REVIEW DRAFT

Juvenile Salmonid Use of Very Large, Shallow, and Tidally-influenced Lakes in the Floodplain of the Lower Columbia River

A Literature Review

Prepared for Bonneville Power Administration
by PC Trask & Associates, Inc.
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Introduction

As part of their complex life cycles, juvenile salmonids use the reaches of the Columbia River between the Bonneville Dam and the Pacific Ocean (the Lower Columbia River or the Columbia River estuary) for rearing and migration. Lakes, ponds, and seasonal wetlands are found at various elevations throughout the floodplain of these reaches. The largest of these landscape water features are the large floodplain lakes located between the I-5 Interstate Bridge and the Lewis River confluence (Reach F of the Lower Columbia River). This paper summarizes a literature review focused on juvenile salmonid use of the largest of these floodplain lakes: Vancouver Lake, Sturgeon Lake, and the Smith and Bybee Lakes complex). This literature review was performed by PC Trask & Associates, Inc. with review and technical guidance by Charles "Si" Simenstad, Research Professor at the School of Aquatic and Fishery Sciences, University of Washington.

The context for the literature review is narrowly focused upon establishing a technical basis for several proposed restoration actions to benefit juvenile salmonids in Vancouver Lake, Sturgeon Lake, and Shillapoo Lake.

It is important for the reader to bear in mind three primary constraints of this review:

1) Along the west coast of Canada and the United States, the presence of tidally-influenced floodplain lakes that are greater than 1000 acres from British Columbia to California is somewhat unique to the Lower Columbia River; therefore, not many pertinent literature sources were found that focused on areas outside this estuary.

2) While sampling of fish, including juvenile salmonids, in the largest of the large, tidally-influences lakes of the Lower Columbia River began in the late 1970s, the drivers for these studies were not salmon-focused. The studies were designed to understand the effects of several hydrologic modification projects and to inform developing management strategies for sport fishing within the lakes. Table 1 illustrates the questions we sought to answer about juvenile salmonid use of large floodplain lakes during our review.

3) It is important to continually note that Bonneville Dam, a major hydrologic modification, constrains the entire Columbia River estuary and that all of the reviewed literature was written about studies under that constrained condition. Such a modification likely biases the result and at least constrains the natural context of floodplain lakes and all fish data collected.

The questions presented in Table 1 were intended to guide the literature search and the structure of this paper.

Table 1. Key questions and preliminary answers about juvenile salmonid use of tidally-influenced large floodplain lakes.

Have researchers found juvenile salmonids in large floodplain lakes?	Yes
Were multiple life histories represented in samples?	Yes
Were evolutionarily significant units (ESUs) identified in research?	No
Were residence times in lakes estimated?	Yes
Were juvenile salmonids found in large floodplain lakes in different months?	Yes
Were specific habitats within the lakes sampled?	Yes
Were piscivorous fish sampled to identify predation effects?	Yes

Background

Tidally-influenced, large floodplain lakes are an interesting geomorphic feature in the Columbia River estuary. While a number of floodplain lakes exist in the fluvial-dominated freshwater reaches of the river, only a few of them are very large. Located north of Portland between river miles 88 and 106, there are ten floodplain lakes that are at least 100 acres in size. Of these ten, only Vancouver and Sturgeon lakes are greater than 1000 acres in size; the complex of Smith and Bybee lakes and their associated sloughs are slightly less than 1000 acres. These are the three lake systems for which our research returned results that addressed many of the questions we asked.

For the purposes of this research, a tidally-influenced, large floodplain lake is defined as a shallow, perennial, lake located within the floodplain of a riverine system that is impacted by the diurnal effects of the ocean tide and that has a surface area of at least 100 acres. Figure 1 illustrates the position of lakes fitting this description within the floodplain of the Columbia River estuary. The largest is Sturgeon Lake at approximately 4800 acres during extreme freshet events.

The lakes of the Columbia River estuary floodplain are highly productive systems for a diversity of fish and wildlife species. For example, chlorophyll *a* (a measure of phytoplankton biomass) in Vancouver Lake ranges from spring concentrations of 4-27 ug/l to summer concentrations of 256-499 ug/l (Boyer et al. 2011). Photosynthesis and productivity tend to be proportionately higher in shallow lakes than in deeper lakes and occur throughout the water column. Because these shallow lakes sit lower in the landscape topography, the ratio of drainage area to lake size typically is high, and shallow lakes in general store more nutrients (Vancouver Lake Watershed Partnership 2011).

Historically, the banks of floodplain lakes were overtopped by major freshet events which influenced their geomorphology (Simenstad et al. 2011). These lakes are historically structured by crevasse splays and relict depositional areas that resulted from higher flow events. Today, hydro regulation upstream causes muted freshet events and, consequently, historical lake bank overtopping occurs less frequently (Simenstad et al. 2011). Under normal flow conditions, the significant volume of these lakes supports long-sinuous channels that serve as the primary hydrological connection to the mainstem estuary. The connectivity between river channels and wetlands makes a ‘boom and bust’ ecology following drought and flooding and is known throughout the world to support rich biodiversity (G. Kattel and P. Gell 2012).

While the role of floodplain lakes in salmon life histories is not certain in the Columbia River estuary, we can begin to extrapolate the ecological importance of these lakes by looking elsewhere where large floodplain lakes exist, especially in estuaries. In the context of this literature review, a broad definition of the Columbia River estuary is used: the entire river downstream of the Bonneville Dam to the Pacific Ocean.

Six species representing 13 listed ESUs and more than 150 populations of salmon and steelhead utilize the Columbia River estuary for rearing and migration (National Marine Fisheries Service [NMFS] 2011). Salmonid genetics data emerging from National Oceanic and Atmospheric Administration (NOAA) Fisheries Science Center indicates that, of samples collected in the estuary, the greatest diversity of juvenile salmon stocks were found in hydrogeomorphic Reach F. While all salmonid information pertaining to large floodplain lakes was reviewed, an assumption in this report is that ocean-type juvenile salmonids (e.g., fall Chinook) use shallow water habitats more extensively and for longer periods than stream-type. Therefore, our interests were primarily focused on findings about Chinook salmon.

Literature Review Process Steps and Assumptions

The literature review was performed by PC Trask & Associates. During the initial effort, the search was extended to all literature sources containing key words such as salmon, juvenile salmon, lakes, large floodplain lakes, and juvenile salmonid habitats. Approximately 31 sources appeared germane enough to be obtained and reviewed. Two additional searches occurred as a result of leads identified through the first effort. Finally screening of these sources produced 20 reports which either provided background material or primary information for this report. Appendix A contains an annotated bibliography of these sources.

An underlying assumption at the onset of this literature review was that little research existed to support the notion that juvenile salmonids use tidally-influenced large floodplain lake habitats for rearing. This assumption is confirmed within the broader literature body primarily because it appears as though tidally-influenced, large, floodplain lakes in Pacific Coast systems are rare. While this search was focused on the six salmonid species of interest to the Columbia River estuary, our initial investigation included floodplain lakes in ecosystems world-wide. For example we reviewed published literature from the Florida Everglades, the Fraser River in British Columbia, the Sacramento River in California, the Pongolo River in South Africa, the Niger River in West Africa, the Orinoco River in Venezuela, and the Amazon River in South America. Few literature sources were identified where salmon species are also found. Targeted geographic efforts (e.g. Kamchatka, Russia and Tongass, Alaska) could uncover additional (likely unpublished) data about salmonids in tidally influenced floodplain lakes (Personal Communication, 8-23-12, Dr. Jack Stanford, University of Montana) but were not considered for further examination within the scope of this literature review.

While a broad search for contemporary literature supporting juvenile salmonid use of tidally-influenced large floodplain lakes yielded limited results, a turning point came when the search was re-directed to the Columbia River estuary and studies dating back to the 1970s. Personal communication with Ray Beamesderfer, Senior Scientist at Cramer Fish Sciences, led to communications with Dave Ward of HDR, Inc., which led to historical reports on Smith, Bybee, and Sturgeon lakes. Published Vancouver Lake data was identified through the Vancouver Lake Watershed Partnership.

