NMFS Exhibit 7

Residence of Winter-Run Chinook Salmon in the Sacramento-San Joaquin Delta: The role of Sacramento River hydrology in driving juvenile abundance and migration patterns in the Delta

Submitted for the “Informational Proceeding to Develop Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources”, scheduled to begin March 22, 2010

Residence of Juvenile Winter-Run Chinook Salmon in the Sacramento-San Joaquin Delta: Emigration Coincides with Pulse Flows and Floodplain Drainage

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Abstract

The Delta provides essential habitat for juvenile Sacramento River winter-run Chinook salmon as they rear and physiologically transform for ocean life. We identified patterns of juvenile migration entering and exiting the Delta by using monitoring data from the lower Sacramento River at Knights Landing and in the western Delta at Chipps Island. Average residence time in the Delta ranges from 2.5 to 3 months, and generally spans from November through April, with the majority of the population leaving in March. The onset of emigration to the Delta at Knights Landing is cued by upstream flows of 15,000 cfs at Wilkins Slough, and emigration from the Sacramento River to Chipps Island follows pulse flows of 20,000 cfs at Freeport. Smolts exit the Delta later in years when the Yolo Bypass floods. Understanding how flows affect residence of winter-run Chinook Salmon in the Delta is crucial to informing current water management decisions seeking to balance water demands and species conservation.

Introduction

Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*) are endemic to California's Central Valley. Only one population of winter-run remains since their freshwater range has been limited from the upper Sacramento River below Keswick Dam to the Sacramento-San Joaquin Delta (Delta). The population's endangered status provides them protection under the federal Endangered Species Act, which affects natural resource uses in the Central Valley. Their sole route from freshwater to the ocean involves rearing and migrating through the Delta. Managing the Delta for this endangered species requires knowledge of when winter-run are in the Delta and how long they rear in the Delta.

Data Sources

Data on size, relative abundance, and residence time in the Delta were obtained for winter-run-sized fish from the following monitoring stations:

1. Knights Landing, rotary screw trap, 1996-2008, California Department of Fish and Game.
2. Sherwood Harbor, midwater and kodiak trawl survey, 1995-2008, U.S. Fish and Wildlife Service.
3. Chipps Island, midwater trawl survey,1995-2008, U.S. Fish and Wildlife Service.

Results and Discussion

1. Size and relative abundance show winter-run rear in the Delta.

Table 1. Mean Fork Length (mm) for juvenile Winter-run Chinook salmon in the Delta, 1995-2008

Color Key for Relative Abundance: High | Medium | Low | None /Rare

Monitoring Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Knights Landing (River Mile 89.5)	47	66	76	87	95	108	127					
Sacramento Trawl (River Mile 55)			68	78	91	101	104	114				
Chipps Island (River Mile 0)				80	105	113	118	127	140			

Winter-run smolts stay in the Delta an average of 2.5 to nearly 3 months. Early fry-sized (<70 mm) winter-run are detected in and north of the Delta starting in October followed by smolt-sized winter-run (>70 mm) starting December through April. These early fry migrants may be the first juveniles detected at Chipps Island in December where they are captured as smolts. The size distribution patterns as juveniles enter and exit the Delta suggest winter-run successfully rear and grow in the Delta. The monthly fork length distributions at the monitor sites indicate growth as the juveniles transit the Delta en route to the estuary. The large smolt-sized juveniles passing Knights Landing in April are likely the bulk of the May population caught at Chipps Island. Data from the monitoring sites clearly indicate rearing occurs in the Delta.

2. Upstream flows drive winter-run juvenile migration into the Delta.

The first autumn pulse flow exceeding 15,000 cfs triggers 50 percent of the population to enter the Delta on average four days following the event. The early migration pattern is abrupt as shown by the steep slope of cumulative catch per unit effort (Figure 1). The key management implication is that flows should be maintained to create sufficient rearing and migratory habitats in the Delta upon the abrupt entry of juveniles into the Delta triggered by pulse flow events.

Figure 1. Upstream flows of 15,000 cfs trigger winter-run juvenile emigration to Knights Landing, north of the Delta.

