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\-0:LOOLDPV(QDUH-(WRNWUXWXUHGLVWULEXWLRQRIZHVWHUQ$ODVND and Yukon juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from United States BASIS surveys, 2002– 13DFQGU)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.XVNRNZLP1XVKDJDNULYHUVWKURXJKWKHLUÀUVWPDWV7KLVUHVXOWVLQODWH 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 VXSSRUWVLJQLÀFDQWQRUWKZDUGPLJUDWLRQRIVWRFNVIURPWKHVRXWKHUQVKHOIDQGUHÁHFWOLPLWHGPL[LQJRIVDOPRQ IURPWKHWZRSURGXFWLRQUHJLRQVGXULQJWKHLUÀUVWPDWV6SDWLDOGLVWULEXWLRQSDWWHUQVDQGFRGHGZLUH tag recoveries provide evidence that the distribution of Yukon River Chinook salmon extends northward into the &KXNFKL6HDGXULQJWKHLUÀUVWPDWVDOWKRXJKWKHMXYHQLOHSUHVHQWLQWKH&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 $ODVNDGXULQJWKHLUÀUVWPRQWKVLQWKHRFHDQ 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 migraWLRQKDVUHOLHGRQWDJJLQJDQGPDUNLQJUHVHDUFK+DUWWDQG 'HOO0\HUVHWDO-DQLFNL)DUOH\HWDO&RXUW- ney et al. 2000), genetic methods have expanded the ability RIUHVHDUFKHUVWRVWXG\PLJUDWRU\EHKDYLRURIVDOPRQ LQWKHRFHDQ7HHODQGHWDO6HHEHWDO5HFHQW developments in single nucleotide polymorphism (SNP) PDUNHUVDQGJHQHWLFEDVHOLQHVSURYLGHHIÀFLHQWDQGDFFXUDWH assignment of Chinook salmon to freshwater origin (Smith HWDO7HPSOLQHWDO613GDWDFDQEHFROOHFWHG and scored very rapidly compared to other genetic markers, WKHUHIRUHLQVLJKWVFDQEHJDLQHGLQWRWKHLUVWRFN origins.

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Farley et al. (2005) initially described migratory pathways of juvenile Chinook salmon in the eastern Bering Sea XQLQ\PDWLRQ MXYHQLOH VL]H GLVWULEXWLRQ H -
constructing migration corridors from size data capitalizes on the fact that much of the variability in juvenile size reÀHFWV WKH WLPH RI RFHDQ HQWU\ LQ\ VSHFLHV DWWHUQ MXYH -
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 VWRFN LGHQWLÀFDWLRQ PHWKRGV

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 2002 VWDUW GDWH WKH VXUYH\ UDQJHG IURP $XJ WR $XJ HQG GDWH UDQJHG IURP 6HSW WR 2FW WR 2FW ,Q DGGLWLRQ VWDUW DQG HQG GDWH HDFK \HDU UHÀHFWHG FKDQJHV LQ YHVVHO DYDLODELOLW\ DQG VXUYH\ FRYHUDJH DQG GHVLJQ 7KH LQLWLDO VXUYH\ 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 ODWLWXGH ZDV XVHG IURP WR

-XYHQLOH &KLQRRN VDOPRQ DQG RWKHU SHODJLF VSHFLHV ZHUH FROOHFWHG ZLWK D VXUIDFH URSH WUDZO PRGHO 1RUWKHDVW 3DFLÀF ,PLWDWLRQ 5RSH 7UDZO ,QF 1HW 6\VWHPV ,QF 5HIHUHQFH WR WUDGH
names does not imply endorsement by the National Marine)LVKHULHV 6HUYLFH 12$$ 7KH WUDZO ZDV P ORQJ DQG KDG KH[DJRQDO PHVK LQ ZLQJV DQG ERG\ DQG D FP PHVK OLQHU LQ WKH FRG HQG 0XOWLSOH WUDZO ZDUSV ZHUH

towed at the surface at an average speed of 4.3 knots, UHVXOWLQJ LQ DQ DYHUDJH YHUWLFDO PRXWK RSHQLQJ RI P DQG KRUL]RQWDO PRXWK RSHQLQJ RI P 6DPSOLQJ GHSWK ZDV
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 WUDZO V\VWHPV DOXPLQXP GRRUV ZLWK P EULGOHV ZHUH XVHG WR VSUHDG WKH QHW 7\SLFDOO\ P DWWDFKHG WR WKH QHW IORDWV
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 WKH VXUIDFH GXULQJ WKH WUDZO 6HYHUDO DGMXVWPHQWV ZHUH XVHG WR
keep the trawl at the surface and trawl doors in the water. A 6LPUDG)6 QHW VRXQGHU ZDV DWWDFKHG WR PRQLWRU WKH ÀVKLQJ
dimensions and trawl geometry during each tow. All trawls were towed astern of the vessel for 30 min at each station. &DWFK SHU XQLW RI ÀVKLQJ HIIRUW &38(ZDV XVHG WR GHVFULEH DEXQGDQFH DQG VSDWLDO GLVWULEXWLRQ LQ WKH VWDQGDUGL]HG XQLW RI ÀVK -
ing effort was effort during a 30-min trawl set. Average area swept by the trawl at each station was 0.25 km².