The remainder of this paper is dedicated to a synthesis of salmon survey data from samplings at three of the largest flood plain lakes in the Columbia River Estuary: Vancouver Lake, Sturgeon Lake, and the Smith and Bybee Lakes complex (Figure 2). Other literature source information is cited as appropriate and an annotated bibliography of other literature reviewed is contained in Appendix A.

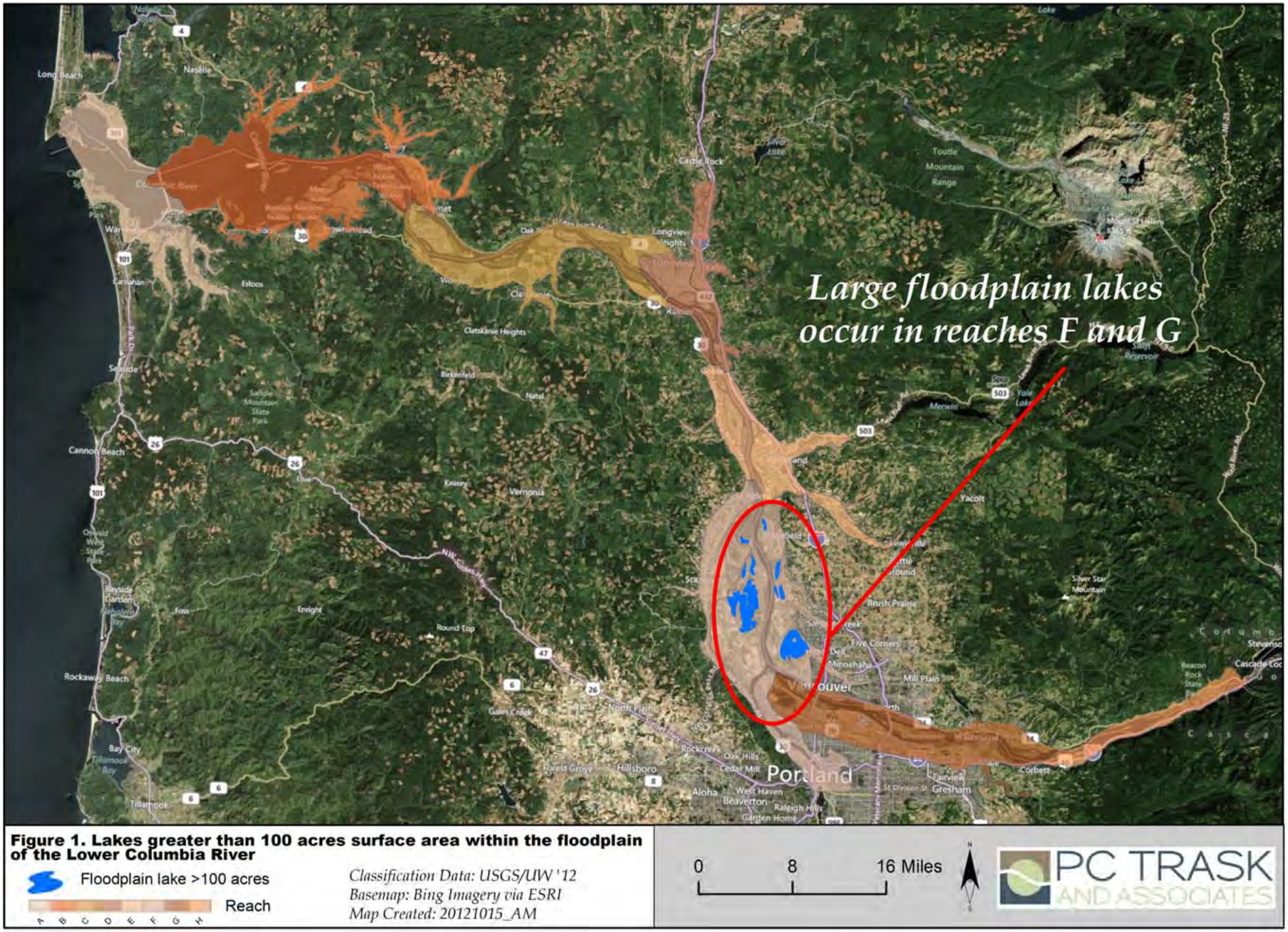

Figure 1. Lakes greater than 100 acres surface area within the floodplain of the Lower Columbia River

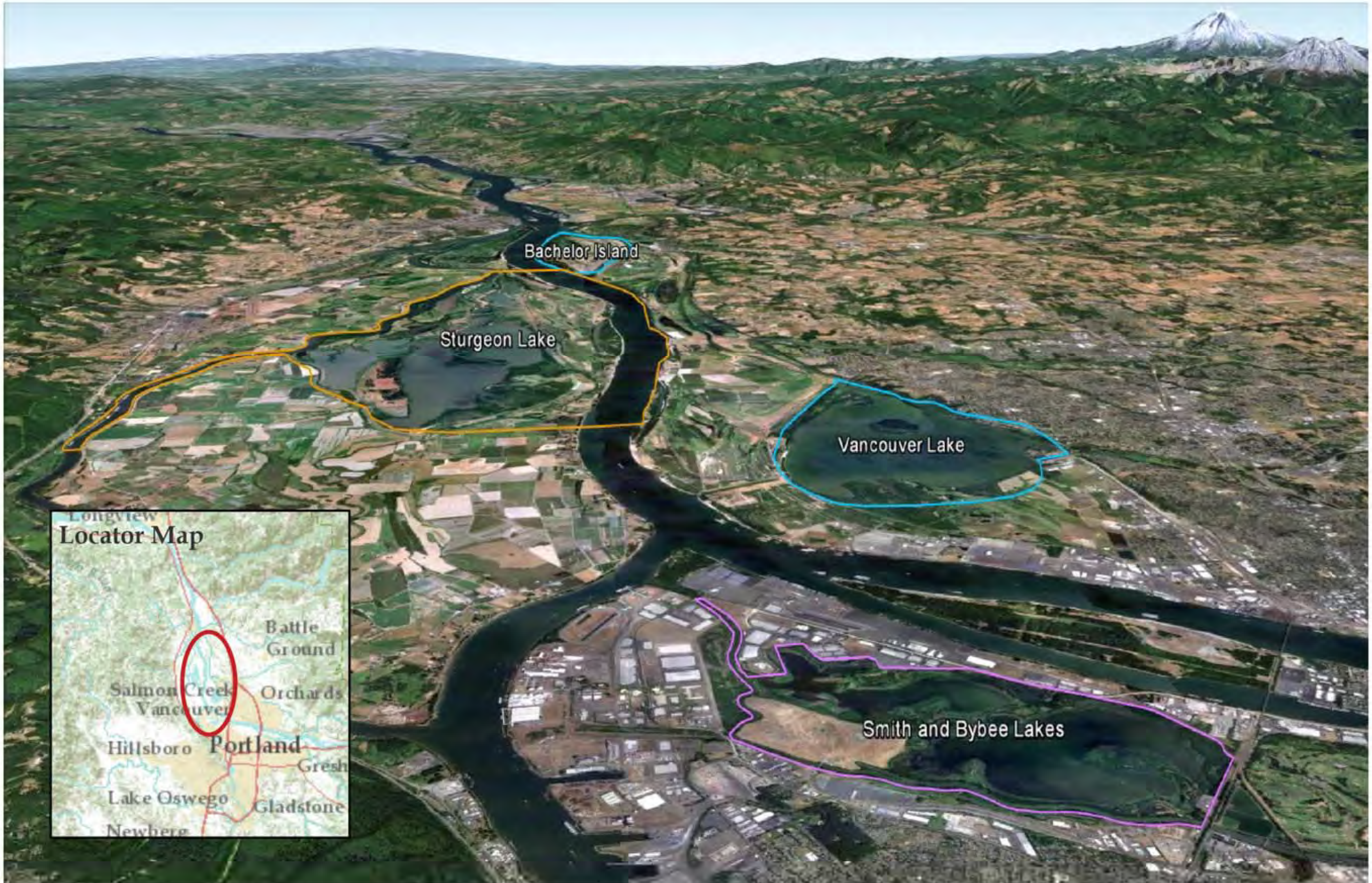

Figure 2. Overview map of the locations of Smith, Bybee, Vancouver, and Sturgeon lakes.