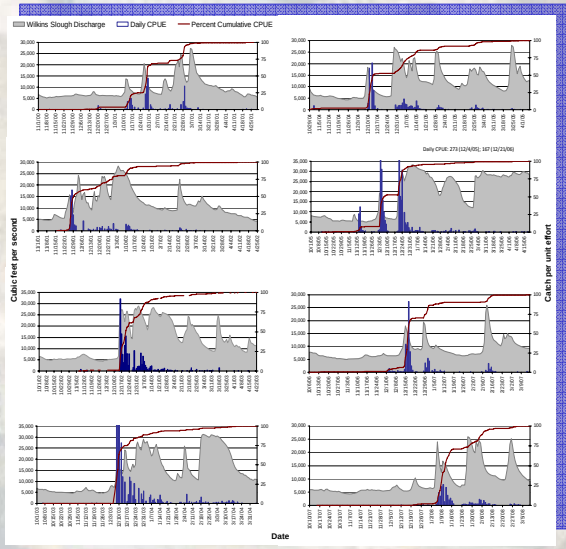
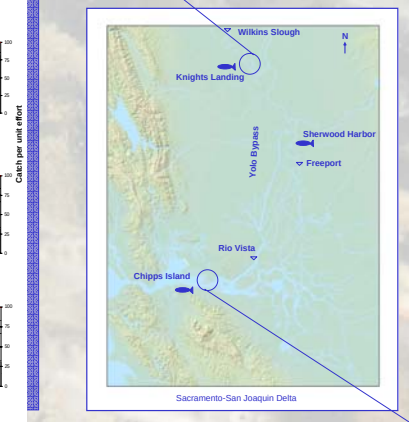


Table 2. Juvenile winter-run emigration to Chipps Island in the month of March.

	Percent of total population exiting in March	Cumulative percent of population captured at Chipps Island by		March Freeport flows		March Rio Vista flows	
		March 1st	March 31st	Minimum (cfs)	Maximum (cfs)	Minimum (cfs)	Maximum (cfs)
1999	37	28	65	34,000	74,700	31,439	83,834
2000	56	19	75	27,100	81,100	22,416	132,056
2001	57	31	88	14,400	46,200	11,391	44,306
2002	36	29	65	17,379	28,806	13,847	24,245
2003	43	43	86	15,600	39,600	12,448	39,219
2004	78	18	96	20,400	71,300	18,068	145,426
2005	33	44	77	19,100	53,900	14,843	47,403
2006	37	9	46	57,586	71,500	60,138	154,051
2007	78	14	92	12,700	33,700	9,700	28,275
2008	45	42	87	9,260	28,000	7,108	25,747
mean	50	28	78	22,754	52,881	20,140	72,456
median	44	29	82	18,240	50,050	14,345	45,855



3. Floodplain inundation influences timing of Delta exit.

A secondary rearing and migratory route into the Delta becomes available to juvenile winter-run Chinook salmon in the Yolo Bypass during flood stage events in the Sacramento River. Chinook salmon rear in the Yolo Bypass floodplain each season it is inundated, and catch at the downstream end of the floodplain was greatest during the receding limb of the floodplain hydrograph (Sommer et al. 2005, North American Journal of Fisheries Management 25:1493-1504).

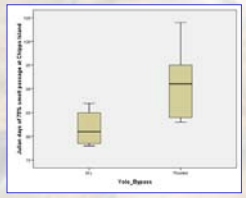


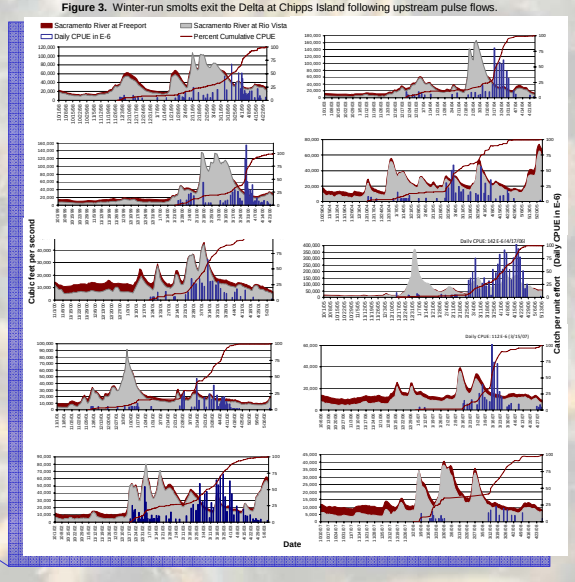
Figure 2. Smolts pass Chipps Island later in years when Yolo Bypass inundates (T-test, p = 0.03, n=4 for dry years; n=6 for flooded years).