6WDWLRQV ZHUH VDPSOHG HYHU\ NP DORQJ WUDQVHFWV RU VWDWLRQV DSSUR[NP DSDUW DQG 6WDQGDUG ZDV D WLPH DQG HDFK WUDQVHFW W\SLFDOO\ RQH WR WZR VWDWLRQV ZHUH
sampled each day. Stations were sampled during daylight ZLWK WKH H[FHSWLRQ WKDW WKH ÀUVW VWDWLRQ HDFK GD\ WKH ÀUVW
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 QRW VLJQLÀFDQWO\ GLIIHUHQW IURP WKH GD\OLJKW VDPSOHV)DU -
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

EHQOLIKLWRUWDJHOOMXHQO&KLQRRNVDOPRQZHUH
HPRIRUDEVHQFHRIDGLSRVHILQRQWKHVHDUHYH
IURPMXHQO&KLQRRNVDOPRQZLWKDEVHQWDGLSRVHILQ
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 packDJH(6,5HZWRQWUKWWKHVSDWLDOGLVWULEX - tion map of juvenile Chinook salmon on the eastern Bering 6KHKHVSDWLDOPHDQVUHPRYHGZLWKDSRO - QLDOUHJUHVVLRQRIWRZVLWQWKHULJLQPRGHO and the spatial covariance of juvenile Chinook salmon was PRGHOHGZLWKDVSKHULFDOYDULRJUDP&RQWKH 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 ZHUHGHWHUPLQHGIURPFRGHGZLUHWDJ-HHWWHWDO UHFRYHULHVDQGIURPJHQHWLFVWRFNLGHQWLILFDWLRQDQDOVV Coded-wire tags were assigned to freshwater origin using WKHFRDVWZLGHPDUNGDWDEDVHPDLQWDLQHGEWKH3DFLILF 6WDWHV0DULQH)LVKHULHV&RPPLVVLRQKWWSZZZUPSFRUJ and by coded-wire tag release information provided by the KLWHKRUVH5DSLGV)LVKDWFKHU5-&

A coast-wide baseline of 42 SNP genetic markers for

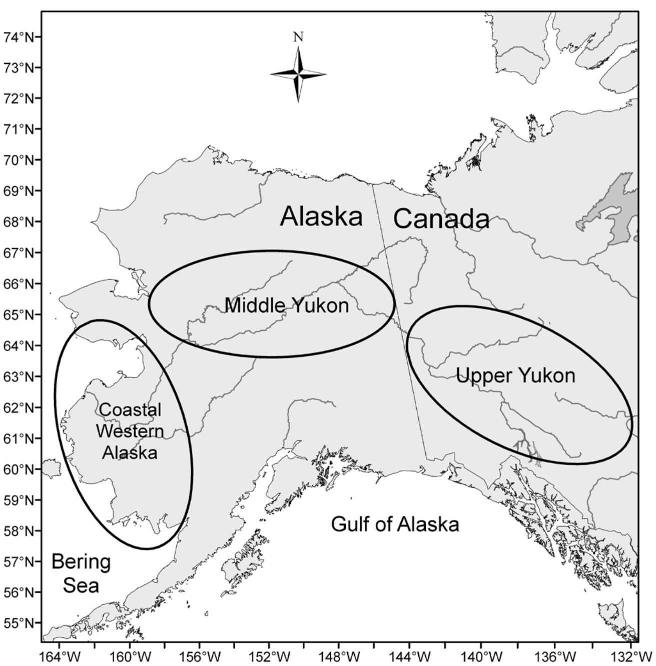

Fig. 1. Approximate locations of regional genetic stock groups of juvenile Chinook salmon (Coastal Western Alaska, Middle Yukon, and Upper Yukon) captured during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf.

&KLQRRNVDOPRQGDWHIURPSODQWHWDOV used to assign freshwater origin of juvenile Chinook salmQGDWDZHUHDYDLOHGIURPMXYHQLOH&KLQRRN VDOPRQWHGXLQHGRQWKHHWKHV HDWDDQWRNPL[WXUHVWLPDWHVIR 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 PLHVWRNDQDOVLVSURJUDPHEHWDO Accuracy of mixed stock assignment to freshwater origins FRQGHLQWKLVDQDOVLVZDVJUHDWHUWKDQRQWKH 7HPSOLQHWDO

Chinook salmon outside of the eastern Bering Sea were not assumed to be present in the area sampled by the U.S. %\$6,6VXUYHLQWKHUHJLRQWRPHDWXUHMXYHQLOH KLWRUWDJWKHUHIRUHRQO&KLQRRNVDOPRQVWRFNVIUR eastern Bering Sea river systems were considered in the mixed stock analysis. Stock groups included in the analysis ZHUHWKH8SSHUXNRQ5LYHUVWRFNJURXSWKH0LGGOHXNRQ 5LYHUVWRFNJURXSWKH&RDVWDO:HVWHUQ$ODVNDVWRFNJURXS DQGDQRWKHUVWRFNJURXS)LJ7KH&RDVWDO:HVWHUQ Alaska stock group included the Lower Yukon Chinook salmon stocks and all other western Alaska stock groups VRXWKRIWKHXNRQ5LYHUH[FHSWWKRVHLQWKH.XVNRNZLP 5LYHUDQG1RUWKRQD3HQLQVXODVWRFNJURXSV)RUVLP - plicity, these two stock groups were combined into a single 2WKHUVWRFNJURXS7KH0LGGOHXNRQVWRFNJURXSLQFOXGHG WULEXWDULHVRIWKHXNRQ5LYHULQ$ODVNDGUDLQLQJWKHLQWHULRU .DQWDJ0RXQWDLQVWKH0LGGOHXNRQVWRFNJURXSLQFOXGHG WULEXWDULHVLQWKHXSSHU.RXNXN5LYHUDQG 7DQDQD5LYHUEDVLQVWKH8SSHUXNRQVWRFNJURXSLQFOXGHG Canadian tributary streams draining the Pelly and Big SalmRQ0RXQWDLQVDQGDQRUDMKLQ

