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# Annotated Bibliography for 2010 Essential Fish Habitat Update

## Approach

The following is a compilation of pertinent information from available literature published since 1998 that updates sections of the Pacific Coast Salmon Essential Fish Habitat document (EFH). This document is organized by task, and secondarily by subject (See below), and mimics the organization of the accompanying EFH Reference Database, provided in Microsoft Access format.

### Task 2. Impassable man-made barriers

Updated information is organized by 44 subjects (one for each barrier). Information for each passage barrier (in same order as Table A-2 in the 1999 EFH document) is provided in a summary table in the following format:

| Category | Data |
|---|---|
| Barrier | e.g. Gorge Lake Dam |
| State | WA, OR, ID, CA |
| USGS HUC | Code |
| Latitude | Lat in Decimal Degrees |
| Longitude | Long in Decimal Degrees |
| Hydrologic Unit, River | USGS HUC Name |
| River | River Name |
| Owner/Operator | Agency or Private Operator Name |
| Authority | Federal License, State License, State Inspected |
| Upstream From Other Impassable Dams | yes/no |
| License period | Begin Year - End Year |
| Fish passage | None, Consideration, Construction |
| Reference | Citation |
| Documents | Web Link (Where Available) |

### Task 3. Threats to salmon EFH

Annotated references are organized by 31 subjects (one for each threat to salmon EFH), 21 previously identified in section 3.2.5 in the 1999 EFH plan, and 10 newly identified by the PFMC:

| Threats Identified in 1999 EFH Document | Newly Identified Threats |
|---|---|
| Agriculture | Pile-driving |
| Artificial Propagation of Fish and Shellfish | Over-water Structures |
| Bank Stabilization | Alternative Energy Development |
| Beaver removal and Habitat Alteration | Liquified Natural Gas Projects |
| Construction/Urbanization | Desalination |
| Dam Construction/Operation | Power Plant Intakes |
| Dredging and Dredged Spoil Disposal | Pesticide Use |
| Estuarine Alteration | Flood Control Maintenance |
| Forestry | Culvert Construction |
| Grazing | Climate Change |
| Irrigation Water Management | |
| Mineral Mining | |
| Introduction/Spread of Nonnative Species | |
| Offshore Oil and Gas Drilling | |
| Road Building and Maintenance | |
| Sand and Gravel Mining | |
| Vessel Operation | |
| Wastewater/Pollutant Discharge | |
| Wetland and Floodplain Alteration | |
| Woody Debris/Structure Removal | |

For each reference, pertinent information relevant to each threat is summarized in brief bullet-point descriptions. Some references provide information for more than one threat, therefore, are repeated in this document to provide easy incorporation of threat-specific information in the revised 2010 EFH document.

### Task 4. Salmon life history

Annotated references are organized by 24 subjects, with the same eight subjects for each of the three salmon species (Chinook, Coho, and Pink) and a category for references pertaining generally to Pacific salmon, mimicking the organization of the essential fish habitat descriptions in section 2.0 of the 1999 EFH document:

| Salmon Life History Subjects |
|---|
| Eggs and Spawning |
| Larvae/Alevins |
| Juveniles (Freshwater) |
| Juveniles (Estuarine) |
| Juveniles (Marine) |
| Adults |

For each reference, pertinent information relevant to each subject is summarized in brief bullet-point descriptions. Some references provide information for more than one subject, therefore, are repeated in this document to provide easy incorporation of subject-specific information in the revised 2010 EFH document.

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# Task 2. Impassable man-made barriers

## Gorge Lake Dam

| Category | Data |
|---|---|
| Barrier | Gorge Lake Dam |
| State | WA |
| USGS HUC | 17110005 |
| Latitude | 48.6978539555272 |
| Longitude | -121.207583128571 |
| Hydrologic Unit | Upper Skagit |
| River | Skagit River |
| Owner/Operator | City of Seattle |
| Authority | Federal License |
| Upstream From Other Impassable Dams | no |
| License period | 1985-2035 |
| Fish passage | Yes |
| Reference | NMFS 2007a |
| Documents | http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm |

## Masonry Dam (Cedar Falls Dam)

| Category | Data |
|---|---|
| Barrier | Masonry Dam (Cedar Falls Dam) |
| State | WA |
| USGS HUC | 17110012 |
| Latitude | 47.4119402374866 |
| Longitude | -121.752428193575 |
| Hydrologic Unit | Lake Washington |
| River | Cedar River |
| Owner/Operator | City of Seattle |
| Authority | River and reservoir operations on the Cedar River are governed by the Cedar River Watershed Habitat Conservation Plan (HCP) |
| Upstream From Other Impassable Dams | Yes - natural barrier of Lower Cedar Falls |
| License period | Begin Year, End Year |
| Fish passage | None - 1.5 upstream of natural fish barrier, Lower Cedar Falls |
| Reference | Kerwin 2001, Seattle Public Utilities 1999 |
| Documents | http://www.scc.wa.gov/index.php/239-WRIA-8-Cedar-and-Sammamish-Basin/View-category.html |

## Tolt Dam

| Category | Data |
|---|---|
| Barrier | Tolt Dam |
| State | WA |
| USGS HUC | 17110010 |
| Latitude | 47.6929455673069 |
| Longitude | -121.689396892902 |
| Hydrologic Unit | Snoqualmie |
| River | South Fork Tolt River |
| Owner/Operator | City of Seattle |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1984-2029 |
| Fish passage | None |
| Reference | Citation |
| Documents | http://www.ferc.gov/industries/hydropower/gen-info/licensing/licenses.xls |

## Keechelus Dam

| Category | Data |
|---|---|
| Barrier | Keechelus Dam |
| State | WA |
| USGS HUC | 17030001 |
| Latitude | 47.3224715200048 |
| Longitude | -121.340129555859 |
| Hydrologic Unit | Upper Yakima |
| River | Yakima River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None currently, but feasibility study being conducted by USBR |
| Reference | WSCC 2001b and USBR 2009 |
| Documents | http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html<br>http://www.usbr.gov/pn/programs/ucao_misc/fishpassage/activities/pn-ydfp-014.pdf |

## Kachess Dam

| Category | Data |
|---|---|
| Barrier | Kachess Dam |
| State | WA |
| USGS HUC | 17030001 |
| Latitude | 47.2648511711711 |
| Longitude | -121.206075994562 |
| Hydrologic Unit | Upper Yakima |
| River | Kachess River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None currently, but feasibility study being conducted by USBR |
| Reference | WSCC 2001b and USBR 2009 |
| Documents | http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html http://www.usbr.gov/pn/programs/ucao_misc/fishpassage/activities/pn-ydfp-014.pdf |

## Cle Elum Dam

| Category | Data |
|---|---|
| Barrier | Cle Elum Dam |
| State | WA |
| USGS HUC | 17030001 |
| Latitude | 47.2453566833616 |
| Longitude | -121.074381937987 |
| Hydrologic Unit | Upper Yakima |
| River | Cle Elum River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None currently, but feasibility study being conducted by USBR |
| Reference | WSCC 2001b and USBR 2009 |
| Documents | http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html http://www.usbr.gov/pn/programs/ucao_misc/fishpassage/activities/pn-ydfp-014.pdf |

## Rimrock Dam

| Category | Data |
| --- | --- |
| Barrier | Rimrock Dam |
| State | WA |
| USGS HUC | 17030002 |
| Latitude | 46.656329052866 |
| Longitude | -121.130118162351 |
| Hydrologic Unit | Naches |
| River | Tieton River |
| Owner/Operator | Tieton Hydropower, L.L.C. |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1991-2041 |
| Fish passage | None currently, but feasibility study being conducted by USBR |
| Reference | WSCC 2001b and USBR 2009 |
| Documents | http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html http://www.usbr.gov/pn/programs/ucao_misc/fishpassage/activities/pn-ydfp-014.pdf |

## Chief Joseph Dam

| Category | Data |
| --- | --- |
| Barrier | Chief Joseph Dam |
| State | WA |
| USGS HUC | 17020005 |
| Latitude | 47.9965599582611 |
| Longitude | -119.627866558278 |
| Hydrologic Unit | Chief Joseph |
| River | Columbia River |
| Owner/Operator | Bonneville Power Administration |
| Authority | U.S. Army Corps of Engineers |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | UCSRB 2007 |
| Documents | http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf |

## Dworshak Dam

| Category | Data |
|---|---|
| Barrier | Dworshak Dam |
| State | ID |
| USGS HUC | 17060306 |
| Latitude | 46.5147829690336 |
| Longitude | -116.294882072761 |
| Hydrologic Unit | Clearwater |
| River | North Fork of the Clearwater River |
| Owner/Operator | U.S. Army Corps of Engineers |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1998-2048 |
| Fish passage | None |
| Reference | NOAA 2008 |
| Documents | http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm |

## Hells Canyon Complex

| Category | Data |
|---|---|
| Barrier | Hells Canyon Complex (Hells Canyon, Oxbow, and Brownlee Dams) |
| State | ID |
| USGS HUC | 17060101 |
| Latitude | 45.2425876747691 |
| Longitude | -116.701069720247 |
| Hydrologic Unit | Hells Canyon |
| River | Snake River |
| Owner/Operator | Idaho Power Company |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1955-2005 - under review |
| Fish passage | None |
| Reference | NOAA 2008 |
| Documents | http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm |

## Opal Springs Dam

| Category | Data |
|---|---|
| Barrier | Opal Springs Dam |
| State | OR |
| USGS HUC | 17070305 |
| Latitude | 44.4861885030002 |
| Longitude | -121.299073788671 |
| Hydrologic Unit | Lower Crooked River |
| River | Crooked River |
| Owner/Operator | Deschutes Valley Water District |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1982-2032 |
| Fish passage | stakeholders are working collaboratively with the dam operator to construct passage facilities at Opal Springs with an estimated completion date in 2012 (NMFS 2009) |
| Reference | NMFS 2009a |
| Documents | http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Mid-Columbia/Mid-Col-Plan.cfm |

## Big Cliff Dam

| Category | Data |
|---|---|
| Barrier | Big Cliff Dam |
| State | OR |
| USGS HUC | 17090005 |
| Latitude | 44.7508115520359 |
| Longitude | -122.28330406883 |
| Hydrologic Unit | North Santiam |
| River | N. Santiam River |
| Owner/Operator | Army Corps of Engineers |
| Authority | Army Corps of Engineers |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | Willamette Biological Opinion (NMFS 2008b) proposes feasibility studies to examine fish passage strategies for Big Cliff Dam |
| Reference | NMFS 2008a, NMFS 2008b |
| Documents | http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_biop?p_id=26588 |

## Cougar Dam

| Category | Data |
|---|---|
| Barrier | Cougar Dam |
| State | OR |
| USGS HUC | 17090004 |
| Latitude | 44.127846501927 |
| Longitude | -122.243588911336 |
| Hydrologic Unit | McKenzie |
| River | McKenzie River |
| Owner/Operator | Army Corps of Engineers |
| Authority | Army Corps of Engineers |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | Construction of trap and haul facilities in 2009 |
| Reference | NMFS 2008a, NMFS 2008b |
| Documents | http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm<br>https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_biop?p_id=26588 |

## Dexter Dam

| Category | Data |
|---|---|
| Barrier | Dexter Dam |
| State | OR |
| USGS HUC | 17090001 |
| Latitude | 43.9230683275151 |
| Longitude | -122.805954576491 |
| Hydrologic Unit | Middle Fork Willamette |
| River | Middle Fork Willamette River |
| Owner/Operator | Army Corps of Engineers |
| Authority | Army Corps of Engineers |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | NMFS 2008b |
| Documents | https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_biop?p_id=26588 |

## Dorena Dam

| Category | Data |
|---|---|
| Barrier | Dorena Dam |
| State | OR |
| USGS HUC | 17090002 |
| Latitude | 43.78672518036 |
| Longitude | -122.954833347273 |
| Hydrologic Unit | Coast Fork Willamette |
| River | Row River |
| Owner/Operator | Army Corps of Engineers |
| Authority | Army Corps of Engineers |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | NMFS 2008b |
| Documents | https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_biop?p_id=26588 |

## Soda Springs Dam

| Category | Data |
|---|---|
| Barrier | Soda Springs Dam |
| State | OR |
| USGS HUC | 17100301 |
| Latitude | 43.3025118547971 |
| Longitude | -122.494953643575 |
| Hydrologic Unit | North Umpqua |
| River | N. Umpqua River |
| Owner/Operator | PacifiCorp |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 2003-2038 |
| Fish passage | A FERC settlement agreement and U.S. Department of the Interior Section 18 fishway prescriptions require the licensee to construct the Soda Springs fish passage facilities by 2010 and ensure adequate performance by 2012. |
| Reference | FERC 2009 |
| Documents | |

## Lost Creek Dam

| Category | Data |
|---|---|
| Barrier | Lost Creek Dam |
| State | OR |
| USGS HUC | 17100307 |
| Latitude | 42.6710371812358 |
| Longitude | -122.675266159417 |
| Hydrologic Unit | Upper Rogue |
| River | Rogue River |
| Owner/Operator | Army Corp of Engineers |
| Authority | Army Corp of Engineers |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | ODFW 2007 |
| Documents | http://www.dfw.state.or.us/fish/nfcp/rogue_river/docs/Conservation_Plan_Rogue_Spring_Chinook_Salmon_Species_Managment_Unit_final_draft_08_2007.pdf |

## Applegate Dam

| Category | Data |
|---|---|
| Barrier | Applegate Dam |
| State | OR |
| USGS HUC | 17100309 |
| Latitude | 42.056394499561 |
| Longitude | -123.115171852736 |
| Hydrologic Unit | Applegate |
| River | Applegate River |
| Owner/Operator | Symbiotics LLC |
| Authority | Federal |
| Upstream From Other Impassable Dams | No |
| License period | In Review |
| Fish passage | None. Starting in 2010, ODFW will begin releases of juvenile coho above the dam, with the aim of reintroducing coho to their historical spawning and rearing habitat. Outmigrating juvenile coho would pass through project facilities (NMFS 2009b) |
| Reference | NMFS 2009b |
| Documents | |

## City of Portland #2 (Bull Run River)

| Category | Data |
|---|---|
| Barrier | City of Portland #2 (Bull Run River) |
| State | OR |
| USGS HUC | 17080001 |
| Latitude | 45.4481618443545 |
| Longitude | -122.148376334657 |
| Hydrologic Unit | Lower Columbia-Sandy |
| River | Bull Run River |
| Owner/Operator | Portland General Electric |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | Expired in 2004 |
| Fish passage | None |
| Reference | NMFS 2008 |
| Documents | http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm |

## Oak Grove Dam

| Category | Data |
|---|---|
| Barrier | Oak Grove Dam |
| State | OR |
| USGS HUC | 17090011 |
| Latitude | 45.1138888904422 |
| Longitude | -121.806111099631 |
| Hydrologic Unit | Clackamas |
| River | Clackamas River |
| Owner/Operator | Portland General Electric |
| Authority | Federal License |
| Upstream From Other Impassable Dams | Yes - above natural barrier |
| License period | 1957-2006 - under review |
| Fish passage | None - above waterfalls that act as natural barrier |
| Reference | NMFS 2008b |
| Documents | https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_biop?p_id=26588 |

## Iron Gate Dam

| Category | Data |
|---|---|
| Barrier | Iron Gate Dam |
| State | CA |
| USGS HUC | 18010206 |
| Latitude | 36.9999492513576 |
| Longitude | -119.703978263203 |
| Hydrologic Unit | Upper Klamath |
| River | Klamath River |
| Owner/Operator | PacifiCorp |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1954-2006 - under review |
| Fish passage | None. A group representing federal, state, and local governments, as well as other non-governmental groups, is currently discussing passage and dam decommissioning options as part of FERC's proposed relicensing of Pacificorp's project (NMFS 2007b). |
| Reference | NMFS 2007b |
| Documents | http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf |

## Lewiston Dam

| Category | Data |
|---|---|
| Barrier | Lewiston Dam |
| State | CA |
| USGS HUC | 18010211 |
| Latitude | 40.7248683805021 |
| Longitude | -122.796134109552 |
| Hydrologic Unit | Trinity |
| River | Trinity River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | USBR 2008 |
| Documents | |

### Dwinnell Dam (Shasta River Dam)

| Category | Data |
|---|---|
| Barrier | Dwinnell Dam (Shasta River Dam) |
| State | CA |
| USGS HUC | 18010207 |
| Latitude | 41.5418707610035 |
| Longitude | -122.37612779742 |
| Hydrologic Unit | Shasta |
| River | Shasta River |
| Owner/Operator | PacifiCorp |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1954-2006 - under review |
| Fish passage | None |
| Reference | ESA 2009 |
| Documents | http://www.dfg.ca.gov/regions/1/ShastaScott/ShastaRiverEIR/ |

### Robert W. Mathews Dam

| Category | Data |
|---|---|
| Barrier | Robert W. Matthews Dam |
| State | CA |
| USGS HUC | 18010102 |
| Latitude | 40.3678668585629 |
| Longitude | -123.433140370552 |
| Hydrologic Unit | Mad - Redwood |
| River | Mad River |
| Owner/Operator | Humboldt Bay Municipal Water District |
| Authority | State Inspected |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | MBMWD 2004 |
| Documents | http://www.hbmwd.com/site_documents/hcp.pdf |

### Coyote Valley Dam

| Category | Data |
|---|---|
| Barrier | Coyote Valley Dam |
| State | CA |
| USGS HUC | 18010110 |
| Latitude | 39.1998913000907 |
| Longitude | -123.184448900252 |
| Hydrologic Unit | Russian River |
| River | E. Fork Russian River |
| Owner/Operator | City of Ukiah, CA |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1982-2032 |
| Fish passage | None |
| Reference | CDFG 2002 |
| Documents | http://www.krisweb.com/krisrussian/krisdb/html/krisweb/biblio/russian_cdfg_coey_2002_draftrestplan.pdf |

## Warm Springs Dam

| Category | Data |
|---|---|
| Barrier | Warm Springs Dam |
| State | CA |
| USGS HUC | 18010110 |
| Latitude | 38.7169103378699 |
| Longitude | -123.009111538084 |
| Hydrologic Unit | Russian River |
| River | Dry Creek |
| Owner/Operator | Sonoma County Water Agency |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1984-2034 |
| Fish passage | None |
| Reference | CDFG 2002 |
| Documents | http://www.krisweb.com/krisrussian/krisdb/html/krisweb/biblio/russian_cdfg_coey_2002_draftrestplan.pdf |

## Scott Dam

| Category | Data |
|---|---|
| Barrier | Scott Dam |
| State | CA |
| USGS HUC | 18010103 |
| Latitude | 39.4068828587822 |
| Longitude | -122.959111000396 |
| Hydrologic Unit | Upper Eel River |
| River | Eel River |
| Owner/Operator | Pacific Gas and Electric Company |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1983-2033 |
| Fish passage | None |
| Reference | NMFS 2002b |
| Documents | http://swr.nmfs.noaa.gov/psd/Final_Potter_Valley_Project_BO.pdf |

## Keswick Dam

| Category | Data |
|---|---|
| Barrier | Keswick Dam |
| State | CA |
| USGS HUC | 18020101 |
| Latitude | 40.6118723137668 |
| Longitude | -122.444121844213 |
| Hydrologic Unit | Sacramento - L. Cow - L. Clear |
| River | Sacramento River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None, NMFS outlines the development of a Fish Passage pilot plan for Keswick Dam in the 2009 Biological Opinion (NMFS 2009c). |
| Reference | USBR 2008, NMFS 2009c |
| Documents | |

## Oroville Dam

| Category | Data |
|---|---|
| Barrier | Oroville Dam |
| State | CA |
| USGS HUC | 18020106 |
| Latitude | 39.5448863638888 |
| Longitude | -121.494079266173 |
| Hydrologic Unit | Lower Feather River |
| River | Feather River |
| Owner/Operator | California Department of Water Resources |
| Authority | California Department of Water Resources |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None currently, but the draft recovery plan for Central Valley winter-run and spring-run Chinook salmon (NMFS 2009d) states "passage feasibility studies, habitat suitability assessments and other related investigations are underway in separate processes ( e.g. FERC relicensing)." |
| Reference Documents | USBR 2008, NMFS 2009d |

## Black Butte Dam

| Category | Data |
|---|---|
| Barrier | Black Butte Dam |
| State | CA |
| USGS HUC | 18020103 |
| Latitude | 39.8178789290414 |
| Longitude | -122.338102140431 |
| Hydrologic Unit | Sacramento - Lower Thomes |
| River | Stoney Creek |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference Documents | NMFS 2002c |

## Whiskeytown Dam

| Category | Data |
|---|---|
| Barrier | Whiskeytown Dam |
| State | CA |
| USGS HUC | 18020112 |
| Latitude | 40.5978713925959 |
| Longitude | -122.538124985038 |
| Hydrologic Unit | Sacramento - Upper Clear |
| River | Clear Creek |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | USBR 2008 |
| Documents | |

## Camp Far West Dam

| Category | Data |
|---|---|
| Barrier | Camp Far West Dam |
| State | CA |
| USGS HUC | 18020126 |
| Latitude | 39.0498949021269 |
| Longitude | -121.316066728767 |
| Hydrologic Unit | Upper Bear |
| River | Bear River |
| Owner/Operator | South Sutter Water District |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1981-2021 |
| Fish passage | None |
| Reference | NMFS 1998 |
| Documents | http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Reports-and-Publications/upload/chnk-ffd.pdf |

## Nimbus Dam

| Category | Data |
|---|---|
| Barrier | Nimbus Dam |
| State | CA |
| USGS HUC | 18020111 |
| Latitude | 38.6369046539253 |
| Longitude | -121.224059168077 |
| Hydrologic Unit | Lower American River |
| River | American River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None, NMFS outlines the development of a Fish Passage pilot plan for Nimbus Dam in the 2009 Biological Opinion (NMFS 2009c). |
| Reference | USBR 2008, NMFS 2009c |
| Documents | |

## Friant Dam

| Category | Data |
|---|---|
| Barrier | Friant Dam |
| State | CA |
| USGS HUC | 18040006 |
| Latitude | 36.9999492513576 |
| Longitude | -119.703978263203 |
| Hydrologic Unit | Upper San Joaquin |
| River | San Joaquin River |
| Owner/Operator | U.S. Bureau of Reclamation |
| Authority | U.S. Bureau of Reclamation |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | USBR 2008 |
| Documents | |

## Camanche Dam

| Category | Data |
|---|---|
| Barrier | Camanche Dam |
| State | CA |
| USGS HUC | 18040005 |
| Latitude | 38.2249175167704 |
| Longitude | -121.021053322927 |
| Hydrologic Unit | Lower Consumnes - Lower Mokelumne |
| River | Mokelumne River |
| Owner/Operator | East Bay Municipal Utility District |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1981-2031 |
| Fish passage | None |
| Reference | Miyamoto and Hartwell 1998 |
| Documents | |

## New Hogan Dam

| Category | Data |
|---|---|
| Barrier | New Hogan Dam |
| State | CA |
| USGS HUC | 18040011 |
| Latitude | 38.1519203151214 |
| Longitude | -120.813047269629 |
| Hydrologic Unit | Upper Calaveras |
| River | Calaveras River |
| Owner/Operator | Calaveras County Water District |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1982-1932 |
| Fish passage | None |
| Reference | DWR 2007 |
| Documents | http://www.water.ca.gov/fishpassage/docs/calaveras/calaveras_assess.pdf |

## Crocker-Huffman Dam

| Category | Data |
|---|---|
| Barrier | Crocker-Huffman Dam |
| State | CA |
| USGS HUC | 18040002 |
| Latitude | 37.5149363332006 |
| Longitude | -120.371023529574 |
| Hydrologic Unit | M. San Joaquin - L. Merced - L. Stanislaus |
| River | Merced River |
| Owner/Operator | Merced Irrigation District |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 1964-2014 |
| Fish passage | Passage options are currently being examined by the California Department of Fish and Game (CDGF 2009) |
| Reference | Vogel 2007, CDFG 2009 |
| Documents | http://www.fws.gov/stockton/AFRP/documents/Final_Crocker_Huffman_Report.pdf |

## Goodwin Dam

| Category | Data |
|---|---|
| Barrier | Goodwin Dam |
| State | CA |
| USGS HUC | 18040010 |
| Latitude | 37.8629269761722 |
| Longitude | -120.62903738698 |
| Hydrologic Unit | Upper Stanislaus |
| River | Stanislaus River |
| Owner/Operator | Oakdale and South San Joaquin Irrigation Districts |
| Authority | Federal License |
| Upstream From Other Impassable Dams | No |
| License period | 2006-2046 |
| Fish passage | None |
| Reference | Yoshiyama et al. 1998 |
| Documents | |