Smith & Bybee Lakes Complex Study Area (Fishman et al. 1987)
Vancouver Lake Study Area (Envirosphere 1983 & 1985)
Sturgeon Lake Study Area (Ward and Rien 1992)

Imagery courtesy of TerraMetrics, Cnes/Spot, and GeoEye via Google. Camera Altitude: 15,586 ft. Map Created: 20121015_AM

Scale varies due to oblique angle. See camera angle for scale reference.

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Information Synthesis of Primary Literature Findings

Four research and sampling papers addressing three of the large floodplain lakes within the Columbia River estuary were reviewed. Envirosphere published two papers describing sampling studies conducted within and around Vancouver Lake (published in 1983 and 1985). Ward and Rein published a paper in 1992 describing sampling efforts that occurred in 1986, 1987, and 1992. And Fishman et al. published a paper in 1987 that described their 1986 sampling events in the Smith and Bybee Lakes complex. The synthesis below provides summaries of these papers including their respective purposes, findings, and conclusions. In addition, a thesis paper by Cynthia Baker (2008) also includes information about sampling events within the Smith and Bybee Lakes complex, along with data for sampling done in smaller floodplain lakes within the estuary. For a brief summary of Baker's findings, we point the reader to the annotated bibliography in Appendix A.

Vancouver Lake Study (1982-1983)

Vancouver Lake, located in the Columbia River floodplain in the Washington shore, encompasses approximately 2300 acres (VLWP 2011). A flushing channel inlet is located on the lake's southwest bank and flushes Columbia River water into the lake; Burnt Bridge Creek also feeds water into the lake. The flushing channel is controlled by a one-way tide gate that allows water to flow into the lake but not out of the lake via that pathway. Lake River is the lake's historical channel connection to the Columbia River. At times, Lake River's flow changes direction and flows into the river as a result of tidal influences backing up water in the Columbia River (Ecology & Environment 2007).

Envirosphere (1983 and 1985) conducted fish sampling in and around Vancouver Lake during 1982 and 1983. The purpose of the studies was to evaluate whether the newly constructed lake flushing channel would divert juvenile salmon and trout from the Columbia River into Vancouver Lake where they could become disoriented and could incur increased mortality from predation, poor water quality, or both. Serendipitously, the flushing channel opening was delayed and the first year of sampling includes both pre- and post-opening data. The secondary study purpose was to evaluate the effect of increased flushing and dredging on resident warm-water species.

During the 1982 sampling, there were eleven sampling stations within Vancouver Lake, four in the Columbia River, and one at Lake River (see Figure 3a and 3b). Sampling occurred from January through December. Envirosphere conducted beach seining in the lake and the river nine times between April and December 1982. Beach seining occurred at least once at each Vancouver Lake sampling locations, except V07, and at each sampling locations within the Columbia River. Also within Vancouver Lake, gill netting was conducted at sampling locations V01, V02, V03, V05, and V07. Envirosphere conducted the gill netting twice in April 1982. Lastly, Envirosphere fished an adult fish weir for 48 continuous hours in December; the weir was located in Lake River at the outlet of Vancouver Lake. The 1983 report does not include tables of raw data for each sampling catch, but it does provide some summary tables and graphs with an accompanying discussion of the results.

Beach seine catches through December 1982 in Vancouver Lake were dominated by warm water species. Juvenile Chinook were caught during the spring and early summer samplings. The presence of juvenile

Figure 3a. Envirosphere 1983 and 1985 Vancouver Lake study area and sampling locations - southern portion.

Sample Locations (by study year)

1982 | 1984 | 1982 & 1984 | Study Site

Projection: NAD_1983_HARN_StatePlane Washington_South_FIPS_4602_Feet
Source of Image: ESRI Online
Map Created: 20121015_AM

0 | 0.375 | 0.75 Miles

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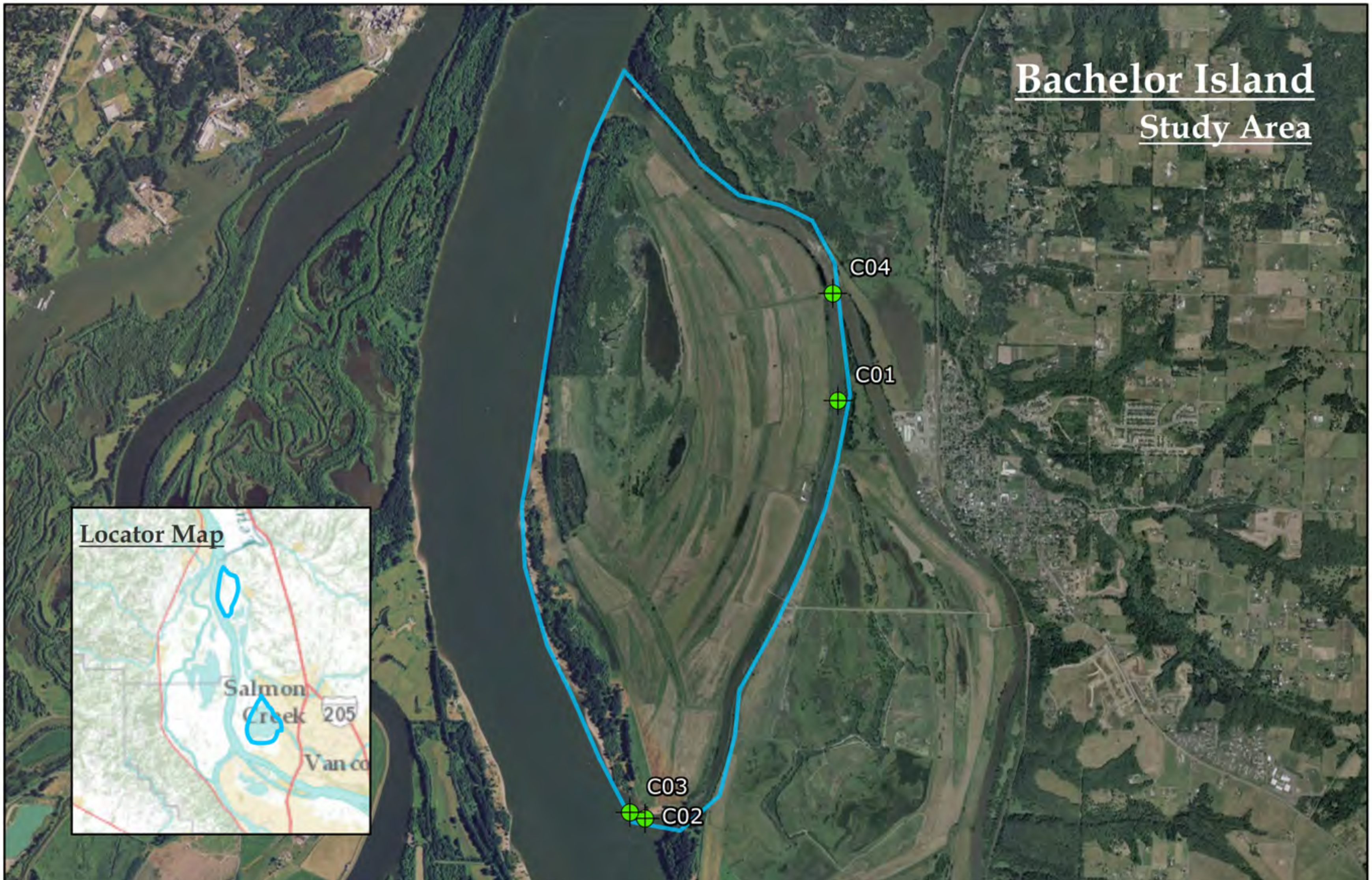

Figure 3b. Envirosphere 1983 and 1985 Vancouver Lake study area and sampling locations - northern portion.