Juvenile mixtures in the northern shelf region (north of °1 ZHUHFRPSDUHGZLWKH[SHFWHGDGXOWVWRFNPL[WXUHVQ WKHXNRQ5LYHU(;SHFWHGDGXOWVWRFNPL[WXUHVZHUHHVWL - mated by the average mixtures present in historical and reFHQWFRPPHUFLDODQGVXEVLVWHQFHKDUYHVWVLQWKHXNRQ5LYHU XNRQ0LFKDHOVRQDQGEURZQ7KH estimates were not corrected for potential stock selective harvest.

RESULTS

Juvenile Chinook salmon were primarily distributed ZLWKLQWKHLQQHUGRPDLQZLWKWKHPDMRULWRIFDWFKHV - PHDVXUHPHQWVDERYHWKH°1RQWKHLQQHUVKHOI7KHKLJKHVW FRQFHQWUDWLRQVRIMXYHQLOH&KLQRRNVDOPRQZHUH 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 BrisWRO%D7KHPLJUDWLRQFRUULGRURIMXYHQLOH&KLQRRNVDOPRQ ZDVPRUHLQVKRUHWKHPRQWKVWKDQRIWKH

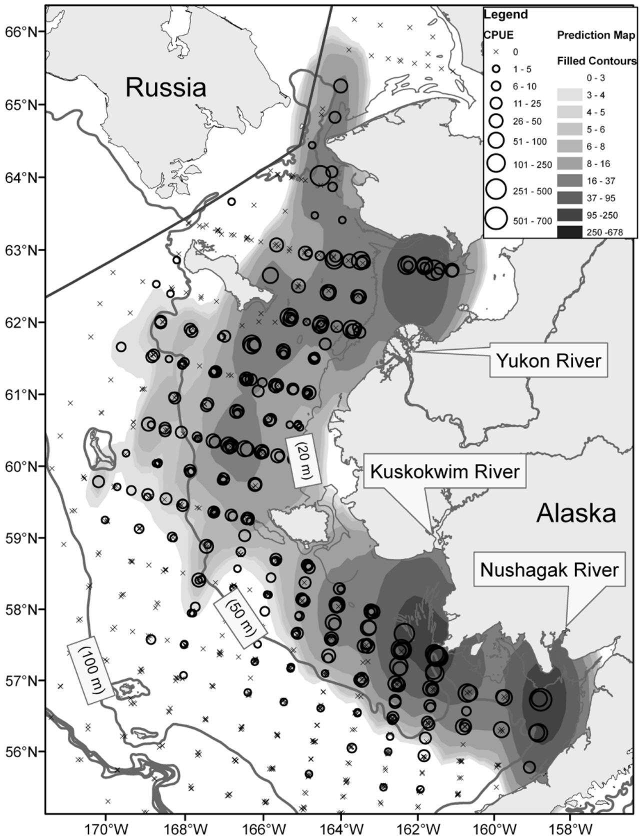

Fig. 2. Distribution of juvenile Chinook salmon during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf (mid August to early October), 2002–2007. Distribution is based on catch per unit RIHRUW&38(ZWKDEQWUDZOKDOIDWKWDQGDUGQW RIHRUW,QLYLGDOWUDZOEDWFKHURYHODLGRQWKH&38(SUHGLF-tion surface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

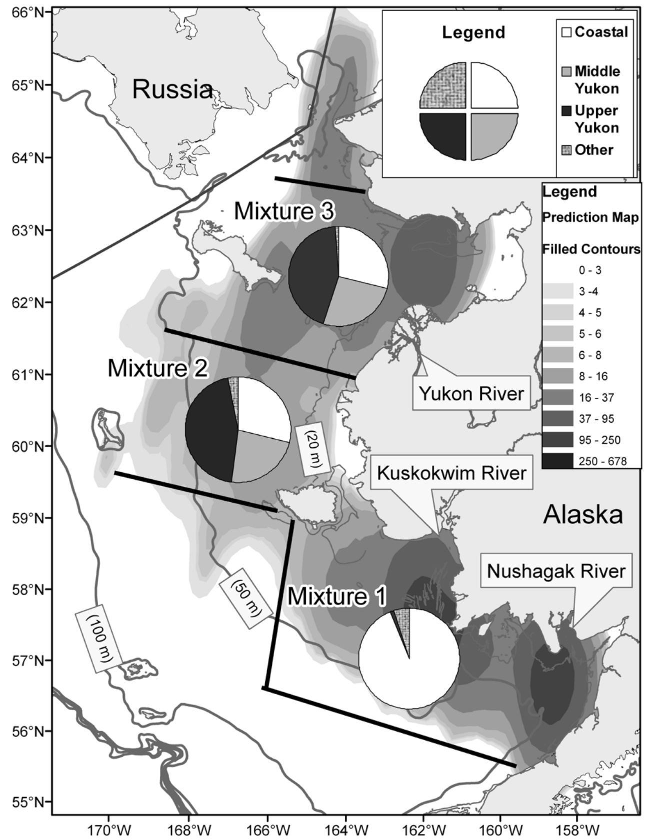

Fig. 3. Genetic stock mixtures of juvenile Chinook salmon (Coastal Western Alaska, Middle Yukon, Upper Yukon, and 'other' stock groups) captured during U.S. BASIS surface trawl surveys on the eastern Bering Sea shelf (mid August to early October), 2002–2006. Mixtures are overlaid on a map of juvenile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