## La Grange Dam

| Category | Data |
|---|---|
| Barrier | La Grange Dam |
| State | CA |
| USGS HUC | 18040002 |
| Latitude | 37.6719319667837 |
| Longitude | -120.444029047118 |
| Hydrologic Unit | M. San Joaquin - L. Merced - L. Stanislaus |
| River | Tuolumne River |
| Owner/Operator | Turlock Irrigation District |
| Authority | Federal |
| Upstream From Other Impassable Dams | No |
| License period | 1964-2016 |
| Fish passage | None |
| Reference | Yoshiyama et al. 1998 |
| Documents | |

## Nicasio Dam

| Category | Data |
| --- | --- |
| Barrier | Nicasio Dam (Seeger Dam) |
| State | CA |
| USGS HUC | 18050005 |
| Latitude | 38.0765883995552 |
| Longitude | -122.754433600334 |
| Hydrologic Unit | Tomales - Drakes Bay |
| River | Nicasio Creek |
| Owner/Operator | Marin Municipal Water District |
| Authority | State Inspected |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | The Central California Coast coho recovery plan (NMFS 2010) lists fish passage at Nicasio Dam as a recovery action for Lagunitas Creek |
| Reference | NMFS 1998, NMFS 2010 |
| Documents | http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Reports-and-Publications/upload/chnk-ffd.pdf |

## Peters Dam

| Category | Data |
| --- | --- |
| Barrier | Peters Dam |
| State | CA |
| USGS HUC | 18050005 |
| Latitude | 37.9969236538179 |
| Longitude | -122.704097035198 |
| Hydrologic Unit | Tomales - Drakes Bay |
| River | Lagunitas Creek |
| Owner/Operator | Marin Municipal Water District |
| Authority | State Inspected |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | NMFS 1998 |
| Documents | http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Reports-and-Publications/upload/chnk-ffd.pdf |

## San Pablo Dam

| Category | Data |
|---|---|
| Barrier | San Pablo Dam |
| State | CA |
| USGS HUC | 18050002 |
| Latitude | 37.9429241306783 |
| Longitude | -122.261080599768 |
| Hydrologic Unit | San Pablo Bay |
| River | San Pablo Cr. |
| Owner/Operator | East Bay Municipal Utility District |
| Authority | State Inspected |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | Leidy et al. 2005 |
| Documents | |

## Anderson Dam

| Category | Data |
|---|---|
| Barrier | Anderson Dam |
| State | CA |
| USGS HUC | 18050003 |
| Latitude | 37.1669443542475 |
| Longitude | -121.629056529562 |
| Hydrologic Unit | Coyote Creek |
| River | Coyote Creek |
| Owner/Operator | Santa Clara Valley Water District |
| Authority | State Inspected |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None |
| Reference | Leidy et al. 2005 |
| Documents | |

### Newell Dam

| Category | Data |
|---|---|
| Barrier | Newell Dam |
| State | CA |
| USGS HUC | 18060001 |
| Latitude | 37.1029470267302 |
| Longitude | -122.073073710986 |
| Hydrologic Unit, River | San Lorenzo - Soquel |
| River | Newell Creek |
| Owner/Operator | City of Santa Cruz |
| Authority | State Inspected |
| Upstream From Other Impassable Dams | No |
| License period | N/A |
| Fish passage | None currently, but the Central California Coast coho recovery plan (NMFS 2010) lists the "removal of all existing summer dams that create a passage impediment to migrating adults or juveniles" as a recovery action for San Lorenzo River |
| Reference | Alley et al. 2004, NMFS 2010 |
| Documents | http://sccounty01.co.santa-cruz.ca.us/eh/environmental_water_quality/SLR_Salmonid_Enhancement_Final.pdf |

## Task 3. Threats to Salmon EFH

### Agriculture

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- Recent studies of the Skagit River delta have estimated that 72% of intertidal and estuarine marsh habitat has been lost, coinciding with the modification of the basin for agriculture and other land uses.

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009)

- Cropping practices in upland areas of the Snake River Basin, the roads, stream crossings, and drainage systems that serve these areas have increased erosion rates and contributed large quantities of fine sediment to spawning riffles. Chemicals and pesticides used to increase crop production can enter the stream as pollutants harmful to fish.
- Conversion of bunch grass prairie to production of annual crops has led to erosion of fine sediments into streams. The sediment is deposited primarily in the lower reaches of streams. Recent changes in agricultural practices, such as no till/direct seed farming,

are aimed at reducing soil erosion and improvement of precipitation filtration into the soil.

WSCC. 2002. Salmonid habitat limiting factors water resource inventory areas 33 (lower) and 35 (middle) Snake watersheds, and lower six miles of the Palouse River. Washington State Conservation Commission. Available: http://www.scc.wa.gov/index.php/288-WRIA-33-34-35-Snake-River-Watershed/View-category.html. (January 2010).

- Best management practices that reduce soil erosion include: no-till/direct seed farming methods (direct seeding into standing wheat stubble for example), installation of terraces, sediment basins, and vegetated filter strips, and enrollment of acreage in the Conservation Reserve Program (CRP, conversion of annual cropland to perennial grass stands for wildlife habitat benefits).
- The Conservation Districts (CDs) and Natural Resources Conservation Service (NRCS) are addressing riparian zone problems with the Conservation Reserve Enhancement Program (CREP). The program is intended to restore riparian forest buffers on agricultural lands adjacent to salmonid bearing streams. The Conservation Reserve Program (CRP) is available through the NRCS to landowners wishing to restore riparian buffers along non-salmonid producing streams. Livestock is fenced out of the buffer and native vegetation is planted. Landowners are compensated at 200% of the agricultural value of the land placed in the buffer over a 10 to 15-year rental agreement. The program pays for all plant materials, fencing, and alternate livestock watering facilities.

Moore, A., C.P. Waring. 2001. The effects of a synthetic pyrethroid pesticide on some aspects of reproduction in Atlantic salmon (Salmo salar L). Aquatic Toxicology 52:1-12.

- The synthetic pesticide cypermethrin, a known contaminant of tributaries supporting spawning salmonid fish, had a significant sublethal impact upon the endocrine system in mature male Atlantic salmon parr, disrupting the reproductive fitness of the population.

Scholz, N.L., N.K. Truelove, B.L. French, B.A. Berejikian, T.P. Quinn, E. Casillas, T.K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 57:1911-1918.

- Neurotoxic pesticides are known to contaminate surface waters that provide habitat for salmonids, including some listed for protection under the U.S. Endangered Species Act. Despite their widespread use, the impacts of these pesticides on the neurological health of wild salmon are not well understood.
- Results suggest that olfactory-mediated behaviors are sensitive to neurotoxicity in salmonids and that short-term, sublethal exposures to these insecticides may cause significant behavioral deficits. Such deficits may have negative consequences for survival and reproductive success in these fish.

DeLorenzo, M.E., G.I. Scott, P.E. Ross. 2001. Toxicity of pesticides to aquatic microorganisms: A review. Environmental Toxicology and Chemistry 20(1):84-98.

- "Microorganisms contribute significantly to primary production, nutrient cycling, and decomposition in estuarine ecosystems; therefore, detrimental effects of pesticides on microbial species may have subsequent impacts on higher trophic levels."
- "There is a great deal of variability in the toxicity of even a single pesticide among microbial species. When attempting to predict the toxicity of pesticides in estuarine ecosystems, effects of pesticide mixtures and interactions with nutrients should be considered. The toxicity of pesticides to aquatic microorganisms, especially bacteria and protozoa, is an area of research requiring further study."

Fulton, M. H., D.W. Moore, E.F. Wirth, G.T. Chandler, P.B. Key, J.W. Daugomah, E.D. Strozier, J. Devane, J.R. Clark and others. 1999. Assessment of risk reduction strategies for the management of agricultural nonpoint source pesticide runoff in estuarine ecosystems. Toxicology and Industrial Health 15:200-213.

- Incorporating integrated pest management (IPM) and best management practices as part of the authorization or permitting can help ensure the reduction of pesticide contamination in estuarine ecosystems.

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- "Overall, streams in the Yakima River basin have been profoundly altered to support the development of irrigated agriculture."
- Water quality in the Yakima River watershed becomes progressively impaired as it moves from the headwaters to the mouth, deteriorating as it proceeds through the agricultural area in the lower watershed prior to entry into the Yakima River.
- Use of multimetric community condition indices (such as percent tolerant species for fish or EPT richness and abundance for invertebrates) indicates that the upper Yakima (Cascades and Eastern Cascades ecoregions) is largely unimpaired.
- "In the Columbia Basin, sites were generally impaired or severely impaired as measured by multiple indicators of conditions that were linked to nutrients and pesticides (e.g., agriculture). All lower Yakima mainstem sites were moderately to severely impaired, corresponding with high levels of pesticides in fish tissues and presence of external abnormalities."
- "Recent studies have identified a strong relationship between concentrations of DDT and suspended sediment in the Yakima River and tributaries draining agricultural lands. This finding suggests that DDT transport to the Yakima River can be effectively controlled by measures that reduce erosion of agricultural soils and limit sediment transport."

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- Current environmental conditions in the Columbia River estuary indicate the presence of contaminants in the food chain of juvenile salmonids including DDT, PCBs, and polyaromatic hydrocarbons. This data also indicates that juvenile salmonids in the Columbia River estuary have contaminant body burdens in the range where sublethal effects may occur.
- The sources of exposure are not clear but may be widespread. Several pesticides and heavy metal contaminants have been sampled in Columbia River sediments (ODEQ 2007). In field studies, juvenile salmon from sites in the Pacific Northwest have demonstrated immunosuppression, reduced disease resistance, and reduced growth rates due to contaminant exposure during their period of estuarine residence.

NMFS. 2002. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service.

- "Agricultural practices may adversely impact the aquatic environment. Stream pollution from agriculture runoff is a persistent cause of damage. Animal wastes, fertilizers, pesticides, and herbicides enter the stream as a result of storm runoff and return flows from irrigation. This has resulted in elevated nutrient levels in the Klamath River and some tributaries. "
- "Agricultural practices that reduce riparian vegetation in turn reduce large woody debris recruitment and simplify the stream channel. Removal of riparian vegetation has also resulted in elevated water temperatures in the Klamath Basin. Temperatures periodically reach levels that are lethal to some fish species. This, combined with elevated nutrient levels, results in stimulation of aquatic plant and algae growth."
- "As water temperatures rise and plants and algae decompose, the level of dissolved oxygen decreases. Dissolved oxygen levels in the Klamath River often fall below the state's water quality objective of 7.0 mg/l."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "Nutrients are applied to agricultural land in several different forms and come from various sources, including commercial fertilizers, manure from animal production facilities (with bedding and other wastes added to the manure), municipal and industrial treatment plant effluent and sludge, legume and crop residues, irrigation water, and atmospheric deposition of nutrients such as nitrogen and sulfur."
- Animal waste (manure) includes fecal and urinary wastes of livestock and poultry; process water (such as from a milking parlor); and the feed, bedding, litter, and soil with which they become intermixed.
- Pollutants contained in manure and associated bedding materials can be transported into marine environments by runoff and process wastewater from rangelands, pastures,

or confined animal facilities. Theses pollutants may include oxygen-demanding substances such as nitrogen, phosphorus, and organic solids; salts; bacteria, viruses, and other microorganisms, as well as sediments that increase organic decomposition. Runoff of animal wastes can cause fish kills due to ammonia, and solids deposited into the marine environment can reduce productivity over extended periods of time due to the accelerated effects of cultural eutrophication.

NMFS. 2010b. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service, Southwest Region.

- "Agricultural operations have degraded habitat and limited both water quality and quantity, especially for interior population units in the Rogue and Klamath rivers. Channelization and stream straightening associated with flood control or agricultural operations reduces habitat by limiting stream complexity and increases stream velocities, which can be detrimental to both adult and juvenile coho salmon life stages."
- "Summer "pushup" dams are still utilized in agricultural and rural communities in the SONCC coho salmon ESU. These temporary dams can alter the streambed, create migration barriers, change stream temperature profiles, and temporarily increase sedimentation."

**Artificial Propogation**

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- Natural populations of salmon are negatively affected by "gene flow," the transfer of genes from hatchery populations to natural ones. Recent studies have indicated that the greater the amount of gene flow and the dissimilarity between the hatchery and wild fish populations in a given watershed, the greater the negative genetic effects. Gene flow can cause a loss in unique identity and traits among natural populations of salmon, and within individual populations that receive hatchery fish.
- The loss of genetic diversity may result in a decrease of the viability of a local salmon population in two ways: 1) Loss of adaptation may occur when genes that evolved in a non-local environment replace those that were locally adapted; and 2) hybridization results in recombinations of sets of genes that were favorable to a local population, leading to loss of individual performance and population productivity that may not show up for a generation or more.
- Loss of fitness can occur because of domesticaion, which is the change in the genetic composition of a population as a result of selection for an artificial, captive environment

National Marine Fisheries Service Chum Biological Review Team. 2003. Preliminary Conclusions Regarding the Updated Status of Listed ESUs of West Coast Salmon and Steelhead. NMFS Northwest Fisheries Science Center; Seattle, WA.

- Potential threats to Hood Canal summer chum salmon from negative interactions with hatchery fish (late-timed Chinook, coho, pink, and fall chum salmon) through predation, competition, behavior modification or disease transfer were identified by the NMFS Chum Biological Review Team.

Bilby, R. E., B. R. Fransen, P. A. Bisson, and J. K. Walter. 1998. Response of juvenile coho salmon (Oncorhynchus kisutch) and steelhead (Oncorhynchus mykiss) to the addition of salmon carcasses to two streams in southwestern Washington, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 55:1909-1918.

- Use of hatchery salmon carcasses as a source of marine derived nutrients was found to increase the density of age 0+ coho salmon and age 0+ and I+ steelhead in small southwestern Washington streams.
- In the Northwest, river systems in which salmon spawn and rear are often nutrient poor and the delivery of marine-derived nutrients by returning salmon carcasses is a key component to potential growth and survival of juvenile fish in the system.

McCubbing, D. J. F. and B. R. Ward. 2000. Stream rehabilitation in British Columbia's Watershed Restoration Program: juvenile salmonid response in the Keogh and Waukwaas rivers, 1998.

- Stream fertilization using hatchery carcasses is being tested with promising results, as an interim measure for recovering certain natural salmonid stocks that have been in decline for reasons not related to hatchery practices

Heath, D.H., J. W. Heath, C.A. Bryden, R. A. Johnson, and C.W. Fox. 2003. Rapid evolution of egg size in captive salmon. Science 299:1738-1740.

- Recent studies have confirmed earlier hypotheses that the benign conditions of a hatchery environment may directly select for increased fecundity of females with a correlated reduction in mean egg size
- Two river populations of Chinook salmon subjected to high levels of hatchery supplemented salmon with decreased egg size over a 20 year period resulted in significant declines in egg size of the wild salmon population
- The effect of selection resulting in decreased egg size could be minimized through modified breeding practices

Campton, D.E. 2004. Sperm competition in salmon hatcheries: the need to institutionalize genetically-benign spawning protocols. Transactions of the American Fisheries Society 133: 1277-1289.

- Sperm competition resulting from mixed-milt fertilizations in single containers can result in domestic changes in life history traits if those traits are correlated phenotypically with sperm potency and fertilization success in vitro.
- Salmon hatcheries should discontinue mixed-milt fertilization and institutionalize alternative spawning protocols that preclude or minimize sperm competition in vitro. Three alternative protocols are recommended: pairwise spawning, nested spawning, and factorial or matrix spawning. The underlying premise of these latter protocols is that every adult selected for broodstock should have an equal opportunity, and probability, of producing an equal number of progeny.

Beckman, B.R., W.W. Dickhoff, W.S. Zaugg, C. Sharpe, S. Hirtzel. 1999. Growth, smoltification, and smolt-to-adult return of spring chinook salmon from hatcheries on the Deschutes River, OR. Transactions of the American Fisheries Society 128:1125-1150.

- The lack of seasonal patterns of growth and development in hatchery fish contrast substantially to that seen in wild fish. A more natural seasonal cycle of physiological development and high spring growth may enhance smoltification and survival to the adult stage.

Bugert, R. M. 1998. Mechanics of supplementation in the Columbia River. Fisheries 23: 11-20.

- Limits on the duration of supplementation programs where the goal is to rebuild natural populations may limit the negative effects of hatchery domestication.

Gharrett, A. J., W. W. Smoker, R. R. Reisenbichler, and S. G. Taylor. 1999. Outbreeding depression in hybrids between odd- and even-brood year pink salmon. Aquaculture 73: 117-130.

- Hatchery fish and gamete transfers that have taken place over hundreds of miles and between ecological provinces or regions is expected to have resulted in reductions in fitness of the receiving hatchery stock.

Larsen, D., B. Beckman, K. Cooper, D. Barrett, M. Johnston, P. Swanson and W. Dickhoff. 2004. Assessment of high rates of precocious male maturation in a spring Chinoook salmon supplementation hatchery program.

- High growth rates of fish in the hatchery may alter the age of maturation, producing exceptionally high numbers of precocious males.
- hatchery water supplies or temperature profiles that do not follow natural patterns may result in incomplete or inappropriately timed growth profiles, smoltification, outmigration, and homing.

Hatchery Scientific Review Group (HSRG). 2004. Hatchery Reform: principles and recommendations of the HSRG. HSRG. Available: http://www.lltk.org/pdf/hsrg/HSRG_Princ_Recs_Report_Full_Apr04.pdf. (October 2009).

- Pages 31-45 describe in detail the HSRG system wide recommendations for hatchery reform for the Puget Sound and coastal Washington hatchery system, including the following recommendations:
    - set goals for all stocks and manage hatchery programs on a regional scale
    - manage success in terms of contribution to harvest, conservation and other goals
    - have clear goals for educational programs
    - operate hatchery programs within the context of their ecosystems
    - operate hatchery programs as either genetically integrated or segregated relative to naturally-spawning populations
    - size hatchery programs consistent with stock goals
    - consider both freshwater and marine carrying capacity in sizing hatchery programs
    - ensure productive habitat for hatchery programs
    - emphasize quality, not quantity, in fish releases
    - use in-basin rearing and locally-adapted broodstocks
    - spawn adults randomly throughout the natural period of adult return
    - use genetically benign spawning protocols that maximize effective population size
    - reduce risks associated with outplanting and net pen releases
    - use hatchery salmon carcasses for nitrification of freshwater ecosystems, while reducing associated fish health risks
    - adaptively manage hatchery programs
    - incorporate flexibility into hatchery design and operation
    - evaluate hatchery programs regularly to ensure accountability for success

Flagg, T., B. Berejikian, J. Colt, W. Dickhoff, L. Harrell, D. Maynard, C. Nash, M. 1 Strom, R. Iwamoto, and C. Mahnken. 2001. Ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations - a review of practices in the Pacific Northwest. National Marine Fisheries Service, NOAA Tech. Memo. NMFS-NWFSC-XX, Seattle, WA.

- Foraging, social behavior, time of spawning, and predator avoidance can differ for fish reared in the hatchery and in the wild. While resulting differences may primarily reduce survival of hatchery-produced salmon and steelhead, negative effects may carry into a naturally produced population where adults of hatchery origin spawn with naturally produced fish.

Ford, M. J., T. A. Lundrigan, and P. C. Moran. 2004. Population genetics of Entiat River spring Chinook salmon. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-60, Seattle, WA.

- The similarity of DNA (deoxyribonucleic acid) collected from natural Entiat River spring Chinook and Entiat NFH samples indicates that Entiat NFH spring Chinook spawn successfully and have introgressed into or may have replaced the natural Entiat River population (Ford et al. 2004).

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia spring Chinook salmon and steelhead recovery plan. Upper Columbia Salmon Recovery Board. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf. (October 2009).

- The primary threat associated with some past and present hatchery programs within the Upper Columbia Basin may be the introgression of out-of-basin stock into local populations, especially within the Entiat and Winthrop subbasins. This threat may have reduced the diversity of spring Chinook and steelhead in the Upper Columbia Basin.

NMFS. 2004a. Interim endangered and threatened species recovery planning guidance. National Marine Fisheries Service, Silver Spring, MD.

- Hatchery supplementation programs may affect the age-at-return of spring Chinook, resulting in more younger-aged hatchery fish spawning in the wild. This could affect reproductive potential and ultimately productivity of naturally produced fish.

NMFS. 2002. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service.

- "Release of large numbers of hatchery chinook into the Klamath Basin has the potential to increase inter-specific competition for resources which could affect survival of young-of-year coho."
- "CDFG and NMFS have evaluated Iron Gate Hatchery practices and implemented changes to help minimize adverse effects to naturally produced salmon and steelhead."
- "For example, release of the 4.9 million chinook salmon smolts produced in 2002 was modified from a three-day forced release in early June to a phased approach beginning in mid-May. These fish will be volitionally released in four or five separate lots over a month long period. CDFG and NMFS expects this release schedule to minimize competition between hatchery and naturally produced fish, as well as competition between hatchery fish."

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- Hatchery actions designed to benefit salmon and steelhead viability sometimes produce only limited positive results. One potential reason for this is that other factors (i.e., limiting factors and threats) can offset or out-weigh the benefits from hatchery actions.
- Hatchery programs can serve an important conservation role when habitat conditions in freshwater depress juvenile survival or when access to spawning and rearing habitat is blocked. Under circumstances like these and in the short-term, the demographic risks

of extinction of such populations likely exceed genetic and ecological risks to natural-origin fish that would result from hatchery supplementation.
- Benefits like this should be considered transitory or short-term and do not contribute to survival rate changes necessary to meet ICTRT abundance and productivity viability criteria. For example, in Puget Sound, eight Chinook
- For example, in Puget Sound, eight Chinook salmon hatchery programs have been specifically implemented to preserve native populations in their natal watersheds. Until, however, the factors limiting Chinook salmon productivity are addressed, the full benefit (i.e., potential contributions to increased viability) of hatchery actions designed to benefit salmon viability may not be realized.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.
- "The management of hatcheries, such as Nimbus Fish Hatchery and Feather River Fish Hatchery (FRFH), can directly impact spring-run and steelhead populations by oversaturating the natural carrying capacity of the limited habitat available below dams. In the case of the Feather River, significant redd superimposition occurs in-river due to hatchery overproduction and the inability to physically separate spring-run and fall-run adults. This concurrent spawning has led to hybridization between the spring-run and fall-run in the Feather River. At Nimbus Hatchery, operating Folsom Dam to meet temperature requirements for returning hatchery fall-run often limits the amount if water available for steelhead spawning and rearing the rest of the year."

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available: http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (December 2009).
- "Hatchery production of spring-run Chinook salmon may threaten the genetic integrity of naturally-spawning populations… Hatchery straying is considered to be an increasing problem due to current practices of offsite releases. Given the large numbers of juveniles released offsite (1,000,000 spring-run), the potential for straying to rivers throughout the Central Valley is high."

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009)
- "Release of large numbers of hatchery fish into streams has been shown to have a negative impact on survival of wild fish due to competition for limited resources. Hatchery fish are often larger relative to their wild counterparts at the same age. When

released into a stream with naturally produced fish, the larger hatchery fish can displace wild fish from their territories and decrease survival of the natural component. Hatchery fish can also be more aggressive than wild fish and disrupt normal foraging behavior."

- "From the genetic standpoint, artificial production involves the controlled mating of fish and subsequent rearing of young in a regulated environment and can have significant impacts on the genetic makeup of hatchery-bred fish. These genetic changes can negatively affect the fitness or biological performance of hatchery fish in the natural environment. In addition, because hatchery fish frequently interbreed with naturally produced fish, the fitness of wild populations can be negatively affected, a particular concern for populations listed under the Endangered Species Act. It should be recognized, however, that hatchery managers increasingly recognize the potential negative effects of husbandry practices and are developing techniques to minimize genetic impacts of hatchery production."

NMFS. 2008b. Willamette Project Biological Opinion. National Marine Fisheries Service. Available: https://pcts.nmfs.noaa.gov/pls/pcts pub/pcts_upload.summary_list_biop?p_id=26588. (October 2009).

- "The Willamette Hatchery was built to mitigate lost natural production of spring Chinook in the Middle Fork Willamette due to the construction and operation of Fall Creek, Dexter, Lookout Point, and Hills Creek dams and reservoirs.
- "The current hatchery program is being used to evaluate the potential for the reintroduction of Chinook to their historic habitat above the dams. Due to extremely poor natural reproduction and the dominance of hatchery-produced fish in the run, hatchery fish likely contain the only genetic remnants of the historic run available. These fish are the only remaining source of fish for outplanting efforts."
- "The hatchery program is also being reformed into an integrated broodstock, where the broodstock incorporates natural-origin fish on a regular basis so that the hatchery broodstock is as similar as possible to the natural-origin population. However, due to the extremely low numbers of natural-origin fish observed recently in this population, significant improvements are needed in the key and secondary limiting factors before this broodstock can be fully integrated."
- "Hatchery programs in the Middle Fork Willamette continue to pose risks and some potential benefits to natural-origin Chinook salmon. Having all hatchery fish marked since 2001 has facilitated determining the status of natural-origin fish in this population. Hatchery fish will continue to represent the majority of natural spawners in this population until other limiting factors are addressed that allow natural production to increase."

