVIRU&RDVWDO:HVWHUQ$ODVND 8SSHU<XNRQ DQG 0LGGOH<XNRQ VWRFN JURXSV ,QWKHQRUWKHUQUHJLRQWKHPL[WXUHFRQWDLQHG8SSHU<XNRQ0LGGOH<XNRQ&RDVWDO:HVWHUQ$ODVNDWRFNVDQG RWKHU :HVWHUQ$ODVND VWRFN JURXSV 0L[WXUHVLPLODUWRPL[WXUHZLWK8SSHU<XNRQ 0LGGOH<XNRQ&RDVWDO:HVWHUQ$ODVNDDQG other western Alaska stock groups. Stock proportions from PL[WXUHDQG FRPELQHGZHUH8SSHU<XNRQ 0LGGOH<XNRQ&RDVWDO:HVWHUQ$ODVNDWRFNVDQG other Western Alaska stock groups.

Stock proportions between juvenile populations and DGXOW KDUYHVWV ZHUH VLPLODU IRU WKH GLIIHUHQW VLJQLILFDQW bias due to incomplete sampling of the juvenile population ZLWKLQWKHQRUWKHUQUHJLRQSURSRUWLRQWKH Coastal Western Alaska stock group in the juveniles from the QRUWKHUQUHJLRQPL[WXUHDQGFRPELQHG6

DVDJKWOKLJKHUWKDQWKHSURSRUWLRQLQWKHKDUYHVW 6RXWKZLWKLQWKHUDQJHRIHVWLPDWHIRU<XNRQ 5LYHUKDUYHVWV<XNRQ5LYHUFKLQRRNSURSRUWLRQWKHLQGLYLGXDOVWRFNJURXSVLQWKHMXYHQLOHSRSXODWLRQVDVVLPLODUWRWKHSURSRUWLRQ HYHQLQWKHKDUYHVWVRIWKHSURSRU tion of the Upper Yukon stock group in the juvenile population ZDVKLJKHUWKDQWKHDYHUDJHSURSRUWLRQLQWKHKDUYHVWVKLJKHUWKDQWKH SURSRUWLRQRIWKHKDUYHVWV8SSHU<XNRQVWRFNJURXS FRPSULVHGDQGRIWKHWRWDOKDUYHVWLQDQG UHVSHFWLYHO\

Coded-wire tags all matched tag codes from the Whitehorse Rapids Fish Hatchery located in Whitehorse, Yukon. Coded-wire tag codes from juvenile Chinook salmon released by the Whitehorse Rapids Fish Hatchery in June are released into the Michie Creek and Wolf Creek drainages, sites of release; however, as no other tagged Canadian juvenile Chinook entered the BASIS survey area in the time span of our survey, all tagged fish were of Whitehorse Rapids Fish Hatchery origin.

Coded-wire tags were recovered at the mouth of the Yukon River and just to the south of Bering Strait. Fig. Coded-wire tags from 2002 were recovered near the mouth of the Yukon River at 64.1°N and at 63.0°N. Coded-wire tags recovered in 2007 were just south of Bering Strait at 65.2°N, confirming the Bering Sea as the outmigration corridor for juvenile Yukon Chinook salmon.

All coded-wire tagged juveniles were age-0 (or fall-type Chinook salmon), a known life-history feature of Chinook

Table 3. Coded-wire tag recoveries from juvenile Chinook salmon captured during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf. Release information provided by the Whitehorse Rapids Fish Hatchery, YRJTC.

		Release Data		Recovery Data				
		Date	Weight (g)	Date	Latitude	Longitude	Length (mm)	Weight (g)
Whitehorse Rapids Hatchery Michie Creek	185061	2-Jun-02	3.2	4-Oct-02	63.0°N	166.0°W	155	49
Whitehorse Rapids Hatchery Michie Creek	185106	10-Jun-02	3.2	3-Oct-02	64.1°N	164.5°W	193	79
Whitehorse Rapids Hatchery Wolf Creek	185102	2-Jun-02	3.1	3-Oct-02	64.1°N	164.5°W	153	43
Whitehorse Rapids Hatchery	18	2007	--	13-Sep-07	65.2°N	168.1°W	176	58
Whitehorse Rapids Hatchery	18	2007	--	13-Sep-07	65.2°N	168.1°W	125	18
Whitehorse Rapids Hatchery	18	2007	--	13-Sep-07	65.2°N	168.1°W	179	58

