Literature Review of Habitat Relationships and Ecology of Juvenile Spring Chinook Salmon in the Lower Willamette River

Principal Investigator: Dr. Stan Gregory, Department of Fisheries & Wildlife, Oregon State University
Research Assistant: Christy Meyer, Profession Science Masters Program, Oregon State University

An Expert Panel was convened by NOAA in 2009 to discuss the ecology and habitat relationships of juvenile spring Chinook salmon (*Oncorhynchus tshawytscha*) and other species of concern as a basis for assessing values of restoration sites and habitat types in the lower Willamette River. The panel based its discussion on expert opinion, field experience, and knowledge of the literature. The parties involved in the lower Willamette River superfund site expressed an interest in developing a review of published literature on habitat relationships and ecology of potentially injured juvenile Chinook salmon in the Willamette River, with an emphasis on the lower Willamette River and Columbia River near the mouth of the Willamette River. The following literature review is a summary of the major findings in published studies of spring Chinook salmon in the Willamette River and regional literature relevant to the biology of spring Chinook salmon in the lower Willamette River.

Structure of Literature Review

The literature review includes summaries of findings and a bibliography of 95 sources of information on spring Chinook salmon in the published literature, including peer-reviewed literature, agency reports, and other credible technical sources. We searched electronic databases at the Valley Library at Oregon State University and a library search for literature in hard copy only. We compiled literature cited in recent major assessments of the Willamette River, including reports from the Willamette River Technical Review Team, the Willamette River Biological Opinion, and the Recovery Plan for Upper Willamette River Spring Chinook Salmon (McElhaney et al. 2007, NMFS 2007, ODFW and NMFS 2010). The reviewed literature included peer-reviewed publications, technical agency reports, non-peer-reviewed proceedings, book chapters, and other literature. We contacted lead resource agencies in the Willamette River Basin (ODFW, NMFS, Portland BES, Portland METRO) to review the developing bibliography and obtain agency documents not available through libraries or online document sources. We provided the draft bibliography of the available literature to NOAA staff for distribution to regional experts for review and comment.

The review of major findings in published literature is organized into the following major sections:

1. Previous major reviews of spring Chinook salmon ecology and life histories
2. Life histories and timing with a focus on potentially injured life stage
3. Habitat use by juveniles
    a. River network
    b. Headwater reaches
    c. Mainstem river and adjacent habitats upstream to Bonneville Dam
    d. Influence of floodplains and riparian areas
4. Food webs and food resources
5. Growth and survival
6. Predation
7. Environmental effects (e.g., temperature, water quality, toxic substances)
8. Movement and timing of movement
9. Adult escapement and run timing as related juvenile life stages
10. Genetics

11. Overview of the relative importance of the lower Willamette River for management and recovery of spring Chinook salmon

The literature review focuses on published technical information but does not address management alternatives or implications of the information for policy decisions. The summary does not include implementation strategies, technical advice on restoration alternatives, or administrative processes.

The bibliography of cited literature follows the review of key findings. We developed an electronic bibliographic database using open source Zotero software. We provided pdf files of all citations to NMFS staff unless the document is not available in pdf format. The electronic database in Zotero includes pdf files for many of the sources.

Citations from outside the Willamette River basin and lower Columbia River were distinguished from Willamette River studies, but relevant findings were reported from other river basins. Geographic location of each study is indicated by the following abbreviations:

LWR	Lower Willamette River
WR	Mainstem Willamette River above Willamette Falls
WRT	Willamette River Tributaries
LCR	Lower Columbia River
CR	Mainstem Columbia River above Bonneville Dam
CRT	Columbia River Tributaries
PS	Puget Sound
PNW	Other Pacific Northwest Rivers
LAB	Laboratory Study

Major Empirical Findings

Previous major reviews of spring Chinook salmon ecology and life histories

- Spring Chinook salmon in Willamette River exhibit at least four major life history patterns of juvenile migration: 1) fry migrants, 2) subyearling migrants – outmigrate in spring, 3) subyearling migrants – outmigrate in fall, 4) yearling migrants (Schroeder et al. 2005). *WR*
- Returning adults of spring Chinook salmon are comprised primarily of yearling life history types, unlike most coastal spring Chinook salmon populations, which are dominated by subyearling life history types. Adult spring Chinook in Interior basins and the Frasier River typically exhibit yearling life histories. The unusual pattern in the upper Willamette River Chinook may reflect an evolutionary difference or a reduction of the subyearling life history stage due to floodplain and habitat degradation along the mainstem Willamette River (Waples et al. 2004). *WR, WRT, CR, CRT, PNW*
- Chinook native to the Lower Columbia and Upper Willamette Rivers exhibit a life history pattern of migrating to the ocean within their first year. Migration timing is tied to distance to the ocean, stream stability, flow, temperature, productivity and weather (Myers et al. 2003). *LCR, WR, WRT*
- Stream-type life history (juvenile residence in freshwater >1 year, generally in snowmelt-dominated areas) Chinook have been nearly extirpated in the Puget Sound due to the presence of dams. To increase the spatial distribution of Chinook that express stream-type life histories, Beechie et al. suggest enabling ocean-type populations (which are genetically similar to stream-type) to recolonize habitats above the dams (Beechie et al. 2006). PS
- In the early 1900s juvenile Chinook migrated through the Columbia throughout the year, reaching the Columbia River estuary in May then again between July and August and staying there for various lengths of time before migrating to the ocean. Chinook life history diversity has declined and today outmigrations are less frequent and timed with hatchery releases. A smaller range of fish sizes is observed today and migrations are more rapid. Early migrant subyearling Chinook are less prevalent in the outmigrating population and upper size range of migrants is larger (subyearling Chinook in Columbia River estuary in 1916 wild origin: 58-92 mm FL, 1966 wild & hatchery origin: 72-83 mm FL, 1980 hatchery origin: 80-93mm FL, 1980 wild & hatchery origin 91-110mm FL. Changes in life history diversity are due to habitat alterations, decreased disturbance regimes (due to flow modifications), fish harvest and hatchery programs (Bottom et al. 2005). *LCR, CR*

Life histories and timing with a focus on potentially injured life stage

- September 1980 - November 1983 study: wild spring Chinook fry migrate past Leaburg Dam in January, February and March. Spring Chinook yearlings migrate in October and November. Hatchery spring Chinook migrations were in March and November, when they were released from hatchery. Hatchery Chinook had traveled past the dam 3 or 4 days after being released. Wild Chinook migrated over a longer period (Zakel and Reed 1984). *WRT*
- Yearling juvenile Chinook salmon contribute more to the runs of returning adults than subyearling juveniles in the Willamette River in most years. This may reflect long-term evolution of life histories, but it also may reflect habitat degradation for fry and subyearling Chinook in the lower Willamette

River and lower Columbia River. The Technical Recovery Team noted that "Changes in river conditions in the Clackamas River, Lower Willamette River, and Columbia River and estuary have likely had an effect on juvenile life history diversity. Specifically, the loss of juvenile rearing areas has reduced the contribution of subyearling migrants to the population (Craig and Townsend 1946, Mattson 1962)." (McElhany et al. 2007) *LCR, WR, WRT*

- Yearling Chinook and steelhead (*O. mykiss*) outmigrating in the Snake River exhibited survival rates of 98.4-100% passing through spill bays without flow deflectors, 92.7-100% in spill bays with flow deflectors, 95.3-99.4% in bypass systems and 86.5-93.4% survival passing thorough turbines (Muir et al. 2001). *CRT*
-
- Stream temperatures are being impacted by climate change which could reduce cold water habitat in headwater streams necessary for spawning (Isaak et al. 2010; Battin et al. 2007). *CRT, PNW*

Habitat use by juveniles

a. River network

- At the mouth of the Columbia River, subyearling Chinook more commonly use areas around the North Jetty whereas yearling Chinook are more prevalent in the navigation channel. Large fish spent 9-24 minutes in the mouth of the Columbia River while subyearling Chinook spent about 160 minutes. Subyearling Chinook released at Bonneville Dam took 4.5 days to reach the mouth of the Columbia whereas yearling Chinook traveled this distance in 3-4 days (McMichael et al. 2006). *LCR*
- Most juvenile spring Chinook tagged and released in late spring and early summer migrate into the lower Willamette and the Columbia River estuary as subyearlings, particularly those from the lower Santiam and the Willamette River downstream of the Santiam (Schroeder, Kenaston, and Krentz 2005; Schroeder, Kenaston, and Lindsay 2003; Schroeder, Kenaston, and McLaughlin 2007; Schroeder and Kenaston 2004). Juveniles tagged & released in late June and July rear in the Willamette or low reaches of eastside tributaries (non-natal) during the summer and outmigrate in the fall/winter and the following spring, particularly those from the McKenzie and North and South Santiam rivers (Schroeder and Kenaston 2004; Schroeder, Kenaston, and McLaughlin 2007). *WR, WRT*
- A Columbia River estuary study captured > 95% of subyearling Chinook in intertidal (beach seines) and pelagic (purse seines) zones. Abundance of subyearling Chinook was greatest from May – September. Few Chinook were caught in channel bottoms, tributaries, sloughs and coves. Larger subyearlings prefer pelagic habitats over intertidal habitats. There were no subyearlings <69 mm found in pelagic catches. In May-August, subyearlings >99mm were common in pelagic areas but were not found in intertidal areas during the same time period (McCabe et al. 1986). *LCR*
- In the Columbia River estuary, yearling Chinook migrating to the ocean use deeper channel habitats, subyearling Chinook use more diverse habitats in the estuary - they also spend more time in the estuary than do yearling Chinook. Subyearling Chinook rear in the Columbia River estuary (timing estimates were measured on Chinook released from Columbia River hatcheries – not Willamette

fish). Using purse seines, catch per effort was greater in the north channel than in the south channel of the estuary (Bottom, Jones, and Herring 1984). *LCR*