NMFS. 2005b. Endangered and threatened species; designation of critical habitat for 12 evolutionarily significant units of West Coast salmon and steelhead in Washington, Oregon, and California. Federal Register 70:170(2 September 2005):52630-52858.

- "The majority of studies evaluating the relative fitness of hatchery and natural salmon have been conducted under conditions of mutual competition. Levels of competition in natural streams may vary depending on the number of released fish and status of the natural population, so understanding the role that competition between hatchery and natural fish plays in determining relative fitness is important. Competitive inferiority of hatchery relative to natural spawners has been clearly documented in breeding behavior studies, and the effects of hatchery rearing on competition are generally more pronounced for males than for females."

NMFS. 2004b. Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act consultation interim protection plan for operation of the Priest Rapids Hydroelectric Project FERC Project No. 2114. NOAA Fisheries Northwest Region Hydropower Division NOAA Fisheries Log Number: 1999/01878.

- Risks associated with artificial production programs within the Upper Columbia River Spring-run Chinook ESU are a concern because of the use of non-native Carson stock for fishery enhancement and hydropower mitigation. However, programs have been initiated to develop locally adapted broodstocks to supplement the natural populations in the ESU. The Carson stock is being phased out at those facilities where straying and natural stock interactions are problematic.

National Marine Fisheries Service. 1998b. Factors Contributing to the Decline of Chinook Salmon: An Addendum to the 1996 West Coast Steelhead Factors For Decline Report. Protected Resources Division, National Marine Fisheries Service. Portland, Oregon.

- "Fall-run chinook salmon have been reared at a number of hatcheries in the Central Valley. The state-run Feather River, Nimbus, and Merced Hatcheries, and the Coleman NFH account for the majority of releases into the Central Valley. Exchanges between hatcheries have been commonplace and probably reduced much of the regional variation among stocks. Furthermore, the practice of releasing fish off-station has resulted in a high proportion of returning adults straying into other basins within the Central Valley. The loss of homing fidelity has probably further eroded the distinctiveness of many stocks and inflated the numbers of naturally spawning adults observed. Based on CWT recoveries, the contribution of hatchery strays to naturally spawning populations may exceed 50% in many basins. There are no accurate estimates for the contribution of hatchery strays to natural spawning populations in most Central Valley basins, and, in the absence of such data, the relative health of these stocks may be overestimated."

**Bank Stabilization**

Schmetterling, D. A., C. G. Clancy, and T. M. Brandt. 2001. Effects of riprap bank reinforcement on stream salmonids in the western United States. Fisheries 26(7): 6-23.

- "Riprap may provide habitat for juvenile salmonids and bolster densities on reaches of streams that have been severely degraded. However, riprap does not provide the intricate habitat requirements for multiple age classes or species provided by natural vegetated banks. Streambanks with riprap have fewer undercut banks, less low-overhead cover and are less likely than natural stream banks to contribute large woody debris to the stream. Lateral streambank erosion."
- "The use of natural materials (i.e., LWD, trees, rootwads, etc.) in bank reinforcement and restoration is a growing practice. These "soft" techniques aim to slow the rate of erosion rather than completely stop lateral erosion."

Garland, R. D., K. F. Tiffan, D. W. Rondorf, and L. O. Clark. 2002. Comparison of subyearling fall Chinook salmon's use of riprap revetments and unaltered habitats in Lake Wallula of the Columbia River. North American Journal of Fisheries Management 22:1283-1289.

- Garland et al. (2002) examined subyearling fall chinook salmon's use of unaltered and riprap habitats in Lake Wallula of the Columbia River using data collected by electrofishing in May 1994 and 1995.
- Based on logistic regression, they found that the probability of fish presence was greater in unaltered shoreline habitats than in riprap habitats. Their model showed that substrate was the most important factor determining subyearling habitat use, but the model did not include other habitat variables known to be important to subyearlings in more diverse systems.
- They suggest that resource managers consider alternative methods of bank stabilization that are compatible with the habitat requirements of the fish that use them.

Williams, G.D., R.M. Thom. 2001. Marine and estuarine shoreline modification issues. White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. Available: wdfw.wa.gov/hab/ahg/finalsl.pdf. (January 2010).

- Armoring of shorelines to prevent erosion and maintain or create shoreline real estate simplifies habitats, reduces the amount of intertidal habitat, and affects nearshore processes and the ecology of a myriad of species.
- Hydraulic effects to the shoreline include increased energy seaward of the armoring, reflected wave energy, dry beach narrowing, substrate coarsening, beach steepening, changes in sediment storage capacity, loss of organic debris, and downdrift sediment starvation.
- Installation of breakwaters and jetties can result in community changes from burial or removal of resident biota; changes in cover and preferred prey species; and predator attraction. As with armoring, breakwaters and jetties modify hydrology and nearshore sediment transport as well as movement of larval forms of many species.

Toft J.D., J.R. Cordell, C.A. Simenstad, and L.A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. North American Journal of Fisheries Management 27(2):465-480.

- Goal of study was to compare relative abundance and behavior of juvenile salmonids and other fishes along modified and undeveloped shorelines in Puget Sound
- Five main habitat types:
  - Cobble beach
  - Sand beach
  - Riprap extending into the upper intertidal zone
  - Deep riprap extending into the subtidal zone
  - Edge of overwater structures
- "…substrate type and slope were an important influence on bottom-dwelling fish densities when shoreline modifications only extended into the upper intertidal zone, whereas effects on pelagic fish densities and behavior were more evident when shoreline modifications extended into shallow subtidal waters (i.e., created deep water at the shoreline…found greater fish densities, larger schools of salmon, and fewer terrestrial riparian insects in salmon diets at these sites)."
- "Juvenile salmonids avoided swimming under overwater structures, whereas surfperch, crabs, and sculpins were observed beneath or adjacent to pilings."
- "Overall, our results indicate that shoreline modifications have the greatest effect on nearshore fish assemblages when the alterations extend from the supratidal zone into the subtidal zone. Our data suggest that the differences in fish behavior and usage between modified and unmodified shorelines were caused by physical and biological effects of the modifications, such as changes in water depth, slope, substrate, and shoreline vegetation."

Rice, C.A. 2006. Effects of shoreline modification on a northern Puget Sound beach: microclimate and embryo mortality in surf smelt (*Hypomesus Pretiosus*). Estuaries and Coasts 29(1):63-71.

- Study evaluated differences in microclimate and biological condition between natural and modified beaches in Puget Sound
- "The modified beach had significantly higher daily mean light intensity, air temperature, and substrate temperature, and significantly lower daily mean relative humidity." – substrate temperatures on the modified beach ranged from 14.4-29.4°C, whereas substrate temperatures on the natural beach only ranged from 12.1-18.2°C
- In general, microclimate conditions on the modified beach were more variable – indicating less buffered environment
- When looking at surf smelt egg survival, proportion of eggs containing live embryos at the modified beach was about ½ of the proportion of eggs containing live embryos at the natural beach

**Beaver Removal**

Pollock, M. M., G. R. Pess and T. 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 24:749-760.

- Pollock et al. (2004) assessed the current and historic distributions of beaver ponds and other coho salmon rearing habitat in the Stillaguamish River, a 1,771-km2 drainage basin in Washington and found that the greatest reduction in coho salmon smolt production capacity originated from the extensive loss of beaver ponds.
- Watershed-scale restoration activities designed to increase coho salmon production should emphasize the creation of ponds and other slow-water environments; increasing beaver populations may be a simple and effective means of creating slow-water habitat.

WSCC. 2002. Salmonid habitat limiting factors water resource inventory areas 33 (lower) and 35 (middle) Snake watersheds, and lower six miles of the Palouse River. Washington State Conservation Commission. Available: http://www.scc.wa.gov/index.php/288-WRIA-33-34-35-Snake-River-Watershed/View-category.html. (October 2009).

- "Beaver ponds, wetlands, oxbow ponds, and side channels connected to the main river channel are all forms of off-channel habitat. Juvenile salmonids (especially coho salmon, rainbow/steelhead trout, and cutthroat trout) seek out this type of habitat for rearing. Off-channel areas provide an abundance of food with fewer predators than would typically be found in the river. These areas also generally have reduced current and large amounts of vegetative and/or woody cover, allowing juvenile salmonids to hide from predators and conserve energy (See Figure 12). Diking, and channelization of rivers, conversion of riparian zones to pasture and cropland, floodplain development, and extermination of beaver all play a roll in destruction of off-channel habitat."

Collen, P., and R.J. Gibson. 2001. The general ecology of beavers (*Castor* spp.), as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish – a review. Reviews in Fish Biology and Fisheries 10(4):439-461.

- "The beaver is a keystone riparian species in that the landscape can be considerably altered by its activities and a new ecosystem created…Although the invertebrates may be fewer per unit area, total number of organisms increases, and diversity increases as the pond ages. In cool, small order streams, the impoundments provide better habitat for large trout, possibly creating angling opportunities. However, at sites where water temperatures rise above their optimum preferenda, salmonids may be replaced by other species, such as cyprinids, catostomids, percids, or centrachids. As the habitat is altered, interactions among co-habiting species may change."
- "Refugia from high or low water flows, low oxygen or high temperatures, may be provided in adverse conditions in winter or summer. However, in some cases dams are

obstructions to upstream migration, and sediment may be deposited in former spawning areas. The practicality and benefits of introducing or restoring beaver populations will vary according to location, and should be considered in conjunction with a management plan to control their densities."

- Beaver dam removal should be done at low flows and after the emergence of salmonid fry to minimize downstream effects
- Article provides a bulleted summary of multiple positive and negative effects of beaver dams and methods for mitigation and removal

Mitchell, S.C., and R.A. Cunjak. 2007. Stream flow, salmon and beaver dams: roles in the structuring of stream fish communities within an anadromous salmon dominated stream. Journal of Animal Ecology 76:1062-1074.

- Calculated Shannon Weiner diversity index and community evenness for sample sites distributed above and below beaver dams preventing upstream migration of Atlantic salmon in Catamaran Brook, New Brunswick, CA over a 15 year period
- Fish community diversity was greatest upstream of beaver dams in reaches that were inaccessible to Atlantic salmon – Atlantic salmon appeared to depress evenness of the fish community, but did not change species richness – the fish community upstream of the beaver dams changes due to replacement of slimy sculpin by Atlantic salmon downstream of the beaver dams
- Locations of beaver dams and autumn flows govern anadromous salmonid spawner distribution, juvenile production, and fish community indices – in streams dominated by anadromous salmonids, community distribution may be a function of obstructions, flows, and the resulting distribution of anadromous salmonids affecting resident species richness, evenness, biomass, and production.

Pollock, M.M., T.J. Beechie, and C.E. Jordan. 2007. Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream channel in the interior Columbia River basin, eastern Oregon. Earth Surface Processes and Landforms 32:1174-1185.

- Looked at extent of localized aggradation behind beaver dams on an incised stream in the interior Columbia River basin to determine usefulness of using beaver dams to restore the channel and the effects of beaver dams on riparian habitat
- The authors found that vertical aggradation rates were initially rapid (as high as 0.47m/year) as entrenched channels filled, but leveled off (about 0.075m/year) as sediment began to cover adjacent terraces
- New riparian vegetation was about at the 0.5m elevation contour above the stream channel – found 5 times more area within 0.5m elevation contour above the stream channel upstream of beaver dams when compared to areas without beaver dams
- Authors suggest that encouraging recolonization of streams by beaver can expand riparian habitat along incised channels

- Beaver dams studied were from 1-6 years old – indicates that restoration can occur fairly rapidly

Westbrook, C.J., D.J. Cooper, and B.W. Baker. 2006. Beaver dams and overbank floods influence groundwater–surface water interactions of a Rocky Mountain riparian area. Water Resources Research, Vol. 42, W06404.

- Examined influence of two in-channel beaver dams and a 10-year flood event on surface inundation, groundwater levels, and flow patterns in a broad alluvial valley during summers of 2002-2005 – 1.5km reach of 4$^{th}$ order Colorado River in Rocky Mountain National Park
- "The beaver dams and ponds greatly enhanced the depth, extent, and duration of inundation associated with floods; they also elevate the water table during both high and low flows. Unlike previous studies we found the main effects of beaver on hydrologic processes occurred downstream of the dam rather than being confined to the near-pond area."
- "Beaver dams on the Colorado River cause river water to move around them as surface runoff and groundwater seepage during both high- and low-flow periods. The beaver dams attenuated the expected water table decline in the drier summer months for 9 and 12ha of the 58ha study area."
- "…we provide empirical evidence that beaver can influence hydrologic processes during the peak flow and low-flow periods on some streams, suggesting that beaver can create and maintain hydrologic regimes suitable for the formation and persistence of wetlands."
- Authors conclude that beaver can influence floodplain structure and function

**Urbanization**

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- Much of the urbanized area in Puget Sound is concentrated near the mouths of rivers and along estuarine shorelines, coinciding with important and sensitive habitat required by salmon.
- Streams in heavily urbanized areas have lost much of their complexity and riparian vegetation. For example, Thornton Creek in the Seattle area lost all of its wetlands and 60% of its open channel network during 100 years of development. The remaining stream system is heavily armored with rock and concrete along its banks, has extensive culverts and pipes, and little native vegetation remains. Despite heavy outplants of salmon into the creek for many years, only a handful of returning adults have been observed in recent years.

- The toxic mix of oil, grease, pesticides and other pollutants carried by stormwater runoff alters the chemical processes of urban streams and creates dramatic shifts in their flow patterns. Recent studies by NMFS and the Seattle Public Utilities have also documented high rates of outright mortality to adult salmon still full of eggs and sperm, even in a creek where habitat had been restored.

Scholz, N.L., N.K. Truelove, B.L. French, B.A. Berejikian, T.P. Quinn, E. Casillas, T.K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 57:1911-1918.

- Studies examining the impacts of urban run-off on urban creeks suggest that the control of polluted runoff from urban streets, lawns and parks and restoration of chemical balance is imperative to fish productivity.

EPA. 2002. National Water Quality Inventory: 2000 Report to Congress. EPA-841-R-02-001. Washington, D.C.: EPA Office of Water. Available: http://www.epa.gov/305b/2000report/. (January 2010).

- The National Water Quality Inventory (EPA 2002) reports that runoff from urban areas is the leading source of impairment to surveyed estuaries and the third largest source of impairment to surveyed lakes. These include construction sediments, oil from autos, bacteria from failing septic systems, road salts, and heavy metals.
- Urban areas have an insidious pollution potential that one-time events such as oil spills do not. Pollutant increases gradually result in gradual declines in habitat quality.

Arkoosh, M.R., E. Casillas, E. Clemons, P. Huffman, A.N. Kagley, T. Collier, J.E. Stein. 2001. Increased susceptibility of juvenile chinook salmon (Oncorhynchus tshawytscha) to vibriosis after exposure to chlorinated and aromatic compounds found in contaminated urban estuaries. Journal of Aquatic Animal Health 13:257-268.

- The findings of Arkoosh et al. (2001) suggest that a higher predisposition to infection and subsequent disease can occur in salmon exposed to chemical contaminants found in urban estuaries of Puget Sound, Washington.

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- Land use modifications in the Yakima River Watershed, including road construction, floodplain encroachment, and bank revetment associated with conversion to urban/suburban development have adversely impacted the quantity and quality of salmonid habitat, and accessibility to habitat in these streams.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "Primary impacts of urbanization include 1) the loss of riparian and shoreline habitat and vegetation and 2) runoff. The removal of upland and shoreline vegetation removal can increase stream water temperatures, reduce supplies of LWD, and reduce sources of prey and nutrients to the water system. An increase in impervious surfaces, such as the addition of new roads, roofs, bridges, and parking facilities, results in a decreased infiltration to groundwater and increased runoff volumes. This also has the potential to adversely affect water quality and water quantity/timing in downstream water bodies (i.e. estuaries and coastal waters)."
- The following are conservation measures to mitigate for urbanization
  1. Implement BMPs (EPA 1993) for sediment control during construction and maintenance operations. These can include avoiding ground disturbing activities during the wet season; minimizing exposure time of disturbed lands; using erosion prevention and sediment control methods; minimizing the spatial extent of vegetation disturbance; maintaining buffers of vegetation around wetlands, streams, and drainage ways; and avoiding building activities in areas of steep slopes and areas prone to mass wasting events with highly erodible soils. Use methods such as sediment ponds, sediment traps, bioswales, or other facilities designed to slow water runoff and trap sediment and nutrients.
  2. Avoid using hard engineering structures for shoreline stabilization and channelization when possible. Use bioengineering approaches (i.e., using vegetation approaches with principles of geomorphology, ecology, and hydrology) to protect shorelines and river banks. Naturally stable shorelines and river banks should not be altered (see Section 4.7).
  3. Encourage comprehensive planning for watershed protection so as to avoid filling and building in floodplain areas affecting EFH. Development sites should be planned to minimize clearing and grading, cut-and-fill, and new impervious surfaces.
  4. Where feasible, remove impervious surfaces such as abandoned parking lots and buildings from riparian and shoreline areas, and reestablish wetlands and native vegetation.
  5. Protect and restore vegetated buffer zones of appropriate width along all streams, lakes, and wetlands that include or influence EFH.
  6. Manage stormwater to duplicate the natural hydrologic cycle, maintaining natural infiltration and runoff rates to the maximum extent practicable.
  7. Where in-stream flows are insufficient to maintain water quality and quantity needed for EFH, establish conservation guidelines for water use permits and encourage the purchase or lease of water rights and the use of water to conserve or augment instream flows in accordance with state and federal water law.
  8. Encourage municipalities to use the best available technologies in upgrading their wastewater systems to avoid combined sewer overflow problems and chlorinated sewage discharges into rivers, estuaries, and the ocean.
  9. On-site disposal systems should be properly designed and installed. They should be located away from open waters, wetlands, and floodplains.

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009)

- "Stream areas that attract concentrations of people can lead to harassment of fish and illegal fishing (poaching). Fish on spawning beds are particularly susceptible to intentional harassment as well as to unintentional disturbances from human activities such as boating and swimming. Continued disturbance can cause spawning adults to abandon a good spawning area and to either spawn in poor habitat or to die before spawning."

NMFS. 2010b. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service, Southwest Region.

- "Substantial development and urbanization in the Rogue River Valley, coastal areas, and other parts of the SONCC coho salmon ESU contribute to habitat impairment. Loss of riparian vegetation, loss of tidal wetlands and floodplains, pollution, stream simplification, and consumptive water use are some of the aspects of urbanization that have degraded habitat of coho salmon near urban centers."
- "Straightening and diking of once braided stream channels to facilitate flood control have reduced the amount of available habitat to rearing coho salmon juveniles, which is common throughout the ESU near small towns and cities. This has resulted in the loss of off-channel rearing and habitat areas that were once available to coho salmon."
- "Riparian vegetation, which once helped shade small streams and rivers, has been removed, elevating stream temperatures. Runoff from city streets and urban lawns has increased nutrient loads in several streams and rivers, creating algae blooms that can eventually deplete the oxygen in a waterway."

**Dams**

Independent Scientific Group. 2000. Return to the River 2000: restoration of salmonid fishes in the Columbia River Ecosystem. NPPC 2000-12, Northwest Power Planning Council, Portland, Oregon.

- Construction of the mainstem dams on the Columbia and Snake rivers profoundly altered the Basin's ecosystem. The dams blocked, to varying extents, both adult fish passage upstream to spawning areas and juvenile fish passage downstream to the estuary and the ocean.

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009).

- The USACE devised various passage technologies including screens to collect juvenile fish for transport around the Snake River dams. These technologies have resulted in an increase of juvenile survival, estimated at 50 to 60 percent by the late 1990s in the area extending from Bonneville Dam to above Lower Granite Dam. However, in drought years, juvenile survival for some species may still be as low as 10 to 15 percent.
- Water flowing through fishways usually comes from the surface of reservoirs; thus, water temperatures in adult fishways may be higher than prevailing river temperatures which often exceed 21°C (70°F). Snake River fall Chinook, sockeye, and steelhead migrations are slowed by high temperatures because the fish seek areas of cooler water, such as tributaries, for refuge. These delays may reduce reproductive success of sockeye and fall Chinook salmon. Water temperatures in excess of 13°C can negatively impact fecundity, egg size, and fertility. These conditions are present during a significant portion of the adult migration season for all species.

Dauble, D. 2000. Assessment of the impacts of development and operation of the Columbia River hydroelectric system on mainstem riverine processes and salmon habitats. Report to Bonneville Power Administration. Final Report, Project No. 199800402.

- The four lower Columbia River dams (McNary, John Day, The Dalles, and Bonneville dams) have removed almost all free-flowing riverine habitat down to Bonneville Dam. The dams have eliminated 175 miles of rapids, pools, and riffles that formerly characterized the lower Columbia River, replacing them with wide, deep, slow-moving reservoir habitat.

Williams, J. G., S. G. Smith, W. D. Muir, B. P. Sanford, S. Achord, R. McNatt, D. M. Marsh, R. W. Zabel, and M. D. Scheuerell. 2004. Effects of the federal Columbia River power system on salmon populations. Final draft for Collaboration Group.

- For the period from 1999 to 2003, the mean estimated survival of Snake River spring/summer Chinook yearlings from McNary Dam tailrace to the Bonneville Dam tailrace was 66.7 percent for hatchery and wild Chinook salmon with a range of 50 percent to 72.8 percent. These data indicate significant losses for Snake River fish migrating through the Columbia River hydrosystem.

Ferguson, J. W., G. M. Matthews, R. L. McComas, R. F. Absolon, D. A. Brege, M. H. Gessel, and L. G. Gilbreath. 2004. Passage of adult and juvenile salmon through Federal Columbia River Power System dams. NOAA Technical Memorandum. June 2004.

- Dam operations such as daytime spill, which appears to reduce forebay residence time, may increase smolt survival due to decreased opportunity for smolt predation by northern pikeminnow and smallmouth bass. Studies conducted at McNary Dam in 2001 found that radio-tagged yearling Chinook salmon had prolonged forebay residence.

Williams, J. G., S.G. Smith, R.W. Zabel, W.D. Muir, M.D. Scheuerell, B.P. Sandford, D.M. Marsh, R.A. McNatt, and S. Achord. 2005. Effects of the Federal Columbia River power system on salmonid populations. NOAA Tech. Memo. NMFS-NWFSC-63. Available : http://www.nwfsc.noaa.gov/assets/25/6061_04142005_152601_effectstechmemo63final.pdf. (October 2009).

- Today, median travel times for yearling Chinook from the Snake River to Bonneville Dam range from 14 days to 31 days depending on flow conditions, an increase of 40 to 50% over travel times measured in 1966 when fish encountered only the four mainstem dams.

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- Increased travel time (migration delay) due to man-made impoundments presents an array of potential survival hazards to migrating juvenile salmon and steelhead: increasing their exposure to potential mortality vectors in the reservoirs (e.g. predation, disease, thermals stress), disrupting arrival timing to the estuary (which likely affects predator/prey relationships), depleting energy reserves, potentially causing metabolic problems associated with smoltification, and for some steelhead and all Chinook salmon, contributing to residualism (a loss of migratory behavior).
- Some juvenile mortality and injury is associated with all routes of dam passage, but turbines generally cause the highest direct mortality rates—generally ranging between 8 and 19 percent.
- The migration of Snake River fall Chinook is slowed or stopped when the fish take refuge in cooler areas (e.g. tributary mouths) and resumes when the general river temperature declines. Delayed adult migration, combined with delayed onset of water temperatures conducive to spawning, delays the onset of spawning. By reducing maximum late summer water temperatures, the Federal Columbia River Power System may have allowed the expression of the fall Chinook yearling outmigration strategy.

Perry, R.W., A. Braatz, M. Novick, J. Lucchesi, G. Rutz, R. Koch, J. Schei, N. Adams, and D. Rondorf. 2007. Survival and migration behavior of juvenile salmonids at McNary Dam, 2005. U.S. Geological Survey, Western Fisheries Research Center, Cook, Washington.

- A significant rate of juvenile mortality (approximately 3-5%) can occur in project forebays, just upstream of the dams where fish can be substantially delayed (median of 15-20 hours) before passing through the dam.
- Perry et al. (2007) found that at McNary Dam in 2005, juvenile mortality associated with the bypass system occurred through predation downstream of the tailrace release outfall (where conditions allowed predators to exploit a point-source stream of bypassed migrants).