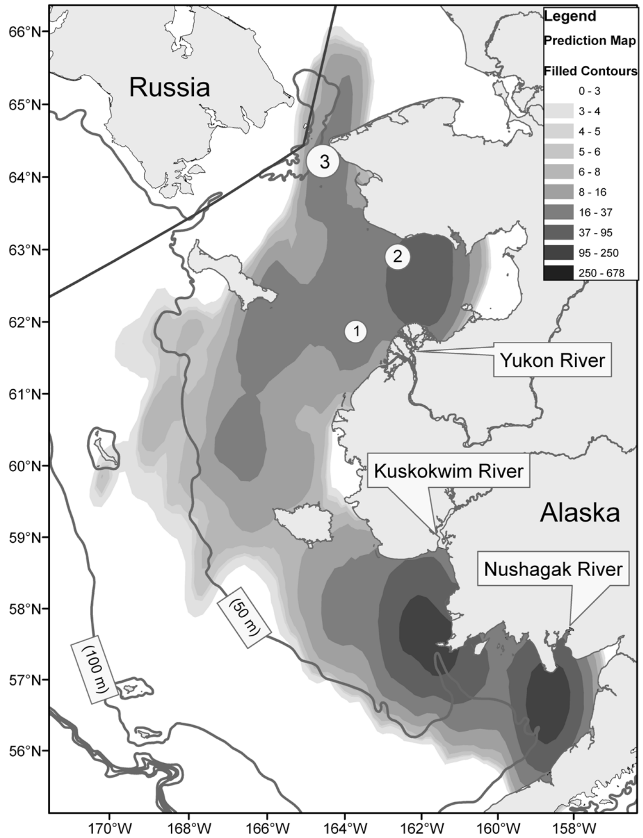

Fig. 4. Locations of coded-wire tag recoveries of Whitehorse Rap- LG)LVKDWFKHU\&KLQRRNVDOPRQIURPWKH+XNRQ5LYHUGXULQJ86 BASIS surface trawl surveys on the eastern Bering Sea shelf (mid August to early October), 2002–2007. Circles indicate coded-wire tag recovery locations and are overlaid on a map of juvenile Chinook salmon distribution. Numbers in each circle indicates the number of coded-wire tags recovered at each location and are overlaid on the &38(SUHGLFWLRQVXUIDFHRI.ULJLQJVSDWLDOPRGHO&RQWRXUVDUH shaded at geometric intervals of the prediction surface.

salmon produced from the Whitehorse Rapids Fish Hatch H\KDWFKHU\KDWFKH\MXYHQLOHPP± JUHDWHUQFDWVPDOOHWKDQWKHDYHUDJHRIMXYH - QLOH&KLQRRNVDOPRQFDSWXUHGGXULQJWKHVXUYH\P JDQKDWFKHU\MXYHQLOHKDGYLVLEOHSDUUPDUNV DWWKHWLPHRIFDSWXUHDYHUDJHGDWH6HSWHPEHU7KH presence of parr marks on hatchery juveniles indicates an ocean entry date much later than most wild juvenile Chinook salmon on the eastern Bering Sea shelf and is consistent with WKHUHFODLVFDWLRQRIWKHVSHFLHVRQVDOPRQ

DISCUSSION

7KHHVWXDULQHDQGHDUO\RFHDQKDELWDWVRIMXYHQLOHVDOP on in the Bering Sea differ from juvenile salmon habitats in the Gulf of Alaska. Juvenile salmon occupy a broad shallow shelf with relatively stable waters in the Bering Sea. In the Gulf of Alaska, juvenile salmon occupy habitats ranging from a network of narrow corridors associated with fjords in southeast Alaska, to the narrow shelf and highly dynamic ZDWHURQWKHFRQILQHVRIWKH%DVNDWR2UU LVWHDO 2000). Migratory corridors of juvenile salmon in summer are largely thought to be constrained to epipelagic waters over the continental shelf once they reach the open ocean LQWKH\$ODVND%URGHXUHWDO2UU LVWHDO)LVKHUHWDO-XQHDPRLJUDWRU\FRUULGRUVLQ DQRSHQRFHDQLQRUHWLRNHWKHEDVHRQ - JUDSKLFDQGEDWKPHWULFIHDWXUHVDQGWKHDVVR - ciation of these features in the Gulf of Alaska (Mundy 2005) often results in the use of the continental shelf to describe MXYHQLOHVDOPRQPLJUDWRU\FRUULGRUVWKHEURDGFRQWLQHQWDO shelf of the Bering Sea provides the opportunity to investigate biological and physical features such as water mass types and frontal regions that structure migratory pathways of juvenile salmon.