- Juvenile Chinook overwinter and rear in the lowest reach of Tryon Creek and the lowest reaches of Crystal Springs, Johnson (overwintering & rearing), Miller and Stephens Creeks (N=70). In Stephens Creek Chinook were most abundant during winter (69% of Chinook sampled) and summer (21.4%), few were observed in the fall (3.7%) and spring (2.4%) (N=42) (Tinus, Koloszar, and Ward 2003a). *LCR, WRT*
- Juvenile Chinook have been found as far as eight miles into the Columbia Slough, where the levee and pump station limit access further into the watershed. Site 8 at the end of the Lower Slough had the highest CPUE of all stations for Chinook, and Chinook were captured at five of the eight sites total sites sampled in the lower Slough (Van Dyke, Storch, and Reesman 2009). Individual Chinook have been captured as far as reach 67 (108th Ave) on Johnson Creek (Van Dyke and Storch 2009).
- Researchers on the Chehalis River near Gray's Harbor (WA) found that an artificial slough provided comparable habitat for juvenile Chinook and coho to a natural slough. Diet composition, otolith growth rates, residence and emigration times were comparable between the natural and created sloughs. Overall composition of stomach contents was similar although ranked order of importance differed between sloughs. Otolith growth rates were not significantly different (Mann-Whitney nonparametric comparison test, P=0.91) between the two sloughs. Eighty-eight percent of all fish exited the sloughs after 48h of residence and all fish exited during low tide. The only measurement that was significantly different was stomach fullness which was significantly lower in the created slough. This might be due to less available prey or a greater predation risk (Miller and Simenstad 1997). *PNW*
- In a 2003-2004 survey of West Linn streams, juvenile Chinook salmon were observed near the mouth of Trillium Creek but not further upstream due a culvert obstructing passage. Chinook were also present in the lower reaches of Mary S. Young Creek; three juvenile Chinook were observed in spring 2004. Researchers believe that movement further upstream is restricted by culverts (Pribyl, Koloszar, and Ward 2004). *LWR*
- A study of urban streams in Clackamas County found Chinook only in Rock Creek. Researchers estimate that Clackamas River Chinook use the lowest reaches of Rock Creek for rearing and overwintering (Tinus, Koloszar, and Ward 2003b). *LWR*

b. Headwater reaches

- In the fall of 1999, Chinook were found in the mainstem Tualatin at the Spring Hill pumping station (Rkm 90.1) and at the mouth of Gales Creek (Rkm 90.9) (did not identify fish as juvenile or adult or spring or fall Chinook). Two of 10 fish collected at Spring Hill were Chinook while 1 of 40 caught at Gales Creek were Chinook (Hughes and Leader 2000). *WRT*
- Juvenile spring Chinook were identified as one of the most abundant species around Confluence Island (confluence of the McKenzie and Willamette Rivers) (Gregory et al. 2008). *WR*
- In the Bridge River, a tributary of the Fraser River in British Columbia, juvenile Chinook and steelhead were nocturnal year round in a downstream reach with higher flows. In a reach with lower flows all fish were nocturnal in the winter, yet in the summer some were active during the day and others were not. All study reaches had similar temperature and light conditions. Researchers

concluded that differences in activity were due to a number of local habitat conditions (not just water temperature or photoperiod) that influence the balance between foraging success and predation threats (Bradford and Higgins 2001). *PNW*

c. Mainstem river and use of adjacent habitats upstream to Bonneville Dam

- Abundance of both hatchery and unmarked juvenile Chinook was significantly greater at sites with greater bank vegetation cover (percent of onshore habitat covered by living plants within 20 m of the waterline) than sites with low bank vegetation cover (<21%). Highest median catch rate was greatest at sites with 71-80% bank vegetation cover (Fiesen et al. 2005).
- In a lower Willamette study >76% of radio-tagged juvenile Chinook were found offshore (>10% of channel width) (Friesen 2005; Friesen et al. 2007). Juvenile salmonids do not use the upper water column at seawalls (Friesen 2005). *LWR*
- In a 2001-2002, lower Willamette study >60% of salmonids were found offshore. Salmonid catches were higher at beach and rock sites than at sites containing riprap and pilings. More juvenile salmonids were captured at alcoves than at any other habitat type (Friesen et al. 2003). *LWR*
- Some juvenile salmonids appear to overwinter in the Portland Harbor (Knutsen and Ward 1991). *LWR*
- Migrating yearling Chinook use Multnomah Channel and other remaining off channel habitats. Of the 21 radio-tagged juvenile Chinook salmon recovered at or below the head of Multnomah Channel, 15 (71%) were detected within the channel, suggesting the majority used that route (Friesen et al. 2007). *LWR*
- No spatial distribution patterns were observed in outmigrating juvenile Chinook (Friesen, Vile, and Pribyl 2007; Ward et al. 1994). *LWR*
- Most hatchery Chinook were captured with electrofishing gear and regardless of catch method, hatchery fish were similar in size (mean FL electrofishing: 155 mm, mean FL beach seining 147 mm). Whereas unmarked fish captured in beach seines were smaller (mean FL: 63 mm) than those caught by electrofishing (mean FL: 115 mm). Unmarked fish in beach seining peaked at two sizes: 45 and 75 mm FL. Electrofishing habitat varied, beach seining habitat was consistently shallow with minimal slope, little structure and small substrate (Thomas A. Friesen 2005). *LWR*
- Between 2000 and 2003, 5,030 juvenile salmonids were captured in the lower Willamette River by electrofishing and beach seining. More than 87% were Chinook salmon. 54% of Chinook were hatchery. Electrofishing catch (varied habitat) was 68% hatchery Chinook whereas beach seine (shallow, minimal slope, little structure, small substrate) was 85% unmarked Chinook (Thomas A. Friesen 2005). *LWR*
- Combined catches of all unmarked and hatchery juvenile Chinook >100 mm FL, were significantly higher (P=0.04) in main channel sites versus off-channel sites during fall. Catches were higher in off-channel sites in winter and spring for these fish, but results were not statistically significant. For unmarked and hatchery fish considered separately, catches of each group were greater at off-channel sites in winter and spring and in the main channel during fall yet these findings were not statistically significant (Thomas A. Friesen 2005). *LWR*

- Juvenile Chinook have been caught in traps in a drainage channel on the Kenagy Farm near Albany (rkm 188). Monitoring began in 2004 when 63 Chinook were caught, 0 were caught in 2005, 6 in 2006 and 2 in 2007. In each year except 2005, the channel was inundated for >50 days (Schroeder, Kenaston, and McLaughlin 2007). *WR*
- A Yakima River study found that juvenile spring Chinook habitat use varies from season to season. Juvenile Chinook chose positions further from shore, with larger substrates and in deeper water as the seasons progressed from spring to winter (Allen 2000). *CRT*
  - Preferred water depth was significantly different between seasons (P<0.001). In spring, most fish were observed at depths between 0.2-0.4 ft, in summer between 0.7-4.1 ft and in fall >4.0 ft. In winter, fish were found at depths between 0.08 and 13.00 feet. Average depth of focal positions (i.e., location in the water column where fish maintained position) was 3 times greater in the fall and winter compared with spring (during this time fish grew from 3cm to 9-10 cm).
  - 99% of spring and winter focal positions occurred where velocities were <1.0 fps (60% of focal positions had velocities <0.20 fps). In summer and fall focal positions occurred in areas averaging velocities of 1.0 fps or greater. 57% of fish were found in water with a velocity <0.2 fps in the spring, in summer velocities were the highest and 45% of fish were in water >1.0 fps, in fall fish moved to slower velocities (<0.2 fps) and in winter the average velocity was the slowest (1/2 that of the spring).
  - In spring juvenile Chinook were observed in a wide range of substrates. In summer and fall juveniles were found mostly over gravel and cobble mixtures. In winter they were found again over a wide range of substrate.
  - In spring, 40% of juvenile Chinook were observed at focal positions <0.2 ft from the river bottom, 4% were found >1.0 ft from the bottom. In summer only 21% were <0.2 ft from bottom and 13% were >1.0 ft from bottom. In fall only 4% of fish were found <0.2 ft from bottom and 26% were >1.0 ft from bottom. In winter over 70% were <0.2 ft from bottom.
  - In terms of distance to the bank, more than 99% of the fish were observed within 10 ft from bank in spring, 76 were observed within 10 ft from bank in summer and 50% were observed within 10 ft from bank in fall. In fall distance to the bank was significantly greater than in all other seasons (P<0.05). Approximately 80% of focal positions in the fall existed less than 20 ft from the bank. In winter 81% of focal positions were within 10 ft from the bank
- In the mid Willamette River, juvenile Chinook were caught near spur dikes and natural banks at water temperatures of 12 ˚C and 16.8˚C respectively. In early spring, juvenile Chinook were observed feeding in slack water between spur dikes. They were not observed at revetments (16.6 ˚C) (Li, Schreck, and Tubb 1984). *WR*

d. Influence of floodplains and riparian areas

- Lower Willamette springtime catches of juvenile Chinook were lowest among habitat types with 0-10% vegetative cover. In winter months, catch per unit effort for all Chinook combined was significantly higher (P<0.01) in areas of sand substrate compared with areas of fine substrate and bedrock. Catches were significantly lower (P<0.01) at sites >10 m deep, than at sites 0.0-3.0 m deep.