Ferguson, J.W., G.M. Matthews, R.L. McComas, R.F. Absolon, D.A. Brege, M.H. Gessel, and L.G. Gilbreath. 2005. Passage of adult and juvenile salmonids through federal Columbia River power system dams. NOAA Tech. Memo. NMFS-NWFSC-64. Available:

http://www.nwfsc.noaa.gov/assets/25/6048_04222005_105920_fishpassagetm64final.pdf. (October 2009).

- Contemporary mechanical screen turbine bypass systems typically have low rates of mortality, less than 2 percent.

Perkins, W.A., and M.C. Richmond. 2001. Long-term, one-dimensional simulation of lower Snake River temperatures for current and unimpounded conditions. Pacific Northwest National Laboratory, Richland, Washington.

- Perkins and Richmond (2001) compared water temperatures in the Lower Snake River for current (impounded) and unimpounded conditions using a mathematical model of the river system.
- The long-term analysis showed that the primary difference between the current and unimpounded river scenarios is that the reservoirs decrease the water temperature variability. The reservoirs also create a thermal inertia effect which tends to keep water cooler later into the spring and warmer later into the fall compared to the unimpounded river condition. Given the uncertainties in the simulation model, inflow temperatures, and meteorological conditions the results show only relatively small differences between current and unimpounded absolute river temperatures.

Axel, G.A., E.E. Hockersmith, D.A. Ogden, B.J. Burke, K.E. Frick, and B.P. Sandford. 2007. Passage behavior and survival for radio-tagged yearling Chinook salmon and steelhead at Ice Harbor Dam, 2005. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington.

- Axel et al. (2007) evaluated the behavior and survival of migrating Snake River yearling Chinook salmon to determine the effects of a recently installed spillway weir at Ice Harbor Dam.
- Survival of migrating Chinook salmon was very high (97%), indicating that the spillway weir was effective in passing fish, while using less water.

Budy, P., G.P. Thiede, N. Bouwes, C.E. Petrosky, and H. Schaller. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. North American Journal of Fisheries Management 22(1):35-51.

- Evidence from literature suggests that mortality that takes place in the estuary and early in their ocean residence is related to earlier hydrosystem experience during downstream migration.
- Recent literature suggests that exposure to hydrosystem facilities causes stress for outmigrating juvenile salmonids and can lead to delayed mortality due to: compromised energetic condition, increased susceptibility to predation, increased susceptibility to disease, and incomplete smoltification.

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine

Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- "Irrigation dams in the lower Shasta River watershed can back up river flow and create impoundments that increase solar input to the river and create habitat supporting non-native fish that prey on juvenile salmonids."
- "Improperly-laddered dams can also impair upstream and downstream dispersal of juvenile coho salmon. To address this issue, restoration funding from CDFG is currently being utilized to remove several irrigation dams (e.g., Aruja and Shasta Valley Water Users Association) along the mainstem Shasta River. Removing these dams should improve water quality conditions while restoring a more natural hydrologic regime."
- "Incentive-based alternatives with willing participants should be investigated as a means of preserving water quality, quantity and coho salmon habitat in the Big Springs area of the upper Shasta River."

Sandford, B.P., and S.G. Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River basin anadromous salmonids, 1990-1997. Journal of Agricultural, Biological, and Environmental Statistics 7(2):243-263.

- Sandford and Smith (2002) found that comparisons of smolt-to-adult return ratio from in-river migrants with different juvenile migration histories showed that, for some stocks in some years, fish entering multiple turbine bypass system channels returned at significantly lower rates than fish that were never detected in a bypass systems.

Tucker, M.E., C.D. Martin and P.D. Gaines. 2003. Spatial and temporal distribution of Sacramento pikeminnow and striped bass at the Red Bluff Diversion Complex, including the Research Pumping Plant, Sacramento River, CA: January 1997 - August 1998. Red Bluff Research Pumping Plant Report Series, Vol. 10. U.S. Fish and Wildlife Service, Red Bluff, California.

- Tucker et al. (2003) found that the temporal distribution of Sacramento pike minnow and striped bass in the Red Bluff Diversion Dam (RBDD) area on the Sacramento River were directly related to RBDD operations. Predators congregated when the dam gates were in, and dispersed when the gates were removed.

Hedgecock, D., M. A. Banks, V. K. Rashbrook, C. A. Dean, and S. M. Blankenship. 2001. Applications of Population Genetics to Conservation of Chinook Salmon Diversity in the Central Valley in Contributions to the Biology of Central Valley Salmonids. Brown, R. L. (ed.), Sacramento, CA: California Department of Fish and Game, pp 45-70.

- Restricted access to historic spawning grounds on the Feather River may be responsible for interbreeding between spring-run and fall-run Chinook salmon in the Lower Feather River.

Fukushima, M., T. P. Quinn, and W. W. Smoker. 1998. Estimation of Eggs Lost from Superimposed Pink Salmon (Oncorhynchus gorbuscha) Redds. Canadian Journal of Fisheries and Aquatic Science 55: 618-625.

- The rate of superimposition is a function of spawning densities and typically occurs in systems where spawning habitat is limited due to passage barriers.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F.W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status Review of Chinook Salmon from Washington, Idaho, Oregon, and California. U.S. Department of Commerce, NOAA Tech. Memo. NMFSNWFSC-35.

- Due to impassable barriers upstream, current spawning in the Central Valley is restricted to the mainstem and a few river tributaries in the Sacramento River, where the habitat is severely degraded.

Merz, J. E., J. D. Setka, G. B. Pasternak, and J. M. Wheaton. 2004. Predicting the benefits of spawning habitat rehabilitation to salmonid fry production in a regulated California River. Canadian Journal of Fisheries and Aquatic Sciences 61: 1433-1446.

- Merz et al. (2004) tested the hypothesis that spawning-bed enhancement increases survival and growth of Chinook salmon embryos in a regulated California stream with a gravel deficit.
- Salmon embryos planted in enhanced gravels had higher rates of survival to the swim-up stage than embryos planted in unenhanced spawning gravels. Intergravel temperature and substrate size were strongly correlated with distance downstream from the lowest nonpassable dam.
- "These findings suggest that spawning-bed enhancement can improve embryo survival in degraded habitat."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "The effects of dam construction and operation on EFH can include 1) migratory impediments, 2) water flow and current pattern shifts, 3) thermal impacts, and 4) limits on sediment and woody debris transport."
- The following are recommended conservation measures to mitigate for Dam effects:
  1. Operate facilities to create flow conditions that provide for passage, water quality, proper timing of life history stages, and properly functioning channel conditions, and to avoid strandings and redd dewatering.
  2. Develop water and energy conservation guidelines for integration into dam operation plans and into regional and watershed-based water resource plans.
  3. Provide mitigation (including monitoring and evaluation) for nonavoidable adverse effects on EFH.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "Juvenile downstream migration patterns have been altered by the presence of dams. Juvenile winter-run, and spring-run on the mainstem Sacramento River, arrive at any given location downstream of Keswick Dam earlier than historical, since they are hatched much further downstream and have less distance to travel. Therefore, in order smolt at the same size and time as historical, they must rear longer within the Sacramento River."

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available: http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (December 2009).

- "In the upper Sacramento River, Lower Feather River, and lower Yuba River, spring-run Chinook salmon spawning may occur a few weeks earlier that fall-spawning, but currently there is no clear distinction between the two because of the disruption of spatial segregation by Shasta and Keswick Dams on the Sacramento River, Oroville Dam on the Feather River, and Englebright Dam on the Yuba River."

Collis, K., S. Adamany, D. Roby, D. Craig, and D. Lyons. 2000. Avian predation on juvenile salmonids in 22 the lower Columbia River. 1998 Annual Report to the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, OR.

- "Study results in 1997 indicated that there were nine major breeding colonies of fish-eating birds that nest on islands in the lower Columbia River and estuary. The majority of these islands are unnatural, created by either the dumping of dredged material or by mainstem dam impoundments."
- "Three Mile Canyon Island and Crescent Island were created by dam impoundment and dredged material disposal, respectively, and so, like Rice Island, are anthropogenic islands. We have few data on the diets of terns nesting at these two upriver colonies but the diet data from Three Mile Canyon Island and the large number of smolt PIT tags recovered at Crescent Island suggest that terns nesting at these two upriver colonies are as or more specialized on juvenile salmonids as a food source compared with terns nesting on Rice Island."

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- "Dams and improperly designed road crossings are obvious impediments to coho salmon passage within the Klamath River Basin, but other less obvious mechanisms can negatively influence fish migration. Insufficient flushing flows can lead to the formation of gravel/sediment berms at tributary confluences, likely impairing adult migration into natal tributary spawning habitat. Preserving cold tributary streamflows and implementing higher mainstem "channel maintenance" flows could alleviate these issues and increase fish passage opportunities within the Klamath HU. Furthermore, removing or modifying the Pacificorp hydropower project with fish ladders could allow coho salmon passage into 30 miles of historic mainstem habitat located above the dams A group representing federal, state, and local governments, as well as other non-governmental groups, is currently discussing passage and dam decommissioning options as part of FERC's proposed relicensing of Pacificorp's project. The outcome of these proceedings has the potential to substantially benefit salmon populations within the basin."

NMFS. 2002b. Biological opinion for the proposed license amendment for the Potter Valley Project (Federal Energy Regulatory Commission Project Number 77-110). National Marine Fisheries Service, Southwest Region. Available: http://swr.nmfs.noaa.gov/psd/Final_Potter_Valley_Project_BO.pdf. (November 2009).

- "Between the project dams on the Eel River there are 12 miles of mainstem spawning and rearing habitat for anadromous fish to rear to smolthood in a regulated system."
- "Scott Dam was constructed in 1921 without fish passage facilities. Anadromous salmon and steelhead have been extirpated from habitat above Lake Pillsbury by the construction of Scott Dam…During hot, dry years if the storage pool is drafted to 15,000 ac-ft before fall-rains, the remaining water is thermally polluted and is released as instream flow usually during September before the onset of cool weather."
- The Potter Valley project has had significant impacts on fish habitat in the Upper Eel River. The project is by far the largest diversion and damming of Eel River flows, and has damaged habitat by lowering summer and early fall flows to the remaining stream below the Project, and by blocking 50 to 150 miles of spawning and rearing habitats above the Project.

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia spring Chinook salmon and steelhead recovery plan. Upper Columbia Salmon Recovery Board. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf. (October 2009).

- "Seven mainstem dams lie between the Wenatchee River and the sea, eight downstream from the Entiat River, and nine between the Methow/Okanogan systems and the estuary. Adult salmon and steelhead losses at each project could be as high as 4% or more in some years (Chapman et al. 1994 and 1995), and juvenile losses at each project can amount to approximately 5-10%. Some of the losses result from physical effects of adult and juvenile/smolt passage. Others derive from altered limnological conditions that increase predation by fish and birds. Whatever the direct causes, losses for Wenatchee adults and juveniles could accumulate to an estimated 25% and 52%, respectively. For Methow River fish, which must pass two additional dams, losses may accumulate to an estimated 31% and 61% for adults and juveniles, respectively. The cumulative loss rates also explain why so much mitigative effort has been allocated to hydroproject-related mortality rates."

McClure, M. M., S. M. Carlson, T. J. Beechie, G. R. Pess, J. C. Jorgensen, S. M. Sogard, S. E. Sultan, D. M. Holzer, J. Travis, B. L. Sanderson, M. E. Power, R. W. Carmichael. 2008. Evolutionary consequences of habitat loss for Pacific anadromous salmonids. Evolutionary Applications 1:300-318.

- "Large portions of anadromous salmonid habitat in the western United States has been lost because of dams and other blockages. This loss has the potential to affect salmonid evolution through natural selection if the loss is biased, affecting certain types of habitat differentially, and if phenotypic traits correlated with those habitat types are heritable. Habitat loss can also affect salmonid evolution indirectly, by reducing genetic variation and changing its distribution within and among populations."
- McClure et al. (2008) compare the characteristics of lost habitats with currently accessible habitats and review the heritability of traits which show correlations with habitat/environmental gradients.
- They found that although there is some regional variation, inaccessible habitats tend to be higher in elevation, wetter and both warmer in the summer and colder in the winter than habitats currently available to anadromous salmonids.
- McClure et al. (2008) present several case studies that demonstrate either a change in phenotypic or life history expression or an apparent reduction in genetic variation associated with habitat blockages. Their results suggest that loss of habitat will alter evolutionary trajectories in salmonid populations and Evolutionarily Significant Units.
- "Changes in both selective regime and standing genetic diversity might affect the ability of these taxa to respond to subsequent environmental perturbations. Both natural and anthropogenic and should be considered seriously in developing management and conservation strategies."

**Dredging**

Newell, R.C., L.J. Seiderer, D.R. Hitchcock. 1998. The impact of dredging on biological resources of the sea bed. Oceanography and Marine Biology Annual Review 336:127-178.

- Dredging adversely affects bottom-dwelling prey species at the site by directly removing or burying immobile invertebrates such as polychaete worms, crustacean, and other Pacific salmon prey types.

EPA. 2000. Environmental screening checklist and workbook for the water transportation industry. Available: www.epa.gov/Region2/capp/cip/water.pdf. (January 2010).

- Dredging can disturb aquatic habitats by resuspending bottom sediments and, thereby, recirculate toxic metals (e.g., lead, zinc, mercury, cadmium, copper etc.), hydrocarbons (e.g., polyaromatics) hydrophobic organics (e.g., dioxins), pesticides, pathogens, and nutrients into the water column (EPA 2000).
- Toxic metals and organics, pathogens, and viruses, absorbed or adsorbed to fine-grained particulates in the material, may become biologically available to organisms either in the water column or through food chain processes.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "The environmental effects of dredging on EFH can include 1) direct removal/burial of organisms; 2) turbidity/siltation effects, including light attenuation from turbidity; 3) contaminant release and uptake, including nutrients, metals, and organics; 4) release of oxygen consuming substances; 5) entrainment; 6) noise disturbances; and 7) alteration to hydrodynamic regimes and physical habitat."
- "Many EFH species forage on infaunal and bottom-dwelling organisms. Dredging may adversely affect these prey species at the site by directly removing or burying immobile invertebrates such as polychaete worms, crustacean, and other EFH prey types (Newell et al. 1998, Van der Veer et al. 1985). Similarly, the dredging activity may also force mobile animals such as fish to migrate out of the project area. Recolonization studies suggest that recovery may not be quite as straightforward. Physical factors including particle size distribution, currents, and compaction/stabilization processes following deposition reportedly can regulate recovery after dredging events. Rates of recovery listed in the literature range from several months for estuarine muds to up to 2 to 3 years for sands and gravels. Recolonization can also take up to 1 to 3 years in areas of strong current but up to 5 to 10 years in areas of low current. Thus, forage resources for benthic feeders may be substantially reduced."
- "The use of certain types of dredging equipment can result in greatly elevated levels of fine-grained mineral particles or suspended sediment concentration (SSC), usually smaller than silt, and organic particles in the water column."
- "Dredging, as well as the equipment used in the process such as pipelines, may damage or destroy spawning, nursery, and other sensitive habitats such as emergent marshes and subaquatic vegetation, including eelgrass beds and kelp beds. Dredging may also modify current patterns and water circulation of the habitat by changing the direction or velocity of water flow, water circulation, or dimensions of the water body traditionally used by fish for food, shelter, or reproductive purposes."
- The following are recommended conservation measures to mitigate for Dredging effects:
  1. Avoid new dredging to the maximum extent practicable. Activities that would likely require dredging (such as placement of piers, docks, marinas, etc.) should, instead, be

sited in deep water areas or designed to alleviate the need for maintenance dredging. Projects should be permitted only for water dependent purposes and only when no feasible alternatives are available.
2. Incorporate adequate control measures to minimize turbidity where the dredging equipment used is expected to create significant turbidity.
3. Undertake multi-season, pre-, and post-dredging biological surveys to assess impacts to animal and submerged aquatic vegetation communities.
4. Provide appropriate compensation for significant impacts (short-term, long-term and cumulative) to benthic environments resulting from dredging.
5. Perform dredging during the time frame when impacts due to entrainment of EFH managed species or their prey are least likely to be entrained. Dredging should be avoided in areas with submerged aquatic vegetation.
6. Reference all dredging latitude-longitude coordinates at the site so that information can be incorporated into a geographical information system (GIS) format. Inclusion of aerial photos may be useful to identify precise locations for long-term evaluation.
7. Test sediments for contaminants as per EPA and USACE requirements.
8. Address cumulative impacts of past and current dredging operations on EFH by considering them as part of the permitting process.
9. Identify excess sedimentation in the watershed that prompts excessive maintenance dredging activities and implement appropriate management techniques to ensure that actions are taken to curtail those causes.
10. Ensure that bankward slopes of the dredged area are slanted to acceptable side slopes (e.g., 3:1) to ensure that sloughing does not occur.
11. Avoid placing pipelines and accessory equipment used in conjunction with dredging operations to the maximum extent possible close to kelp beds, eelgrass beds, estuarine/salt marshes, and other high value habitat areas.

Nightingale, B., and C.A. Simenstad. 2001. Dredging activities: Marine issues. White Paper, Research Project T1803, Task 35, Overwater Whitepaper. University of Washington, Seattle, WA. http://depts.washington.edu/trac/bulkdisk/pdf/507.1a.pdf

- "…synthesizes scientific information on the effects of dredging activities on marine habitats. Direct and long-term effects, dredge methods, regulatory framework, contaminated sediment issues, and a separate bibliography of contaminated sediment-related reports are also presented."
- "…maintenance dredging conversion of shallower subtidal to deeper subtidal habitats is much more frequent than new construction dredging conversion of intertidal to subtidal habitats, which is rarely allowed." – loss of intertidal and shallow subtidal coastal habitats creates a potential loss in production and carrying capacity – recovery rates range from months to years, but are difficult to quantify based on lack of long-term pre- and post-project monitoring
- Direct effects of dredging:
    - Entrainment mortalities

    - Behavioral effects
    - Contaminant release
    - Increased turbidity
    - Fish injury due to suspended sediment exposure
    - Decreased dissolved oxygen levels
    - The effects of noise
- "Most relevant issue is likely the fish ability to avoid plumes and dredge areas…clearer understanding of the effects of dredging on a variety of marine fishes would come from a further synthesis of what is known about the life-history strategies, water column use, and timing of a wide variety of marine fishes in specific areas. This would enable further development of site- and species-specific environmental windows to avoid entrainment and limit risks."
- Provides a list of specific recommendations to limit the effects of dredging on marine organisms

Harvey, B.C., and T.E. Lisle. 1998. Effects of suction dredging on streams: A review and an evaluation strategy. Fisheries 23(8):8-17.

- "Suction dredging for gold in river channels is a small-scale mining practice whereby streambed material is sucked up a pipe, passed or a sluice box to sort out the gold, and discarded as tailings over another area of bed…The scientific literature contains few peer-reviewed studies of the effects of dredging, but knowledge of dredging practices, and the biology and physics of streams suggests a variety of mechanisms linking dredging to aquatic resources."
- "Fishery managers should be especially concerned when dredging coincides with the incubation of embryos in stream gravels or precedes spawning runs soon followed by high flows. We recommend that managers carefully analyze each watershed so regulations can be tailored to particular issues and effects."
- Authors suggest that current level of uncertainty about the effects of dredging requires managers to operate under the assumption that dredging is harmful to aquatic resources
- Authors suggest a strategy to:
    - "evaluate interactions between suction dredging and other activities and resources;
    - use this information to regulate dredging and other activities;
    - monitor implementation of regulations and on- off-site effects of dredging; and
    - adapt management strategies and regulations according to new information."

**Estuarine Alteration**

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- Puget Sound has been heavily altered by human development, with 33% of shorelines modified with bulkheads or other armoring and 73% of wetlands in major deltas of Puget Sound rivers have been lost in the last 100 years.
- The Salmon Recovery Funding Board has awarded $195 million in grants to improve degraded salmon habitat, including fixing and removing 132 barriers to fish migration, riparian vegetation plantings along 96 miles of streams, removing 19 dikes and tide gates to allow freshwater and saltwater to mix to create 6 miles of transition habitat for out-migrating salmon, and working with landowners to protect habitat through conservation easements and property acquisitions.

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- With changes in the Columbia River flow regime, the availability of shallow (between 10 cm and 2 m depth), low-velocity (less than 30 cm/s) habitat in the Columbia River Estuary now appears to decrease at a steeper rate with increasing flow than during the 1880s, and the absorption capacity of the estuary appears to have declined.

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. NOAA Tech. Memo., NMFS-NWFSC-69.

- Fresh et al. (2005) found that estuarine habitats clearly contribute to the viability and persistence of salmon populations in a number of ways. The amount of estuarine habitat that is accessible affects the abundance and productivity of a population. The distribution, connectivity, number, sizes, and shapes of estuarine habitats affect both the life history diversity and the spatial structure of a population.

Clark, K. W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson. 2009. Quantification of pre-screen loss of juvenile steelhead in Clifton Court Forebay. California Department of Water Resources Bay-Delta Office, Sacramento, CA.

- The California Department of Water Resources (DWR) conducted a study in 2005, 2006, and 2007 to assess and quantify steelhead pre-screen losses within Clifton Court Forebay of California's State Water Project.
- Results of the steelhead pre-screen loss studies indicated that the pre-screen loss of PIT tagged juveniles steelhead is between 78 ±4% and 82 ±3% within Clifton Court Forebay.
- "As striped bass continue to be linked to pre-screen loss, the predator removal investigations conducted in the 1990's should be revisited. Moderate reductions in predator numbers could yield an increase in steelhead survival. Facilitating greater public fishing pressure may assist in this regard."

- "Additionally, as avian predation was shown to occur, further avian predation investigations should be conducted with an emphasis on diet composition and consumption-rate. Avian diet composition and consumption rate studies would provide information on prey selectivity of the avian predators near the radial gates and the magnitude of pre-screen loss rate due to avian predation."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "Dikes, levees, ditches, or other water controls at the upper end of a tidal marsh can cut off all tributaries feeding the marsh, preventing freshwater flushing and annual flushing, annual renewal of sediments and nutrients, and the formation of new marshes. Water controls within the marsh proper intercept and carry away freshwater drainage, block freshwater from flowing across seaward portions of the marsh, increase the speed of runoff of freshwater to the bay or estuary, lower the water table, permit saltwater intrusion into the marsh proper, and create migration barriers for aquatic species. In deeper channels where reducing conditions prevail, large quantities of hydrogen sulfide are produced that are toxic to marsh grasses and other aquatic life. Acid conditions of these channels can also result in release of heavy metals from the sediments."
- "Long-term effects on the tidal marsh include land subsidence (sometimes even submergence), soil compaction, conversion to terrestrial vegetation, greatly reduced invertebrate populations, and general loss of productive wetland characteristics. Loss of these low-salinity environments reduces estuarine fertility, restricts suitable habitat for aquatic species, and creates abnormally high salinity during drought years. Low-salinity environments form a barrier that prevents the entrance of many marine species, including competitors, predators, parasites and pathogens."
- The following are recommended conservation measures to mitigate for Estuarine Alteration effects:
- 1. Minimize the loss of riparian habitats as much as possible.
- 2. The diking and draining of tidal marshlands and estuaries should not be undertaken unless a satisfactory compensatory mitigation plan is in effect and monitored.
- 3. Wherever possible, "soft" approaches (such as beach nourishment, vegetative plantings, and placement of large woody debris) to shoreline modifications should be utilized.
- 4. Include efforts to preserve and enhance EFH by providing new gravel for spawning areas; removing barriers to natural fish passage; and using weirs, grade control structures, and low flow channels to provide the proper depth and velocity for fish.
- 5. Construct a low-flow channel to facilitate fish passage and help maintain water temperature in reaches where water velocities require armoring of the riverbed.
- 6. Replace in-stream fish habitat by providing rootwads, deflector logs, boulders, rock weirs and by planting shaded riverine aquatic cover vegetation.

- 7. Use an adaptive management plan with ecological indicators to oversee monitoring and ensure mitigation objectives are met. Take corrective action as needed.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "Outmigrant juvenile salmonids in the Delta have been subjected to adverse environmental conditions created by water export operations at the CVP and SWP facilities. Specifically, juvenile salmonid survival has been reduced by: (1) water diversion from the mainstem Sacramento River into the Central Delta via the Delta Cross Channel (DCC); (2) upstream or reverse flows of water in the lower San Joaquin River and southern Delta waterways; (3) entrainment at the CVP/SWP export facilities and associated problems at Clifton Court Forebay; and (4) increased exposure to introduced, non-native predators such as striped bass (Morone saxatilis), largemouth bass (Micropterus salmoides), and sunfishes (Centrarchidae spp.) within the waterways of the Delta while moving through the Delta under the influence of CVP/SWP pumping."

Bottom, D.L., C.A. Simenstad, J. Burke, A.M. Baptista, D.A. Jay, K.K. Jones, E. Casillas, and M.H. Schiewe. 2005. Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. NOAA Tech. Memo., NMFS-NWFSC-68.