Table 2. (VWLPDWHVRIVWRFNPL[WXUHFRPSRVLWLRQDQGFRQILGHQFHLQWHUYDOV 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\LQFDQWRQEHUMXYHQLOH 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\ DYHUDJH VDPSOH GDWH RI PL[WXUH DQG ZDV 6HSWHPEHU DQG 6HSWHPEHU UHVSHFWLYHO\ DYHUDJH VDPSOH GDWH RI PL[WXUH ZDV DQ 2FWREHU DQG 6HSWHPEHU

6WRFN PL[WXUHV GLIIHUHG E\ UHJLRQ DQG ORFDWLRQ RQ WKH)LJ ,Q WKH VRXWKHUQ UHJLRQ WKH PL[WXUH VWRFN SURSRUWLRQV RI WKH &RDVWDO :HVWHUQ $ODVND 8SSHU <XNRQ DQG 0LGGOH <XNRQ VWRFN JURXSV ,Q WKH QRUWKHUQ UHJLRQ WKH PL[WXUH FRQWDLQHG 8SSHU <XNRQ 0LGGOH <XNRQ &RDVWDO :HVWHUQ $ODVND DQG RWKHU :HVWHUQ $ODVND VWRFN JURXSV 0L[WXUH ZDV VLPLODU WR PL[WXUH ZLWK 8SSHU <XNRQ 0LGGOH <XNRQ &RDVWDO :HVWHUQ $ODVND DQG other western Alaska stock groups. Stock proportions from PL[WXUH DQG FRQWDLQHG 8SSHU <XNRQ 0LGGOH <XNRQ &RDVWDO :HVWHUQ $ODVND DQG other Western Alaska stock groups.

Stock proportions between juvenile populations and DGXOW KDUYHVW ZHUH VLPLODU EXW WKHUH LV SRWHQWLDO IRU VLJQLILFDQW bias due to incomplete sampling of the juvenile population within the northern shelf region. The proportion of the Coastal Western Alaska stock group in the juveniles from the QRUWKHUQ VKHOI UHJLRQ PL[WXUH DQG FRQWDLQHG 6

ZDV KLJKHU WKDQ WKH SURSRUWLRQ LQ WKH KDUYHVW 6KRUW\ZLWKLQ WKH HDVWHUQ %HULQJ 6HD 5LYHU KDUYHVW DQG ZKLFK WKH SURSRUWLRQ RI WKH PLGGOH <XNRQ VWRFN JURXS LQ WKH MXYHQLOH SRSXODWLRQ ZDV VLPLODU WR WKH SURSRUWLRQ REVHUYHG LQ LWV KDUYHVW 7KH SURSRU tion of the Upper Yukon stock group in the juvenile population was lower than the average proportion in its harvest. The proportion of the Coastal Western stock group was higher than the proportion in the harvest. Stock proportions comparisons were made to the harvest in June and respectively.

Coded-wire tags all matched tag codes from the Whitehorse Rapids Fish Hatchery on the Yukon River. Coded-wire tag codes from juvenile Chinook salmon released from the Whitehorse Rapids Fish Hatchery indicate that release locations contributed to the juvenile information regarding recoveries. However, as no other tagged Canadian juvenile Chinook entered the ocean, it is not possible to assign other origins to the Whitehorse Rapids Fish Hatchery.

Coded-wire tags were recovered at the mouth of the Yukon River and just to the north in the Bering Strait. Coded-wire tags from 2002 were recovered near the mouth of the Yukon River at Canadian latitudes were detected the mouth of the Bering Strait at the continental shelf which is the main migration 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 VKHOI5HOHDVHLQIRUPDWLRQSURYLGHGE\WKH:KLWHKRUVH5DSLGV+DWFKHU\<5-7&

		Release Data		Recovery Data				
		Date	Weight (g)	Date	Latitude	Longitude	Length (mm)	Weight (g)
Whitehorse Rapids ÞDWFKHU\0LFKLH Creek	185061	2-Jun-02	3.2	4-Oct-02	63.0°N	166.0°W	155	49
Whitehorse Rapids ÞDWFKHU\0LFKLH Creek	185106	10-Jun-02	3.2	3-Oct-02	64.1°N	164.5°W	193	79
Whitehorse Rapids ÞDWFKHU\ROI Creek	185102	2-Jun-02	3.1	3-Oct-02	64.1°N	164.5°W	153	43
Whitehorse Rapids ÞDWFKHU\	18	2007	--	13-Sep-07	65.2°N	168.1°W	176	58
Whitehorse Rapids ÞDWFKHU\	18	2007	--	13-Sep-07	65.2°N	168.1°W	125	18
Whitehorse Rapids ÞDWFKHU\	18	2007	--	13-Sep-07	65.2°N	168.1°W	179	58