Catches were significantly higher (p<0.01) at sites containing 21-60% vegetation compared with sites of 0-10% vegetation (Thomas A. Friesen 2005). *LWR*

- Naturally produced, juvenile spring Chinook use seasonal floodplains near the convergence of the Willamette and Columbia. Floodplains near the lower Willamette River are used by juvenile Chinook salmon originating from the upper Willamette, lower Columbia and upper Columbia summer-fall ESUs (Teel et al. 2009). *LWR*
- During winter, all juvenile Chinook (marked & unmarked) catches were significantly lower (p<0.01) at seawall sites than at beach, mixed and riprap sites. During summer, juvenile Chinook catch was significantly (P=0.04) lower at seawall sites than sites of mixed habitat. During spring and fall, no significant difference among habitat use was detected. For unmarked Chinook >100 mm FL, catch was significantly higher at mixed-habitat sites compared to seawalls in winter and autumn (P<0.01 and P=0.04). For hatchery Chinook >100mm FL, catch was significantly higher at riprap and mixed habitats compared to seawalls in winter (P<0.01) (Thomas A. Friesen 2005). *LWR*
- The Yolo Bypass, a floodplain of the Sacramento River in CA, provides better habitat for juvenile Chinook rearing and migration than do adjacent river channels. Apparent growth rate in 1998 was 0.80 +/- 0.06 in Yolo Bypass versus 0.52 +/- 0.02 mm/day in the Sacramento River. In 1999, Yolo Bypass growth rate was 0.55 +/- 0.06 versus 0.43 +/- 0.03 in the Sacramento River. Fork length of Chinook in Yolo Bypass was approximately 8 mm greater in 1998 and about 6.9 mm greater in 1999 compared with juvenile Chinook in the Sacramento River (Sommer et al. 2001). *PNW*
- Juvenile Chinook were present in diverse habitats in the Yolo bypass in winter –spring. Mean abundance varied between riparian (46.9/ha) agricultural (20.9/ha) and natural vegetated (27.5/ha) habitat types. Yet these differences were not significantly different. Salmon were collected in low velocity habitat; none were collected in habitat exposed to a current. Hatchery salmon reared in the floodplain for a mean 33 days in 1998, 56 days in 1999 and 30 days in 2000. Salmon were significantly larger (P< 0.001) at the outlet of the floodplain compared with the floodplain entry. Significantly higher (P<0.0001) rates of stranded Chinook were observed in floodplains with engineered water control structures (concrete weir scour ponds) versus isolated earthen ponds. Survival rates in seasonal floodplains were comparable to those of nearby perennial river channels (Sommer, Harrell, and Nobriga 2005). *PNW*
- In the Duwamish estuary, an urban, industrialized estuary that feeds the Puget Sound, juvenile fall Chinook abundance was significantly greater (p=0.047) in a restored reach compared to a non-restored reach. In the restored reach a 45-m embayment had been created, commercial structures and foundations removed, uplands re-contoured and re-vegetated and an intertidal flat was created. Based on findings, researchers propose that restoration sites with large access points in brackish water might provide more function than sites without these characteristics (Cordell et al. 2011). *PS*
- Juvenile Chinook outmigrating used floodplain habitat when its access was restored. In the Salmon River estuary juvenile Chinook densities peaked in an unobstructed wetland (reference site) ($0.04/m^2$) and in a site from which a dike had recently been removed ($0.035/m^2$). In both years, Chinook densities were consistently lowest (as low as $0/m^2$) in a site with limited access due to the presence of a ditch and limited river access (Gray et al. 2002). *PNW*

Food webs and food resources

- Invertebrate communities of the lower Willamette River were assessed in May-June 2003 using drift nets, Dende-plates, and ponar dredges. 37,897 organisms from 44 taxa were identified (Friesen et al. 2005).
  - 12,649 organisms were identified from in 20 drift net samples. Only two EPT species (Ephemeroptera, Plecoptera, Trichoptera-indicators of higher water quality) were found in the 29 taxa identified. The Hilsenhoff Biotic Integrity scores (HBI) overall indicated good water quality. Cladocerans (bosminids and daphnia) were the most abundant organisms in the drift samples. Cladocerans (45.9%), copepods (26.0%), and aquatic insects (17.7%) constituted the majority (89.6%) of organisms in the drift. Drift density was low at rock outcrops and seawalls but high at riprapped sites and floating structures. HBI scores indicated fairly poor water quality at a seawall. Taxa richness (number of taxa) was higher at beach, riprap, and mixed habitat sites than at floating, rock outcrop, and seawall sites. Densities of major taxa in drift differed among habitats.
  - Samples from suspended Dende plates contained fewer taxa than samples from drift nets, but nine EPT taxa were collected. HBI score indicated fairly poor water quality. Daphnia and chironomids were the most abundant taxa (94.9% of the 21,520 organisms identified). Other abundant taxa included amphipods (*Corophium* and *Eogammarus*) and the caddisfly *Agraylea* spp. Density was highest at riprapped sites.
  - Oligochaetes and chironomids were the most abundant invertebrates in the benthic samples (1,482 and 1,076 organisms/m^2, respectively), comprising 82.5% of all benthic organisms collected. Pelycopods (bivalves) and amphipods (*Corophium*) accounted for 11.4% of the total. HBI score indicated fair to good water quality. Beaches had relatively high species diversity, taxa richness, and EPT taxa richness.
- Oligochaetes and chironomids were the most abundant invertebrates in a study of revetments in the mid-reach of the Willamette River (rkm 93-106)(Hjort et al. 1984). EPT taxa (indicators of higher water quality) were more abundant in this study of the mid-Willamette than observed by Friesen et al. (2005) in the lower Willamette. *WR*
- Low gradient reaches (dominated by agricultural or urban land use) of the Tualatin River basin exhibited low taxonomic richness, little to no EPT taxa (mayfly, stonefly, caddisfly) and dominance by a few taxa. High gradient reaches (typically forested) in the basin exhibited high EPT richness and high taxonomic richness (Cole 2002). *WRT*
- *Daphnia* composed 91% by abundance and 43% weight of the diet of juvenile Chinook salmon studied in the lower Willamette. *Daphnia* are abundant in the lower Willamette River (present in 20.4% of drift sample sites with a density of 3.2/m^3; mean densities of 4,997/m2 in Dende-plate samples. Cladocerans represent abundant prey items for juvenile Chinook salmon in the lower Willamette River (Thomas A. Friesen 2005). *LWR*

- Given the abundance of zooplankton, aquatic insects, oligochates, amphipods, and other aquatic invertebrates in the lower Willamette, competition between juvenile Chinook salmon or competition with other fish species for food items is unlikely (Thomas A. Friesen 2005). *LWR*
- Juvenile Chinook in the Prescott-Kalama section of the Columbia River (63 km downstream of Portland) selectively feed on *Daphnia.* During 1968, cyclopoids were equally or more abundant than *Daphnia,* yet *Daphnia* were favored. In September 1968, cyclopoid populations were nearly 4 times that of *Daphnia* yet 98% of juvenile Chinook stomach contents were *Daphnia*. Of items identified, insects were the most common stomach contents in the spring and fall whereas zooplankton were mostly common in July, August and September of 1968 and August, September and October of 1969 (Craddock et al. 1976). *LCR*
- A study of the feeding ecology of subyearling Chinook found that "leafhoppers, aphids, ants and seed bugs (Lygaeidae) were among the most preferred prey items (Rondorf et al. 1990). Zooplankters, including the cladocerans Daphnia spp. and Bosmina spp., and calanoid and cycloid copepods were consistently least preferred in all habitats". They also found that Daphnia only became significant components of subyearling Chinook diet in reservoir reaches where physical habitat was highly altered, was primarily due to the high availability of Daphnia and the low abundance of other preferred prey items in these highly altered environments, and that feeding on Daphnia may entail higher foraging costs per energy unit gained.
- A study in the Columbia River estuary found that juvenile Chinook fed primarily on emerging chironomids, accounting for 85.3% of the total Index of Relative Importance for all fish observed. Juvenile Chinook from emergent marsh sites had an average Index of Feeding Intensity of 0.91% versus 0.56% in the forested site. This suggests that more insects were present and there was higher stomach fullness in juvenile Chinook found in emergent marsh habitats than in forested and scrub-shrub wetland areas. As fish increased in size, diet changed from chironomids to a more diverse diet of larger insects and benthic invertebrates (Lott 2004). *LCR*
- Juvenile Chinook in the Hanford reach of the Columbia feed primarily on midges (diptera: chironomidae). 64% of their diet was comprised of adult midges and 17% of larval midges in 1968. In 1969 percentages were 58% adult and 18% larval. Trichoptera, Hemiptera and Collembola collectively made up 7% of Chinook diet in 1968 and 15% in 1969. Juvenile Chinook fed primarily on a few insect groups that were drifting, floating or swimming. Fry consumed mostly small midges while fingerlings also fed on larger insects. Number of insects consumed and total stomach biomass increased from March to July (Becker 1973). CR

Growth and survival

- Average fork lengths of hatchery Chinook were 1-14 mm greater at downstream sites than upstream sites in the lower Willamette River during a study in 2000-2004. The difference in average lebgth indicates that juvenile Chinook salmon are growing as they migrate through the lower Willamette River. Unmarked sub-yearling Chinook fork lengths were 1-6 mm greater at downstream sites, also indicating growth along the lower Willamette River (Friesen et al. 2007). *LWR*
- A cluster analysis of data collected between 1992 and 2003 in the Snake River (Idaho) found that in wider, warmer streams juvenile Chinook salmon survival was negatively correlated with

temperature whereas in narrower, cooler streams juvenile Chinook survival was positively correlated with flow (likely tied to habitat availability) (Crozier and Zabel 2006). *CRT*

Predation

- A review of 45 field studies from 1959–1996 that explicitly tested the importance of direct effects of predation on anadromous salmonid prey found that 80% of the studies concluded that predation was important (Mather 1998). PNW
- Examination of stomach contents in northern pikeminnow in the McKenzie River, Santiam River, and mainstem Willamette River and its tributaries during spring of 1976 and 1977 observed salmonids in only 2% of the fish sampled (Buchanan, Hooton, and Moring 1981).
- A 2001-2002 study captured few predator fish in the lower Willamette. This combined with stomach contents of predators captured indicated that predation might not be a major threat to juvenile Chinook in the lower Willamette (Friesen et al. 2003). *LWR*
- In spring 2000, stomach contents of smallmouth and largemouth bass between the mouths of the Yamhill (upstream of Willamette Falls) and the Santiam Rivers were examined. The study did not observe predation of salmonids by bass downstream of Albany. An unidentifiable salmonid was found in one fish stomach and an additional eight stomachs contained remains that were unidentified and might have been salmonids (Summers and Daily 2004). *WR*
- A 2005 PIT tag study conducted in the Columbia River estuary found that spring/summer yearling Chinook were more vulnerable to Caspian tern predation than they were to cormorant predation. Double-crested cormorant salmonid consumption maxed out at 6% of the bird's diet in the latter half of June. Caspian tern diets near the Columbia River estuary were comprised of an average of 31% juvenile salmonids. During the second week of May, consumption of juvenile salmonids peaked at 75% of the bird's diet. An estimated 26% (~1.4 million) of these were yearling Chinook and 16% (~0.8 million) sub-yearling Chinook (Collis et al. 2007). *LCR*
- Predation of juvenile salmonids by northern pikeminnow downstream of the Bonneville Dam is highest in summer months (spring predation indices maxed at 20 while summer predation indices maxed at 30 below the dam). Amount of predation was higher in the Columbia River downstream of Bonneville Dam than in mid reaches of the Columbia River or the lower Snake River. (Proportion of 1990-1993 predation index/km downstream of Bonneville was 5.63 in spring and 3.82 in summer; in the middle Columbia River spring predation index range was 0.16-0.97 and summer 0.02 – 1.85; lower Snake River spring range was 0.25 – 1.17 and no summer measurements were taken) (Ward et al. 1995). *LCR, CR*
- Agencies are attempting to manage pikeminnow predation on juvenile salmonids in the lower Columbia and Snake Rivers by fishery harvest. From 1991 to 1996 approximately 12% of pikeminnow were harvested (Friesen and Ward 1999). Computer models predict that northern pikeminnow predation on juvenile salmonids has decreased 25% due to fishery management (Friesen and Ward 1999). *LCR*
- During peak emigration periods, northern pikeminnow predation in free flowing, natural rivers is not as great as that exhibited adjacent to dams or near hatchery release sites. Of 1127 pikeminnow collected in the McKenzie, Santiam and Willamette (between Buena Vista and Independence) only