Juvenile Chinook salmon were primarily distributed ZLWKLQWKHGHSWKPWKURXJKWKHIURQWDOPHDQW WPLGGOHRIWKUHKWKHPLGGOH2FWRHDQ the highest densities of juvenile Chinook salmon were found close to river mouths of primary Chinook salmon-producing rivers in the eastern Bering Sea (Yukon, Kuskokwim, and 1XVKDJDNULYHUV7KLVUHVXOWDWHGLVSHUVDOIURIUHVK - water entry points than typically found in Gulf of Alaska VWUHDPWVSHFLHQVDOPRQ)LVKHUHWDOKLV likely the effect of later ocean entry dates and slower marine dispersal rates of juvenile Chinook salmon on the eastern Bering Sea shelf.

Foraging behavior of salmon within the Coastal Domain PD\SOD\DNH\UROHLQMXYHQLOH&KLQRRNVDOPRQ KDEWDWDQGGLVSHUVDOUDWHVZLWKLQWKHUU¿WRPHDWE 7KH&RDVWDOGRPDLQW\SLFDOO\QLQZWHUGHSWKV m on the eastern Bering Sea Shelf (Schumacher and Stabeno DQLLVDVVRFLDWHGZLWKUHOHDVHWHFRQVWDEOLW\ tight pelagic-benthic coupling, and high benthic productivLW*UHEPHLHUHWDOKWKUXJKWKXDEXQFRSKRQVWR WKH&RDVWDOGRPDLQDYDULHW\RIIRUDJHVSHFLHVKDGFDSWXUHQ DQ3DFL¿FVDQGODQFHDQFKDUWHUWKHSULQFLSDOSUH\RIMXYH - nile Chinook salmon (Farley et al. in press). It is possible that feeding behavior of Chinook salmon on these forage ¿VKVSHFLHPD\EHUHVWULFWLQJWRGHHSHUGLVSHUVDOIUR the Coastal Domain. An apparent preference for the Coastal Domain is also seen in coho salmon (Farley et al. 2005) ZKLFKDUHQRUHOWLDWHGRQWKHIRUDJH¿VKVSHFLHVLQ the Coastal Domain (Farley et al. in press).

7KHGHJUHHRIDFFHVVWRWKH<XNRQ5LYHUJHQHUDWLRQMX - YHQLOHVDOPRQSRSXODWLRQVLIIHUHQFHJLRQH broad migratory corridor of juvenile Chinook salmon and later survey sampling dates in the northern Bering Shelf region resulted in most juvenile Chinook salmon from this reJLRQRUWKZLWKLQVWUDLWRIKDEWDWWKHQDUURZ migratory corridor and earlier sampling dates in the southern shelf region resulted in a higher proportion of the juvenile VDOPRQSRSXODWLRQRUWKLQVWUDLWRIKDEWDWWKHQ - ability to distinguish between primary stock groups contrib-

uting to the southern shelf index area also limits our ability WRHDOXWKHKHWKHNYHUÀWVMXHQHLQ salmon stocks in this region.

Stock mixtures of juvenile salmon did not support sigQLÀFDQW RQWKDUG PLJUDWLRQWRNYURWKHWKHQ KHUÀWLQDPLWH PLJQRDPRQURGLIIHUHQW SURGKWLRQJHLRQXLQWKHUJWRPHDWH-XQH Chinook salmon in the southern region were primarily from WKHRWDWHQNDWRNJUXKHRH the presence of juveniles from the southern region would increase the proportion of juvenile Chinook salmon assigned to the Coastal Western Alaska stock group. Similarity in juvenile salmon stock mixtures from both spatial strata in the northern region indicates that if juveniles from the southern shelf region were migrating north, they would need to be HQWLQWKRQWKHQDWLDWWUDWD KLVLVQ - likely, given the apparent dispersal rates of juvenile Chinook salmon from the southern region. Comparisons between stock proportions of the juvenile population in the northern KHUJLRQQXYHQLOHKDUYHWVDOGVXSSRUW VLJQLÀFDQWRQWKDUGPLJUDWLRQWKHQWRNVVLJ - QLÀFDQWRHMXYHQLOHVDPRQURWKHQ shelf were migrating north, the estimated proportions of the RWDWHQNDWRNJURXSVLJQLÀFDQWO higher in the northern shelf region than expected for Yukon 5LYHU&KLQRRNVDPRQSURSRUWLRQRWDWHQ Alaska stocks in the northern shelf region was within the UDQJHFWH IRU MXYHQLOH &KLQRRN VDPRQ WRN differences between the juveniles and historic harvests are most likely the result of reduced production of the Upper Yukon stock group relative to historic returns to the Yukon 5LYHUQHLPLWHGRQWKDUGPLJUDWLRQ of juvenile Chinook salmon from the southern shelf region is consistent with the interpretation of size and distribution data summarized by Farley et al. (2005).