Sample Locations (by study year)

1982 & 1984

Study Site

Projection: NAD_1983_HARN_StatePlane Washington_South_FIPS_4602_Feet
Source of Image: ESRI Online
Map Created: 20121015_AM

0 0.4 0.8 Miles

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Chinook in April suggests that the fish moved into the lake prior to Envirosphere's initial sampling (Envirosphere 1983). Envirosphere suggests that the fish may have arrived during high Columbia River discharge levels in February and March 1982, when the lake was slightly warmer than the river and would have enhanced food conversion efficiency and growth rate.

Fish in the 1982 samples from the Columbia River were dominated by juvenile Chinook salmon and threespine stickleback; some juvenile coho salmon were also caught in the River samples. Juvenile Chinook density was higher in the lake than in the river in April. However, that changed as temperatures in the lake rose and fewer quantities of juvenile Chinook were caught in the lake; catches of juvenile Chinook continued to be relatively high in the Columbia River into July.

The 1984 sampling occurred from January through September. There were only seven stations within the lake during 1984; V01, V05, V06, V07, and V09 were not sampled and V12 was added. The Columbia River and Lake River sampling locations remained the same as the 1982 locations. In 1984, the same beach seine, gill net, and adult weir sampling gear was used as was used in the 1982 samplings. While the methods of setting and fishing each were the same as the previous efforts, the report is unclear about whether the frequency was consistent between the two sampling years. In the 1984 sampling, Envirosphere also fished a juvenile fyke net in the incoming water upwelling from the flushing channel. The fyke net was fished for 72 continuous hours in June and in July.

The 1985 report does include tables of data for each sampling catch, but it does not include a discussion of the results and draws no conclusions. A summary of 1984 catch data for juvenile Chinook and coho combined are summarized in Table 2. The report data indicate that the largest fish catches throughout the study area occurred in June (511.5 salmon recorded) and July (829.5 salmon recorded); some data in the report tables were recorded as averages between multiple seine hauls at the same location on a given date, resulting in fractions of fish in the results. No salmon were caught in the adult fish weir. Like the results discussion indicated for the previous year's samples, there was a marked change in the quantity of salmon caught in the lake as the seasons progressed, with a sharp decline between July and August (see Table 2).

Table 2. Summary of combined numbers of juvenile Chinook and coho salmon caught by Envirosphere during 1984 at sampling locations in Vancouver Lake and adjacent waters.

Sampling Location	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep	Grand Total
BWCO*	0	0	0	0	68	179	0	0	**247**
C01	1	0	4.5	15	23	20	6	0.5	**70**
C02	0	0	0	17	5.5	42.5	6.5	0.5	**72**
C03	0	0	2	4	13	13	3	4	**39**
C04	0	4	4	8	59	44	0	0	**119**
FCFN†	0	0	0	0	45	6	0	0	**51**
FCSH**	0	0	0	0	100	91	0	0	**191**
OWCO‡	0	0	0	0	88	118	0	0	**206**
V02	1	4	17	47	68	313	2	0	**452**
V03	0	0	1	0	2	0	1	0	**4**
V04	0	2	0	2	1	1	0	0	**6**
V08	0	0	9	14	25	2	1	0	**51**
V10	0	1	23	4	1	0	0	0	**29**
V11	1	0	4	0	5	0	0	0	**10**
V12	3	0	4	2	8	0	0	0	**17**
Grand Total	**6**	**11**	**68.5**	**113**	**511.5**	**829.5**	**19.5**	**5**	**1564**

Mapped sampling locations: CO1 – CO4, L01, and V-01 – V-12 (see Figures 3a and 3b)
*Unmapped sampling locations: *Backwater Columbia River; †Flushing Channel Fyke Net; **Flushing Channel Seine Haul; ‡Open Water Columbia River.*

Sturgeon Lake Study (1986, 1987, 1992)

Sturgeon Lake is centrally located on Sauvie Island which is situated between the Columbia River and Multnomah Channel, just downstream from the confluence of the Willamette and Columbia rivers. The Gilbert River connects Sturgeon Lake to Multnomah Channel (see figures 1 and 4). Much of Sauvie Island is surrounded by dikes; some of the dikes are natural features resulting from historic deposition and others are man-made features purposefully designed to prevent flooding of agricultural fields. The dikes have also historically prevented natural flushing and general water exchange between Sturgeon Lake and the surrounding river and channel system. In addition, hydro regulation has further reduced water exchange. In order to restore water exchange directly with the Columbia River, the artificial Dairy Creek bypass channel was created in 1987 on the Lake's eastern shoreline. Sturgeon Lake is shallow and mud-bottomed with a few deeper drainage channels within it (Ward and Rien 1992). Since the mid-1800s, its size has shrunk and its shape has changed; average surface area of the lake varies from 1,900 to 4,800 acres, depending on surrounding flow events (Klingeman 1987).

Ward and Rien (1992) studied the relative abundance of juvenile salmonids in Sturgeon Lake before and after completion of the Dairy Creek bypass channel. Ward and Rien conducted sampling during three years: 1986, 1987, and 1992. In 1986, they sampled juvenile salmonids and their potential predators throughout Sturgeon Lake and the Gilbert River using beach seines, gill nets, a boat electrofisher, and a trap net. The sampling was conducted in three 48-hour periods at approximately two-week intervals between May 13 and-June10.

In 1987 and 1992, Ward and Rien sampled two experimental sites and two control sites in March, April, May, and July. The experimental sites were located in the Gilbert River near Sturgeon Lake and in the Dairy Creek bypass channel (see Figure 4). The control sites were located in Multnomah Channel and the Columbia River in proximity to the experimental sites, respectively. In 1987, they used gill nets, an electrofishing boat, and beach seines to sample the experimental sites and they used beach seines and purse seines to sample Columbia River and Multnomah Channel control sites, respectively. In 1992, Ward and Rien conducted similar sampling as they did in 1987, except, they did not use gill nets or purse seines at the experimental or control sites, respectively.

In 1986, all juvenile salmon collected were caught in or near the Gilbert River; none were caught near the planned bypass channel. In 1987 and 1992, the vast majority of those collected were caught at the control sites. Table 3 provides a summary of catch data for the three sampling years. In 1987, none were caught in the Dairy Creek bypass channel; however, in 1992, a relatively small number were caught in the bypass. No size measurements were recorded; therefore, no conclusions can be drawn about the life history stages of the salmonids in the lake. Ward and Rien (1992) did speculate that the combination of fluctuating flows in the Columbia and the presence of a culvert on Dairy Creek (under a roadway) may strand juvenile salmonids in the lake or force them to migrate through Sturgeon Lake to the Gilbert River.

Table 3. Summary of juvenile salmonid* catch totals by month at sampling locations in Sturgeon Lake and adjacent waters.

	Sampling Dates								
Sampling Locations	5/1986	6/1986	3/1987	4/1987	5/1987	3/1992	4/1992	5/1992	Grand Total
Columbia River	N/A	N/A	92	99	119	40	10	44	**404**
Dairy Creek Channel	N/A	N/A	0	0	0	0	3	11	**14**
Gilbert River	7	1	16	0	1	16	1	4	**46**

Sampling Locations	Sampling Dates 5/1986	6/1986	3/1987	4/1987	5/1987	3/1992	4/1992	5/1992	Grand Total
Multnomah Channel	N/A	N/A	68	8	12	34	42	17	**181**
Sturgeon Lake	6	0	0	0	0	0	0	0	**6**
Grand Total	**13**	**1**	**176**	**107**	**132**	**90**	**56**	**76**	**651**

**The vast majority of juvenile salmonids caught were Chinook salmon. A total of 16 coho salmon and 23 steelhead trout were caught and are included in the above total catch numbers.*

Smith and Bybee Lakes Study (1986)

Smith and Bybee lakes complex is located near the confluence of the Willamette and Columbia rivers and covers a cumulative area of approximately 1800 acres; it is surrounded by a series of sloughs including the Columbia River Slough. The two lakes are shallow and interconnected by channels and marshy areas (Fishman et al. 1987). In the 1980s, an earthen dam was built between the head of the north arm of the Columbia Slough and Bybee Lake; it created a constant high-water system. In 2003, a water control structure was installed within the earthen dam. The one-way gates of the water control structure allow the Columbia River's high flows, along with precipitation, to fill the lakes. A fish ladder provides an opening for juvenile fish to enter the lakes. In August of each year, the water control structure is opened to allow summer drawdown.