2% contained salmonids in their stomachs. Pikeminnow are probably opportunistic, preying on the food source that is most abundant or easiest to catch (Buchanan et al. 1981). *WR, WRT*

- A study of smallmouth bass predation on hatchery and wild juvenile salmonids in the Yakima River, Washington from 1998-2001 observed that consumption rates increase during the spring. In May, ocean-type Chinook salmon made up 47% of the fish species found in bass stomachs. Annual consumption by smallmouth bass accounted for approximately 200,000 juvenile salmon annually. The study found that predation was greater on subyearling Chinook salmon, which tend to be smaller, more likely to be naturally produced, and present for a longer period than hatchery fish (Fritts and Pearsons 2004). *CRT*
- Based on field sampling from 1983-1986, annual predation rate in the John Day Reservoir was estimated to be 2.7 million juvenile salmonids. The three major fish predators were Northern pikeminnow (78% of predation), walleye (13%), and smallmouth bass (9%). Fish predation was estimated to account for a loss of 14% of the juvenile salmonids that passed through the reservoir. Predation differed by season and location, with highest predation in summer and at highest densities of juvenile Chinook salmon migration (Rieman et al. 1991). *CR*
- Studies of predation on juvenile salmonids in the Columbia River are generally consistent in observing higher predation rates by northern pikeminnow than other fish predators (Zimmerman 1999, Zimmerman and Ward 1999(David L. Ward and Zimmerman 1999). Smallmouth bass increase their consumption of juvenile salmonids in spring during outmigration of young salmon (Zimmermann 1996). Smallmouth bass densities or consumption rates have not increased after pikeminnow reductions, indicating that compensatory predation may not be substantial (Ward and Zimmermann 1996).
- Bioenergetics models of northern pikeminnow, smallmouth bass, and walleye projected that predation on juvenile salmonids in the Columbia River is influenced by climate and river temperatures. Recent consumption rates (1978-1996) would have been greater than the long-term average and the period from 1947-1977 would have been lower. Dam construction would have been likely to increase predation on juvenile salmonids(Petersen and Kitchell 2001). *CR*
- A study of fish stomach contents in a 6-km reach of the Columbia River downstream of the unimpounded Hanford Reach in May and June 1990 observed that juvenile salmonids were present in two-thirds of the smallmouth bass and accounted for 59% of the diet by weight. Estimates of daily consumption rates of smallmouth bass ranged from 1.0 to 1.4 salmonids per predator (Tabor, Shively, and Poe 1993). *CR*
- Predation by smallmouth bass and largemouth bass accounted for approximately 0.5% of the juvenile salmon produced or migrating though Lake Washington, WA. Predation rates throughout the year were relatively low, but 50% of the diet of smallmouth bass was comprised of juvenile salmonids in June (Tabor et al. 2007). *PS*
- Predation on juvenile salmonids in the John Day Reservoir from 1983-1986 was greatest for northern pikeminnow (0.7 prey/predator), followed by channel catfish (0.5), walleye (0.2), and smallmouth bass (0.04). For each predator, consumption rates varied by reservoir area, month, time of day, and predator size or age (Vigg et al. 1991). Modeling and field sampling both indicate that

predation rates on migrating juvenile salmonids vary spatially, seasonally, and as a function of prey density (Petersen and DeAngelis 1992; Petersen 1994). *CR*

- Fish predators in the John Day Reservoir consumed juvenile salmonids in May and August during the peak period of downstream migration and switched to other prey when abundance of juvenile salmonids declined (Poe et al. 1991). *CR*
- A review of the effects of smallmouth bass on native fish in the Pacific Northwest, including anadromous salmonids, concluded that the direct effects are variable but potentially substantial (0 to 3.89 salmon consumed per predator each day). These consumption rates by smallmouth bass could account for 0 to 35% of wild salmon during outmigration. Effects of smallmouth bass potentially will increase as the species expands in range or abundance. Effects of predators are not limited to direct predation, and future studies should examine non-consumptive effects, such as lower spawning success (Carey et al. 2011). *PNW*

Environmental effects (e.g., temperature, water quality, toxic substances)

- Juvenile fall Chinook from polluted estuaries are more susceptible to disease than are juvenile fall Chinook from unpolluted estuaries. Chemical contaminants in polluted estuaries are linked to reduced health and survival of juvenile Chinook salmon in the Pacific Northwest (Arkoosh et al. 1998). *PNW*
- A computer model projected that salmon spawning time might change by 0.7-1.1 days per generation in response to temperature changes caused by dams (Angilletta et al. 2008). *LAB*
- Analysis within the Willamette Subbasin Plan show that limiting factors in Portland have significant impacts on upriver populations. Based on the Ecosystem Diagnosis and Treatment modeling approach (EDT Model), restoring conditions in Portland is the second most important priority overall for restoring populations throughout the Clackamas Basin, and is particularly important to Lower Clackamas spring and fall Chinook. "Under a restored condition, the lower Willamette adds considerable rearing habitat that would be used by juvenile fall Chinook as they move toward the estuary" (pg.3-441, (Columbia River Basin Fish and Wildlife Program 2009).
- Adult Chinook migrate in the lower Willamette when DO levels equal or exceed 3.5mg/L (Alabaster 1988). *This has been a critical limitation historically, but such low oxygen concentrations are not observed currently in the well-mixed open water in the lower maninstem* (notation by panel members). *LWR*
- In a lab study, exposure to the pesticide diazinon had no effect on swimming behavior or visual food capture. Diazinon significantly inhibited olfactory-mediated alarm responses at concentrations as low as 1.0 mg/L. Homing behavior was impaired at 10.0 mg/L. Loss of alarm responses could increase effects of predation (Scholz et al. 2000). *LAB*
- A summary of scientific research found that at dissolved copper concentrations of 0.18–2.1 µg/L above ambient concentrations, juvenile salmonids reduce predator avoidance by 8-57%. This is consistent with dissolved copper concentrations that affect behavior, growth and primary production which are 0.75 – 2.5µg/L. Salmonids avoid water containing dissolved copper if they can detect it as in concentrated point source pollution. However, where pollution is diffuse (non point

sources) detection is less likely (Hecht et al. 2007). *LAB*

- Leukocytes of juvenile Chinook from hatcheries and a non-urban estuary demonstrated a secondary immune response that was significantly greater than the primary response (as expected). When exposed to the same foreign antigen, juvenile Chinook from urban estuaries did not exhibit the heightened secondary immune response (Arkoosh et al. 1991). *PS*
- Juvenile Chinook injected with PCBs and PAHs in a lab setting exhibited suppressed primary and secondary immune responses (number of plaque forming cells) to TNP-LPS, an antigen (Arkoosh et al. 1994). *LAB*
- A study in the Puget Sound found that juvenile fall Chinook salmon from a polluted estuary had a significantly higher mortality rate when exposed to the fish pathogen *Vibrio anguillarum* than did fish from a non-urban estuary. Average concentrations of PAHs and PCBs in fish stomachs and livers (PCBs) were significantly higher in fish from the urban estuary versus fish from the nonurban estuary (Arkoosh, Casillas, et al. 1998). *PS*
- Juvenile Chinook caged in the Duwamish waterway (a superfund site in the Puget Sound) showed no significant differences ($p<0.05$) in gene response to pollution when compared with a control group of Chinook. However, at the site with highest PAH concentrations, there was a noticeable suppression of gene expression in caged fish. Findings suggest that both PAHs and PCBs in this remediated site were not bioavailable due to their low waterborne concentrations (PAH <1ng/L & PCBs not detectable). Sediment concentrations were higher yet unavailable to caged fish (PAHs, 1482 to 6711 ng/g & PCBs 421 to 1160 ng/g) (Browne et al. 2010). *PS*
- In a laboratory study, juvenile Chinook foraging rates for planktonic (*Artemia*) prey were highest at turbidity levels at and below 150 NTU. Foraging rates for surface (*Drosophila*) and benthic (*Tubifex*) prey decreased in clear water and were highest at intermediate turbidity levels (35-150 NTU). Increased feeding in turbid conditions, despite lower visibility, is likely due to reduced threat from predators (Gregory and Northcote 1993). *LAB*
- In a lab setting, juvenile Chinook hovered near the bottom of an experimental stream in both clear conditions (<1 NTU) and in the presence of bird and fish predator models, in all turbidity levels. Yet in turbid settings, responses to predators were of shorter duration (Gregory 1993). *LAB*
- A cluster analysis using long-term mark-recapture-release data from snowmelt-fed streams in the Salmon River basin, Idaho found that different populations of juvenile spring-summer Chinook respond differently to climate change. Generally, juvenile survival in wide, warm streams was negatively correlated with temperature and survival in narrow, cool streams was positively correlated with flow. Findings also show that temperature is negatively correlated with all juvenile survival. Increases in temperature cause rapid snow pack melts, changing the timing and magnitude of flows, while air temperature increases, increase stream temperature (Crozier and Zabel 2006). *CRT*
- Models predict that Snake River Chinook will respond negatively to changes in streamflow and temperature that are expected from climate change. In all 4 populations examined, mean abundance decreased 20-50% and the probability of extinction increased from 0.1-0.4 to 0.3-0.9 under both climate change scenarios. Differences in habitat likely contributed to differing responses by individual populations, therefore maintaining habitat diversity will help to buffer Chinook from

the impacts of climate change (Crozier, Zabel, and Hamlet 2007). *CRT*

- Juvenile Chinook exposed to PAHs at levels found in urban estuaries exhibited "toxicant-induced starvation". Researchers predict that observed reductions in biomass and lipid stores would result in juvenile Chinook mortality in winter months (Meador et al. 2006). *PS*