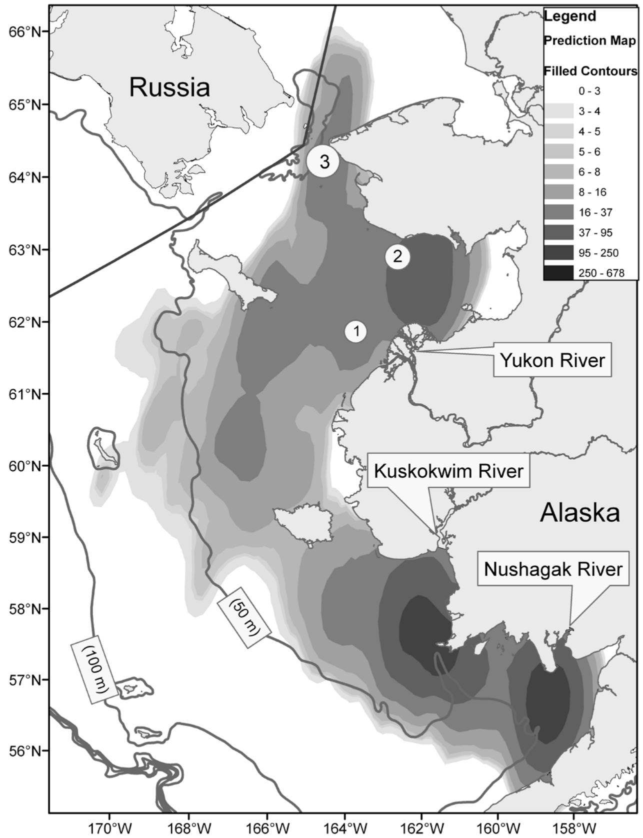

Fig. 4. Locations of coded-wire tag recoveries of Whitehorse Rap- LG)LVKHDWFKHU\&KLQRRNVDOPRQIURPWKHXNRQ5LYHUGXULQJ86 BASIS surface trawl surveys on the eastern Bering Sea shelf (mid August to early October), 2002–2007. Circles indicate coded-wire tag recovery locations and are overlaid on a map of juvenile 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.ULJLQJ(SDWLDOPRGHO&RQWRXUVDUH shaded at geometric intervals of the prediction surface.

salmon produced from the Whitehorse Rapids Fish Hatch H\KDWFKHU\MXYHQLOHPP± JHUWKDQFDQWVDOHWKDQWKHDYHUDJHRIMXYH - QLOHVDOPRQFDSWXUHGGXULQJWKHVXUYH\PP JDQ KDWFKHU\MXYHQLOHVWLOOKDG YLVLEOHSDUU PDUNV DWWKHWLPHRIFDSWXUHDYHUDJHDWRIWLPHVWKH 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 WKHUFDOLFDWLRQRIHYHQWVSHFLHVVDOPRQ

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 ZDWHUVRIWKHQRUWKHUQ*XOIRI$ODVND 2UVLHWDO 2000). Migratory corridors of juvenile salmon in summer are largely thought to be constrained to epipelagic waters over the continental shelf once they reach the open ocean LQWKH*XOIRI$ODVND 2UVLHWDO)LVKHUHWDO-XYHQLOHVDOPRQPLJUDWRU\FRUULGRUVLQ DQRSHQRFHDQHQYLURQPHQWDUHOLNHO\GHILQHGE\WRSR - JUDSKLFDQGEDWK\PHWULFIHDWXUHVDQGWKHFORVHDVVR - ciation of these features in the Gulf of Alaska (Mundy 2005) often results in the use of the continental shelf to describe MXYHQLOHVDOPRQPLJUDWRU\FRUULGRUV7KHEURDGFRQWLQHQWDO 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 ZLWKLQWKHLQQHUGRPDLQ WKHWKUHVKROGWKDWWKHUHZHUHWZRPHDW PLGGOHWRXWHUVKHOIWKH PLGGOHRIWKHVKHOIDQ 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 1XVKDJDNULYHUV7KLVVXJJHVWVDODWHGLVSHUVDOIURPIUHVK - water entry points than typically found in Gulf of Alaska VWXGLHVWKHPSWRVKLQRRNVDOPRQLQWKHVHVWXGLHVLV 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\UROHLQFRQMXQFWLRQZLWKVDOPRQ KDEWDWDQGGLVSHUVDOUDWHVZLWKLQWKHLQQHUGRPDLQWKHUHDWH\ FRDVWDOGRPDLQWSLFDOO\ORQJLWXGLQDOO\DQGVKRUHWKV m on the eastern Bering Sea Shelf (Schumacher and Stabeno DQLVZHOOPL[HGZLWKUHODWLYHO\VWDEOHZDWHUFROXPQDELOLW\ tight pelagic-benthic coupling, and high benthic productivLW*UHEPHLHUHWDO7KLVWURSKLFVWUXFWXUHDOORZVSRSXODWLRQV WKHFRDVWDOGRPDLQWRVXSSRUWODUJHSRSXODWLRQVRIIRUDJHILVKVSHFLHVLQFOXGLQJ DQ3DFLILFVDQGODQFHDQGVFKDUWKHVHDUHLPSRUWDQWSUH\IRUMXYH - nile Chinook salmon (Farley et al. in press). It is possible that feeding behavior of Chinook salmon on these forage ILVKVSHFLHVPD\EHDIDFWRULQWKHLUREVHUYHGGLVSHUVDOIURP the Coastal Domain. An apparent preference for the Coastal Domain is also seen in coho salmon (Farley et al. 2005) ZKLFKDUHDOVRUHODWHGWRWKHDEXQGDQFHRIIRUDJHILVKVSHFLHVLQ the Coastal Domain (Farley et al. in press).