Fishman et al. (1987) conducted a study within and around the Smith and Bybee lakes system during the spring, summer, and fall, 1986. The purpose of the study was to provide background information necessary to manage the lakes for recreational fishing (a Smith & Bybee Lakes management goal at that time). The study was designed to collect population and habitat use information for fish species in the study area (see Figure 5). Field data collected included numerical abundance of fish by species, biomass by species group and season, and the sampling location habitat type. Occasional data was collected for temperature and water depth.

The study monitored 29 electrofishing sampling stations (see Figure 5) that represented a variety of habitat types. Stations were located in Smith Lake, Bybee Lake, Smith Channel (connecting the two lakes), Columbia Slough, and North Columbia Slough. While the study resulted in the identification of seventeen (17) distinct species, as well as cottids (sculpins), the only salmonids collected were juvenile Chinook salmon. The juvenile Chinook salmon were only represented in the spring data collection events; summer and fall sampling events did not result in salmonids being collected. This study was conducted prior to the water control structure development and the study assumed that the juvenile Chinook entered the system in February, during the spring freshet, when the lakes were connected to the Columbia Slough as the high flows overtopped the earthen dam. In early June 1986, the lakes were again connected to the slough when another high water flow event topped the dam; Fishman et al. posit that the juvenile Chinook salmon left the lakes during this event.

The Chinook were collected in a variety of habitat types: open water (mid-Bybee Lake), open water/smartweed complex, no-flow channel (Smith Channel), dam pool (Bybee Lake, near the earthen dam), and tidal slough (Columbia Slough and North Columbia Slough) (see Table 4). Juvenile Chinook salmon were the most abundant species (by numbers collected) of the groups collected during the spring sampling event. Fishman et al. conducted a comparison of the Chinook caught in the lakes and in the sloughs and they suggested that those caught in the lakes were larger than those collected in the sloughs.

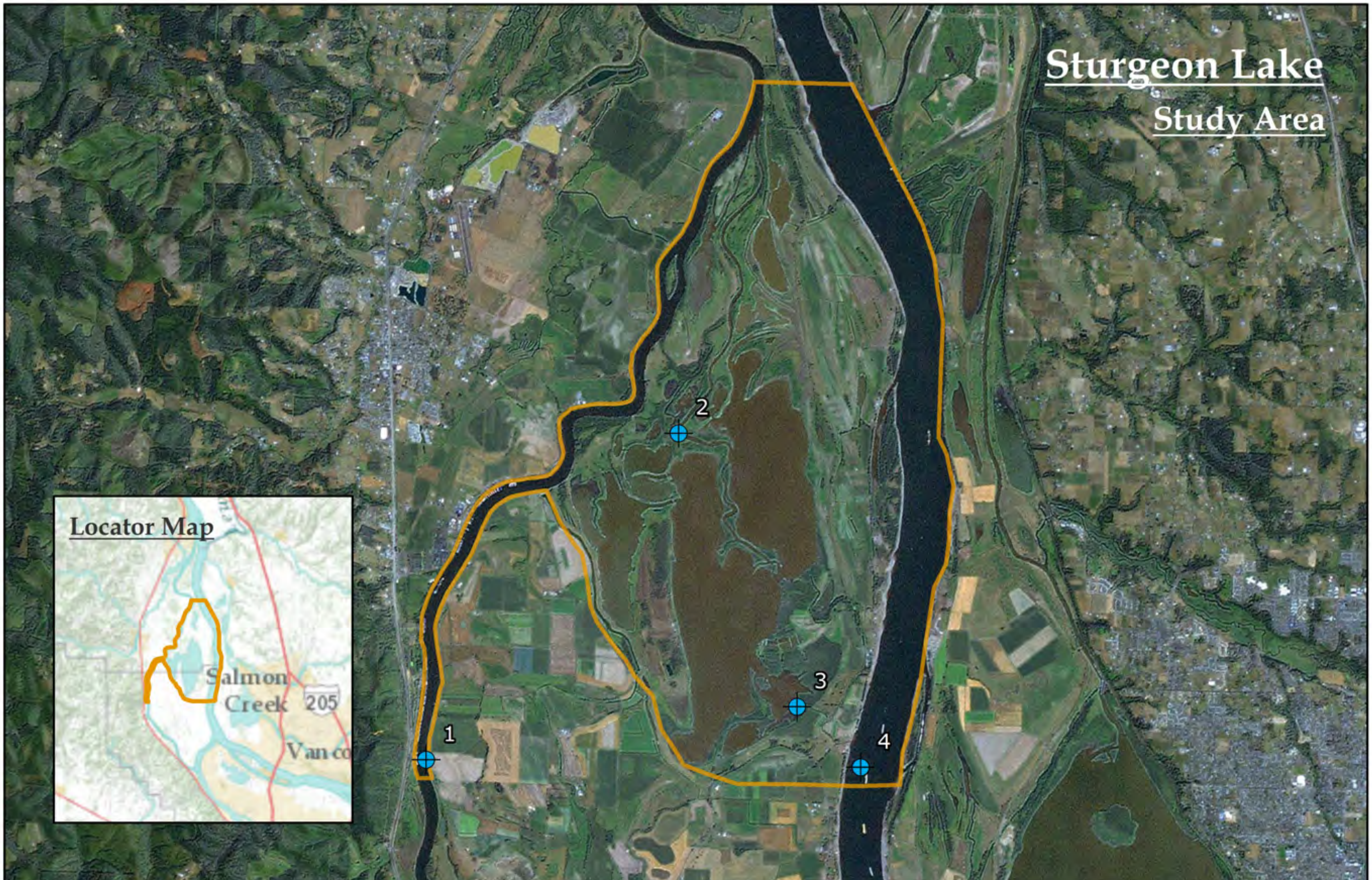

Figure 4. Ward and Rien 1992 Sturgeon Lake study area and sampling locations.

Sample Locations (by study year)

1987 & 1992

Study Site

Sampling sites were located throughout Sturgeon lake and Gilbert River in 1986 (Ward and Rien 1992).

Projection: NAD_1983_HARN_StatePlane Washington_South_FIPS_4602_Feet
Source of Image: ESRI Online
Map Created: 20121015_AM