In years when Yolo Bypass floodplain is inundated, smolts leave the Delta later. 75% of smolts exit the Delta nine days later when the Yolo Bypass is available as a rearing and migratory route. This emigration trend may support the theory that juvenile salmon take advantage of floodplain habitats to rear and that emigration coincides with drainage of the floodplain.

4. Delta exit follows pulse flows, with majority leaving in March.

The first emigration to Chipps Island occurs on average 9 days following Sacramento River flow events exceeding 20,000 cfs, measured at Freeport (Figure 3). These early emigrants represent passage through the only available route along the lower Sacramento River and North Delta distributaries since the secondary route through Yolo Bypass becomes available upon inundation later in the season. In a typical year, 50 percent of the population leaves the Delta at Chipps Island during the month of March (Table 2). During this month, smolts migrating through the North Delta experience Sacramento River flow ranging from median flows of 18,240 cfs to 50,050 cfs, measured at Freeport.

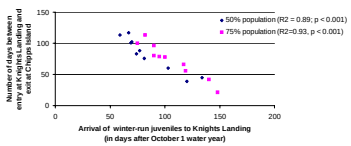
Figure 3. Winter-run smolts exit the Delta at Chipps Island following upstream pulse flows.



5. The earlier winter-run enter the Delta, the longer they stay.

Juvenile residence time in the Delta is a function of time of entry into the Delta, which is triggered by upstream Sacramento River flows. Given the consistency in timing of smolt exit from the Delta in March (Table 2, Figure 3), the earlier in the season juveniles enter the Delta, the longer their residence time in the Delta (Figure 4). In a Two-way ANOVA, residence time is significantly related to arrival time ($p < 0.001$) and flooding of the Yolo Bypass ($p = 0.10$).

Figure 4. Residence time of winter-run juvenile population is inversely correlated with time of Delta entry.



Conclusions

1. Winter-run Chinook salmon rear in the Delta an average of 2.5 to 3 months starting in the late fall through early spring. Half of the population exit the Delta at Chipps Island between March 1 and 31.
2. Autumn upstream flows exceeding 15,000 cfs trigger a large portion of the emigrating juvenile population into the Delta on average four days after the event.
3. Emigrating smolts start leaving the Delta in the late winter on average nine days after pulse flows exceeding 20,000 cfs, measured at Freeport.
4. The early emigrating smolts leaving the Delta at Chipps Island have only the Sacramento River system available as their migratory route.
5. Residence time in the Delta is a function of when juveniles enter the Delta and flooding of the Yolo Bypass. Earlier arrival to the Delta yields longer residence time. Availability of floodplain rearing habitats provide for longer residence time.

These findings can help managers provide for rearing and migratory habitats in the Delta while winter-run Chinook salmon are present.

NMFS Exhibit 7
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Residence of Winter-Run Chinook Salmon in the Sacramento-San Joaquin Delta: The role of Sacramento River hydrology in driving juvenile abundance and migration patterns in the Delta