- "The results indicate that habitat and food-web changes within the estuary and other factors affecting salmon population structure and life histories have altered the estuary's capacity to support juvenile salmon. Diking and filling activities that decrease the tidal prism and eliminate emergent and forested wetlands and floodplain habitats have likely reduced the estuary's salmon-rearing capacity."
- "Restoration of estuarine habitats, particularly diked emergent and forested wetlands, and flow manipulations to restore historical flow patterns might significantly enhance the estuary's productive capacity for salmon. It is possible that historical changes in population structure and salmon life histories, however, prevent salmon from fully utilizing the productive capacity of estuarine habitats even in their presently altered state. Therefore, efforts to improve or restore the estuary for salmon must be developed in concert with hatchery, harvest, and upriver habitat improvements to recover those life history types that can benefit from estuary restoration."
- "A sound historical and evolutionary context for interpreting modern estuarine habitat conditions and for developing salmon recovery strategies is needed. Without proper context, recovery actions may inappropriately target those few salmon life history types and habitats that are abundant today, further reinforcing salmon decline symptoms rather than expanding the basin's productive capacity. A strategy that continues emphasis on improving survival of a few Chinook salmon (O. tshawytscha) dominant types, particularly large hatchery yearlings and subyearlings with short estuarine residence times, may further narrow the distributions of size, migration timing, and

rates of migration. This would result in concentrated use of the estuary and thus would prevent salmon from utilizing its full productive potential."

- The following specific recommendations are offered for restoring the Columbia River's estuary:
    1) Adopt an Explicit Ecologically Based Conceptual Framework for Estuary Management and Restoration.
    2) Protect and Restore Opportunity for Salmon to Access Emergent and Forested Wetlands in the Estuary and Riparian Wetlands in the Tidal Floodplain.
    3) Reacquire Phenotypic Diversity of Salmon, Including a Broader Range of Sizes, Times of Entry, and Periods of Residency in the Estuary.
    4) Monitor Variations in Life History Diversity, Habitat Use, and Performance of Juvenile Salmon in the Estuary.
    5) Review the Scientific Basis for Proposed Habitat and Bathymetric Changes in the Estuary Relative to the Restoration Goals of the Columbia Basin Fish and Wildlife Program.
    6) Use Physical Observations and Hydrodynamic Modeling to Assess the Effects of Bathymetric Change, Flow Regulation, and Alternative Restoration Designs on Habitat Opportunity for Juvenile Salmon.
    7) Review Results of Estuarine Predation Studies in the Context of Salmon Population and Habitat Change.
    8) Assess the Effects of Altered Habitats and Food Webs on the Capacity of the Estuary to Support Juvenile Salmon.

Schmetterling, D. A., C. G. Clancy, and T. M. Brandt. 2001. Effects of riprap bank reinforcement on stream salmonids in the western United States. Fisheries 26(7): 6-23.

- "Riprap may provide habitat for juvenile salmonids and bolster densities on reaches of streams that have been severely degraded. However, riprap does not provide the intricate habitat requirements for multiple age classes or species provided by natural vegetated banks. Streambanks with riprap have fewer undercut banks, less low-overhead cover and are less likely than natural stream banks to contribute large woody debris to the stream. Lateral streambank erosion."
- "The use of natural materials (i.e., LWD, trees, rootwads, etc.) in bank reinforcement and restoration is a growing practice. These "soft" techniques aim to slow the rate of erosion rather than completely stop lateral erosion."

USBR. 2008. Central Valley Project and State Water Project operations criteria and plan biological assessment. U.S. Bureau of Reclamation Mid-Pacific Region, Sacramento, California.

- "As juvenile salmon from the Sacramento basin migrate through the Delta toward the Pacific Ocean, they encounter numerous junctions in the river and Delta channels (both natural and human-made). Tow such junctions are located near Walnut Grove at the

Delta Cross Channel (DCC) (a man-made channel with operable gate at the entrance) and Georgiana Slough (a natural channel)."

- "Significant amounts of flow and many juveniles salmon from the Sacramento River enter the DCC (when gates are open) and Georgiana Slough. Mortality of juvenile salmon entering the central Delta is higher than for those continuing downstream in the Sacramento River. This difference in mortality could be caused by many factors: the longer migration route through the central Delta to the western Delta, exposure to higher water temperatures, higher predation rates, exposure to seasonal agricultural diversions, water quality impairments due to agricultural and municipal discharges, and a more complex channel configuration making it more difficult for salmon to successfully migrate to the western Delta and ocean."

U.S. Fish and Wildlife Service. 2000. Impacts of riprapping to ecosystem functioning, lower Sacramento River, California. U.S. Fish and Wildlife Service, Sacramento Field Office, Sacramento, California. U.S. Fish and Wildlife Service, Sacramento Field Office, Sacramento, California. Prepared for US Army Corps of Engineers, Sacramento District.

- Like many large rivers, the lower Sacramento River exhibits fragmentation and disconnection from ecological processes. Much of the degradation results from river meandering and erosion being Over half (more in certain reaches) of the Sacramento River's banks within the lower 194 miles have been riprapped, mainly from 4 decades of work by the Corps of Engineers' Sacramento River Bank Protection Project (SRBPP).
- Riprapping prevents the recruitment of new LWD along the armored banks, and it reduces the retention of LWD inputted from nonarmored areas. The cumulative loss of LWD functioning for the lower river is now at least 67-90 percent, or more, compared to pre-SRBPP conditions.
- The use of set-back levees to achieve bank protection goals offers the best mitigation solution. Set-back levees allow both site- and reach-level impacts to be fully avoided, and they maximize habitat enhancement opportunities.

**Forestry**

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- Several large tributaries in the Klamath Glen HSA historically supported healthy coho salmon populations, but timber harvesting and construction of the associated road network has impaired instream habitat conditions throughout much of the HSA.
- For example, McGarvey, Tarup, Tectah, and Ah Pah Creeks all suffer from excessive sediment input that has simplified instream habitat, limited food production, and lowered spawning and rearing success.

- High sediment loads resulting from upslope timber harvesting and road building in the Scott River watershed have simplified tributary rearing habitat, while sediment flushed from those tributaries often accumulates at tributary confluences, impairing mainstem-tributary connectivity.

Voight, H.N., and D.B. Gale. 1998. Distribution of fish species in tributaries of the lower Klamath River: an interim report, FY 1996. Yurok Tribal Fisheries Program, Habitat Assessment and Biological Monitoring Division Technical Report No. 3, Klamath, California.

- In many Klamath River tributaries large sediment loads (resulting from timber harvesting and construction of the associated road network) have accumulated at their confluence with the Klamath River, potentially interrupting tributary dispersal of coho salmon during winter months.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "Four major categories of forestry activities can adversely affect EFH: 1) construction of logging roads, 2) creation of barriers, 3) removal of streamside vegetation, and 4) disturbance associated with log transfer facilities."
- "Logging road construction can destabilize slopes and increase erosion and sedimentation. Two major types of erosion occur: mass wasting and surface erosion. Mass movement of soils, commonly referred to as landslides or debris slides, is associated with timber harvest and road building on high hazard soils and unstable slopes. Both frequency and size of debris slides are increased when logging roads are built on, or timber is harvested from, these unstable land forms. The result is increased erosion and sediment deposition in downslope waterways."

Flanders, L.S., J. Cariello. 2000. Tongass road condition survey report. Technical Report 00-7. Douglas, AK: Alaska Department of Fish and Game, Southeast Regional Office of the Habitat and Restoration Division.

- Logged streams have been associated with higher water temperatures, lower base flows and higher peak flows, and low oxygen levels that have resulted in significant mortalities of pink and chum salmon.

Beschta, R.L., M.R. Pyles, A.E. Skaugset, C.G. Surfleet. 2000. Peak flow response to forest practices in the western Cascades of Oregon, U.S.A. Journal of Hydrology 233:102-120.

- The effects of clearcut silviculture were evaluated using long-term peakflow records for three small watersheds (60-101 ha) and six large basins (62-640 km2) in the western Cascades of Oregon, USA.
- In the smaller basins, clearcut silviculture lead to increases in flood flows.

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- "Bad roads have not only contributed excessive sediment loads to the stream system through erosion of road surfaces, cut and fill slopes, and road ditches, they have also increased the erosiveness of the stream environment by channelizing diffuse flow and delivering it rapidly to the stream, thereby increasing peak flows."
- "The effect of forestry activities on erosion is largely associated with the creation and use of the transportation system, especially during wet periods . Selective harvest practices and riparian buffers effectively minimize the direct delivery of sediment to streams from logging practices."

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- "The amount of historic timber harvest activities and the manner in which forestry was historically practiced have also contributed significantly to the decline in local salmon populations. Timber harvesting in riparian zones and on steep or unstable slopes, inappropriate forest road construction, and draining of forested wetlands have altered the delivery and rate of water to rivers, increased the amount of loose sediment, limited the amount of large woody debris entering rivers, raised water temperatures, and generally altered other important freshwater salmon and bull trout habitat conditions needed by all life stages."
- "Increased frequency and magnitude of high stream flows is due in part to the loss of forest cover from timber harvesting and the routing of surface runoff from forest roads into streams; thus the naturally challenging hydrology of the basin is exacerbated. High flows have contributed to scouring upstream salmon spawning beds, and smothering downstream spawning beds with high sediment levels. Peak flows may also flush juvenile salmon out of normally slower moving reaches of the river that are used for rearing habitat. In the future, climate change may lead to wetter winters and drier summers, aggravating the current flow challenges."

NMFS. 2002b. Biological opinion for the proposed license amendment for the Potter Valley Project (Federal Energy Regulatory Commission Project Number 77-110). National Marine Fisheries Service, Southwest Region. Available: http://swr.nmfs.noaa.gov/psd/Final_Potter_Valley_Project_BO.pdf. (November 2009).

- "Ongoing forest activities on non-Federal lands are likely to continue to degrade essential salmonid habitat values. Environmental impacts identified with timber harvest may include increased sediment production from roads and other sources, loss of large woody debris recruitment, reduced function of riparian areas, reductions in water quality and quantity, increased water temperatures and loss of channel complexity."

EPA. 1998. South Fork Trinity River and Hayfork Creek Sediment Total Maximum Daily Loads. U.S. EPA Region 9. 75 pp. Available: http://www.epa.gov/region09/water/tmdl/trinityso/fsftmdl.pdf. (December 2009).

- "Roads, skid trails and landings in the South Fork basin that are improperly located,designed, constructed or maintained may cause: 1) increased surface erosion and chronic fine sediment production and delivery to streams, and 2) episodic and occasionally catastrophic delivery of fine and coarse sediment to streams from crossing failures, gully development and landslides generated from improper placement. This has direct and immediate adverse impacts immediately downstream from the failures, but it can also affect areas much farther downstream and much farther into the future. This appears to be especially problematic in the highly erodible and unstable geologic terranes in the western third of the watershed."

NMFS. 2010b. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service, Southwest Region.

- "Substantial timber harvesting has occurred throughout the Southern Oregon/Northern California Coast (SONCC )coho salmon ESU. In many SONCC coho salmon streams, lack of large woody debris results in decreased cover and reduced storage of gravel and organic debris. Lack of large woody debris (LWD) has also resulted in loss of pool habitat and a reduction in overall habitat and hydraulic complexity in a variety of coho salmon streams. LWD also provides cover from predators and shelter from high flow events.
- "Timber harvest actions combined with rainfall events can cause stream bank erosion, landslides, and mass wasting, resulting in higher sedimentation rates than historical amounts throughout the SONCC coho salmon range. This can cause a reduction in food supply, increases in fine sediments which can destroy spawning gravels, and increase severity of peak flows during storm season. The removal of overhead canopy cover results in increased solar radiation reaching the stream, which results in increased water temperatures."
- "Several forest practices and management plans have been enacted in the Klamath Basin. The Northwest Forest Plan (NFP) is an integrated, comprehensive design for ecosystem management, intergovernmental and public collaboration, and rural community economic assistance for federal forests in western Oregon, Washington, and northern California. Since adoption of the NFP in 1994, timber harvest and road building have decreased dramatically on federal lands within the range of the Northern spotted owl, including federal lands within the Klamath River Basin [i.e., Six River Klamath, and Shasta-Trinity National Forests] and road decommissioning has increased."

**Grazing**

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009)

- Grazing by sheep and cattle removes riparian vegetation and eliminates natural shade. The lack of shade frequently results in increased water temperatures. The reduced input of leaves, insects, and other organic material limits the amount of food available to fish and their prey. Trampling of stream banks by grazing cattle can cause the banks to collapse, increasing the input of fine sediment. Fecal material from cattle can introduce excessive concentrations of nutrients which, in warm, slow-moving streams, can result in low levels of dissolved oxygen (eutrophication).

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- The lower reaches of Klamath River estuarine tributaries such as Salt Creek, Hunter Creek and Terwer Creek often suffer from poor water quality and compromised riparian function, primarily due to unregulated cattle grazing adjacent to the stream channel.
- Riparian fencing projects implemented in cooperation with willing landowners would immediately improve habitat conditions within these critical watersheds by minimizing streambank erosion and rehabilitating riparian habitat, but further study will ultimately be necessary to fully understand how the lower Klamath River estuary and associated off-channel habitat function to provide for the different life stages of anadromous salmonids.

Bayley, P. B. and H. W. Li. 2008. Stream fish responses to grazing exclosures. North American Journal of Fisheries Management 28:135-147.

- Eight paired reaches of northeastern Oregon streams were selected such that one reach was an established livestock exclosure and a neighboring, geomorphologically similar reach was open to grazing.
- The greater density of age-0 O. mykiss in exclosures was attributed to the potential food supply and to increases in undercut banks, instream bank vegetation, width : depth ratio, and several riparian vegetation variables.
- These results are promising with respect to improvement of salmonid habitat through prevention of grazing, but the exclosures are too small and infrequent to be effective at the population or basin-wide level.

Strand, M., and R. W. Merritt. 1999. Impacts of livestock grazing activities on stream insect communities and the riverine environment. American Entomologist 45(1): 13-26.

- "Much of the riparian habitat along western rangeland has been altered fundamentally by livestock grazing… Relatively simple habitat restoration measures, including cattle exlusion and bank stabilization, have proved quite successful in reversing this trend and promoting recovery of native riparian vegetation.  Vegetative recovery has, in turn, improved instream conditions for trout and their invertebrate prey in rangeland streams."

Clary, W.P., and W.H. Kruse.  2003.  Chapter 11: Livestock grazing in riparian areas: environmental impacts, management practices and management implications.  *In*  Baker, M.B. et al. (eds) Riparian areas of the southwestern United States: hydrology, ecology, and management.  CRC Press LLC, Boca Raton, FL.

- "Excessive grazing and trampling impacts by cattle and other ungulates causes mechanical damage to shrubs and small trees, reduction or elimination of woody seedlings and saplings, exposed soils, shift of herbaceous species from native species to weedy or exotic species with root systems that have lesser soil-holding capabilities and widening or encasement of stream channels."
- The following are grazing management principles recommended to preserve riparian habitat:
    - Grazing during seasons when grazing habitat is less vulnerable to degradation
    - Rotate the areas utilized for livestock grazing to prevent over-use of any riparian area
    - Adjust grazing season to coincide with times when livestock are more attracted to upland areas
    - Manage grazing to retain adequate herbaceous vegetation cover and height on streambanks and overflow areas to promote protection of streambanks, reduce use of riparian plant communities, encourage sediment entrapment and bank building, dissipate stream energy and improve aquifer recharge.
    - Allow for adequate regrowth time and rest for plants that are grazed.
    - Monitor grazing activities because changes can occur rapidly in riparian areas.
    - Active, continuous, hands-on management is required to have a successful riparian grazing management program.

Saunders, W.C., and K.D. Fausch. 2007. Improved grazing management increases terrestrial invertebrate inputs that feed trout in Wyoming rangeland streams. Transactions of the American Fisheries Society 136(5):1216-1230.

- "Research in forest and grassland ecosystems worldwide indicates that terrestrial invertebrates can be a significant source of prey for fish, providing about 50% of their annual energy."
- Authors examined the importance of terrestrial invertebrates as a prey source for brown trout *Salmo trutta* and brook trout *Salvelinus fontinalis* in rangeland streams and how it can be modified by grazing practices – sampled falling invertebrate input and trout diets in five pairs of streams with either high-density, short-duration (HDSD) grazing or season-long (SL) grazing
- Biomass of riparian vegetation and terrestrial invertebrate input were 2-3 times greater in HDSD reaches than SL reaches, but differences were only significant during late summer due to high variability

- 57% of afternoon diets in both reaches consisted of terrestrial prey
- Total trout biomass was more than twice as high in HDSD reaches compared to SL reaches – suggests that grazing practices have the potential to influence terrestrial invertebrate input and fish populations.

Gregory, J.S., and B.L. Gamett. 2009. Cattle trampling of simulated bull trout redds. North American Journal of Fisheries Management 29(2):361-366.

- "Listing of bull trout *Salvelinus confluentus* under the Endangered Species Act and concerns over livestock stepping on bull trout redds have led many U.S. Department of Agriculture Forest Service managers to remove livestock from bull trout spawning areas once spawning begins…policy has extensive ramifications for livestock producers…a lack of data precludes evaluation of the benefit of livestock removal to bull trout populations."
- Authors used simulated bull trout redds to assess the probability that cattle in grazing allotments would step on redds
- "During the 14-21 day grazing period, 15-83% of the simulated redds were affected by trampling. When the control period was standardized to the same time period as the treatment, cattle were found to be responsible for affecting 12-78% of simulated redds and breaking 6-49% of the clay targets. Impacts were higher in pastures where cattle stocking intensity was higher, but impacts were also determined by site conditions adjacent to the simulated redds."

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54:419-431.

- "Livestock seek out water, succulent forage, and shade in riparian areas, leading to trampling and overgrazing of streambanks, soil erosion, loss of streambank stability, declining water quality, and drier, hotter conditions. These changes have reduced habitat for riparian plant species, cold-water fish, and wildlife, thereby causing many native species to decline in number or go locally extinct. Such modifications can lead to large-scale changes in adjacent and downstream ecosystems."
- "…recent studies clearly document that livestock continue to degrade western streams and rivers, and that riparian recovery is contingent upon total rest from grazing."
- Paper summarizes effects of grazing on streams and riparian areas in the western U.S. through review of results of published experimental studies and comparative studies of grazed vs. protected areas
- "Livestock grazing was found to negatively affect water quality and seasonal quantity, stream channel morphology, hydrology, riparian zone soils, instream and streambank vegetation, and aquatic and riparian wildlife. No positive environmental impacts were found. Livestock were also found to cause negative impacts at the landscape and regional levels…most recent scientific studies document that livestock grazing continues to be detrimental to stream and riparian ecosystems in the West."

Zoellick, B.W. 2004. Density and biomass of redband trout relative to stream shading and temperature in southwestern Idaho. Western North American Naturalist 64(1):18-26.

- Examined density and biomass of redband trout in relation to stream temperature in headwater reaches of two creeks in southwestern Idaho
- The two study creeks differed in shading (80% vs. 46%) and solar insolation (7.9 vs. 15.1mJ/m$^2$/day)
- "Trout density was negatively correlated with increases in water temperatures and solar insolation in both streams. Trout biomass increased with stream shading and was negatively correlated with solar insolation. Warmer water temperatures in Big Jacks Creek were likely due to historical summerlong livestock grazing, which drastically reduced riparian shading."
- Found almost 3-fold difference in trout density and biomass between the grazed and ungrazed (shaded and unshaded) stream.

Carline, R.F., and M.C. Walsh. 2007. Responses to riparian restoration in the Spring Creek watershed, central Pennsylvania. Restoration Ecology 15(4):731-742.

- Applied experimental treatments designed to enhance riparian habitats and stream function in two grazed streams in central Pennsylvania and compared treatment streams to one ungrazed control stream – monitored treatment streams before and 3-5 years after treatment
- "Few changes were found in channel widths and depths, but channel-structuring flow events were rare in the drought period after restoration. Stream bank vegetation increased from 50% or less to 100% in nearly all formerly grazed riparian buffers. The proportion of fine sediments in stream substrates decreased in Cedar Run but not in Slab Cabin Run (both treatment streams). After riparian treatments, suspended sediments during base flow and storm flow decreased 47-87% in both streams. Macroinvertebrate diversity did not improve after restoration in either treated stream. Relative to Spring Creek (control stream), macroinvertebrate densities increased in both treated streams by the end of the posttreatment sampling period."
- "Despite drought conditions that may have altered physical and biological effects of riparian treatments, goals of the riparian restoration to minimize erosion and sedimentation were met. A relatively narrow grass buffer along 2.4km of each stream was effective in improving water quality, stream substrates, and some biological metrics."
- "Excluding livestock from the riparian zone allowed grasses to quickly colonize and stabilize stream banks."

Clary, W.P. 1999. Stream channel and vegetation responses to late spring cattle grazing. Journal of Range Management 52(3):218-227.

- Conducted 10-year grazing study on a cold, mountain meadow riparian system in central Idaho – established six pastures to study the effects of no grazing, light grazing (20-25% utilization), and medium grazing (35-50% utilization) during late June – treatments were in comparison to heavier historic grazing

- "Stream channels narrowed, stream width-depth ratios were reduced, and channel bottom embeddedness decreased under all 3 grazing treatments…Streambank stability increased and streamside willow communities increased in both height and cover under all 3 treatments. Plant species richness increased on both streamside and dry meadow areas during the years of grazing and moderate drought. The numbers of species receded to near original levels in the ungrazed and light grazed pastures in 1996, a wet post-grazing year, primarily due to a decrease in forb species. Streamside graminoid height growth was similar among treatments after 1 year of rest."
- "Most measurements of streamside variables moved closer to those beneficial for salmonid fisheries when pastures were grazed to 10 cm of graminoid stubble height; virtually all measurements improved when pastures were grazed to 14 cm stubble height, or when pastures were not grazed. Many improvements were similar under all 3 treatments indicating these riparian habitats are compatible with light to medium late spring use by cattle."
- Authors suggest that all three treatments applied were within the annual ability of the site to recover from grazing
- Suggest that 10-15 cm of forage stubble should remain after the grazing season to limit potential impacts to riparian plant communities.

McIntosh, B.A., J.R. Sedell, R.F. Thurow, S.E. Clarke, G.L. Chandler. 2000. Historical changes in pool habitats in the Columbia River Basin. Ecological Applications 10(5):1478-1496.

- Compared a historical stream survey (1934-1945) to a current stream survey (1987-1997) to assess changes in pool frequencies in the Columbia River Basin
- "…the frequencies of large and deep pools have decreased significantly since the 1930s…In natural streams (watersheds minimally affected by human activities), large-pool frequencies increased or remained the same in 96% of the streams. In commodity streams (watersheds managed predominately for extraction of resources), large- and deep-pool frequencies decreased in 52% and 54% of the streams, respectively. Despite differences in stream size and the level of human activities, the magnitude and direction of these changes were consistent. Land ownership did not influence trends; pools decreased significantly on both private and public lands. Only where entire watersheds or headwaters were designated as wilderness or roadless areas did pools consistently remain unchanged or increase."
- "We conclude that the persistent effects of human activities have simplified stream channels and reduced large- and deep-pool frequencies in watersheds outside of designated wilderness and road-less areas in the Columbia River Basin."
- Spatial resolution for specific land-use practices was too coarse to tie specific practices to individual watersheds, so no cause-and-effect relationship could be determined
- Article provides a very good historical summary of grazing and grazing practices in the Pacific Northwest.

Scrimgeour, G.J., and S. Kendall. 2002. Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. Environmental Management 29(6):824-844.

- Used livestock enclosures and stream surveys to evaluate the effects of livestock grazing on riparian and stream attributes, water chemistry, and algal biomass over a two-year period in the Cypress Hills grassland plateau, Alberta, Canada
- Livestock enclosures consisted of four treatments partially replicated in three streams
    - Early season grazing (June-August)
    - Late season grazing (August-September)
    - All season grazing (June-September)
    - Livestock absent controls
- "Livestock grazing significantly decreased streambank stability, biomass of riparian vegetation, and the extent to which aquatic vegetation covered the stream channels compared with livestock-absent controls. Water quality comparisons indicated significant differences among the four livestock grazing treatments in Battle and Graburn creeks but not in Nine Mile Creek. In Graburn Creek, the concentration of total phosphorus in the all-season livestock grazing treatment was significantly higher than that in the livestock-absent control, and the early season and late season grazing treatments. Concentrations of soluble reactive phosphorus in the all-season livestock grazing treatment also exceeded that in livestock-absent control. In contrast, differences in water quality variables in the remaining 22 comparisons were minor even when differences were statistically significant. Effects of livestock grazing on algal biomass were variable, and there was no consistent pattern among creeks. At the watershed scale, spatial variation in algal biomass was related with concentrations of $NO_2^-$ and $NO_3^-$ and soluble reactive phosphorus in two of the four study creeks…exclusion of livestock for the two summer-fall periods typically resulted in a three- to fivefold increase in riparian vegetation biomass and a twofold increase in the extent to which vegetation covered stream channels."
- Authors found no meaningful differences in early vs. late grazing treatments
- Authors suggest that a natural disturbance grazing schedule similar to historic bison grazing (i.e., large amount of grazing and then time of recovery with no grazing) would be acceptable to both conservation groups and managers

Manoukian, M., and C.B. Marlow. 2002. Historical trends in willow cover along streams in a southwestern Montana cattle allotment. Northwest Science 76(3):213-220.