0 0.5 1 Miles

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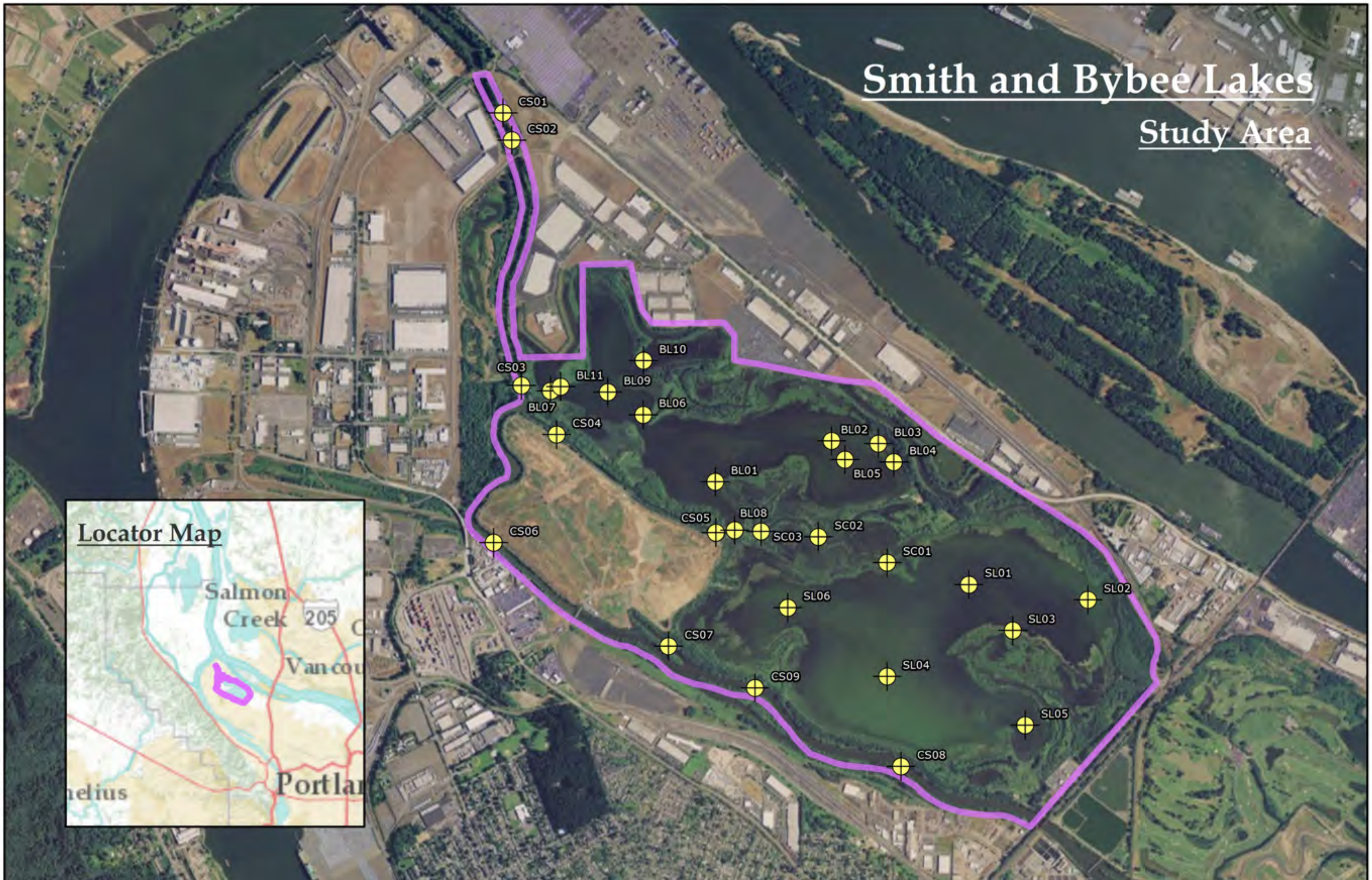

Figure 5 Fishman et al. 1987 Smith and Bybee lakes study area and sampling locations.

Sample Locations (by study year)

1986

Study Site

Projection: NAD_1983_HARN_StatePlane Washington_South_FIPS_4602_Feet
Source of Image: ESRI Online
Map Created: 20121015_AM

0 0.25 0.5 Miles

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The juvenile Chinook caught ranged in size from 59 – 146 mm fork lengths; the mean fork length of all juvenile Chinook measured was 102.2. Those caught in the lakes had a mean length of 114.31 mm while those caught in the slough had a mean length of 88.07 mm. Stomach contents of the Chinook revealed that they primarily ate cladocerans, followed by copepods, and a small amount of insects. Stomach analyses of other fish species collected did not indicate that juvenile Chinook were a prey item for those species.

Table 4. Summary of number of juvenile Chinook salmon caught by date at sampling habitats in Smith and Bybee lakes and the Columbia Slough.

Habitat		1986 Sampling Dates						Grand
Codes	Habitat Types	04/30	05/02	05/09	6/26	10/24	10/25	Total
L2EM1	Smartweed Swamp	1	2	N/A	0	0	N/A	**3**
L2EM1/UB3	Open Water/Smartweed	N/A	6	N/A	0	0	N/A	**6**
L2UB3	Open Water	2	N/A	N/A	0	0	N/A	**2**
L2UB3*	Dam Pool	13	N/A	N/A	0	0	N/A	**13**
PSS/EM1	Willow/Smartweed Swamp	8	0	N/A	0	0	N/A	**8**
PUB3	No-flow Channel	N/A	5	N/A	0	0	N/A	**5**
R1UB3	Tidal Slough	N/A	N/A	44	0	N/A	0	**44**
	Grand Total	**24**	**13**	**44**	**0**	**0**	**0**	**81**

N/A indicates the habitat was not sampled during the sampling date.

Discussion

Our initial assessment of the studies conducted on Vancouver, Sturgeon, Smith and Bybee lakes and their surrounding river and slough channels provide evidence that juvenile salmonids use the large floodplain lakes of the lower Columbia River to some degree. There are some consistent conclusions between the three studies that we can use to answer our own original questions. The results of all three studies suggest that water temperature may be a limiting factor in timing of juvenile salmonids use of the floodplain lakes. Stomach analyses in all cases suggest that predation on juvenile salmonids is not a significant threat in these lakes. There is also apparent agreement that juvenile Chinook are the predominant salmonids using these lakes; limited numbers of coho and steelhead were also collected, but Chinook were the most abundant species of juvenile salmonids collected.

While the studies do allow us to draw some cautious inferences, there are also barriers to extrapolating some broad overarching conclusions. The studies were conducted under differing sample designs and do not allow for direct comparisons of the juvenile salmonid rearing habitat characteristics of each of these lakes when compared to the others. The results do not provide information about the functional values, absolute or relative, of rearing habitat within each lake studied. The Fishman et al. (1987) study was well designed for sampling fish presence in various habitat types within Smith and Bybee lakes. And, while it has a limited number of sample dates, it includes a thorough set of data collected for each sampling event. Conversely, the Envirosphere (1983, 1985) studies for Vancouver Lake include an abundance of sampling dates and data; however, they lack a variety of habitat types. There was a bias toward the open water habitats with little to no representation of the vegetated portions of the lake shoreline areas. Finally, the Ward and Rien work on Sturgeon Lake included well-placed control and experimental sampling sites but included a relatively small number of sampling sites given the large surface area of the lake.

It is important to remember that the purposes of the three studies were also different. The Fishman et al. (1987) study was focused on recreational fish management. And, while the Envirosphere (1983, 1985) study purpose did include concerns about juvenile salmonids, the question was from the perspective of contributing to mortality and not rearing. Only the Ward and Rien (1992) study on Sturgeon Lake was directly focused on the relative abundance of juvenile salmonids.

A final caution is necessary around the assumption that the absence of juvenile salmonids in summer sampling implies that they migrated out of the lakes as temperatures rose. This is especially critical when discussing lakes that are only connected during high water events that overtop dams, water control structures, or dikes. It is possible that, rather than being absent because the juvenile salmonids migrated out of the lakes during a summer high water event, they had already experienced mortality from high temperatures and/or low dissolved oxygen levels prior to the flushing event. None of the sampling methods in the primary literature reviewed herein were designed to explore this possibility.

In looking back to the questions we originally asked in Table 1, we have some basic answers to some and are left with a lack of answers for others:

Have researchers found juvenile salmonids in large floodplain lakes?

Yes, there are juvenile salmonids rearing in the large, tidal freshwater floodplain lakes of the Columbia River estuary. The evidence from these three studies show the greatest abundance of salmonids in the lakes is fall Chinook with fewer coho. In fact, during a portion of the sampling events in the Envirosphere (1983, 1985) study, salmonid densities were greater in the lake than in the mainstem estuary. Again, it is important to remember that the purposes, levels of effort, and scopes of each of the studies were different.

Were multiple life histories represented in samples?

Two life history types were evident where estimating age was included in the study design: young-of-the-year and yearlings (Age 0 and Age 1, respectively). No adult salmonids were caught during sampling. Therefore, based on the data from these three studies, it appears that rearing and out-migrating salmonids can occupy the lakes and that in-migrating adults are not straying or detoured into the lakes.

Were ESUs identified in research?

None of the three study designs included methods for identifying ESU origins of the fish sampled. Fish seem to enter some of the lakes as early as February, but we have no other clues to help us know from where they are originating within the Columbia River system. Emerging juvenile salmonid genetics data from the NOAA Fisheries Science Center and the University of Washington indicate that, of all eight reaches in the estuary, Reach F may be one of the reaches with high ESU diversity.