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ABSTRACT

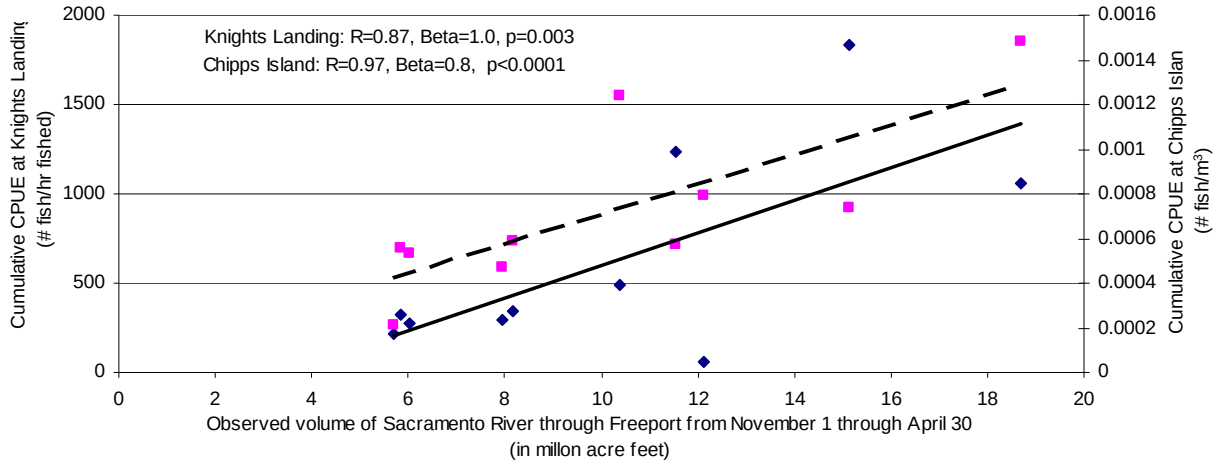
The Sacramento-San Joaquin Delta provides essential habitat for juvenile Sacramento River winter-run Chinook salmon as they rear and physiologically transform for ocean life. We identified patterns of juvenile abundance and migration entering and exiting the Delta by using monitoring data of winter-run sized fish based on assumed growth and size on date of catch criteria from the lower Sacramento River at Knights Landing and Sacramento and in the western Delta at Chipps Island.

Sacramento River hydrology drives both smolt abundance and emigration patterns in the Delta. The catch of winter run per unit effort is highly correlated with Sacramento River flows. Annual cumulative winter run smolt abundance entering the Delta at Knights Landing (measured as number of winter run per hour fished) and exiting at Chipps Island (measured as number of winter run per m^3) are each positively correlated with the cumulative volume of Sacramento River (measured at Freeport) during the emigration season; and neither abundance estimate is significantly correlated with annual spawner abundance (multiple regression, Knights Landing: R^2=0.76, F=12.6, p=0.003; Chipps Island: R^2=0.93, F=53.7, p<0.0001). Emigration patterns in the Delta are dependent on autumn and winter Sacramento River flow patterns. The first autumn pulse flow exceeding 15,000 cfs at Wilkins Slough triggers emigration of half the cumulative winter run catch at Knights Landing on average four days following the event, with the remaining population continuing to emigrate into the Delta during subsequent pulse flow events. The early emigrants leave the Delta at Chipps Island before spring on average 9 days following Sacramento River winter flow events exceeding 20,000 cfs, measured at Freeport.

Sacramento River hydrology also creates diversity in migratory routes and rearing habitats for winter run, when peak winter discharge allows for inundation of the Yolo Bypass floodplain. Patterns of winter run emigration from the floodplain are responsive to the floodplain's hydrograph, such that timing and frequency of floodplain drainage contributes to the temporal and size diversity of emigrants leaving at Chipps Island.

Sacramento River hydrology is related to average winter run residence time in the Delta, which is primarily a function of time of entry into the Delta. In a typical year, at least half of the cumulative catch at Chipps Island leaves the Delta during the month of March. Average residence time in the Delta ranges from 2.5 to 3 months, and generally spans from November through April.

Figure 1. Higher volume of flows during the winter run migration period results in greater abundance of winter run smolts entering the Delta at Knights Landing (diamonds, solid line) and subsequently exiting at Chipps Island (squares, dashed line), 1999-2008.



The hydrology of the Sacramento River drives winter-run smolt abundance and emigration patterns in the Delta. The annual cumulative winter run smolt abundance is highly dependent on the amount of flows in the Sacramento River, such that higher volume of water flowing in the river during the winter run emigration period results in greater abundance of winter run smolts both entering the Delta at Knights Landing (multiple regression, R^2=0.76, F=12.6, p=0.003), and subsequently exiting the Delta at Chipps Island (multiple regression, R^2=0.93, F=53.7, p<0.0001; Figure 1). This positive correlation between smolt abundance, expressed as annual cumulative CPUE at either sampling location, is not significantly correlated with annual spawner abundance (p>0.25).

Sacramento River flow data are from Interagency Ecological Program's Dayflow Sacramento station to represent flows at Freeport in the Sacramento River (http://www.water.ca.gov/dayflow/). The observed total volume of flow through Freeport during the winter run migratory period was calculated as the sum of mean daily flows from November 1 through April 30 of each year, and translated into million acre feet per emigration season.