- Used air photos taken in 1942, 1965, and 1987 to measure willow canopy cover along streams within a USDA Forest Service grazing allotment
- Compared cover from each year to assess changes over the 46-year record – goal was to assess effectiveness of changes in livestock grazing management
- "Willow canopy cover fluctuated along the streams in the allotment, but the general trend was upward from 1942 to 1987. Willow stem population demography was evaluated to ascertain whether historic grazing patterns had affected stem replacement.

Stem age classes were normally distributed with a replacement cycle similar to those reported in other areas of the western United States and Canada. These data suggest that extended periods of rest (>3 yr) are not necessary for willow recovery if livestock or wildlife use is closely controlled…Short rest periods (<3 yr) are probably inadequate for willow recovery without concurrent changes in season and intensity of use."

- "…it appears that cattle grazing during 1942 to 1987 did not affect natural turnover patterns and that individual willows could continue to produce replacement stems at a sufficient rate under rest rotation grazing to expand willow canopy cover."
- "…the 46-yr photographic record of Long Creek indicates that long periods of nonuse can be avoided through close control of season and intensity of ungulate use. The photo record also supports the recommendation…that grazing practices might have to be in place for several decades before degraded riparian vegetation begins to improve."

Humphrey, J.W., and G.S. Patterson. 2000. Effects of late summer cattle grazing on the diversity of riparian pasture vegetation in an upland conifer forest. Journal of Applied Ecology 37(6):986-996.

- Authors present results from 9 years of monitoring the effects of cattle grazing on the diversity and composition of riparian pasture vegetation in an upland conifer forest in northern Scotland – used two treatments:
    - Late summer grazing (average stocking density 2.25-2.5 cows/ha – free range over 40-ha experimental site from early August to late September)
    - ungrazed
- Assessments of plant species richness and abundance were made prior to grazing in 1988, and in 1991 and 1997 in the three main vegetation types – calcareous springs, acid grassland, and rush pasture
- "Grazing had a significant effect on plant species richness, which declined in ungrazed plots and remained static in grazed plots over the 1988-97 period. There were no recorded effects of grazing on species abundance, nor on the frequency of rare sedges and herbs of particular conservation importance. Litter cover (dead plant material) was significantly higher in ungrazed plots, which may be a causal factor in declining richness values."
- Cattle utilized acid grassland and calcareous spring vegetation to a significantly greater degree than rush vegetation, but utilization appeared to be related to availability
- "Cattle grazing is of potential value as a management tool for species-rich grasslands in upland forests provided that: areas to be grazed are large enough to minimize localized impacts and allow free ranging of the cattle; the economics and practicalities of stock husbandry are considered; the type of grazing management used is linked clearly to management objectives…Over the experimental period cattle grazing has been effective in preventing a decline in plant species richness in all three of the vegetation types under study."

Weigel, B.M., J. Lyons, L.K. Paine, S.I. Dodson, and D.J. Undersander. 2000. Using stream macroinvertebrates to compare riparian land use practices on cattle farms in southwestern Wisconsin. Journal of Freshwater Ecology 15(1):93-106.

- Compared aquatic macroinvertebrate assemblages among stream segments within continuously grazed pastures, intensive rotationally grazed pastures, undisturbed grassy vegetative buffer strips, and undisturbed woody vegetative buffer strips – collected macroinvertebrate and stream sedimentation data from four streams in each land use category in two consecutive years – used upstream reference site to account for watershed condition
- "Watershed condition tended to have greater influence on macroinvertebrate measures than local riparian land use. However, local riparian land use influences were apparent if watershed condition was statistically accounted for with analysis of covariance."
- "Stream reaches with intensive rotational grazing tended to have macroinvertebrate assemblage characteristics intermediate of the buffer and continuously grazed reaches. Although we detected some differences in macroinvertebrate assemblages that apparently reflected very local land use, our results suggest the macroinvertebrates were mostly responding to large-scale watershed influences."
- "In this study, we found the macroinvertebrate assemblage responded in a way that suggests higher organic pollution in continuously grazed reaches than the woody buffer reaches."
- "We found that continuously grazed reaches, the reaches with the most erodible banks and embeddedness of coarse substrates, have the highest species and generic richness and lowest representation of EPT taxa."

**Irrigation**

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- Irrigation water storage and delivery affects the flow timing regime and transfers flow into streams that otherwise would not naturally have flow. In the Yakima watershed, anadromous salmonid adults migrating to the upper watershed may be falsely attracted into lower watershed streams that are carrying operational spills or irrigation return flows of upper Yakima water that has been conveyed through the irrigation delivery network to the lower watershed. These fish may spawn in streams where habitat conditions are not suitable for egg incubation or for successful early rearing after emergence.
- Historically, the hydrologic cycle in each of the four major basins (Roslyn, Kittitas, Upper Yakima, and Lower Yakima) of the Yakima watershed was characterized by extensive exchange between the surface, hyporheic, and groundwater zones. This exchange would have occurred mainly in the vast alluvial valleys and floodplains, which would

have functioned as hydrologic buffers, distributing the energy of peak flows and moving cool, spring melt water out onto the floodplain.

- The diversions at Sunnyside and Wapato typically divert one half of the entire river flow during the irrigation season (May-October), while Prosser diverts 1400 cfs most of the year, both for irrigation and power production. Because of regulation and withdrawals for irrigation, the Yakima River experiences periods of both dewatering and elevated flows relative to the historic discharge regime .

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- Overbank flow events, important to habitat diversity, have become rare in the Columbia River, in part because flow management and irrigation withdrawals prevent high flows and in part because diking and revetments have increased the "bankfull" flow level (from about 18,000 to 24,000 m3/s).

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- "The mainstem Scott and Shasta Rivers, and their low gradient tributaries favored by coho salmon, suffer many of the ailments common to drainages supporting extensive agricultural development. High summer diversion rates throughout both valleys limit mainstem and tributary flow levels, raise water temperatures, and lower water quality, making the mainstem Scott and Shasta Rivers unsuitable for rearing juvenile coho salmon."
- "Earthen "push up" dams are still employed in some areas of the Scott Valley to divert streamflow for agriculture. These seasonal dams often block fish migration, and downstream reaches can go dry when diverters fail to release minimum bypass flows."
- "To address these issues, restoration efforts should focus on working cooperatively with local ranchers to increase irrigation efficiency and water conservation through the implementation of "fish friendly" diversion structures and mandatory bypass flows. Incentives for local landowners with adjudicated water rights to forgo diverting during critical periods remains an important, yet currently not sufficiently funded, mechanism to establish coordinated water strategies in the Scott River and Shasta River."

Herren, J.R. and S.S. Kawasaki. 2001. Inventory of water diversions in four geographic areas in California's Central Valley. Pages 343-355. In: Contributions to the Biology of Central Valley Salmonids. R.L. Brown, editor. Volume. 2. California Fish and Game Fish Bulletin 179.

- As of 1997, 98.5 percent of the 3,356 diversions included in a Central Valley database were either unscreened or screened insufficiently to prevent fish entrainment. Most of the 370 water diversions operating in Suisun Marsh are unscreened.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "The diversion and storage of natural flows by dams and diversion structures on Central Valley waterways have depleted streamflows and altered the natural cycles by which juvenile and adult salmonids base their migrations. As much as 60 percent of the natural historical inflow to Central Valley watersheds and the Delta have been diverted for human uses. Depleted flows have contributed to higher temperatures, lower dissolved oxygen (DO) levels, and decreased recruitment of gravel and large woody debris (LWD). More uniform flows year round have resulted in diminished natural channel formation, altered food web processes, and slower regeneration of riparian vegetation. These stable flow patterns have reduced bedload movement caused spawning gravels to become embedded, and decreased channel widths due to channel incision, all of which has decreased the available spawning and rearing habitat below dams."

Bottom, D.L., C.A. Simenstad, J. Burke, A.M. Baptista, D.A. Jay, K.K. Jones, E. Casillas, and M.H. Schiewe. 2005. Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. NOAA Tech. Memo., NMFS-NWFSC-68.

- "The magnitude and timing of river flow, which significantly influence estuarine habitat of juvenile salmon, have been highly modified at the watershed level. The predevelopment flow cycle of the Columbia River has been totally reshaped by hydropower regulation and irrigation withdrawal. While there is a prominent climate signal in river-flow variability over the period of the analysis (1859–present), the magnitude of maximum spring-freshet flow has decreased more than 40% from the predevelopment period (1859–1899) to the present. Flow regulation is responsible for approximately 75% of this loss, irrigation withdrawal for approximately 20%, and climate change for approximately 5%."

Institute For Natural Systems Engineering. 1999. Evaluation of interim instream flow needs in the Klamath River: Phase I final report. Prepared for the Department of Interior. Utah Water Research Laboratory, Utah State University.

- "Depletion of stream flows in the Scott River and almost every tributary within this subbasin are associated with severe limitations for coho and steelhead juvenile rearing habitat availability and stranding of juvenile fall chinook, coho, and steelhead during the irrigation season in average and below average water years. Diversion of water for agricultural purposes, and the associated agricultural return flows, are attributed to higher than normal water temperatures and degraded water quality in both the Shasta and Scott River systems. Spring run chinook and spring run steelhead are considered to be extinct or at best remnant populations in the Scott and Shasta rivers and is attributed to poor summer flow conditions. Iron Gate Dam also blocked access to several cool water springs."

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- "People in the Dungeness River basin have been working for over ten years to address the chronic low flow problems there. The Agricultural Water Users Association and Jamestown S'Klallam Tribe obtained federal and state funding to improve irrigation infrastructure and conveyance efficiency. In the last five years, these actions have helped reduce the amount of water used for irrigation by one third, leaving more water in the river at times when salmon most need it. Additional conservation projects to improve summer flows are proposed in the Dungeness plan."

NMFS. 2002b. Biological opinion for the proposed license amendment for the Potter Valley Project (Federal Energy Regulatory Commission Project Number 77-110). National Marine Fisheries Service, Southwest Region. Available: http://swr.nmfs.noaa.gov/psd/Final_Potter_Valley_Project_BO.pdf. (November 2002).

- "The Potter Valley project has had significant impacts on fish habitat in the Upper Eel River. The project is by far the largest diversion and damming of Eel River flows, and has damaged habitat by lowering summer and early fall flows to the remaining stream below the Project, and by blocking 50 to 150 miles of spawning and rearing habitats above the Project."

**Mineral Mining**

Baldwin, D. H., J. F. Sandahl, J. S. Labenia, and N. L. Scholz. 2003. Sublethal effects of copper on coho salmon: Impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. Environmental Toxicology and Chemistry 22:2266-2274.

- Baldwin et al. (2003) examined the sublethal effects of copper on the sensory physiology of juvenile coho salmon (Oncorhynchus kisutch).
- Results indicate that copper is broadly toxic to the salmon olfactory nervous system. Consequently, short-term influxes of copper to surface waters may interfere with olfactory-mediated behaviors that are critical for the survival and migratory success of wild salmonids.

Suttle, K. B., M. E. Power, J. M. Levine and C. McNeely. 2004. How fine sediment in rIverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14: 969-974.

- Suttle et al. (2004) experimentally manipulated fine bed sediment in a northern California river and examined responses of juvenile salmonids and the food webs supporting them.
- Increasing concentrations of deposited fine sediment decreased growth and survival of juvenile steelhead trout. These declines were associated with a shift in invertebrates

toward burrowing taxa unavailable as prey and with increased steelhead activity and injury at higher levels of fine sediment.
- The linear relationship between deposited fine sediment and juvenile steelhead growth suggests that there is no threshold below which exacerbation of fine-sediment delivery and storage in gravel bedded rivers will be harmless, but also that any reduction could produce immediate benefits for salmonid restoration.

Gilvear, D. J., T. M. Waters, A. M. Milner. 2006. Image analysis of aerial photography to quantify changes in channel morphology and instream habitat following placer mining in interior Alaska. Freshwater Biology 34:389-398.
- "Placer mining for alluvial deposits of gold in a number of stream systems in interior Alaska represents a major disturbance to the stream bed and affects habitat for biotic communities."
- "Image analysis demonstrated that a wide range of water depths and instream mesoscale habitats existed prior to mining. During mining, the stream was confined to a channelized reach with negligible deep water or habitat diversity."
- "It is suggested that geomorphological recovery and associated habitat recovery takes a number of large flood events and is likely to require more than 10 years."

NMFS. 2002. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service.
- "Mining operations continue in the Klamath Basin, including suction dredging, placer mining, gravel mining, and lode mining. These mining operations can adversely affect spawning gravels, result in increased poaching activity, decreased survival of fish eggs and juveniles, decrease benthic invertebrate abundance, adversely affect water quality, and impact stream banks and channels."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.
- "Potential impacts from mining include 1) adverse modification of hydrologic conditions so as to cause erosion of desirable habitats, 2) removal of substrates that serve as habitat for fish and invertebrates, 3) conversion of habitats, 4) release of harmful or toxic materials, and 5) creation of harmful turbidity levels."
- "The effects of mineral mining on EFH depend on the type, extent, and location of the activities. Minerals are extracted using several methods. Surface mining involves suction dredging, hydraulic mining, panning, sluicing, strip mining, and open-pit mining (including heap leach mining). Underground mining uses tunnels or shafts to extract minerals by physical or chemical means."
- "Mining operations can release harmful or toxic materials and their byproducts, either in association with actual mining, or in connection with machinery and materials used for mining. Mining can also introduce levels of heavy metals and arsenic that are naturally found within the stream bed sediments."

- "Commercial operations may also involve road building, tailings disposal and leaching of extraction chemicals, all of which may create serious impacts to EFH. Cyanide, sulfuric acid, arsenic, mercury, heavy metals, and reagents associated with such development are a threat to EFH. Improper or in-water disposal of tailings may be toxic to managed species or their prey downstream."
- The following are recommended conservation measures to mitigate for mining:
  1. Avoid mineral mining in waters and streams containing EFH.
  2. Schedule necessary in-water activities when the fewest species/least vulnerable life stages of federally managed species will be present.
  3. Use an integrated environmental assessment, management, and monitoring package in accordance with state and federal law. Allow for adaptive operations to minimize adverse effects on EFH.
  4. Avoid spills of dirt, fuel, oil, toxic materials, and other contaminants into EFH. Prepare a spill prevention plan and maintain appropriate spill containment and water repellent/oil absorbent cleanup materials on hand.
  5. Treat wastewater (acid neutralization, sulfide precipitation, reverse osmosis, electrochemical, or biological treatments) and recycle on site to minimize discharge to streams. Test wastewater before discharge for compliance with federal and state clean water standards.
  6. Minimize opportunities for sediments to enter or affect EFH. Use methods such as contouring, mulching, and construction of settling ponds to control sediment transport. Monitor turbidity during operations, and cease operations if turbidity exceeds predetermined threshold levels. Use turbidity/sediment curtains to limit the spread of suspended sediments and minimize the area affected.
  7. Reclaim, rather than bury, mine waste that contains heavy metals, acid materials, or other toxic compounds if leachate can enter EFH through groundwater.
  8. Restore natural contours and plant native vegetation on site after use to restore habitat function to the extent practicable. Monitor the site for an appropriate period of time to evaluate performance and implement corrective measures if necessary.
  9. Minimize the aerial extent of ground disturbance (e.g., through phasing of operations), and stabilize disturbed lands to reduce erosion.

NMFS. 2010b. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service, Southwest Region.

- "All California instream suction dredge mining has been suspended following the Governor's signature on a new state law. The ban will be in effect until CDFG completes a court-ordered environmental review of its permitting program, expected in late summer 2011. The moratorium on instream suction dredge mining took effect immediately as an urgency measure, prohibiting the use of vacuum or other suction dredging equipment for instream mining in reliance on any permit previously issued by CDFG. The moratorium does not apply to suction dredging operations performed for the regular maintenance of energy or water supply management infrastructure, flood control, or navigational purposes.”

**Nonnative Species**

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia spring Chinook salmon and steelhead recovery plan. Upper Columbia Salmon Recovery Board. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf. (October 2009).

- A critical uncertainty in the management of Salmon in the Upper Columbia River is the effect of invasive species on the viability of listed populations in the Upper Columbia Basin.
- Brook trout is an invasive species within the Upper Columbia Basin that competes with bull trout for food and space. Research is needed to assess the direct and indirect effects of invasive species (including invasive plants) on the abundance and survival of spring Chinook, steelhead, and bull trout in the Upper Columbia Basin.
- American shad may affect the abundance and survival of spring Chinook and steelhead in the lower Columbia River. It is possible that the growing population of shad is competing directly with juvenile Chinook and steelhead by cropping food sources important to salmonids in the lower Columbia River. It is also possible that the large numbers of shad in the lower river contribute to the growth of northern pikeminnow, smallmouth bass, and walleye, which are important predators of salmon and steelhead.

Zimmerman, M.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 128:1036-1054.

- A predator-prey study in the impounded and unimpounded lower Columbia River indicated relatively high rates of juvenile salmonid consumption by smallmouth bass during the summer.
- Smallmouth bass preyed on relatively small juvenile salmonids. They consumed few steelhead, preyed on smaller chinook salmon in spring than northern pikeminnow, and consumed far more subyearling chinook salmon in summer than yearling chinook salmon in spring. An important consequence of size-selective predation would be increased vulnerability of wild juvenile salmonids, which are typically smaller than those reared in hatcheries.

Nobriga, M.L. & M. Chotkowski. 2000. Recent historical evidence of centrarchid increases and tulle perch decrease in the Delta. Interagency Ecological Program Newsletter 131:23-27.

- Nobriga and Chotkowski (2000) found a significant increasing trend in nonnative centrarchid species that prey on juvenile salmonids in the Sacramento-San Joaquin Delta in correspondence with increasing spread of nonnative aquatic macrophytes.

Cohen, A.N., and P.B. Moyle. 2004. Summary of data and analyses indicating that exotic species have impaired the beneficial uses of certain California waters. A report submitted to the State Water Resources Control Board on June 14, 2004.

- The introduction of exotic Asiatic freshwater clams Corbicula fluminea and Potamocorbula amurensis in the Sacramento-San Joaquin estuary disrupted the normal benthic community structure and depressed phytoplankton levels in the estuary due to the highly efficient filter feeding of the introduced clams.
- The decline in the levels of phytoplankton reduces the population levels of zooplankton that feed upon them, and hence reduces the forage base available to salmonids transiting the Delta and San Francisco estuary which feed either upon the zooplankton directly or their mature forms.

NMFS. 2002b. Biological opinion for the proposed license amendment for the Potter Valley Project (Federal Energy Regulatory Commission Project Number 77-110). National Marine Fisheries Service, Southwest Region. Available: http://swr.nmfs.noaa.gov/psd/Final_Potter_Valley_Project_BO.pdf. (November 2009).

- The introduction of nonnative Sacramento pike minnow in the mainstem Eel River has increased the risk of predation of juvenile salmonids. Sacramento pikeminnow impacts are exacerbated by the presence of dam structures and reservoirs, and by summer thermal conditions and low flow that provide ideal conditions for Sacramento pikeminnow in the reservoir and mainstem Eel River.

Sanderson, B. L., K. A. Barnas, and A. M. Wargo. 2009. Nonindigenous species of the Pacific Northwest: an overlooked risk to endangered salmon. BioScience 59:245-256.

- “Throughout the Pacific Northwest, the causes of salmon population declines have been dominated by a discussion of the impact of the all-H’s—hydrosystem, hatchery, harvest, and habitat. This all-H-centric view has largely ignored the impacts of key Nonindigenous species (NIS) in Pacific Northwest watersheds, which may rival the detrimental effects of the all-H’s. For example, on a per-run basis, the mortality attributed to NIS predation may be similar to that associated with juvenile passage through each of the eight dams on the Columbia and Snake rivers, estimated at approximately 5% to 15% per dam.”
- “Despite clear evidence of the impact of NIS, a consideration of their role still falls outside all-H thinking. To illustrate this point and to quantify the level of funding directed to studies of nonnative species, we analyzed the $385 million that the Bonneville Power Administration (BPA) Fish and Wildlife program has allocated to research, restoration and enhancement projects from 2007 to 2009.”
- “Results of our survey indicate that of the $385 million distributed by BPA over the three-year study period, only approximately 0.3% was directed in whole or in part toward research on the impacts of NIS, and slightly less than 1% of funds were allocated to efforts to control nonindigenous fish species.”

- "Future opportunities for understanding and managing NIS already exist within ongoing research and management programs. For example, as a cohort of juvenile salmon travel from their natal habitats to the ocean, what proportion of those individuals is lost to predation by nonnative species? Because many of the major NIS predators are popular game fishes managed by state agencies, the predator biomass data needed to quantify predation rates on salmonids are quite likely available. Additionally, native predator programs exemplify how the region might develop similar programs to mitigate the damage imposed by NIS and improve the chances of recovery for native species at risk. Only with a broad examination of NIS ecology and impacts by both existing and new research programs can we begin to answer questions that are key to evaluating the cumulative impact of NIS on salmonids."

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- Found in lakes, rivers, and streams, smallmouth bass (Micropterus dolomieu) have relatively large mouths that enable them to consume juvenile fish, including salmonids.
- Smallmouth bass are the dominant predators in reservoirs of the lower Snake River and are co-dominant with northern pikeminnow and percids in certain reaches of the Snake River.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "From October 1976 to November 1993, CDFG conducted 10 mark/recapture studies at the SWP's Clifton Court Forebay to estimate pre-screen losses using hatchery-reared juvenile Chinook salmon. Pre-screen losses ranged from 69 percent to 99 percent. Predation by striped bass is thought to be the primary cause of the loss."

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia spring Chinook salmon and steelhead recovery plan. Upper Columbia Salmon Recovery Board. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf. (October 2009).

- "Exotic species are more likely to interact with spring Chinook, steelhead, and bull trout because exotics have not had time to segregate spatially or temporally in their resource use. For example, there is a possibility that brook trout interact with spring Chinook, steelhead, and bull trout in the upper basin."

**Offshore Drilling**

Helvey, M. 2002. Are southern California oil and gas platforms essential fish habitat? ICES Journal of Marine Science 59:S266-S271. Available: icesjms.oxfordjournals.org/cgi/reprint/59/suppl/S266.pdf. (January 2010).

- Physical, chemical, and biological disturbances that can result from offshore oil and gas operations include:
    - Noise from seismic surveys, vessel traffic, and construction of drilling platforms or islands, traffic from vessels.
    - Physical alterations to habitat from the construction, presence and eventual decommissioning and removal of facilities such as islands or platforms, storage and production facilities, and pipelines to onshore common carrier pipelines, storage facilities, or refineries.
    - Waste discharges including well drilling fluids, produced waters, surface runoff and deck drainage, domestic waste waters generated from the offshore facility, solid-waste from wells (drilling muds and cuttings) and other trash and debris from human activities associated with the facility.
    - Oil spills.

Heintz, R.A., S.D. Rice, A.C. Wertheimer, R.F. Bradshaw, F.P. Thrower, J.E. Joyce, J.W. Short. 2000. Delayed effects on growth and marine survival of pink salmon Oncorhynchus gorbuscha, after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208:205-216.

- Heintz et al. (2000) report delayed effects on the growth and marine survival of pink salmon Oncorhynchus gorbuscha, which were exposed to oil as embryos under conditions similar to those observed after the 'Exxon Valdez' oil spill.
- Pink salmon eggs were incubated in water that became contaminated with polynuclear aromatic hydrocarbons (PAHs) after percolating through gravel coated with weathered oil.
- Pink salmon exposed to an initial concentration of total PAH equal to 5.4 ppb experienced a 15% decrease in marine survival compared to unexposed salmon. A delayed effect on growth was measured in juvenile salmon that survived embryonic exposure to doses as low as 18 ppb PAH.
- The demonstration of delayed effects on growth and survival support claims of delayed effects in pink salmon after the 'Exxon Valdez' oil spill, and indicate the potential for population-level effects resulting.

Wertheimer, A.C., R.A. Heintz, J.F. Thedinga, J.M. Maselko, S.D. Rice. 2000. Straying of adult pink salmon from their natal stream following exposure as embryos to weathered Exxon Valdez crude oil. Transactions of the American Fisheries Society 129:989-1004.