&RGHZUHWDJ UHFRYHULHRIMXYHQLOH &KLQRRN salmon near the Bering Strait provide evidence that Yukon 5LYHU &KLQRRN VDPRQGLVWULEXWLRQDQGWHQ RQWKDUG LQWRWKHULQJWUDLW KHREHQ SDWWHUQMXYHQLOH Chinook salmon distribution and coded-wire tag recoveries)LJXUHWKDWMXYHQLOH&KLQRRNVDPRQGLVWULEXWL - tions can also extend into the Chukchi Sea. Although the SURSRUWLRQRIMXYHQLOH&KLQRRNVDPRQWKDWDUHOLNHO to migrate into the Chukchi Sea is small relative to their total marine distribution, anticipated changes in Arctic climate DQGVHDLFHFRXOGLQFUHDVHWKHSURSRUWLRQRIMXYHQLOH VDPRQPLJUDWLQJLQWRWKH&KXNFKL6HD0XUWDO KHQRUWKZDUGH[WHQWRIMXYHQLOH&KLQRRNVDPRQGLV - tribution into the Chukchi Sea was primarily due to catches LQDQHUZWKUHFRUGHDUFWLFVHDLFHDQGDQ FHSWLRQDOZDUPSKDVH0XUWDORQWKDUG DGYHFWLRQPLJUDWLRQRIMXYHQLOH &KLQRRN VDPRQ V LQFRQWUDVWWRWKHEHFNRVLJQLÀFDQWRQWKDUGDGYHFWLRQ migration observed in juvenile Chinook salmon from the VRXWKHUQVKHOIUHJLRQLPDUÀWGLIIHUHQWPDULQH habitats (water depths, freshwater discharge levels, seasonal FXUUHQWVXUIDFHWHPSHUDWXUHVHIIHFWRIVPSO differences in the behavior or life-history of juvenile Chinook salmon from the two regions.

,IKLWRIGLIIHUHQWKDWFKHU\ FDQQRWLQGLIIHUHQWPDULQHGLVWULEXWLRQWKHUHRHWLRQ DSSURSULDWHWRKDUDFWHUL]HWKHGLVWULEXWLRQRIMXYHQLOH stocks with hatchery coded-wire tag recoveries alone. Stock LGHQWLÀFDWLRQGDWDDUHQHHGHGWRGHWHUPLQHPDULQH GLVWULEXWLRQRIMXYHQLOH&KLQRRNDUHFKDUDFWHUL]HG as stream-type Chinook salmon (also known as spring-type as they generally enter the marine habitat in the spring) (GilEHUWDWFKHUMXYHQLOH&KLQRRNVDPRQDUHFKDU - acterized as ocean-type Chinook salmon (also known as falltype as they enter the marine habitat in the fall), which have a IUHVKZDWHUDJHRIRUUHDOLIH KLVWRULHVRUKDWFKHUMXYHQLOH&KLQRRNVDPRQ are not completely unique. Several unmarked or wild juvenile Chinook salmon were similar in size to or smaller than hatchery Chinook salmon and had visible parr marks during HSWHPEHUKLVVXJJHVWWKDWRFHDQWSHDJHMXYHQLOHV DUHSUHVHQWLQDOOSRSXODWLRQVWKRXJKWKHUHDUHOLNHO to represent only a minor portion of the total juvenile popuODWLRQHQWLPLQDQRFHDQWSHMXYHQLOH&KL - QRRNVDPRQPDULQHHDUFWLQWHDO - JHWKDQUHODJHRQHRH&KLQRRNVDPRQ ZLOMXYHQLOHWRNKHUHHUHVKZDWHUDJH MXYHQLOH&KLQRRNVDPRQSRSXODWLRQVSKDVL] - es the importance of freshwater age plasticity in stream-type Chinook salmon as part of their natural life-history variation and not simply an artifact of hatchery rearing (Beckman and LFNKR