7KHGHWHFWLRQRIWKH<XNRQ5LYHUVWRFNRIMX - YHQLOH&KLQRRNVDOPRQZDVOLPLWHGE\FRQILQLQJWKH broad migratory corridor of juvenile Chinook salmon and later survey sampling dates in the northern Bering Shelf resulted in most juvenile Chinook salmon from this reJLRQEHLQJZLWKLQWKH<XNRQ5LYHUVWUDWDRIWKHEDVHOLQH migratory corridor and earlier sampling dates in the southern shelf region resulted in a higher proportion of the juvenile VDOPRQSRSXODWLRQUHWXUQLQJWRWKHVWUDWDRIWKHEDVHOLQH - ability to distinguish between primary stock groups contrib-

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

Stock mixtures of juvenile salmon did not support sig- QLFDQW RQWKDUG PLJUDWLRQWRNVURWKHWKHQ KHUÀWLQJLPLWH PL[LQRDPRQUR GLIIHUHQW SURGXFWLRQUHJLRQVGXULQJWKHLUUVWVXPPHUDWVHD-XYHQLOH Chinook salmon in the southern region were primarily from WKHRDVWDOWHVWHUQNDWRNJURXSKHUHIRUH 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 HTXDOOUWLQWKHRUWKHUQVSDWLDOVWUDWD KLVLVXQ- 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 KHUJLRQDQMXYHQLOH KDUYHVWVDOVRGLGQRWVXSSRUW VLJQLFDQWRQWKDUG PLJUDWLRQWKHQWRNVLJ- QLFDQWQXPEHURIMXYHQLOH&KLQRRNVDOPRQIURPWKHQ shelf were migrating north, the estimated proportions of the RDVWDOWHVWHUQNDWRNJURXSZRXOGEHVLJQLFDQWO higher in the northern shelf region than expected for Yukon 5LYHU&KLQRRNVDOPRQSURSRUWLRQRIRDVWDOWHVWHUQ Alaska stocks in the northern shelf region was within the UDQJHH[SHFWHG IRU MXYHQLOH &KLQRRN VDOPRQWRN 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 5LYHUKXQWHUHWOLPLWHGQRWKDUGPLJUDWLRQ 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).

&RGHGZLUHWDJ UHFRYHULHVRIMXYHQLOH &KLQRRN salmon near the Bering Strait provide evidence that Yukon 5LYHU &KLQRRN VDOPRQGLVWULEXWLRQH[WHQGV QRUWKZDUG LQWRWKHHULQJ6WUDLW KHEURDG SDWWHUQRIMXYHQLOH Chinook salmon distribution and coded-wire tag recoveries)LJXUHVXJJHVWWKDWMXYHQLOH&KLQRRNVDOPRQGLVWULEX- tions can also extend into the Chukchi Sea. Although the SURSRUWLRQRIMXYHQLOH&KLQRRNVDOPRQWKDWDUHOLNHO to migrate into the Chukchi Sea is small relative to their total marine distribution, anticipated changes in Arctic climate DQGVHDLFHPDLQFUHDVHWKHSURSRUWLRQRIMXYHQLOH VDOPRQPLJUDWLQJLQWRWKHKXNFKLHDH0RVVDO KHQRUWKZDUG H[WHQVLRQMXYHQLOH &KLQRRN VDOPRQGLV- tribution into the Chukchi Sea was primarily due to catches LQ HDU ZLWK UHFRUG QRUWKHUQ LFH DQ DQ H[FHSWLRQDOZDUPVXPPHU0RVVDOQRUWKZDUG DGYHFWLRQRI PLJUDWLRQMXYHQLOH &KLQRRN VDOPRQV LQFRQWUDVWWRWKHEHFNRVLJQLFDQWQRUWKZDUGDGYHFWLRQ migration observed in juvenile Chinook salmon from the QRUWKHUQUHJLRQLPSOLHUPDUNHGGLIIHUHQFHPDULQH

habitats (water depths, freshwater discharge levels, seasonal FXUUHQWVVXUIDFHWHPSHUDWXUHVHUJHYHRILPSO differences in the behavior or life-history of juvenile Chinook salmon from the two regions.