- Numbers of strays (adult salmon returning to a nonnatal stream), straying rates, and distribution of strays were estimated for pink salmon incubated in oil-contaminated gravel and for an unexposed control group.

- Although the frequency of observed strays was 30% and 9% (respectively) higher than the controls for the low- and high-dose groups, the differences among treatments were not statistically significant, and the rates did not increase with total polynuclear aromatic hydrocarbon dose. Exposed fish tended to be recovered at a greater distance from the natal stream than were control fish.
- Our results do not support the hypothesis that oil exposure of embryos in intertidal spawning grounds was responsible for the high rates of straying of wildstock pink salmon that were observed in Prince William Sound after the Exxon Valdez oil spill.

Carls, M.G., R.E. Thomas, S.D. Rice. 2003. Mechanism for transport of oil-contaminated water into pink salmon redds. Marine Ecology Progress Series 248:245-255.

- Carls et al. (2003) demonstrated that tides and the resultant hydraulic gradients provide a mechanism for groundwater transport of soluble and slightly soluble contaminants (such as oil) from beaches surrounding streams into the hyporheic zone where pink salmon eggs incubate. Oil may reach nearshore areas and affect productive nursery grounds or areas containing high densities of fish eggs and larvae.

Carls, M.G., S.D. Rice, J.E. Hose. 1999. Sensitivity of fish embryos to weathered crude oil: Part 1. Low Level exposure during incubation causes malformations and genetic damage in larval Pacific herring (Clupea pallasi). Environmental Toxicology and Chemistry 18:481-493.

- Pacific herring eggs were exposed for 16 days to weathered Alaska North Slope crude oil. Exposure to an initial aqueous concentration of 0.7 parts per billion polynuclear aromatic hydrocarbons (PAHs) caused malformations, genetic damage, mortality, and decreased size and inhibited swimming. Total aqueous PAH concentrations as low as 0.4 ppb caused sublethal responses such as yolk sac edema and immaturity consistent with premature hatching.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "These disturbances include 1) noise from seismic surveys, vessel traffic, and construction of drilling platforms or islands, traffic from vessels, 2) physical alterations to habitat from the construction, presence and eventual decommissioning and removal of facilities such as islands or platforms, storage and production facilities, and pipelines to onshore common carrier pipelines, storage facilities, or refineries, 3) waste discharges including well drilling fluids, produced waters, surface runoff and deck drainage, domestic waste waters generated from the offshore facility, solid-waste from wells (drilling muds and cuttings) and other trash and debris from human activities associated with the facility, 4) oil spills, and 5) platform storage, and pipeline decommissioning."
- "Noise sources may generate sound pressure that can disrupt or damage marine life. Oil and gas activities may generate noise from drilling activities, construction, production facility operations, seismic exploration and supply vessel and barge movements (see

Section 4.5). The impacts of oil exploration related seismic energy releases may interrupt and cause fish to disperse from the acoustic pulse with possible disruption to their feeding patterns."

- "Oil spills are a serious potential source of contamination to the marine environment from oil and gas development. Offshore oil and gas development will inevitably result in some oil entering the environment. Most spills are expected to be of small size, although there is a potential for large spills to occur. Many factors determine the degree of damage from a spill, including the type of oil, size and duration of the spill, geographic location of the spill, and the season. Although oil is toxic to all marine organisms at high concentrations, certain species are more sensitive than others."
- "In whatever quantities, lost oil can affect habitats and living marine resources. Accidental discharge of oil can occur during almost any stage of exploration development, or production on the outer continental shelf (OCS) or in nearshore coastal areas. Oil spills can occur from many possible sources including equipment malfunction, ship collisions, pipeline breaks, other human error, or severe storms. "
- The following are recommended conservation measures to mitigate for Dam effects:
  1. Conduct pre-project biological surveys in consultation with NMFS to determine the extent and composition of biological populations or habitat in the proposed production area. On the basis of the site-specific surveys a determination will be made whether or not the operations are likely to have an adverse effect upon EFH, or that a special biological population/habitat does not exist. Based on the information in the surveys, the following may be recommended:
  a. Redesign facilities to accommodate habitat concerns.
  b. Operate during those periods of time, as established in consultation with NMFS, that do not adversely affect biological resources.
  c. Modify operations to ensure that significant biological populations or habitats deserving protection
  are not affected.
  2. Limit the discharge of produced waters into marine and estuarine environments. Re-inject produced waters into the oil formation whenever possible.
  3. Avoid discharge of muds and cuttings into the marine and estuarine environment. Use methods to grind and re-inject such wastes down an approved injection well or use onshore disposal wherever possible. When not possible, provide for a monitoring plan to quantitatively assess whether effluent discharges are meeting the needs of EFH.
  4. Limit placement of causeways or structures in the nearshore marine environment.
  5. Encourage the use of geographic response strategies that identify EFH and environmentally sensitive areas and identify appropriate cleanup methods to include the prestaging of response equipment.
  6. Use methods to transport oil and gas that limit the need for handling in environmentally sensitive areas, including EFH.
  7. Prohibit drilling of the first development well into the targeted hydrocarbon formations during hazardous or sensitive environmental conditions, such as broken ice.

8. Prohibit drilling of exploration wells into untested formations during hazardous or sensitive environmental conditions.

**Road Building**

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- "Implementing measures to reduce sediment input from upslope sources is critically necessary within the mid-Klamath River HSA, where vast road networks continue to degrade and contribute fine sediment into the stream environment."
- "Little-used road segments and skid trails should be decommissioned when possible; those not decommissioned should be upgraded and maintained to reduce hydrologic connectivity between upslope road surfaces and the aquatic environment."
- "Large, severe wildland fires can also precipitate chronic sediment routing between upslope sources and stream channels, particularly when coupled with salvage logging. Landscapes scorched by intense fire lose soil integrity as plant and tree roots degrade, triggering landslides that introduce large quantities of sediment into creeks and rivers. Re-establishing a more natural fire regime of smaller, more frequent controlled burns can help prevent the buildup of understory vegetation that fuel large, hot, catastrophic fires."
- "In light of the heavy road development within much of the HSA, impaired fish passage at road crossings is commonly a bottleneck to migrating coho salmon. Many roads administered by the California Department of Transportation have faulty or poorly designed culverts that block upstream and downstream migration."
- "Problem culverts should first be inventoried and ranked in order to optimize use of limited funding resources."

Trombulak, S.C., C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14(10):18-30.

- Trombulak and Frissell (200) reviewed scientific literature on the ecological effects of roads and found support for the general conclusion that they are associated with negative effects on biotic integrity in both terrestrial and aquatic ecosystems.

Madej, M.A. 2001. Erosion and sediment delivery following removal of forest roads. Earth Surface Processes and Landforms 26:175-190.

- Erosion control treatments were applied to abandoned logging roads in California, with the goal of reducing road-related sediment input to streams and restoring natural hydrologic patterns on the landscape. Treatment of stream crossings involved excavating culverts and associated road fill and reshaping streambanks. A variety of techniques were applied to road benches, which included decompacting the road surface, placing unstable road fill in more stable locations, and reestablishing natural surface drainage patterns.

- Sediment delivery from treated roads in upper, middle and lower hillslope positions was 10, 135, and 550 m of sediment/kilometer of treated roads, respectively. In contrast, inventories of almost 500 km of forest roads in adjacent catchments indicate that untreated roads produced 1500 to 4700 m of sediment/km of road length.
- Although road removal treatments do not completely eliminate erosion associated with forest roads, they do substantially reduce sediment yields from abandoned logging roads.

Castro, J. 2003. Geomorphologic impacts of culvert replacement and removal: avoiding channel incision. Portland, OR: U.S. Fish and Wildlife Service - Oregon Fish and Wildlife Office.

- Channel incision can often occur downstream of a culvert and generally moves upstream, potentially affecting fish habitat and impeding fish passage. An existing culvert can act as a grade control, halting the upstream progression of a headcut and causing further channel regrade.

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- Actions that destabilize the landscape in high slope areas such as logging or road construction increase the frequency and severity of mass wasting events, leading to increased sedimentation.
- Stormwater runoff (particularly from roads), surface erosion, and increased streambank erosion are the main contributors of turbidity in the water column that may affect survival of eggs or fish.
- Bad roads have not only contributed excessive sediment loads to the stream system through erosion of road surfaces, cut and fill slopes, and road ditches, they have also increased the erosiveness of the stream environment by channelizing diffuse flow and delivering it rapidly to the stream, thereby increasing peak flows.

NMFS. 2002. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service.

- “Roads associated with timber harvesting account for a large portion of the erosion occurring in logged areas. Poor road design, location, construction and maintenance caused erosion of all types: mass soil movement, surface, gullies, and stream bank. Harvesting has expanded from established roads into more inaccessible terrain and areas of greater environmental risk.”
- “Road systems, skid trails, and landings where the soils become compacted may also accelerate runoff.”

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- The effects of roads on aquatic habitat can be profound and include 1) increased deposition of fine sediments, 2) changes in water temperature, 3) elimination or introduction of migration barriers such as culverts, 4) changes in streamflow, 5) introduction of non-native plant species, and 6) changes in channel configuration.
- Roads can lead to increased rates of natural processes such as debris or landslides and sedimentation when slopes are destabilized and surface erosion and soil mass movement increases.
- Erosion is most severe when poor construction practices are allowed, combined with inadequate attention to proper road drainage and maintenance practices. Mass movement risks increase when roads are constructed on highhazard soils and overly steep slopes. In steep areas prone to landslides, rates of mass soil movements affected by roads include shallow debris slides, deep-seated slumps and earthflows, and debris flows.
- The following are recommended conservation measured to mitigate for road building:
  1. Avoid locating roads near fish-bearing streams. Roads should be sited to avoid sensitive areas such as streams, wetlands, and steep slopes.
  2. Incorporate erosion control and stabilization measures into road construction plans to reduce erosion potential.
  3. Build bridges when possible. If culverts are to be used, they should be sized, constructed, and maintained to match the gradient and width of the stream, so as to accommodate 100-year flood flows, but equally to provide for migratory passage of adult and juvenile fishes. Utilize guidelines provided in the document: "Guidelines for Salmonid Passage at Stream Crossing," NOAA Fisheries, Southwest Region, October 2001 (http://swr.nmfs.noaa.gov/hcd/NMFSSCG.PDF).
  4. Locate stream crossings in stable stream reaches.
  5. Design bridge abutments to minimize disturbances to streambanks and place abutments outside of the floodplain whenever possible.
  6. Avoid road construction across alluvial floodplains, mass wastage areas, or braided stream bottom lands unless site-specific protection can be implemented to ensure protection of soils, water, and associated resources.
  7. Avoid side-casting of road materials into streams year-round.
  8. Use only native vegetation in stabilization plantings.
  9. Maintenance practices should not cause existing problems to worsen.

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- "5,451 miles of road development occurs in the Olympic and Mt. Baker-Snoqualmie National Forest land surrounding Puget Sound. A majority of stream crossings in the national forest road system in the Pacific Northwest cannot tolerate more than a 25-year flow event without the failure of culverts and other structures associated with the road system."

Beschta, R.L., M.R. Pyles, A.E. Skaugset, C.G. Surfleet. 2000. Peak flow response to forest practices in the western Cascades of Oregon, U.S.A. Journal of Hydrology 233:102-120.

- "Federal land management agencies in the Pacific Northwest are expending large sums of money to alter and obliterate roads on forested watersheds, partially because of concerns about forestry related peakflow increases…While forest roads may represent an important issue in mountainous terrain (e.g. slope stability, surface erosion), the analysis by Thomas and Megahan (1998) of the identical peakflow data sets used by Jones and Grant (1996) and our analysis of modified peakflow data sets for the same small watersheds do not support the concept that relatively large peakflows are increased by forest practices. "

Flanders, L.S., J. Cariello. 2000. Tongass road condition survey report. Technical Report 00-7. Douglas, AK: Alaska Department of Fish and Game, Southeast Regional Office of the Habitat and Restoration Division.

- "Velocity is the most common cause of fish passage restriction in culverts. If a culvert is installed at too steep a gradient or the culvert width is significantly narrower than the streambed width, the water velocity will be increased within the culvert. Very slight changes in the slope of the culvert and the roughness of the substrate within the culvert may significantly change velocity and the ability of fish to pass through the culvert during all of the times of year when they normally move upstream or downstream. Other frequent causes of fish passage problems include perching of the culvert outlet above the water surface, blockage by excessive substrate or woody debris within the culvert and structural damage to the culvert. In most cases, multiple factors interact to restrict fish passage."

NMFS. 2001. Guidelines for salmonid passage at stream crossings. NOAA Fisheries, Southwest Region, Long Beach, CA.

- This document provides guidelines for design of stream crossings to aid upstream and downstream passage of migrating salmonids. It is intended to facilitate the design of a new generation of stream crossings, and assist the recovery of threatened and endangered salmon species. These guidelines are offered by the National Marine Fisheries Service, Southwest Region (NMFS-SWR), as a result of its responsibility to prescribe fishways under the Endangered Species Act, the Magnuson-Stevens Act, the Federal Power Act, and the Fish and Wildlife Coordination Act. The guidelines apply to all public and private roads, trails, and railroads within the range of anadromou salmonids in California.
- The following are the alternative methods for designing or replacing culverts. The document describes them in detail:

- Active Channel Design Method
  - The Active Channel Design method is a simplified design that is intended to size a culvert sufficiently large and embedded deep enough into the channel to allow the natural movement of bedload and formation of a stable bed inside the culvert.
- Stream Simulation Design Method
  - The Stream Simulation Design method is a design process that is intended to mimic the natural stream processes within a culvert. Fish passage, sediment transport, flood and debris conveyance within the culvert are intended to function as they would in a natural channel.
- Hydraulic Design Method
  - The Hydraulic Design method is a design process that matches the hydraulic performance of a culvert with the swimming abilities of a target species and age class of fish. This method targets distinct species of fish and therefore does not account for ecosystem requirements of non-target species.

NMFS. 2010b. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service, Southwest Region.

- “In many instances, ongoing maintenance of these roads is lacking or non-existent, leading to continuing impact. Where roads cross salmonid bearing streams, improperly placed culverts have blocked access to many stream reaches. Landslides and chronic surface erosion from road surfaces are large sources of sediment across the range of the species. Roads also have the potential to increase peak flows with consequent effects on the stability of stream substrates and banks. The consequent impacts on habitat include reductions in spawning, rearing and holding habitat, and increases in turbidity.”
- “Across the SONCC ESU, this excessive sediment has contributed to decreased survival to emergence as spawning gravels are filled with fine sediments, reduced carrying capacity for juvenile salmonids due to pool filling and reduced feeding and growth due to high turbidity levels.”

**Sand Gravel Mining**

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- “Mining of sand and gravel is extensive and occurs by several methods. These include wet-pit mining (i.e., remove material from below the water table), dry-pit mining on beaches, exposed bars and ephemeral streambeds, and subtidal mining. Sand and gravel mining in riverine, estuarine, and coastal environments can create EFH impacts including 1) turbidity plumes and resuspension effects, 2) removal of spawning habitat, and 3) alteration of channel morphology.”

- "Mechanical disturbance of EFH spawning habitat by mining equipment can also lead to high mortality rates in early life stages. One result is the creation of turbidity plumes which can move several kilometers downstream. Sand and gravel mining in riverine, estuarine, and coastal environments can also suspend materials at the sites. Sedimentation may be a delayed effect, because gravel removal typically occurs at low flow when stream has the least capacity to transport fine sediments out of the system. Another delayed sedimentation effect results when freshets inundate extraction areas that are less stable than before."
- "Additionally, extraction of sand and gravel in riverine ecosystems can directly eliminate the amount of gravel available for spawning if the extraction rate exceeds the deposition rate of new gravel in the system. Gravel excavation also locally reduces the supply of gravel to downstream habitats."
- "Mining can also alter channel morphology by making the stream channel wider and shallower. Consequently, the suitability of stream reaches as rearing EFH may be decreased, especially during summer low-flow periods when deeper waters are important for survival."
- The following are recommended conservation measures to mitigate for mining:
  1. Avoid sand/gravel mining in waters containing EFH. Many factors influence site selection for a gravel or sand mining site.
  2. Identify upland or off-channel (where channel will not be captured) gravel extraction sites as alternatives to gravel mining in or adjacent to EFH, if possible.
  3. Design, manage, and monitor sand and gravel mining operations to minimize potential direct and indirect impacts to EFH if operations in EFH cannot be avoided. This includes, but is not limited to, migratory corridors, foraging and spawning areas, stream/river banks, intertidal areas, etc.
  4. Minimize the areal extent and depth of extraction.
  5. Include restoration, mitigation, and monitoring plans in sand/gravel extraction plans.

Rempel, L. L. and M. Church. 2009. Physical and ecological response to disturbance by gravel mining in a large alluvial river. Canadian Journal of Fisheries and Aquatic Sciences 66:52-71.

- The role of sediment transport during high flows for restoring fish habitat was demonstrated following an experimental gravel removal from Fraser River, B.C. Effects of mining on the fish community could not be confirmed. Benthic invertebrates recolonized the removal site immediately after mining, and differences in community composition compared with three reference sites disappeared during the first flood. Results suggest that physical changes due to this mining operation fell within the range to which local aquatic populations are accustomed during flooding, because the ecological response was modest and short-lived.

Norman, D. K,, C. J. Cederholm, and W. S. Lingley. 1998. Flood plains, salmon habitat, and sand and gravel mining. Washington Geology 26 (2/3): 3-20.

- "Avulsion is characteristized by a sudden change in the course of a river that causes it to break through a low point such as a meander neck (to form an oxbow lake) or to rush into a gravel pit. Avulsion events occur in gravel pit lakes because the pit surface is lower than the river."
- "When a river breaches a pit, the river biota can be catastrophically changed. Water temperatures may rise during summer and early fall because the relatively slack water in the pits is exposed to sunlight for long periods. While moderate increases in water temperature can increase growth rates, large increases can cause disease outbreaks and may kill significant numbers of adult and juvenile fish."
- "Pits that are warmer than the adjacent river may be ideal habitat for warm-water fish, such as largemouth bass or yellow perch, which are predators of juvenile salmon."
- The following are effects of avulsion to the river channel:
    - Lowering the river bed upstream and downstream of mining operations, causing river bed erosion and channel incision and bank erosion and collapse.
    - Changing aquatic habitat
    - Unnaturally simplifying the complex natural stream system.
    - Increasing suspended sediment.
    - Abandoning reaches of spawning gravels or damaging these gravels by channel erosion or deposition of silts in spawning and rearing reaches.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127(6):979-994.

- Studied the effects of gravel mining upstream, on-site, and downstream for one large mine in each of three Ozark Plateaus gravel bed streams – also sampled invertebrates and fish at disturbed and reference riffles for 10 small mines
- "Gravel mining significantly altered the geomorphology, fine-particle dynamics, turbidity, and biotic communities."
- "Stream channel form was altered by increased bank-full widths, lengthened pools, and decreased riffles in affected reaches."
- "Fine particulate organic matter transported from riffles to pools was decreased. Biofilm organic content was decreased on flats and increased on remaining riffles. Density and biomass of large invertebrates and density of small invertebrates were reduced at the small, more frequently mined sites. Total densities of fish in pools and game fish in pools and riffles were reduced by the large mines. Silt-sensitive species of fish were less numerous downstream from mines."
- "Attempts to mitigate or restore streams impacted by gravel mining may be ineffective because the disturbance results from changes in physical structure of the streambed over distances of kilometers upstream and downstream of mining sites. Stream morphology was changed by lack of gravel bedload, not by how bedload was removed. Mining gravel from stream channels results in irreconcilable multiple-use conflicts."

Stanislaus River. Report Produced for the Stanislaus River Group. Carl Mesick Consultants, El Dorado, CA.

- Compared characteristics of mined and unmined riffle reaches in the Stanislaus River, CA using historic and current spawning riffle maps
- "Over time, the upstream most riffles in the unmined reaches typically became degraded whereas the downstream riffles usually contain abundant gravel and still function as high quality spawning and rearing habitat. Conversely, the riffles in the mined reaches are typically isolated between ditches or ponds, and so the gravel is scoured away during high flows due to the absence of recruitment."
- Long ditches, 100 to 160ft wide, and large in-river pits were indicative of mined areas – unmined areas were relatively narrow, 60 to 80ft wide, and contained high densities of spawning riffles
- Historical maps indicate loss of upstream spawning riffles and creation of new riffles downstream by newly scoured and deposited materials
- Gravel scoured from riffles in mined reaches is likely absorbed by ditches and pits, which prevents the recruitment of new gravel in mined reaches – suggests that ditches and pits act as a sink for downstream gravel recruitment.

**Vessel Operation**

Haas, M.A., C.A. Simenstad, Jr., J.R. Cordell, D.A. Beauchamp, B.S. Miller. 2002. Effects of large overwater structures on epibenthic juvenile salmon prey assemblages in Puget Sound, Washington. Prepared for the Washington State Transportation Commission, Washington State Department of Transportation, the U.S. Department of Transportation, and Federal Highway Administration. Final research report No. WA-RS 550.1. 114 p. Available: http://depts.washington.edu/trac/bulkdisk/pdf/550.1.pdf. (January 2010).

- Disruption of vegetation, substrate coarsening, and decreased density of epibenthos at ferry terminals in Puget Sound, Washington, can all be partly attributed to propeller wash of vessels.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "An increase in the number and size of vessels can generate more wave and surge effects on shorelines. These vessel-wake, wash events can affect shorelines depending on the wake wave energy, the water depth, and the type of shoreline. Vessel wakes can cause a significant increase in shoreline erosion, impact wetland habitat, and increase water turbidity."
- The following are recommended conservation measures to mitigate for Dam effects:
  1. Locate marinas in areas of low biological abundance and diversity, for example, avoiding dense beds of eelgrass or other submerged aquatic vegetation including macroalgae.

2. Excavate uplands to create marina basins rather than converting intertidal or shallow subtidal to deeper subtidal for basin creation.
3. Avoid the disturbance of beds, mudflats and wetlands as part of the project design. In situations where such impacts are unavoidable, appropriate compensatory mitigation should be incorporated into the project with the approval of appropriate regulatory agencies.
4. Leave marine riparian buffers in place to enhance intertidal microclimate and nutrient input.
5. Adequate monitoring on the success of mitigation efforts should be included as part of the project and incorporated into a mitigation and monitoring plan.
6. Conduct preconstruction surveys by qualified biologists/botanists to identify and map areas of invasive plant species existing within potential project construction areas. Eradication of non-native species should be conducted well in advance of construction.
7. Include low-wake vessel technology, appropriate routes, and best management practices for wave attenuation structures as part of the design and permit process. Vessels should be operated at sufficiently low speeds to reduce wake energy, and no-wake zones should be designated near sensitive habitats.
8. Incorporate best management practices to prevent or minimize contamination from ship bilge waters, antifouling paints, shipboard accidents, shipyard work, maintenance dredging and disposal, and nonpoint source contaminants from upland facilities related to vessel operations and navigation.
9. Locate mooring buoys in water deep to avoid grounding and minimize affects of prop wash. Use subsurface floats or other methods to prevent contact of the anchor line with the substrate.
10. Collect and treat runoff from parking lots and other impervious surfaces to remove contaminants prior to delivery to any receiving waters
11. Locate facilities in areas with sufficient water velocities to dissipate fuels and pollutants from vessels and maintain temperature and dissolved oxygen levels within acceptable ranges.
12. Locate marinas where they do not interfere with drift sectors determining the structure and function of adjacent habitats.

Neira, C., F. Delgadillo-Hinojosa, A. Zirino, G. Mendoza, L. A. Levin, M. Porrachia, D. D. Deheyn. 2009. Spatial distribution of copper in relation to recreational boating in a California shallow-water basin. Chemistry and Ecology 25:417-433.

- Neira et al. (2009) examined the overall effect of the number of boats on the copper levels in the water column and sediment, along with their spatial variability within Shelter Island Yacht Basin (SIYB), San Diego, CA.
- They identified a horizontal gradient of increasing dissolved copper in sediment from outside to the head of SIYB which was coincident with the increasing number of boats. Spatial models found “hotspots” of copper concentration. In the sediment, dissolved

copper exceeded the effect range of 34 mg/kg (where adverse effects to fauna may occur).
- "Potential negative ecological effects of copper on benthic fauna include lowered diversity, impaired reaction to predation, reduced colonization and burrowing, reduced feeding rate or survivorship, impaired habitat selection, fertilization, embryonic development and chemosensation, and inhibition or larval settlement."