Movement and timing of movement

- 2000 – 2003 study documented juvenile Chinook present in lower Willamette all year with highest occurrences in winter and spring. Small, unmarked fish were observed in December and January, when in water work occurs. Average migration rate of radio-tagged fish was 11.3 km/day. (12.4 km/day for hatchery fish and 8.4 km/day for naturally-produced fish) (Friesen et al. 2007). *LWR*
- Juvenile spring Chinook outmigration through the lower Willamette begins in late fall and continues through the following summer. Fish counts were highest in winter and spring. A study of radio-tagging 95 juvenile Chinook between 2001 and 2003 estimated that average migration rate was 11.3 km/day and median residence in the lower Willamette was 3.4 days. Chinook migration rates and river flow and fork length were positively correlated (r^2 = 0.408 and 0.353, respectively). Travel rates in the lower portion of the Lower Willamette including Portland Harbor were significantly slower (8.1 km/d) than travel rates in the reach above Portland Harbor (11.7 km/d). Unmarked Chinook (presumably wild) traveled significantly slower (8.4 km/d) than hatchery Chinook (12.4 km/d). (Friesen 2005). *LWR*
- Hatchery and unmarked juvenile Chinook caught by electrofishing peaked between January and April and declined to near zero in June. Peak catches of juvenile Chinook (hatchery & unmarked) caught by beach seining occurred one month later than those caught using electrofishing. Unmarked fish caught in seining peaked in April or May and declined to nearly zero in July (Friesen 2005). *LWR*
- Between 2000 and 2002, juvenile Chinook counts in the lower Willamette began to increase in November, peaked in April and decreased by July. During this time, sub-yearling Chinook salmon migration rates were 8.6 km/day. Residence time in the lower Willamette was 4.9 days. In 2002, small fish migrated faster than larger fish, contrary to the previous year (Friesen et al. 2003). *LWR*
- Yearling Chinook migrate through the Portland Harbor in 2-3 days. Abundance of yearling Chinook peaked in the latter half of March, subyearling Chinook peaked in mid May (Ward et al. 1994). *LWR*
- Between 1987 and 1988, peak runs in the LWR of yearling Chinook occurred in mid to late March, shortly after releases from hatcheries upstream. Subyearling Chinook were first seen in late April, peaked in mid-May and were present in the LWR through June. Yearling Chinook migration rate was not tied to river flow in 1988, 1989 or 1990. Yearling Chinook traveled through the Portland Harbor during the day and at night. Migration rate during the day was 9.8 km/24 hours. Night migration rate was 8.5 km/24 hours. Most yearling Chinook migrated thru Multnomah Channel, subyearling Chinook migrated through the mouth of the Willamette River. Subyearling Chinook spend more time in the harbor than yearling Chinook and likely were feeding while migrating (Knutsen and Ward 1991). *LWR*
- Juvenile spring Chinook salmon of Willamette River origin comprised 6% of the 426 individuals sampled at the mouth of the Sandy River in 2007 and 2008. Discussion of this finding with the senior author indicated that it was not possible to determine whether these fish moved upstream from the

Willamette River or were the offspring of adult Chinook salmon that had been used in past hatchery practices or adult strays. Juvenile Chinook were present in all months in 2008 and all months except January and February 2007 (Sather et al. 2009). *CR, CRT*

- A study of juvenile Chinook near Hanford in the Columbia River found that increases and decreases in river flows and rising temperatures were the primary environmental factors influencing outmigration (Becker 1973). *CR*
- Migration rates are generally higher in the dammed sections above Bonneville and slower in the estuarine sections (Friesen 2005 , Giorgi et al. 1997), but then increase again at the Astoria Bridge (McMichael et al. 2010). *LWR*
- The travel time for yearling Chinook in the 236 km stretch of river from the Bonneville Dam to the mouth of the Columbia is roughly a median of 3.1 days for juvenile Chinook, with a travel rate of 75-100 km/d in the upper estuary and 40 km/d in the lower (McMichael et al. 2010). *LCR*
- In the Bridge River (a tributary of the Fraser River in British Columbia) seasonal activity patterns of fish were examined in an upper and lower reach. In the lower reach, juvenile Chinook were almost all nocturnal throughout the year, emerging from substrate at dusk to feed on drift organisms, the moving to river margins and resting on sand or silt as night light levels set in. In the upper reach (slower moving water) fish exhibited a similar activity pattern during the winter. In other seasons however, fish were seen in the water column during the day. More fish were observed during the day compared to dusk in the summer than in the spring or fall. Visible fish counts generally increased throughout the day, from morning to dusk. Differences in activity are credited to a tradeoff between efficient foraging and predation risk (Gregory and Northcote 1993). *PNW*

Adult escapement and run timing as related to juvenile life stages

- A 1997-1999 study of north Clackamas County streams found that most streams lacked adequate cover, off channel habitat, large wood and shading. Spawning of *Oncorhynchus spp*. was constrained by high quantities of silt, sand and fine organic matter in studied streams (Friesen and Zimmerman 1999). *LWR*
- According to the 2005 Oregon native fish status report, the Clackamas spring Chinook population failed criteria for productivity and reproductive independence. Between 1990 and 2001, 60-95% of this population was estimated to be hatchery fish. Productivity fell below 1.2, failing the productivity criteria (Goodson et al.). *LWR*
- 48% mortality was observed for adult spring Chinook outplanted above dams in the Middle Fork Willamette River. Mortality rates varied from near 0-90% during the study period due to interaction of environmental and biological factors. Mortality was higher for female than males and also higher for groups released early in the year. Returning adult spring Chinook spend time in freshwater environments during warmest time of the year and are likely more susceptible to prespawning mortality (Keefer et al. 2010). *WR, WRT*
- A 2003-2005 survey of streams in Wilsonville observed that 2.9% of fish surveyed were salmon or trout. Chinook salmon were found in lower reaches of Boeckman and Coffee Lake Creeks only in winter, but they were found in Meridian Creek in winter, spring and summer. IBI scores rated all of the 91 stream reaches as unacceptable. High amounts of silt substrate, high erosion and low quantities of large wood were observed (Koloszar, Ward, and Pribyl 2006). *WRT*

- Columbia River spring Chinook typically spawn in small and medium-sized tributaries between late July and late September and migrate through the lower Columbia between February and May. Spawning and rearing areas have been impacted by: "reduction of stream flow and blockage by irrigation projects and splash dams, blockage by hydroelectric projects, inundation of spawning areas by impoundments, and destruction of spawning and rearing areas by siltation, debris, or pollution from sewage, farming, logging, and mining."(p4) (Fulton 1968) *CR*
- In 1886 Chinook salmon runs were large in the Clackamas between March and July. Migrating Chinook were observed in the Clackamas as late as October 15th (Abernethy 1886). LWR
- An 1886 bulletin noted that Chinook runs began in the Clackamas between March and April, sometimes February and that spawning began in September. By 1886, a decline in Chinook runs had already been observed compared with previous years (Barin 1886). *LWR*
- Spring Chinook adults are in the lower Willamette River beginning in and the majority pass the Willamette Falls in May and June, based on counts at the falls. Counts of spring Chinook jacks (i.e., precocious males that return early) peak in the lower Willamette in mid June (Howell et al. 1985). *LWR*
- Prespawn mortality of outplanted spring Chinook Salmon in the Willamette River is caused by a combination of environmental factors (especially water temperature), fish condition, disease and energetic status. In 2008, a year of low temperatures and high discharge rates, mortality rate was uncommonly low (9.4%) in Fall Creek. In 2009 with high water temperatures (>25° C) prespawn mortality rates were 84.8% for PIT-tagged and 89.5% for radio-tagged fish. Prespawn mortality was significantly ($p<0.05$) associated with physical condition of the adult salmon. In the North Fork Middle Fork (another Willamette tributary) in 2009, prespawn mortality was measured at 27% for radio-tagged and 40% for PIT-tagged fish. All adults that died prior to spawning were infected by pathogens (Mann et al. 2010). *WR, WRT*

Genetics

- Most natural populations of upper Willamette River spring Chinook have been extirpated. McKenzie River is the only self-sustaining natural population and ~26% of these are hatchery fish (estimate from 2000-2004) (Good, Waples, and Adams 2005). *WRT*
- Genetic analysis of stock composition of subyearling Chinook salmon in floodplain wetland and mainstem habitats of the lower Willamette River indicated that spring Chinook salmon originating from the Willamette River made up a substantial proportion of the samples and contributed 16–71% to samples from wetland habitats. Spring Chinook salmon from lower Columbia River populations were present in both wetland (17%) and river (16%) samples in spring 2005, and subyearlings from summer–fall-run populations in the middle and upper Columbia River contributed to spring wetland samples in 2006 (26%). Study concluded that floodplain restoration would benefit habitat for spring Chinook salmons during winter and spring periods in the lower Willamette River (Teel et al. 2009). *LWR*
- Genetic studies of juvenile Chinook in the Columbia River estuary suggest that upper Willamette River spring Chinook rear in off-channel wetland habitats, specifically marsh habitats, in the estuary (Lundrigan et al. 2004). LC*R*

Overview of the relative importance of the lower Willamette River for management and recovery of spring Chinook salmon