KHUHFRPPHQGDWLRQVDUHEDVHGRQWKH U.S. BASIS survey data as it applies to juvenile Chinook salmon populations on the eastern Bering Sea shelf. Juvenile &KLQRRNVDPRQUHSUHVHQWLQWUDZODEOHKDELWDWWKHUH - fore, the effect of non-trawlable habitats needs to be considered when applying survey data to juvenile Chinook salmon populations, particularly in the southern shelf region. Limited mixing of juvenile Chinook salmon from different production regions (northern and southern shelf regions) is thought to ocFXUGXULQJWKHUJWRPHDWHRWKHUWRNPL[WXUH of juvenile Chinook salmon within each region will be needed to evaluate the status of managed stock groups. Although MXYHQLOH &KLQRRNVDPRQVWRNVFDQWHQRQWKDUG LQWRWKHKXNFKLHWKHSURSRUWLRQRIMXYHQLOH&KLQRRN salmon present in the Chukchi Sea is small relative to the total PDULQHGLVWULEXWLRQMXYHQLOHRIMXYHQLOHVDPRQ - ever, it is also important to recognize that changes in Arctic climate and the loss of sea ice could increase the proportion RIMXYHQLOH&KLQRRNVDPRQUHQWLQWKH&KXNFKL6HD GXULQJWKHUJWRPHDWH

ACKNOWLEDGMENTS

:H WKDQN WKH FDSWDLQV DQG FUHZ RI WKH)9 *Sea Storm*,)9 *Northwest Explorer* DQG WKH 12\$\$ VKLS *Oscar Dyson* IRU WKHLU HIIRUWV DQG VXSSRUW RI WKH VXUYH\V :H WKDQN -D PDO 0RVV (LQ .LUN &KULVWLQD)HUJXVRQ DQG 0LFKDHO (ULNVRQ IRU WKHLU DVVLVWDQFH DQG ODERUDWRU\ DQDO\VLV DQG DFFXUDWHO\ UHSRUWLQJ .\OH 2OHVLN DQG 2UHQ 'DYLV IRU WKHLU KHOS ZLWK PDQ\ DVSHFWV RI WKH %\$- SIS surveys. We thank Andy Barclay and Judy Berger from the Gene Conservation Laboratory for their support with laboratory analysis of genetic mixtures. We also thank Kate 0HVVHQJHU DQG 'HEE\ 7KRPSVRQ DQG 5DGKDNULVKQD 6DKHEL IRU WKHLU KHOS ZLWK WKH DQDO\VLV RI WKHLU helpful comments on earlier drafts of this manuscript. Prin- FLSDO IXQGLQJ IRU WKLV ZRUN ZDV SURYLGHG E\ 12\$\$ Fisheries, Alaska Fisheries Science Center, and the Alaska 3DFLILF &RDVWDO 6DOPRQ 5HFRYHU\ ,QLWLDWLYH \$GGLWLRQDO VXSSRUW ZDV SURYLGHG E\ \$)'* DQG by the Alaska Department of Fish and Game (ADFG) for the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative.

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\$UGHQ 5 +RHKOHUW & \$VOODV & 6QGULGJH HOOHU 7HWHUVRQ DQG RQOH DQG 6KLHZ \$FRRUGLQWHG UHVHDUFK SODQ IRU HVWXDULQH DQG RFHDQ UHVHDUFK RQ 3DFLILF VDOPRQ 1 3DF \$QDGU)LVK &RPP 'RF LH

%HFNPDQ % DQG 1LFNKRO 3DWLFLW\R PRWLQ LQ ULQFKLQR VDOPRQ JHWLRQ IRU JURZWK DQG LQIOXQFH RI JURZWK IDFWRU ,-)LVK %LRO

%UDQ 6 DQG 6HWKHQ DUH VFLHWV SHQ PRQ FRPSHFLDO VDOPRQ ILVKHULHV and management strategies. Alaska Department of Fish DQG *DPH 'LYLVLRQ RI &RPPHUFLDO)LVKHULHV 5HJLRQDO ,QIRUPDWLRQ 5HSRUW 1R \$YDLODEOH DW Z DGIJ VWDWH DN XV)HG3)'5,5\$GI

&RRSHU RI WKH)UDQ .0 2ULJLQ RI MXYHQLOH 3DFLILF VDOPRQ UHFRYHUHG IURP FRDVWDO ZDWHUV RI WKH %HULQJ VHD LQ DGGLWLRQ WR WKH WKHPDO PDUNV DQG FRGHG ZLUH WDJV)LVK 5HV