Were residence times in lakes estimated?

We do not have similar enough information from our entire focus area to narrow down how long individual fish are likely to rear in the lakes, only the timing of their relative abundance, and all but the Vancouver Lake studies did not occur over a timeframe that might involve extended residence. Sampling confirms that juveniles are present in Vancouver Lake as early as January and as late as August. Although sampling in Smith and Bybee lakes was conducted well into October, the data represent juvenile salmonids were only present in April and May; sampling did not begin until late-April. Sampling in Sturgeon Lake only occurred during spring and juveniles were only confirmed in the lake during May. Each study discusses the possible arguments for when the juveniles enter and leave each lake; however, no conclusive data is provided.

Were juvenile salmonids found in large floodplain lakes during different months?

In all cases, salmonids were present in the first months sampled. We do not have conclusive information about the month in which salmonids begin to enter the lakes (see the discussion in the previous paragraph). In the samples reviewed in the large floodplain lakes, high juvenile salmonid counts correlated with the spring freshet. A study design that includes complete twelve-month cycles would help to definitively understand when the salmonids enter the large floodplain lakes.

Were specific habitats within the lakes sampled?

Not in all cases. All three study designs included sampling in open water habitats. Only the Fishman et al. (1987) studies in Smith and Bybee lakes specifically targeted the diverse habitat types within its study area. As a result, we know that juvenile salmon are using the open water habitats in the lakes. We are left wanting more information about the use of the more complex and vegetated aquatic habitat types in the lakes. A replication of the Fishman et al. (1987) study design in Vancouver Lake and Sturgeon Lake would help to support more definitive answers about the habitat types within which the juvenile salmon are occurring.

Were piscivorous fish sampled to identify predation effects?

Consistently among the three studies reviewed, there is some inconclusive evidence that piscivorous predation is not a major threat in the sampled lakes. Where stomach contents of the predator species were examined, there was little to no evidence of juvenile salmonids. At least one of the studies also suggested that predation by piscivorous birds was insignificant.

Summary

The effort of this literature search and review resulted in finding few sources about juvenile salmonid use of large floodplain lakes in tidally-influenced river systems. The literature reviewed in depth begins to answer some of our initial questions. However, the questions answered also beg for more support. Each study was designed for different purposes and uses separate approaches to collect the data each required.

During the literature search, we did find that additional unpublished survey data exists for the Vancouver Lake/Lake River complex; and Smith and Bybee Lakes/Columbia Slough. The data is not included in this report but effort is underway to attain it. While targeted to a variety of fish species, this unpublished data likely contains additional information about juvenile salmonids and other important Columbia River species such as sturgeon. For example, personal communication on April 25, 2012 with Stacie Kelsey (Washington Department of Fish and Wildlife) indicated that all life histories of sturgeon were represented in Vancouver Lake/Lake River.

While there were few sources, these three primary data sets do represent a set of valuable baseline studies upon which we can build.

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Vancouver Lake Watershed Partnership. 2011. Technical foundation for future management of Vancouver Lake. Vancouver, WA.

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Appendix A – Annotated Bibliography of Additional Literature Sources

Baker, Cynthia F. 2008. Seasonal floodplain wetlands as fish habitat in Oregon and Washington. Dissertation presented on March 17, 2008.

This study examines fish assemblages in fifteen seasonal floodplain wetlands in four geographic regions: coastal, upper Columbia River estuary, Puget Sound, and eastern Oregon/Washington. The wetlands ranged in size from 5 to 607 hectares (12 to 1500 acres) with a median of approximately 41 hectares (101 acres). The wetlands were a mix of palustrine and riverine saltwater tidal, freshwater tidally-influenced, and freshwater with no tidal influence systems. Five of the systems studies are contained within reaches F and G on the Columbia River. Findings indicated that once fish entered wetlands, wholesale movement into and out of wetlands did not occur until summer desiccation. Movement into and out of wetlands were triggered by water level, temperature, barometric pressure, and lunar phase. No evidence was found to support the concept that floodplain wetlands are “predator traps” for juvenile salmonids. Baker asserts that further understanding of the ecological values of floodplain systems may be useful to guide restoration efforts in these systems.

Brown, Tom G. 2002. Floodplains, flooding, and salmon rearing habitats in British Columbia: a review. Canadian Science Advisory Secretariat Research Document 2002/007. Fisheries and Oceans Canada, Nanaimo, B.C.

The purpose of this review paper was to examine relationships between floodplains, flooding, and juvenile salmon habitats. Impacts from upland human actions as well as natural processes were also explored. Floodplains provide many forms of juvenile salmonid habitat: seasonal wetlands, temporary tributaries, off-channel ponds, sloughs, flood-channels, and seasonal drainages. When compared to lentic habitats, these seasonal habitats generally support a different mix of invertebrates, often have more modified water temperatures, and may have different water quality concerns. Many of these seasonal habitats support higher densities of juvenile salmon and have higher growth rates than main channel habitats. The review also includes a list of many knowledge gaps and recommendations. Focal species for coastal riverine and palustrine habitats are coho salmon and cutthroat trout. The floodplain off-channel pond features of this paper are not categorized by a size description but appear to be smaller features.

Bryant, Mason D., Brian J. Frenette, and Katherine T. Coghill. 1996. Use of the littoral zone by introduced Anadromous salmonids and resident trout, Margaret Lake, southeast Alaska. Alaska Fishery Research Bulletin, vol. 3, No. 2. 13 p.

This study looks at the colonization of a 54.6-hectare (135-acre) lake following installation of a fish bypass at a waterfall downstream of the lake. Margaret Lake is a deep lake on Margaret Creek, which drains to Margarita Bay approximately 0.5 mile downstream. When the fish bypass was opened in 1990, anadromous salmonids moved into the lake: pink, chum, and coho salmon, steelhead, searun cutthroat trout, and anadromous dolly varden. Sampling was conducted at ten permanent sites around the lake shoreline using beach seines that were 30 meters (98.4 feet) long and 1.5 meters (4.9 feet) deep. While the area and depth sampled are similar to the shallow character of large floodplain lakes, Margaret Lake is not a floodplain lake and provides deeper water habitats with colder temperature strata available to fish. The lake watershed also has greater immediate topographic relief than a floodplain lake associated with lower perennial streams.

Buell, James W. 1972. Anadromous salmonid fishery problems, possible solutions, and other considerations relating to the proposed flushing channel for Lake Vancouver, Washington. StreamNet Library, Vancouver Lake Watershed Partnership Bibliography. Portland, OR.

This paper examines potential solutions and considerations associated with two key problems: 1) entrainment of juvenile outmigrant salmonids into the flushing channel and Vancouver Lake with high subsequent mortality and 2) the possible attraction of adult Columbia River salmonids into Vancouver Lake via Lake River causing a delayed upstream migration. Potential solutions put forth to resolve the first problem include screening the intake, providing compensatory mitigation, and developing a juvenile fish bypass. Potential solutions to the second problem include shutting down flushing operations during adult migration, screening the mouth of Lake River, and providing effective fish passage structures.

Caromile, Stephen J., William R. Meyer, and Chad S. Jackson. 2000. 1998 warmwater fish survey of Vancouver Lake, Clark County. Washington Department of Fish and Wildlife, Olympia, WA.

The survey catalogs warmwater fish survey results from 1998. The Introduction and Background section provides good description of the lake characteristics and history. A brief habitat description in the Results and Discussion also provides a useful illustration of the lake's character. It is noteworthy that a brief mention is given to white sturgeon being captured during a separate fish capture operation taking crappie for the warmwater hatchery.

Halupka, Karl C., Mason D. Bryant, Mary F. Wilson, and Fred H. Everest. 2000. Biological characteristics and population status of anadromous salmon in southeast Alaska. General Technical Report PNW-GTR-468. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 255 p.