- A 2001-2002 study of 23 reaches of 8 Portland streams (Balch, Crystal Springs, Johnson, Kelley, Miller, Saltzman, Stephens and Tryon) identified all but 4 reaches as severely impaired according to Index of Biotic Integrity scores. During this year-long study, 614 salmonids were collected, 9% of which were Chinook salmon. Salmon were most abundant in Stephens Creek; 67% of Chinook were found here (Graham and Ward 2002). *LWR*
- Outmigrating fry have been affected by high water temperatures and industrial waste in the Lower Willamette River. This is especially problematic during low flow seasons (late spring and early summer) (Craig and Townsend 1946; Mattson 1963). *LWR*
- Fish diversity in the lower Willamette River has increased from the 1940s to the 1990s. Only 4 species were collected near Portland in 1945 versus 39 species in 1993. The increase in diversity is partially attributed to increased water quality. The Willamette in the 1940s contained high levels of industrial and domestic sewage and low dissolved oxygen levels (Farr and Ward 1993). *LWR*
- Diversity of fish communities in the Willamette River has increased during the last century, but a substantial portion of the increased diversity is a result of the introduction and range extension of non-native fish species. Proportion of non-native fish species in the fish community increases in the downstream reaches of the mainstem Willamette River (LaVigne et al. 2008)
- Sixty two percent of streams in Lower Willamette have unstable streambeds (2nd highest of all Willamette subbasins), 50% have high fine sediments (2nd highest of subbasins). Sixty percent of streams in Lower Willamette subbasin have high riparian human disturbance (3rd highest). Thirty nine percent of the total stream length in the Lower Willamette subbasin has low quality fish cover (highest of all Willamette subbasins). Lower Willamette ranks 2nd only to Tualatin subbasin in terms of length of stream with poor water quality. Eighty-two percent of Lower Willamette stream length exceeds temperature standard. Fifty percent of stream extent has high phosphorus and 22% high nitrogen. Stream length with high levels of total solids was 24% in Lower Willamette subbasin (Mulvey, Leferink, and Borisenko 2009). *LWR*
- River sediment in the Portland Harbor is contaminated with PAHs, PCBs, metals and pesticides. Spring Chinook provide the largest recreational fishery in the lower Willamette River. Downstream of the Portland Harbor site in the Columbia River, there is recreational fishing of spring Chinook. PAHs and metals have been found throughout the Portland Harbor site. Chlorinated pesticides and PCBs are present at elevated concentrations. PAHs, metals, DDT and DDE and PCBs in excess of their respective TELs (Threshold Effects Level - concentration below which adverse biological effects rarely occur) have been detected in various reaches of the harbor (Azzato et al. 2003). *LWR*
- Models in the Snohomish basin predict that restoration in lower-elevation habitats will be more successful over the next 50 years than restoration in higher-elevation basins. Models also predict that because climate change impacts on hydrology are greatest in higher elevations (on the rain/snow line, where there will be a shift to more rain due to climate change) and restoration is concentrated in lower elevations, salmon distributions will be shifted to lower elevations (Battin et al. 2007). *PNW*

- The pesticides simazine, atrazine, chlorpyrifos, metolachlor, diazinon and carbaryl were detected in 80-100% of water samples taken at the Willamette/Columbia confluence. Concentrations of these contaminants (up to 300 ng/L) and frequency of detection was greater here than at other sites (Warrendale – RM141 and the Beaver Army Terminal-RM53.8). The toxic compounds dioxins, dibenzofurans, PCBs, organochlorine pesticides and PAHs have been detected throughout the Columbia River basin and highest concentrations of many of these were measured in the Portland-Vancouver area (Fresh et al. 2005). *LWR, LCR*
- From the confluence of the Willamette and Columbia Rivers upstream to the Urban Services Boundary (south of the Sellwood Bridge) 89% of off-channel habitat and 79% of shallow water habitat present in 1888 was eliminated by 2001. Fifty three percent of the Willamette's banks in this area have been hardened by human built structures and all riparian wetlands have been eliminated. Between 1998 and 2002, the reach between river miles 0 and 24.8 was 303(d) listed for fecal coliform, dieldrin, DDT, DDE, PAHs, biological criteria (skeletal deformities in juvenile pikeminnow), mercury, aldrin, temperature, PCBs, manganese, iron and pentachlorophenol (Columbia River Basin Fish and Wildlife Program 2009). *LWR*

Citations

1. Abernethy, A.S. 1886. Salmon in the Clackamas River. In *Bulletin of the U.S. Fish Commission*, 332. Washington Government Printing Office.
2. Alabaster, J. 1988. "The Dissolved Oxygen Requirements of Upstream Migrant Chinook Salmon, Oncorhynchus Tshawytscha, in the Lower Willamette River, Oregon." *Journal of Fish Biology* 32 (4): 635-636.
3. Allen, Mark. 2000. "Seasonal Microhabitat Use by Juvenile Spring Chinook Salmon in the Yakima River Basin, Washington." *Rivers* 7 (4): 314-332.
4. Angilletta Jr, M. J, E. Ashley Steel, K. K Bartz, J. G Kingsolver, M. D Scheuerell, B. R Beckman, and L. G Crozier. 2008. "Big dams and salmon evolution: changes in thermal regimes and their potential evolutionary consequences." *Evolutionary Applications* 1 (2): 286–299.
5. Arkoosh, M. R, E. Casillas, E. Clemons, A. N Kagley, R. Olson, P. Reno, and J. E Stein. 1998. "Effect of Pollution on Fish Diseases: Potential Impacts on Salmonid Populations." *Journal of Aquatic Animal Health* 10 (2): 182–190.
6. Arkoosh, M. R., E. Clemons, M. Myers, and E. Casillas. 1994. "Suppression of B-Cell Mediated Immunity in Juvenile Chinook Salmon (Oncorhynchus Tshawytscha) After Exposure To Either A Polycyclic Aromatic Hydrocan or To Polychlorinated Biphenyls." *Immunopharmacology and Immunotoxicology* 16 (2) (January): 293-314. doi:10.3109/08923979409007096.
7. Arkoosh, Mary R., Edmundo Casillas, Ethan Clemons, Bruce McCain, and Usha Varanasi. 1991. "Suppression of Immunological Memory in Juvenile Chinook Salmon (Oncorhynchus Tshawytscha) from an Urban Estuary." *Fish & Shellfish Immunology* 1 (4) (October): 261-277. doi:16/S1050-4648(05)80065-8.
8. Azzato, B., J. Gardiner, L. Harris, and M. Jacobi. 2003. *Coastal and Estuarine Hazardous Waste Site Reports, April 2003: Portland Harbor*. Coastal Protection and Restoration Division, Office of Response and Restoration,NOAA. http://docs.lib.noaa.gov/rescue/NOAA_E_DOCS/E_Library/ORR/coastal_estuarine_hazardous_waste_site_rpts/2003_04.pdf.
9. Barin, L.T. 1886. "Salmon in the Clackamas River." *Bulletin of the United States Fish Commission* 6: 111-112.
10. Battin, J., M. W Wiley, M. H Ruckelshaus, R. N Palmer, E. Korb, K. K Bartz, and H. Imaki. 2007. "Projected Impacts of Climate Change on Salmon Habitat Restoration." *Proceedings of the National Academy of Sciences* 104 (16): 6720.
11. Becker, C. 1973. "Food and Growth Parameters of Juvenile Chinook Salmon, Oncorhynchus Tshawytscha, in Central Columbia River." *Fishery Bulletin* 71 (2): 387- 400.
12. Beechie, T., E. Buhle, M. Ruckelshaus, A. Fullerton, and L. Holsinger. 2006. "Hydrologic regime and the conservation of salmon life history diversity." *Biological Conservation* 130 (4): 560–572.
13. Bottom, D., K. Jones, and M. Herring. 1984. *Fishes of the Columbia River Estuary: Final Report on the Fish Work Unit of the Columbia River Estuary Data Development Program*. Corvallis: Oregon Department of Fish and Wildlife.
14. Bottom, D., C. Simenstad, J. Burke, A. Baptista, D. Jay, K. Jones, E. Casillas, and M. Schiewe. 2005. *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon*. NOAA Technical Memorandum. NOAA, August.
15. Bradford, M. J, and P. S Higgins. 2001. "Habitat-, season-, and size-specific variation in diel activity patterns of juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss)." *Canadian Journal of Fisheries and Aquatic Sciences* 58 (2): 365–374.

16. Browne, E., M. Kelley, G. D Zhou, L. Y He, T. McDonald, S. Wang, B. Duncan, J. Meador, K. Donnelly, and E. Gallagher. 2010. "In Situ Biomonitoring of Juvenile Chinook Salmon (onchorhynchus Tshawytscha) Using Biomarkers of Chemical Exposures and Effects in a Partially Remediated Urbanized Waterway of the Puget Sound, Wa." *Environmental research* 110: 675-683.
17. Buchanan, D. V, R. M Hooton, and J. R Moring. 1981. "Northern squawfish (Ptychocheilus oregonensis) predation on juvenile salmonids in sections of the Willamette River basin, Oregon." *Canadian Journal of Fisheries and Aquatic Sciences* 38 (3): 360–364.
18. Carey, Michael P., Beth L. Sanderson, Thomas A. Friesen, Katie A. Barnas, and Julian D. Olden. 2011. "Smallmouth Bass in the Pacific Northwest: A Threat to Native Species; a Benefit for Anglers." *Reviews in Fisheries Science* 19 (3): 305-315. doi:10.1080/10641262.2011.598584.
19. Cole, Michael B. 2002. *Assessment of Macroinvertebrate Communities in Relation to Land Use, Physical Habitat, and Water Quality in the Tualatin River Basin, Oregon: Final Report*. ABR, Inc. Environmental Research & Services.
20. Collis, K., D. D Roby, D. E. Lyons, Y. Suzuki, J. Y. Adkins, L. Reinalda, N. Hostetter, and L. Adrean. 2007. Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River: 2006 Final Season Summary. Draft.
21. Columbia River Basin Fish and Wildlife Program. 2009. *Willamette Subbasin Plan, Appendix J. Draft EDT Assessment of Aquatic Habitat in the Lower Willamette River Mainstem*.
22. Cordell, J. R, J. D Toft, A. Gray, G. T Ruggerone, and M. Cooksey. 2011. "Functions of restored wetlands for juvenile salmon in an industrialized estuary." *Ecological Engineering* 37: 343-353.
23. Craddock, Donovan, Theodore Blahm, and William Parente. 1976. "Occurrence and Utilization of Zooplankton by Juvenile Chinook Salmon in the Lower Columbia River." *Transactions of the American Fisheries Society* 105 (1) (January): 72-76. doi:10.1577/1548-8659(1976)105<72:OAUOZB>2.0.CO;2.
24. Craig, J.A., and L.D. Townsend. 1946. *An Investigation of Fish-Maintenance Problems in Relation to the Willamette Valley Project*. Special Scientific Report. U.S. Fish and Wildlife Service.
25. Crozier, Lisa G., and Richard W. Zabel. 2006. "Climate Impacts at Multiple Scales: Evidence for Differential Population Responses in Juvenile Chinook Salmon." *Journal of Animal Ecology* 75 (5) (September): 1100-1109. doi:10.1111/j.1365-2656.2006.01130.x.
26. Crozier, Lisa G., Richard W. Zabel, and Alan F. Hamlet. 2007. "Predicting Differential Effects of Climate Change at the Population Level with Life-Cycle Models of Spring Chinook Salmon." *Global Change Biology* 14 (2) (November): 236-249. doi:10.1111/j.1365-2486.2007.01497.x.
27. Van Dyke, E.S., and A. J. Storch. 2009. ABUNDANCE AND DISTRIBUTION OF FISH SPECIES IN CITYOF PORTLAND STREAMS. COMPLETION REPORT 2009. City of Portland Bureau of Environmental Services Portland, OR 97204-1912.
28. Van Dyke, E.S., A. J. Storch, and M.J. Reesman. 2009. SEASONAL COMPOSITION AND DISTRIBUTION OF FISHSPECIES IN THE LOWER COLUMBIA SLOUGH. COMPLETION REPORT 2009. City of Portland Bureau of Environmental Services Portland, OR 97204-1912.
29. Farr, R.A., and D.L. Ward. 1993. "Fishes of the Lower Willamette River, Near Portland, Oregon." *Northwest Science* 67 (1): 16-22.
30. Fresh, K.L., E. Casillas, L.L. Johnson, and D.L. Bottom. 2005. *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability*. U.S. Department of Commerce, NOAA.
31. Friesen, T. A, and M. P Zimmerman. 1999. *Distribution of Fish and Crayfish, and Measurement of Available Habitat in Urban Streams of North Clackamas County: Final Report, 1997-1999*. Clackamas: ODFW.