,I WKH LWVRI GLIIHUHQWZLOGDQKDWFKHU\ FDQQRWVLQ GLIIHUHQWPDULQHGLVWULEXWLRQWKHUHEHWLRQV DSSURSULDWHWRFKDUDFWHUL]HWKHGLVWULEXWLRQRIMXYHQLOH stocks with hatchery coded-wire tag recoveries alone. Stock LGHQWLFDWLRQGDWDDUHQHHGHGWRGHWHUPLQHPDULQH GLVWULEXWLRQRIMXYHQLOH&KLQRRNDUHFKDUDFWHUL]HG as stream-type Chinook salmon (also known as spring-type as they generally enter the marine habitat in the spring) (Gil- EHUWHWFKHUMXYHQLOH&KLQRRNDUHFKDU- acterized as ocean-type Chinook salmon (also known as fall-type as they enter the marine habitat in the fall), which have a IUHVKZDWHUDJHRIDJH IUHVKZDWHUOLIH KLVWRULHVZLOGDQKDWFKHUMXYHQLOH&KLQRRNVDOPRQ 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 6HSWHPEHUKLVVXJJHVWVWKDWRFHDQWSHDJHMXYHQLOHV DUHSUHVHQWLQWKHSRSXODWLRQWKRXJKWKHUHDUHOLNHO to represent only a minor portion of the total juvenile population.HQWLPLQJRIRFHDQWUDQMXYHQLOH&KL- QRRNVDOPRQPDULQHHDUWLQWDOODW- JHWWKHSUHVHQFHDJHRQHRFHDQ&KLQRRNVDOPRQ ZLOGMXYHQLOHVWRNKHSUHVHQFHRIUHVKZDWHUDJH MXYHQLOH&KLQRRNVDOPRQLQWKHSRSXODWLRQHPSKDVL]- 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 'LFNKRII

KHFRQFOXVLRQVDUHEDVHGRQWKH U.S. BASIS survey data as it applies to juvenile Chinook salmon populations on the eastern Bering Sea shelf. Juvenile &KLQRRNVDOPRQUHSUHVHQWLQWUDZODEOHDEWDWVWKHUH- 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 ocFXUGXULQJWKHLUUVWVXPPHUDWVHDWKHUHWRNPL[WXUHV of juvenile Chinook salmon within each region will be needed to evaluate the status of managed stock groups. Although MXYHQLOH &KLQRRNVDOPRQWRNVFDQQWHQG QRUWKZDUG LQWRWKHKXNFKLHDWKHSURSRUWLRQRIMXYHQLOH&KLQRRN salmon present in the Chukchi Sea is small relative to the total PDULQHGLVWULEXWLRQMXYHQLOHMXYHQLOH VDOPRQ- ever, it is also important to recognize that changes in Arctic climate and the loss of sea ice could increase the proportion RIMXYHQLOH&KLQRRNVDOPRQUHVLGLQJLQWKHKXNFKLHD GXULQJWKHLUUVWVXPPHUDWVHD

ACKNOWLEDGMENTS

:HWKDQNWKHFDSWDLQVDQGFUHZRIWKH)9 *Sea Storm*,)9 *Northwest Explorer* DQGWKH12\$6KLS *Oscar Dyson* IRUWKHLUHIIRUWVLQVXSSRUWRIWKHVHVXUYH\V:HWKDQN-D PHV0XUSK\(LQ.LUNSDWULFNDQG)HPDQGR QURPDQ(ULNLWRUWKHLUDERDUGWKHVKLSV DQGDWDLD.DZDNDQG2OHJ(VDQIURPWKH12 \$\$IRUWKHLUVXSSRUWRIWKH% 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 0HUQDYLHZDQGHDOLQJWRHGLPLU5DGFKHQNR 6DNK,52DQGWKHDQRQ\PRXVUHYLHZHUIRUWKHLU helpful comments on earlier drafts of this manuscript. Principal funding support for this work was provided by NOAA Fisheries, Alaska Fisheries Science Center, and the Alaska 3DFLILF6DOPRQ&RYHQDQW,QLWLDWLYH\$% SIS surveys. Additional funding was provided by the Alaska Department of Fish and Game (ADFG) for the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative.

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\$UGHQ%5\$VKHOOHUW(%VLOOODV\$1GULGJH HOOHH7HWHUVRQDUGDQGHQOHDQ 6WKLHZ\$FRRUGLQDWHGUHVHDUFKSODQIRU HVWXDULQHDQGRFHDQUHVHDUFKRQ3DFLILFVDOPRQ1VKHU LH

%HNPDQ%DQG1LFNKR 3DWLFLWR PRWLRQLQJULQFKLQRRNVDOPRQJHWLRQVWRUWK DQLPDONUHZRUWKDFWRU,-)LK12

)LVDQG6HDOKRQQDUH3UHWHH SHQVLQFRQFRPPHFLDOVDOPRQILVKHULHV and management strategies. Alaska Department of Fish DQG*DPHDLVLRQRI&RPPHUFLDO)LVKHULHV5HJLRQDO ,QIRUPDWLRQ5HSRUWV\$DOLDEOHDW VDGIJVWDWHDNXV)\$GGVD,5\$GI

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(QLURQPHQWDO5HVHDUFK,QVWLWXWH(6,\$UF*,6)HDWXUH\$UFKLWHFWXUHDQG\$OLRUQLD (QYLURQPHQWDO6\VWHPV5HVHDUFK,QVWLWXWH

)DUOH\0.0,OLGHUHWKHPDO marked pink and chum salmon in the coastal waters of WKHHDVWHUQ%HULQJ6HD)LVK5HV

)DUOH\-0XUSK\-0RVV DQG A. Middleton. 2005. Distribution, migration pathways, and size of Western Alaska juvenile salmon along the HDVWHUQ%HULQJ6HDVKHOI\$ODVND)LVK5HV ±