&UHVVLH VWDWLVWLFV IRU 6SDWLDO 'DWD -RKQ HQ\HUV NSS

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%DQ)LFK 2ULJLQ FKL DQG VDOPRQ RQ WKH %HULQJ)LVKHULHV 6HFWLRQ \$ODVND 'H- partment of Fish and Game, Divisions of Sport Fish and &RPPHUFLDO)LVKHULHV)LVK 'DWD 6HULHV (QLURQPHQWDO DWDO 6HD 5HVHUFK ,QVWLWXWH (6, \$UF*,6 \$WODV DUH (HOHQ 6WDWH DOLIRUQLD

(QLURQPHQWDO 6\VWHPV 5HVHDUFK ,QVWLWXWH)DUOH\ DQG .0 ,LGHQ HI WKH PDUNHG marked pink and chum salmon in the coastal waters of WKH %HULQJ VHD)LVK 5HV

)DUOH\ - 0 - 0XUSK\ 2 DQG -0 RQ A. Middleton. 2005. Distribution, migration pathways, and size of Western Alaska juvenile salmon along the HDVWHUQ %HULQJ 6HD VKHOI)LVK 5HV ±

)DUOH\ - 0 - 0XUSK\ - +HPDQ DQG (LQ ,QXUDULHV RI WKH HDVWHUQ %HULQJ VHD MXYHQLOH VDOPRQ)LVK \$PS

)LWFK - 0 & *UXPDQ 2 DQG - 3LFNHU & 7KH (RI WKH \$ODVND %DUGLQ 5 0DF)DUODQH 5 *RUH - 0RULV DQG 6H 6RPSDULQJ of the coastal distributions and abundances of juvenile 3DFLILF VDOPRQ IURP FRQWUDVWLQJ DUHDV RI WKH %HULQJ DQG \$ODVND)LVK \$PS ±

*LEHUW & 6DOPRQ RI WKH 'LYHUV 8 6 %XU)LVK %XOO

*UDKH - 0 - (2YHUDQ 6 0RUUL (DUH -U & RUPDFN * .( )UHH)\$ FDQ DQG FX\$ \$MD 1R DQG - VDO WKH HDVWHUQ %HULQJ 6HD 6FLHQFH ±

+DUWW \$ & DQG 0 -%HOO 6HDVRQDO PLJUDWLRQ DQG JURZWK RI MXYHQLOH 3DFLILF VDOPRQ LQ WKH RSHQ VHD 1 3DF)LVK %XOO

+HDUG : 5 /LIH KLVWRU\ RI SLQN VDOPRQ *In* 3DFLILF VDOPRQ OLIH KLVWRULHV *Edited by* C. Groot and L. 0DUJROLV 8%& 3UHVV SS ±

-HQHWV % % DQG))LFK \$ FRQVLGHUHG WLFDWLRQ RI PDFURUJDQLVPV DWODQWLF ±

/LQG DQG - %URDGKHDG 2ULJLQ RI WKH DODVND VDOPRQ RI WKH 'LYLVLRQ HGXFDWLRQ \$ODVND Department of Fish and Game, Division of Commercial)LVKHULHV 5HJLRQDO ,QIRUPDWLRQ 5HSRUW 1R DQFKRU- age.

0DUWLQ & &KLWPDQ) DFKPHW (&R DQG 6 6KURGH *LWWULEXWLRQ DQG PHDQ DEXQGDQFH RI MXYHQLOH VDOPRQ LQ WKH %HULQJ 6HD 8 6 'HSW &RPPHUFH 12\$\$ 7HFK 0HPR 106 \$)6& 1RDD 6HD *UDQW 3URJUDP)LQDO 5HSRUW

0XQ 3 5 H WKH %HULQJ VHD EURDQ oceanography. University of Alaska, Alaska Sea Grant &ROOHJH 3URJUDP)DLUEDQNV SS

0XUSK\ - 2 DQG 6 \$EH &RPSDULVRQ RI FKLQRRN VDOPRQ WUDZO FDWFK HIILFLHQF\ RI WKH)9 *Northwest Explorer*, 59 *TINRO* DQG 59 *Kaiyo Maru* during the 2002 BASIS survey. N. Pac. Anadr. Fish &RPP 'RF 1R SS \$YDLODEOH DW ZZZ QSDIF org).

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[illegible] tribution, diet, and growth in the northern Bering and [illegible]

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