32. Friesen, T.A., J. S Vile, and A. L Pribyl. 2007. “Outmigration of Juvenile Chinook Salmon in the Lower Willamette River, Oregon.” *Northwest Science* 81 (3): 173.
33. Friesen, Thomas A. 2005. *Biology, Behavior, and Resources of Resident and Anadromous Fish in the Lower Willamette River: Final Report of Research, 2000-2004*. Oregon Department of Fish and Wildlife, March.
34. Friesen, Thomas A., and David L. Ward. 1999. “Management of Northern Pikeminnow and Implications for Juvenile Salmonid Survival in the Lower Columbia and Snake Rivers.” *North American Journal of Fisheries Management* 19 (2): 406-420. doi:10.1577/1548-8675(1999)019<0406:MONPAI>2.0.CO;2.
35. Friesen, Thomas A., Howard K. Takata, John S. Vile, Jennifer C. Graham, Ruth A. Farr, Martyne J. Reesman, and Bonnie S. Cunningham. 2003. *Relationships Between Bank Treatment/Nearshore Development and Anadromous/Resident Fish in the Lower Willamette River: Annual Progress Report July 2001-June 2002*. Oregon Department of Fish and Wildlife, February.
36. Fritts, Anthony L., and Todd N. Pearsons. 2004. “Smallmouth Bass Predation on Hatchery and Wild Salmonids in the Yakima River, Washington.” *Transactions of the American Fisheries Society* 133 (4): 880-895. doi:10.1577/T03-003.1.
37. Fulton, L. A. 1968. *Spawning Areas and Abundance of Chinook Salmon (oncorhynchus Tshawytscha) in the Columbia River Basin: Past and Present*. US Dept. of the Interior, Bureau of Commercial Fisheries.
38. Giorgi, A. E., T. W. Hillman, J. R. Stevenson, S. G. Hays, and C. M. Peven. 1997. “Factors That Influence the Downstream Migration Rates of Juvenile Salmon and Steelhead through the Hydroelectric System in the Mid-Columbia River Basin.” *North American Journal of Fisheries Management* 17 (2): 268-282. doi:10.1577/1548-8675(1997)017<0268:FTITDM>2.3.CO;2.
39. Good, T., R. Waples, and P. Adams. 2005. *Updated Status of Federally Listed Esus of West Coast Salmon and Steelhead. U.s. Dept. Commer. Noaa Tech. Memo.*
40. Goodson, Kevin, Nicklaus Ackerman, Stephanie Gunckel, Ray Beamesderfer, Lisa Krentz, Paul Sheerer, Chris Kern, and David Ward. *2005 Oregon Native Fish Status Report: Volume I Species Management Unit Summaries - Willamette Spring Chinook*.
41. Graham, Jennifer C., and David L. Ward. 2002. *Distribution of Fish in Portland Tributary Streams: Annual Report 2001-02*. Oregon Department of Fish and Wildlife, November.
42. Gray, A., C. A Simenstad, D. L Bottom, and T. J Cornwell. 2002. “Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River estuary, Oregon, USA.” *Restoration Ecology* 10 (3): 514–526.
43. Gregory, R. S. 1993. “Effect of Turbidity on the Predator Avoidance Behaviour of Juvenile Chinook Salmon (oncorhynchus Tshawytscha).” *Canadian Journal of Fisheries and Aquatic Sciences* 50 (2): 241–246.
44. Gregory, R. S., and T. G. Northcote. 1993. “Surface, Planktonic, and Benthic Foraging by Juvenile Chinook Salmon (Oncorhynchus Tshawytscha) in Turbid Laboratory Conditions.” *Canadian Journal of Fisheries and Aquatic Sciences* 50 (2): 233–240.
45. Gregory, S., R. Wildman, D. W Hulse, C. Enright, and A. Branscomb. 2008. *Confluence Island: an assessment of current and future opportunities for ecological restoration at the confluence of the McKenzie and Willamette Rivers*.
46. Hecht, S., D. Baldwin, C. Mebane, T. Hawkes, S. Gross, and N. Scholz. 2007. *An Overview of Sensory Effects on Juvenile Salmonids Exposed to Dissolved Copper: Applying a Benchmark Concentration Approach to Evaluate Sublethal Neurobehavioral Toxicity*. U.S. Dept Commer. NOAA Tech. Memo. NOAA, October.

47. Howell, P., K. Jones, D. Scarnecchia, L. LaVoy, W. Kendra, D. Ortmann, C. Neff, C. Petrosky, R. Thurow, and L. Everson. 1985. "Final Report Stock Assessment of Columbia River Anadromous Salmonids Volume I: Chinook, Coho, Chum and Sockeye Salmon Stock Summaries."
48. Hughes, Michele L., and Kevin A. Leader. 2000. *Distribution of Fish and Crayfish, and Measurement of Available Habitat in the Tualatin River Basin*. Oregon Department of Fish and Wildlife, December.
49. Isaak, D. J, C. H Luce, B. E Rieman, D. E Nagel, E. E Peterson, D. L Horan, S. Parkes, and G. L Chandler. 2010. "Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network." *Ecological Applications* 20 (5): 1350–1371.
50. Keefer, M. L., G. A. Taylor, D. F. Garletts, G. A. Gauthier, T. M. Pierce, and C. C. Caudill. 2010. "Prespawn Mortality in Adult Spring Chinook Salmon Outplanted Above Barrier Dams." *Ecology of Freshwater Fish* 19 (3) (September): 361-372. doi:10.1111/j.1600-0633.2010.00418.x.
51. Knutsen, C.J., and D.L. Ward. 1991. *Behavior of Juvenile Salmonids Migrating Through the Willamette River Near Portland, Oregon*. Oregon Department of Fish and Wildlife, July.
52. Koloszar, J. A., D.L. Ward, and A.L. Pribyl. 2006. *Surveys of Fish Species and Habitat in Wilsonville Streams*. Oregon Department of Fish and Wildlife.
53. LaVigne, Henry R., Robert M. Hughes, Randall C. Wildman, Stanley V. Gregory, and Alan T. Herlihy. 2008. "Summer Distribution and Species Richness of Non-native Fishes in the Mainstem Willamette River, Oregon, 1944–2006." *Northwest Science* 82 (2): 83-93. doi:10.3955/0029-344X-82.2.83.
54. Li, H. W., C.B. Schreck, and R.A. Tubb. 1984. *Comparison of Habitats Near Spur Dikes, Continuous Revetments, and Natural Banks for Larval, Juvenile, and Adult Fishes of the Willamette River*. Corvallis, OR: Oregon Cooperative Fishery Research Unit Department of Fisheries and Wildlife, Oregon State University, September.
55. Lott, M. 2004. Habitat-Specific Feeding Ecology of Ocean-Type Juvenile Chinook Salmon in the Lower Columbia River Estuary. University of Washington.
56. Lundrigan, T. A, P. Moran, D. J Teel, A. R Marshall, S. F Young, and D. L Bottom. 2004. *Conservation and Genetic Stock Identification: A Study Investigating the Stock-Specific Distribution and Performance of Juvenile Chinook Salmon in the Columbia River Estuary*.
57. Mann, R.D., C.C. Caudill, M.L. Keefer, C.A. Peery, C.B. Schreck, and M.L. Kent. 2010. *Migration Behavior and Spawning Success of Spring Chinook Salmon in Fall Creek and the North Fork Middle Fork Willamette River: Relationships Among Fate, Fish Condition, and Environmental Factors*. Idaho Cooperative Fish and Wildlife Research Unit.
58. Mather, Martha E. 1998. "The role of context-specific predation in understanding patterns exhibited by anadromous salmon." *Can. J. Fish. Aquat. Sci.* 55 (S1): 232-246. doi:10.1139/d98-002.
59. Mattson, C.R. 1963. *An Investigation of Adult Spring Chinook Salmon for the Willamette River System, 1946-51*. Portland: Oregon Fish Commission.
60. McCabe, G., R. Emmett, W. Muir, and T. Blahm. 1986. "Utilization of the Columbia River Estuary by Subyearling Chinook Salmon." *Northwest Science* 60 (2): 113-124.
61. McElhany, P., M. Chilcote, J. Myers, and R. Beamesderfer. 2007. *Viability Status of Oregon Salmon and Steelhead Populations in the Willamette and Lower Columbia Basins: Part 6 - Upper Willamette Chinook (Review Draft)*. Seattle, WA: National Marine Fisheries Service Northwest Fisheries Science Center, June.
62. McMichael, G.A., R.A. Farr, B.J. Bellgraph, J.A. Carter, K.D. Ham, P.S. Titzler, and M.L. Hughes. 2010. Migratory Behavior and Survival of Juvenile Salmonids in theLower Columbia River and Estuary in 2009. Final Report. PNNL 19545. Pacific Northwest National Laboratory Richland, Washington 99352.