The report reviews five southeast Alaska salmon stocks for biological characteristics and population trends in the context of managing salmon diversity and in regard to conceptual issues in ecology and evolutionary biology. Each species report includes evaluation of natural and human-caused risk factors that may contribute to salmon abundance declines. The review makes no distinction between floodplain lakes and lakes outside the floodplain, nor does it distinguish between lakes that are tidally-influenced and those that are not. Among the conclusions regarding coho, the review states that smolts from lakes or rivers tend to be larger than those from streams; stocks rearing in lake watersheds had higher mean freshwater ages (MFWAs) and more age classes than stocks in other watershed types; and lake stocks tended to have higher survival-to-return rates than river or stream stocks. No lake-versus-other watershed types variation comparisons are provided for the other four salmon stocks.

Henning, Julie A. 2004. An evaluation of fish and amphibian use of restored and natural floodplain wetlands. Final Report EPA Grant CD-97024901-1. Washington Department of Fish and Wildlife, Olympia, WA. 81 p.

The results of this study indicate that restored wetlands are supporting higher abundances of juvenile coho salmon than natural wetlands (non-regulated wetlands with no water-control structures). Salmon are using restored areas but in lower numbers compared to off-channel habitat. Unexpectedly, few salmon were captured in the beaver pond study area that had deep water, annual river connectivity, woody debris and woody riparian and adequate water quality conditions. Discussion is presented to exercise caution in extrapolating the beaver pond results without understanding the context of the study. Temporal out-migration was found between yearling coho and young of the year coho. The discussion includes acknowledgement that floodplain wetlands have "slipped through the cracks." Fish biologists have primarily focused on habitats related to in-stream riverine processes while wetland scientists have focused on wetland characteristics such as nutrient cycling, soils, vegetation, and water chemistry.

Henning, Julie A. 2005. Floodplain emergent wetlands as rearing habitat for fishes and the implications for wetland enhancement. Thesis paper presented on February 28, 2005.

This study examines the degree to which fish use emergent wetlands and to determine the influence of wetland enhancement on fish communities in the Chehalis River floodplain. The influence of wetland enhancement on coho salmon is quantified. Coho was the dominant salmonid species at all study sites. Dissolved oxygen concentrations decreased in emergent wetlands throughout the season and were near lethal limits for juvenile salmon by June of each study year. Survival depended on movement to the river before water quality decreased and/or wetlands became isolated and stranding occurred. Yearling coho salmon benefited from rearing in enhanced wetland habitats where growth and survival were comparable to studies of juvenile coho in off-channel habitats. Other species of interest that were captured during sampling included (juvenile) Chinook salmon, chum salmon, coastal cutthroat trout, and pacific lamprey. The study concludes that off-channel habitats, oxbows, beaver ponds, emergent wetlands, and enhanced wetlands are supporting a diversity of fishes and that floodplain management should focus on maintaining this habitat complexity.

Henning, Julie A. and Greg Schirato. 2006. Amphibian use of Chehalis River floodplain wetlands. Northwestern Naturalist, Vol. 87, No. 3. 6 p.

Study objectives were to quantify and compare amphibian use across the floodplain at six study sites and to determine the effect of wetland restoration on amphibians. During the course of the study, fish were also captured in all the study wetlands. Those wetlands with the greatest abundance of native non-game fishes had the highest abundance of amphibians.

Henning, Julie A. Robert E. Gresswell, and Ian A. Fleming. 2011. Juvenile salmonid use of freshwater emergent wetlands in the floodplain and its implications for conservation management. North American Journal of Fisheries Management, Vol. 26, No. 2, 10 p.

The purpose of this study was to quantify the use of floodplain freshwater emergent wetlands by juvenile coho salmon in a large river system. Results of this study suggest that enhancing freshwater wetlands using water control structures can benefit juvenile salmonids, at least in the short term, by providing conditions for greater growth, survival, and emigration. Coho salmon were the most abundant salmonid captured in the wetlands; two age-groups were collected (age 0 and age 1) and all were naturally produced.

Koehler, Michelle E., Kurt L. Fresh, David A. Beauchamp, Jeffery R. Cordell, Charles A. Simenstad, and David E. Seiler. 2006. Diet and bioenergetics of lake-rearing juvenile Chinook salmon in Lake Washington. Transactions of the American Fisheries Society, Vol. 135, No. 6. 11 p.

Due to the many human modifications of rivers, some ocean-type Chinook salmon populations have had to incorporate lacustrine habitats into their life histories. In this study, naturally- and hatchery-produced juvenile Chinook salmon rearing in the littoral zone of Lake Washington were studied. As temperatures increased in the littoral zone in June, the juvenile's diets shifted from littoral to limnetic prey. This coincided with the juvenile fish shifting from the littoral to the limnetic habitats, the spring bloom of *Daphnia* spp (plankton), and increasing fish size. The naturally-produced Chinook salmon had high consumption rates; the hatchery-produced juveniles entered the lake during the spring *Daphnia* bloom and did not present competition for the naturally-produced juveniles. While Lake Washington is not a floodplain lake, this study does offer some insights to ocean-type Chinook adapting to modified habitats in a highly urbanized setting, especially with the benefit of highly productive food sources in the lake.

Morgan, Amy and Frank Hinojosa. 1996. Winter habitat utilization by juvenile salmonids: a literature review. Northwest Indian Fisheries Commission. Olympia, WA. 28 p.

This study had four specific purposes: 1) summarize information from the literature that describes the characteristics of winter habitat; 2) identify key issues that must be resolved in developing a winter habitat monitoring methodology in the context of watershed analysis; 3) describe how winter habitat has been identified and measured in other studies; and 4) recommend watershed analysis monitoring methods to measure changes in winter habitat availability. Fifteen habitat types are defined according to the literature reviewed. While a few slack water and off-channel features are included, floodplain lakes are not among them. Description is provided for behavioral influences on winter habitat selection and physical characteristics of preferred winter habitat for Chinook, coho, cutthroat, and steelhead.

Pollock, Michael M., George R. Pess, and Timothy J. Beechie. 2004. The importance of beaver ponds to coho salmon production in the Stillaguamish River basin, Washington, USA. North American Journal of Fisheries Management, Vol. 24, 12 p.

This study examines the importance to coho salmon of beaver dams within a coastal river system. Characteristics of the ponds include slow current velocities and large edge-to-surface-area ratios with extensive cover and highly productive vegetation and aquatic invertebrate communities. Similar to floodplain lakes, these slow waters mean energy expenditures for foraging are less than would be required in higher velocity streams and rivers. The importance of beaver ponds is illustrated through comparisons of salmonid growth and survival between reaches upstream of beaver dams and unimpounded reaches.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology, Vol. 64. 9 p.

The purpose of this study was to investigate the distribution and abundance of juvenile salmonids in various main-channel and off-channel habitats in two interior rivers in southwest British Columbia. Habitats sampled included main-channel pools, main-channel riprap, side channels, and off-channel ponds along the Coldwater River and Nicola River. The largest of the off-channel ponds was only 2.4 acres.

U.S. Army Corps of Engineers. 2007. Review of biological research on juvenile and adult salmonids and survival at Vancouver Lake. Portland District of U.S. Army Corps of Engineers, Portland, OR. 17 p.

This synthesis of information available on juvenile and adult salmonids at Vancouver Lake was prepared to support the Portland District U.S. Army Corps of Engineers' involvement in promoting improvement of tidally influenced off-channel habitat in the lower Columbia River. The primary literature reviewed included: U.S. Fish and Wildlife Service's 1976 and 1977 flushing channel pre-construction survey findings; Envirosphere's 1984 Vancouver Lake flushing channel post-construction salmonid monitoring revised final report; and Fishman Environmental Service's 2002 summary report for a first-phase investigation to identify data gaps about the Vancouver Lake flushing channel affects to salmonids. In addition to providing valuable information on the history of the lake, the review focuses on examining a set of critical concerns that expand upon the questions posed in the Envirosphere 1983 and 1985 monitoring efforts. Considerations for future research include gaining more detailed information to remove assumptions about fish behavior, impacts of structures on fish passage, and quality and use of available riparian habitat in the lake.