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)LQH-07UX&6RPPHUDQG2UL-3LFR %HULQJ6HDFODVVLILFDWLRQ5 0DF)DUODQH5 %URRN-0RUULVHQ(FKRSDULQJ of the coastal distributions and abundances of juvenile 3DFLILFVDOPRQRIWUHFRUGVRIQDWLRQDOWKHQ)LVKHULHV%XOOHWLQ

*LOEHUW&+7KHRWKHUVDOPRQRIWKHULYHU6 %XOOHWLQ

*UDPHU-0-(2YHUODQG60RUQ)DUH -U(&RUPDFN.(-)UHH)\$FDO\VHV\$EXQGDQFH FRPPXQLW\VWUXFWXUHLQWKHHDVWHUQ%HULQJ6HD ±

+DUWW\$&DQG0%'HOO0LJUDWLRQ DQGJURZWKRIMXYHQLOH3DFLILFVDOPRQLQWKHJHG WUDQV,QW1RUWK3DF)LVK&RPP%XOO

+HDUG:5/LIHKLVWRU\RIFKXPVDOPRQ *In* 3DFLILFVDOPRQOLIHKLVWRULHV *Edited by* C. Groot and L. 0DUJROLV8%&3UHVV9DQFRXYHUSS±

-HDQHWWH%*%URGPDQQ-)LFXV\$ FRGHIRUHGGLFDWLRQVRIPDFURRUJDQLVPV DWDEDVH±

.LQQDQ-%RDQGKLQULJLQRI &KL QRRNVDOPRQLQWKHULYHUVRIWKH\$ODVND Department of Fish and Game, Division of Commercial)LVKHULHV5HJLRQDO,QIRUPDWLRQ5HSRUW1RUWK age.

0DUWLQ&KLWPDQ(DFKPHWH(1 DQG6FKURGHU/LWWOLHU YHQWLRQDQG VDOPRQ MXYHQLOHVDOPRQ RIWKH LQWKH 1XOQDJD 86IWRPPHUFH\$2FWH RYLVLRQ6HD(QYLURQPHQWDO\$W3URJUDP)LQDO5HSRUW

0X\$35H 7KH%HULQJ6HD EXDQ oceanography. University of Alaska, Alaska Sea Grant &ROOHJH3URJUDP)DLUEDQNVSS

0XUSK\-2)DUN DQG%DOD WUDDO FRPSDULVRQRIILVKLQJ HIILFLHQF\RIWKH)9 *Northwest Explorer*, 59 *TINRO* DQG59 *Kaiyo Maru* during the 2002 BASIS survey. N. Pac. Anadr. Fish &RPP SS\$YDLODEOHDWZZZQSDIF org).

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$QUDWXHOHSLQ DQ KRZRORG LV-tribution, diet, and growth in the northern Bering and &XNFKLVHDV WK 3DFLQGU)LK &RPP%XYDLODEOHDWZQDIFRUJ

2UV-$ -DQ :DHQFNH0DULQHGLVWULEXWLRQ and origin of pre-recruit chinook salmon, *Oncorhynchus tshawytscha* LQ RXWKHDVWHUQ $ODVND)LK %XO ±

2UV-$ 99 WXUGHYDQ -00XUSK *RUWHQ* and B.L. Wing. 2000. Seasonal habitat use and early PDULQHRUMXYHQLOHDFLILFVDOPRQWKHDVW-HQ$ODVND 3DFLQGU)LK &RPP%XYDLODEOHDWZQDIFRUJ

6KRXDFKHU -DQ 3-6WDEHQR\LWVDOPRQ of the Bering Sea. *In* *7KH9RO7KHJOREDOFRDVWDO RFHDQ UHJLRQDOVWXGLHVDQGWKHVH\QWKHVHQ RUN* SS±

H-(& DOFDO55DPDNULVKQDQDQ(H 63JRWSLQEWKHQRYHOEHOHFWLRQDG-vances in high throughputgenotyping with non-model organisms. *In* Methods in molecular biology, single nu-FOHWLGHSRO\PRUSKLVPV(GLWLRQ *Edited by* Anton $QDUKDQ3UHVVDULQJHSS

3HDUVRQ(-5LPRWD-ZJ0RQYDDQ-(HLJUDWLRQ R3DFLF5LPFKRRRQVDOPRQWKKLJKQHLJKWVVLJKWV IURPJHWLFGDWD(QYLURQRDOK± PLWKRQ0DQ(H

Single-nucleotide polymorphisms (SNPs) provide rapid and accurate estimates of the proportions of U.S. and FDQDGLDQRULJLQFKLQRRNVDOPRQFDXJKWLQWKH<XNRQULYHU-PRXWK)LK0DQDJH PSOLQJ-(HOH SNPs provide high-throughput resolution for migratory studies of Chinook salmon. N. Pac. Anadr. Fish Comm. %XOSS$YDLODEOHDWZQDIFRUJ

<XNRQULYHU-RLQW7HFKQLFDO&RPPLWWHH-7& <XNRQULYHUVDOPRQVXPPDU\DQG season outlook. Alaska Department of Fish and Game, 'LYLVLRQRI&RPPHUFLDO)LVKHULHV5HJLRQDO,QIRUPD-WLRQ5HSRUW1R$-$QFKRUDJH$YDLODEOHDW ZZZDGIJVWDWHDNXVSXEVSHGID5,5$ pdf).