63. McMichael, G.A., G.E. Johnson, J.A. Vucelick, G.R. Ploskey, and T.J. Carlson. 2006. *Use of Acoustic Telemetry to Assess Habitat Use of Juvenile Chinook Salmon and Steelhead at the Mouth of the Columbia River: Final Report*. Pacific Northwest National Laboratory, February.
64. Meador, J.P., F.C. Sommers, G.M. Ylitalo, and C.A. Sloan. 2006. "Altered Growth and Related Physiological Responses in Juvenile Chinook Salmon (onchrhynchus Tshawytscha) from Dietary Exposure to Polycyclic Aromatic Hyddrocarbons (pahs)." *Canadian Journal of Fisheries and Aquatic Sciences* 63 (10): 2364-2376. doi:10.1139/F06-127.
65. Miller, J. A, and C. A Simenstad. 1997. "A Comparative Assessment of a Natural and Created Estuarine Slough as Rearing Habitat for Juvenile Chinook and Coho Salmon." *Estuaries and Coasts* 20 (4): 792–806.
66. Muir, W. D, S. G Smith, J. G Williams, and B. P Sandford. 2001. "Survival of Juvenile Salmonids Passing Through Bypass Systems, Turbines, and Spillways with and Without Flow Deflectors at Snake River Dams." *North American Journal of Fisheries Management* 21 (1): 135–146.
67. Mulvey, M., R. Leferink, and A. Borisenko. 2009. *Willamette Basin Rivers & Streams Assessment*. Hillsboro: Oregon Department of Environmental Quality, June.
68. Myers, J., C. Busack, D. Rawding, and A. Marshall. 2003. *Historical Population Structure of Willamette and Lower Columbia River Basin Pacific Salmonids*.
69. Petersen, James H, and James F Kitchell. 2001. "Climate regimes and water temperature changes in the Columbia River: bioenergetic implications for predators of juvenile salmon." *Can. J. Fish. Aquat. Sci.* 58 (9): 1831-1841. doi:10.1139/f01-111.
70. Poe, Thomas P., Hal C. Hansel, Steven Vigg, Douglas E. Palmer, and Linda A. Prendergast. 1991. "Feeding of Predaceous Fishes on Out-Migrating Juvenile Salmonids in John Day Reservoir, Columbia River." *Transactions of the American Fisheries Society* 120 (4): 405-420. doi:10.1577/1548-8659(1991)120<0405:FOPFOO>2.3.CO;2.
71. Pribyl, Alena L., James A. Koloszar, and David L. Ward. 2004. *Abundance and Distribution of Fish Species in West Linn Streams: Final Report 2003-04*. Oregon Department of Fish and Wildlife.
72. Rieman, Bruce E., Raymond C. Beamesderfer, Steven Vigg, and Thomas P. Poe. 1991. "Estimated Loss of Juvenile Salmonids to Predation by Northern Squawfish, Walleyes, and Smallmouth Bass in John Day Reservoir, Columbia River." *Transactions of the American Fisheries Society* 120 (4): 448-458. doi:10.1577/1548-8659(1991)120<0448:ELOJST>2.3.CO;2.
73. Rondorf, Dennis W., Gerard A. Gray, and Robert B. Fairley. 1990. "Feeding Ecology of Subyearling Chinook Salmon in Riverine and Reservoir Habitats of the Columbia River." *Transactions of the American Fisheries Society* 119 (1): 16-24. doi:10.1577/1548-8659(1990)119<0016:FEOSCS>2.3.CO;2.
74. Sather, N. K, G. E Johnson, A. J. Storch, D. J. Teel, J. R Skalski, T. A Jones, E. M Dawley, et al. 2009. *Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats in the Vicinity of the Sandy River Delta, Lower Columbia River, 2008*. PNNL-18450, final report submitted to the Bonneville Power Administration by Pacific Northwest National Laboratory, Oregon Department of Fish and Wildlife, National Marine Fisheries Service, and University of Washington.
75. Scholz, N. L, N. K Truelove, B. L French, B. A Berejikian, T. P Quinn, E. Casillas, and T. K Collier. 2000. "Diazinon disrupts antipredator and homing behaviors in chinook salmon (Oncorhynchus tshawytscha)." *Canadian Journal of Fisheries and Aquatic Sciences* 57 (9): 1911–1918.
76. Schroeder, R., K. Kenaston, and L. Krentz. 2005. *Spring Chinook in the Willamette and Sandy Basins: Annual Progress Report October 2004-September 2005*. Salem, OR: ODFW.
77. Schroeder, R., K. Kenaston, and R. Lindsay. 2003. *Spring Chinook in the Willamette and Sandy Rivers: Annual Progress Report October 2002-September 2003*. Salem, OR: ODFW.
78. Schroeder, R., K. Kenaston, and L. McLaughlin. 2007. *Spring Chinook in the Willamette and Sandy Basins: Annual Progress Report October 2005-September 2007*. Salem, OR: ODFW.

79. Schroeder, R.K., and K.R. Kenaston. 2004. *Spring Chinook in the Willamette and Sandy Basins: Annual Progress Report October 2003 - September 2004*. Salem, OR: ODFW.
80. Sommer, T., M. Nobriga, W. Harrell, W. Batham, and W. Kimmerer. 2001. "Floodplain Rearing of Juvenile Chinook Salmon: Evidence of Enhanced Growth and Survival." *Canadian Journal of Fisheries and Aquatic Sciences* 58 (2): 325-333. doi:10.1139/cjfas-58-2-325.
81. Sommer, Ted, William Harrell, and Matthew Nobriga. 2005. "Habitat Use and Stranding Risk of Juvenile Chinook Salmon on a Seasonal Floodplain." *North American Journal of Fisheries Management* 25 (4) (November): 1493-1504. doi:10.1577/M04-208.1.
82. Summers, Jodene, and Kin Daily. 2004. *Willamette River Bass Diet Study - Spring 2000*. Oregon Department of Fish and Wildlife.
83. Tabor, Roger A., Brian A. Footen, Kurt L. Fresh, Mark T. Celedonia, Francine Mejia, David L. Low, and Linda Park. 2007. "Smallmouth Bass and Largemouth Bass Predation on Juvenile Chinook Salmon and Other Salmonids in the Lake Washington Basin." *North American Journal of Fisheries Management* 27 (4): 1174-1188. doi:10.1577/M05-221.1.
84. Tabor, Roger A., Rip S. Shively, and Thomas P. Poe. 1993. "Predation on Juvenile Salmonids by Smallmouth Bass and Northern Squawfish in the Columbia River near Richland, Washington." *North American Journal of Fisheries Management* 13 (4): 831-838. doi:10.1577/1548-8675(1993)013<0831:POJSBS>2.3.CO;2.
85. Teel, David, Cyndi Baker, David Kuligowski, Thomas Friesen, and Barbara Shields. 2009. "Genetic Stock Composition of Subyearling Chinook Salmon in Seasonal Floodplain Wetlands of the Lower Willamette River, Oregon." *Transactions of the American Fisheries Society* 138 (1) (January): 211-217. doi:10.1577/T08-084.1.
86. Tinus, E.S., J.A. Koloszar, and D.L. Ward. 2003a. *Abundance and Distribution of Fish in City of Portland Streams: Final Report 2001-03*.
87. ———. 2003b. *Abundance and Distribution of Fish in Clackamas County Urban Streams: Final Report 2002-03*. October.
88. Vigg, Steven, Thomas P. Poe, Linda A. Prendergast, and Hal C. Hansel. 1991. "Rates of Consumption of Juvenile Salmonids and Alternative Prey Fish by Northern Squawfish, Walleyes, Smallmouth Bass, and Channel Catfish in John Day Reservoir, Columbia River." *Transactions of the American Fisheries Society* 120 (4): 421-438. doi:10.1577/1548-8659(1991)120<0421:ROCOJS>2.3.CO;2.
89. Waples, R. S, D. J Teel, J. M Myers, and A. R Marshall. 2004. "Life-History Divergence in Chinook Salmon: Historic Contingency and Parallel Evolution." *Evolution* 58 (2): 386–403.
90. Ward, D. L, A. A Nigro, R. A Farr, and C. J Knutsen. 1994. "Influence of Waterway Development on Migrational Characteristics of Juvenile Salmonids in the Lower Willamette River, Oregon." *North American Journal of Fisheries Management* 14 (2): 362–371.
91. Ward, D. L, J. H Petersen, and J. J Loch. 1995. "Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River." *Transactions of the American Fisheries Society* 124 (3): 321–334.
92. Ward, David L., and Mark P. Zimmerman. 1999. "Response of Smallmouth Bass to Sustained Removals of Northern Pikeminnow in the Lower Columbia and Snake Rivers." *Transactions of the American Fisheries Society* 128 (6): 1020-1035. doi:10.1577/1548-8659(1999)128<1020:ROSBTS>2.0.CO;2.
93. Zakel, Jeffrey C., and Donald W. Reed. 1984. *Downstream Migration of Fish at Leaburg Dam, McKenzie River, Oregon 1980 to 1983*. Oregon Department of Fish and Wildlife, June.
94. Zimmerman, Mark P. 1999. "Food Habits of Smallmouth Bass, Walleyes, and Northern Pikeminnow in the Lower Columbia River Basin during Outmigration of Juvenile Anadromous

Salmonids." *Transactions of the American Fisheries Society* 128 (6): 1036-1054. doi:10.1577/1548-8659(1999)128<1036:FHOSBW>2.0.CO;2.

95. Zimmerman, Mark P., and David L. Ward. 1999. "Index of Predation on Juvenile Salmonids by Northern Pikeminnow in the Lower Columbia River Basin, 1994–1996." *Transactions of the American Fisheries Society* 128 (6): 995-1007. doi:10.1577/1548-8659(1999)128<0995:IOPOJS>2.0.CO;2.