**Wastewater/Pollutants**

Michael, J. H. 2003. Nutrients in salmon hatchery wastewater and its removal through the use of wetland constructed to treat off-line settling pond effluent. Aquaculture 226:213-225.
- "The presence of nutrients in the wastewater of salmonid hatcheries is of growing concern to water quality managers. Presently, Washington State regulations require quiescent settling to remove settleable and suspended solids from the water but do not as yet address nutrient concerns."
- "In order to evaluate the load of nutrients discharged by salmon hatcheries, the Washington Department of Fish and Wildlife (WDFW) initiated two studies. Water from the Issaquah Hatchery, located in a watershed with identified excessive levels of anthropogenic phosphorus in the aquatic system, was monitored for total phosphorus for more than a year at the points of diversion from the creek, at the points of water return to the creek, and at the point of discharge from the off-line settling pond."
- "Monitoring showed that the hatchery's contribution to watershed phosphorus levels was low and that the primary phosphorous input from the hatchery appeared to be the process water as opposed to water from the off-line settling system."
- "In order to evaluate the efficacy of a constructed wetland in the removal of nutrients from a conventional offline settling system, WDFW installed a constructed wetland at the Dungeness Hatchery. Over the course of 4 years of monitoring, the wetland removed most of the solids, phosphorus, and nitrogenous compounds, which resulted in a reduction in biological oxygen demand (BOD) of the influent water. At times, the offline settling system actually increased the level of some of the nutrients, suggesting that treatment of hatchery effluent will need to include a combination of quiescent settling, constructed wetland, and some sort of process water treatment if anthropogenic solids and nutrients are to be more completely removed. The constructed wetland also provided habitat used by amphibians and birds for breeding and foraging. At facilities in locations with sufficient land base available to develop a constructed wetland, it should be possible to reduce the nutrient input to receiving waters and provide additional habitat for aquatic animals."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "There are many potential impacts from point-source discharge, but it is important to note that pointsource discharges and resulting altered water quality in aquatic environments does not necessarily result in adverse impacts to either marine resources or EFH. Because most point-source discharges are regulated by the state or EPA, effects to receiving waters are generally considered in those cases. Pointsource discharges can adversely affect EFH by 1) reducing habitat functions necessary for growth to maturity, 2) modifying community structure, 3) bioaccumulation, and 4) modifying habitat."
- The following are recommended conservation measures to mitigate for Wastewater effects:
  1. Locate discharge points in coastal waters well away from shellfish beds, sea grass beds, coral reefs, and other similar fragile and productive habitats.
  2. Reduce potentially high velocities by diffusing effluent to acceptable velocities.
  3. Determine benthic productivity by sampling prior to any construction activity related to installation of new or modified facilities. Outfall design (e.g., modeling concentrations within the predicted plume or likely extent of deposition along a productive nearshore), should be developed with input from appropriate resource and Tribal agencies.
  4. Provide for mitigation when the degradation or loss of habitat from placement and operation of the outfall structure and pipeline.
  5. Institute source-control programs that effectively reduce noxious materials to avoid introducing these materials into the waste stream.
  6. Ensure compliance with pollutant discharges regulated through discharge permits which set effluent discharge limitations and/or specify operation procedures, performance standards, or best management practices.
  8. Discharges should be treated to the maximum extent practicable, including implementation of up-todate methodologies for reducing discharges of biocides (e.g., chlorine) and other toxic substances.
  9. Use land-treatment and upland disposal/storage techniques where possible. Use of vegetated wetlands as natural filters and pollutant assimilators for large-scale discharges should be limited to those instances where other less damaging alternatives are not available and the overall environmental and ecological suitability of such an action has been demonstrated.
  10. Avoid siting pipelines and treatment facilities in wetlands and streams. Since pipelines and treatment facilities are not water dependent with regard to positioning, it is not essential that they be placed in wetlands or other fragile coastal habitats. Avoiding placement of pipelines within streambeds and wetlands will also reduce inadvertent infiltration into conveyance systems and retain natural hydrology of local streams and wetlands.

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- "In two of the most urban watersheds, King County's Comprehensive Plan and Regional Wastewater Service Plan both support the use of reclaimed water to help meet the region's diverse water supply needs. A specific goal is to use reclaimed water to assist the region in balancing needs of the environment and people. In 2004, King County used or distributed 268 million gallons of reclaimed water in place of drawing new potable water. Through substituting reclaimed water for potable water in operations at its two wastewater treatment plants alone, King County is leaving approximately 700,000 gallons of water per day in streams and rivers. This represents only a fraction of the potential of reclaimed water to benefit instream flows for salmon in the region, and King County is embarking on a regional water supply plan to bring a larger supply of reclaimed water to the region."

NMFS. 2009e. The use of treated wood products in aquatic environments: Guidelines to West Coast NOAA fisheries staff for Endangered Species Act and Essential Fish Habitat consultations in the Alaska, Northwest and Southwest Regions. NOAA Fisheries, Southwest Region.

- Main contaminants of concern in treated wood products are copper and polycyclic aromatic hydrocarbons (PAHs)
- "It is widely acknowledged that creosote and copper-treated wood products leach contaminants into the aquatic environment. The rate of leaching for both categories of products drops off rapidly following installation. For copper treated products…Effect level thresholds may only be exceeded for short periods of time. Copper can accumulate in sediments, where its bioavailability depends upon site-specific conditions. While the initial rate of leaching from creosote-treated pilings drops off rapidly, leaching stays elevated at easily detectable levels for many years and perhaps decades…PAHs from creosote also accumulate in sediments, where they are subject to degradation. However, the high molecular weight fraction can take a long time to degrade and contains known mutagens, teratogens, and carcinogens, which are most often associated with impacts to benthic species."
- "For copper, the most sensitive sublethal endpoint may be salmonid olfaction. This may be impacted by an increase in dissolved copper concentrations as low as 0.79 ug/L above background levels…However, the models and studies related to copper treated wood products show the impacts are localized and only prevalent with large surface area uses (such as bulkheads) in many cases. For creosote, the main impact of concern is accumulation in the sediments…Sediment impacts are also expected to occur on a localized scale. The impacts may occur for a longer period of time and at lower treated wood densities than the potential impacts of copper-treated products."
- In general, copper-treated products are considered to be safer than creosote-treated products
- In general, most projects using treated wood products do not pose a measurable risk to aquatic organisms unless large amounts of treated wood are used – keeping this in mind, each project needs to be evaluated on a case-by-case basis taking local conditions into consideration.

Arkoosh, M.R., and T.K. Collier. 2002. Ecological risk assessment paradigm for salmon: analyzing immune function to evaluate risk. Human and Ecological Risk Assessment 8(2):265-276.

- "Our research identifies and supports the possibility that certain environmental contaminants can alter salmon survival, and as a result may contribute to these species being at risk."
- "We have shown that juvenile Chinook salmon are exposed to polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) as they migrate through a contaminated urban estuary in Puget Sound WA. Immune function was analyzed in these fish by examining the ability of their anterior kidney and splenic leukocytes to produce a primary and secondary *in vitro* plague-forming cell (PFC) response to the hapten, trinitrophenyl (TNP), and by determining their susceptibility to a marine pathogen, *Vibrio anguillarum*. We found that fish outmigrating from the urban estuary produced a significantly lower PFC response to TNP and were more susceptible to the pathogen, compared to juvenile salmon collected from a rural estuary during their outmigration. In the laboratory, we exposed juvenile Chinook salmon collected from a hatchery to either a PCB technical mixture or a PAH compound to determine if these contaminants have the potential to alter immune function in salmon. Indeed, we found that salmon exposed in the laboratory to either the PCB mixture or the PAH also produced lower PFC responses and were more susceptible to disease compared to animals treated with the solvent vehicle. In summary, contaminants such as PAHs and PCBs are demonstrated to influence salmon health, and thus have the potential to adversely impact salmon populations."
- Authors conclude that juvenile salmon from polluted estuaries are at an increased risk for being immunosuppressed and more susceptible to disease than salmon from less polluted waters
- Authors point out studies that suggest that small decrease in first-year mortality could potentially reduce downward population trends and point to reducing contaminant levels as one way to accomplish this

**Wetland Alteration**

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- More than 50% of the original marshes and spruce swamps in the estuary have been converted to industrial, transportation, recreational, agricultural, or urban uses. More than 3,000 acres of intertidal marsh and spruce swamps have been converted to other uses since 1948. Many wetlands along the shore in the upper reaches of the estuary have been converted to industrial and agricultural lands after levees and dikes were constructed.

WSCC. 2002. Salmonid habitat limiting factors water resource inventory areas 33 (lower) and 35 (middle) Snake watersheds, and lower six miles of the Palouse River. Washington State Conservation Commission. Available: http://www.scc.wa.gov/index.php/288-WRIA-33-34-35-Snake-River-Watershed/View-category.html. (October 2009).

- "An extensive wetland complex was present near Dodge until the early 1900s when a local farmer channelized Pataha Creek, a Snake River tributary, to drain the wetlands. The channel modification coupled with conversion of thousands of acres of perennial grasslands to dryland wheat production led to rapid downcutting throughout the length of the stream channel. The historic floodplain became a terrace which no longer had a water table to support riparian vegetation."

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- "A mere 2% to 3% of the historic estuarine mudflats, saltwater marshes and wetlands remain for juvenile Chinook to use as they make their way from freshwater and the saltwater wedge out into the Sound as they head for the ocean waters."

Sommer, T., B. Harrell, M. Nobriga, R. Brown, W. Kimmerer, and L. Schemel. 2001a. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:(8)6-16.

- "Unlike conventional flood control systems that frequently isolate rivers from ecologically-essential floodplain habitat, California's Yolo Bypass has been engineered to allow Sacramento Valley floodwaters to inundate a broad floodplain. From a flood control standpoint, the 24,000 ha leveed floodplain has been exceptionally successful based on its ability to convey up to 80% of the flow of the Sacramento River basin during high water events."
- "…field studies demonstrate that the bypass seasonally supports 42 fish species, 15 of which are native. The floodplain appears to be particularly valuable spawning and rearing habitat for the splittail (*Pogonichthys macrolepidotus*), a federally listed cyprinid, and for young Chinook salmon (*Oncorhynchus tshawytscha*), which use the Yolo Bypass as a nursery area. The system may also be an important source to the downstream food web of the San Francisco Estuary as a result of enhanced production of phytoplankton and detrital material…alternative flood control systems can be designed without eliminating floodplain function and processes…"
- "Like natural floodplains, habitat diversity in the Yolo Bypass is much higher than adjacent river channels…has a mosaic of habitats including wetlands, ponds, riparian corridors, and upland areas…data on splittail and salmon growth support observations that natural river-floodplain systems can result in higher fish production on the floodplain than in river channels."

- "…possible improvements to the Yolo Bypass include the construction of more wetlands for wildlife, fixing fish passage and stranding problems at the floodplain weirs, and increasing the frequency of floodplain inundation in drier years."

**Woody Debris Removal**

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia spring Chinook salmon and steelhead recovery plan. Upper Columbia Salmon Recovery Board. Available: [http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf](http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf). (October 2009).

- Loss of large woody debris and floodplain connectivity have reduced rearing habitat for Chinook, steelhead, and bull trout in larger rivers (e.g., Wenatchee, Entiat, Methow, and Okanogan rivers) in the Upper Columbia Basin.

Benda, L. E., D. J. Miller, T. Dunne, G. H. Reeves, and J. K. Agee. 2001. Dynamic Landscape Systems. In River Ecology and Management, Lessons from the Pacific Coastal Ecoregion. Edited by Naiman, R. J. and R. E. Bilby. Springer Verlag New York, Inc. 175 Fifth Avenue, New York, NY 10010. Pages 261-288.

- Woody debris recruitment is a long-term process since it first requires the presence of a functioning riparian zone comprised of large trees, and second, a means of getting the tree into the stream (i.e. flood, wind storm, landslide, beaver falling a tree, etc.).

Sedell, J. R., P. A. Bisson, F. J. Swanson, and S. V. Gregory. 2000. What We Know About Large Trees That Fall Into Streams and Rivers. Interior Columbia Ecosystem Management Project.

- The most productive habitats for salmonid fish are small streams associated with mature and old-growth coniferous forests where large organic debris and fallen trees greatly influence the physical and biological characteristics of such streams.

Bilby, R. E. and P. A. Bisson. 2001. Function and Distribution of Large Woody Debris. In River Ecology and Management, Lessons from the Pacific Coastal Ecoregion. Edited by Naiman, R. J. and R. E. Bilby. Springer-Verlag New York, Inc. 175 Fifth Avenue, New York, NY 10010. Pages 373-398.

- Large woody debris stabilizes streambeds and banks, captures spawning gravels, encourages pool formation, provides resting and hiding cover for salmonids, and creates habitat for insects and other forage important to salmonids.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "The clearing of the riparian forests removed a vital source of snags and driftwood in the Sacramento and San Joaquin River basins. This has reduced the volume of LWD input needed to form and maintain stream habitat that salmon depend on in their various life stages. In addition to this loss of LWD sources, removal of snags and obstructions from the active river channel for navigational safety has further reduced the presence of LWD in the Sacramento and San Joaquin Rivers, as well as the Delta."

Collins, B.D., D.R. Montgomery, A.D. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland rivers. Canadian Journal of Fisheries and Aquatic Sciences 59:66-76.

- Collins et al. (2002) examined changes in wood abundance and functions in Puget Lowland rivers from the last ~150 years of land use by comparing field data from an 11-km-long protected reach of the Nisqually River with field data from the Snohomish and Stillaguamish rivers and with archival data from several Puget Lowland rivers.
- "Current wood abundance is one to two orders of magnitude less than before European settlement in the Snohomish and Stillaguamish basins. Most importantly, wood jams are now rare because of a lack of very large wood that can function as key pieces and low rates of wood recruitment. These changes in wood abundance and size appear to have fundamentally changed the morphology, dynamics, and habitat abundance and characteristics of lowland rivers across scales from channel unit to valley bottom."
- "Establishing the condition of the riverine landscape before European settlement sets a reference against which to evaluate contemporary conditions and develop restoration objectives."

Dugan, J.E., D.M. Hubbard, D.L. Martin, J.M. Engle, D.M. Richards, G.E. Davis, K.D. Lafferty, R.F. Ambrose. 2000. Macrofauna communities of exposed sandy beaches on the Southern California mainland and Channel Islands. p. 339-346 In: D.R. Brown, Mitchell, K.L., Chang, H.W., eds. Proceedings of the Fifth California Islands Symposium. Minerals Management Service Publication #99-0038. Available: http://www.werc.usgs.gov/chis/DuganetalMMS00.pdf. (January 2010).

- Species richness, abundance, and biomass of macrofauna (e.g., sand crabs, isopods, amphipods and polychaetes) associated with beach wrack are higher compared to beach areas with lower amounts of wrack or that are groomed.
- Beach grooming can substantially alter the macrofaunal community structure of exposed sand beaches. In addition, there are concerns that beach grooming efforts to remove wrack may also harm the eggs of the grunion (Leuresthes tenuis), an important prey item of Pacific salmon.

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- Historically large woody debris in Gold Creek, a Yakima River tributary, included large "old growth" trees, which would serve as stable key pieces in debris jams. "In-channel wood likely was a critical channel roughness element, dissipating stream energy and maintaining the stability of the alluvial channel."
- All of the large, old growth timber in the lower watershed was logged by 1990; there is now little or no residual key-piece size LWD in-channel and no opportunity for recruitment of new LWD key pieces. Although there is a substantial amount of small and medium sized woody debris in Gold Creek (and more is recruited from the banks with each flood), most all of it is readily mobilized by flood flows. Pieces are not large enough to provide bank protection, stable debris jams and stable LWD-related channel features.
- Potentially, the reintroduction of stable LWD features would restore bank stability, and aid in the return of deep pools and prolong the period when upstream fish passage is possible.

WSCC. 2002. Salmonid habitat limiting factors water resource inventory areas 33 (lower) and 35 (middle) Snake watersheds, and lower six miles of the Palouse River. Washington State Conservation Commission. Available: http://www.scc.wa.gov/index.php/288-WRIA-33-34-35-Snake-River-Watershed/View-category.html. (October 2009).

- "Large woody debris or (LWD) is an important component of stream habitat. Large trees that fall into streams, or are carried in by landslides and floods stabilize streambeds, collecting spawning gravels and encouraging pool formation. Woody debris also provides cover for salmonids and their prey. In the past woody debris was removed to aid navigation, transport logs downstream, speed floodwaters downstream, or remove barriers to salmonid migration. Large woody debris is lacking in many streams because of these activities and the reduction or modification of riparian vegetation. Unfortunately woody debris recruitment is a long-term process since it first requires the presence of a functioning riparian zone comprised of large trees, and second, a means of getting the tree into the stream."

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- Log jams in rivers form cool pools and back eddies, providing nursery areas for young fish and resting place for adults migrating upstream. Counts in the Stillaguamish River show current conditions provide approximately 1 piece of large woody debris for every river mile, compared with the desired 80 pieces per mile. This results in a significant loss of channel complexity and function for rearing and refuge.
- Over the next ten years, people of the Stillaguamish will create 51 engineered log jams to provide immediate channel complexity. As riparian planting and other restoration actions take place, the habitat forming processes that contribute large woody debris to the river will recover.

Bisson, P. A. and R. E. Bilby. 2001. Organic Matter and Trophic Dynamics. In River Ecology and Management, Lessons from the Pacific Coastal Ecoregion. Edited by Naiman, R. J. and R. E. Bilby. Springer-Verlag New York, Inc. 175 Fifth Avenue, New York, NY 10010. Pages 373-398.

- "Inputs of coarse particulate organic matter (CPOM) to headwater streams are transformed through processes of microbial decomposition, consumption by macroinvertebrates, and physical abrasion to fine particles and dissolved organic matter, which are utilized by aquatic communities downstream."
- "Human activities depriving streams of nutrients and organic matter or reducing the capacity of aquatic communities to store and process these materials (e.g., removal of streamside vegetation, loss of coarse woody debris, and reduction of salmon carcasses) often lead to changes in the trophic system that ultimately impair salmonid productivity."

Montgomery, D. R. and J. M. Buffington. 2001. Channel Processes, Classification, and Response. In River Ecology and Management, Lessons from the Pacific Coastal Ecoregion. Edited by Naiman, R. J. and R. E. Bilby. Springer-Verlag New York, Inc. 175 Fifth Avenue, New York, NY 10010. Pages 13-42.

- "LWD provides significant control on the formation and physical characteristics of pools, bars, and steps, thereby influencing channel type and the potential for change in sediment storage and bedform roughness in response to altered sediment supply, discharge, or LWD loading. LWD may also decrease the potential for channel widening by armoring stream banks: alternatively it may aid bank erosion by directing flow and scour toward channel margins. Furthermore, bed surface textures and their response potential are strongly controlled by hydraulic roughness resulting from inchannel LWD and debris-forced bedforms."

NMFS. 2002. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service.

- "Increases in sediment contributions to streams are generally attributable to changes in rates of erosion on hillslopes through such processes as increased landslide activity, sheetwash erosion associated with road management activities (construction and maintenance) and yarding operations, and fires (both wildfires and controlled burns). Significant increases in the sediment supplied to streams can cause channel aggradation, pool filling, additional bank erosion, and losses of channel structures and habitat diversity. Stable large woody debris structures within the stream channel may be lost through direct removal, channel aggradation, debris torrents, or gradual attrition through lack of recruitment. These losses result in a reduction in sediment storage capacity, fewer and shallower scour pools, and a reduction of instream cover for fish."

NMFS. 2008b. Willamette Project Biological Opinion. National Marine Fisheries Service. Available: https://pcts.nmfs.noaa.gov/pls/pcts pub/pcts_upload.summary_list_biop?p_id=26588. (October 2009).

- "Over time, flood control tends to reduce channel complexity (e.g., reduces the frequency of side channels, and woody debris recruitment) and reduces the movement and recruitment of channel substrates. Side channels, backwaters, and instream woody debris accumulations have been shown to be important habitat features for rearing juvenile salmonids."
- "All woody debris that streams transport from the watersheds above Cougar, Blue River, and Trail Bridge dams (about half of the McKenzie's historic contributing area above Vida) is now trapped in reservoirs and fails to reach lower portions of the river system. Such wood is thought to have once contributed to the maintenance of high-quality salmonid habitats downstream by influencing how river channels interacted with their banks and floodplains and by providing hydraulic diversity and hiding cover. The wood could have created logjams, secondary channels, pools and stable gravel deposits, all habitats utilized by salmonids and the invertebrates upon which they feed."

Sweeney, B. W., Bott, T. L. Jackson, J. K. Kaplan, L. A. Newbold, J. D. Standley, L. J. Hession, W. C., and R. J. Horwitz. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. National Academy of Sciences 101:14132-14137.

- Sweeney et al. conducted a study of16 streams in eastern North America shows to examine the effects of riparian deforestation on stream processes.
- Sweeney et al. measured the number of pieces of large woody coarse particulate organic matter as an ancillary habitat variable in this project and found the number to be significantly higher in the forested reaches [average (SE): 24.6 (3.0) versus 3.6 (0.9) for the deforested reaches.

NMFS. 2010b. Biological Opinion: Klamath Project Operations. National Marine Fisheries Service, Southwest Region.

- "Substantial timber harvesting has occurred throughout the Southern Oregon/Northern California Coast (SONCC )coho salmon ESU. In many SONCC coho salmon streams, lack of large woody debris results in decreased cover and reduced storage of gravel and organic debris. Lack of large woody debris (LWD) has also resulted in loss of pool habitat and a reduction in overall habitat and hydraulic complexity in a variety of coho salmon streams. LWD also provides cover from predators and shelter from high flow events.

**Pile-Driving**

Caltrans. 2001. Fisheries Impact Assessment, Pile Installation Demonstration Project for the San Francisco - Oakland Bay Bridge, East Span Seismic Safety Project. 59 p.

- The fisheries monitoring program during pile installation demonstration project (PIDP) for the San Francisco-Oakland Bay Bridge Seismic Safety Project documented near-term fish mortalities and the likelihood of a high rate of delayed mortality of differing sizes and species of fish that have swim bladders.
- Surveys with a fathometer before, during, and after pile driving indicated that fish schools did not move away from the PIDP site and suggested that the PIDP barge tended to aggregate fish.
- Based on acoustic measurements and experiments using shiner surfperch held in cages, the delayed mortality zone for pile driving using the large hammer without attenuation is estimated to extend out at least about 150 meters (about 500 feet) and possibly up to about 1,000 meters (3,280 feet) from the pile. The size of the IMZ and DMZ will vary with the species, species, size, physiological condition of the fish and environmental conditions.

Carlson, T.J., G. Ploskey, R.L. Johnson, R.P. Mueller, M.A. Weiland, P.N. Johnson. 2001. Observations of the behavior and distribution of fish in relation to the Columbia River navigation channel and channel maintenance activities. Prepared for the U.S. Army, Corps of Engineers, Portland District by Pacific Northwest National Laboratory, U.S. Department of Energy. 35 p. + appendices. Available: http://www.osti.gov/bridge/product.biblio.jsp?osti_id=787964&queryId=4&start=0. (January 2010).

- Underwater sounds generated by impact pile driving activities are within the frequency range to which juvenile salmonids have been observed to show an avoidance response.
- However, the duration of sound at fish avoidance frequencies is very short, on the order of 0.025 seconds per impact, which is below the 5-second duration found necessary to elicit avoidance responses from juvenile salmonids in laboratory studies.

Fisheries Hydroacoustic Working Group. 2008. Agreement in principle for interim criteria for injury to fish from pile driving activities. Memorandum to applicable agency staff, June 12, 2008. 4 pp.

- The Fisheries Hydroacoustic Working Group (FHWG) membership consists of the National Marine Fisheries Service (Northwest and Southwest Regions), the U.S. Fish and Wildlife Service (Regions 1 and 8), the U.S. Federal Highway Administration, the California Department of Transportation, the Oregon Department of Transportation, and the Washington State Department of Transportation.
- This agreement in principle was concluded at a meeting in Vancouver, Washington on June 10-11,2008 with key technical and policy staff from the signatory agencies and national experts on sound propagation activities that affect fish and wildlife species of concern.

- The agreed upon criteria identify sound pressure levels of 206 dB (re: 1 µPa) peak pressure and 187 dB (re: 1 µ$Pa^2$-sec) accumulated sound exposure level(SEL) for all listed fish except those that are less than 2 grams. In that case, the criteria for the accumulated SEL will be 183 dB (re: 1 µ$Pa^2$-sec).
- The agencies agreed to review the science periodically and revise the threshold and cumulative levels as needed to reflect current information.
- Behavioral impacts to fish and impact to marine mammals are not addressed in this agreement. Sub-injurious effects will continue to be discussed in future meetings.

Stadler, J.H. and D.P. Woodbury. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. Proceedings of Inter-Noise 2009, August 23-29, 2009, Ottawa, Canada. 8 pp.

- "A cooperative effort between several Federal and State transportation and resource agencies along the west coast of the United States has recently resulted in the establishment of interim criteria for the onset of physical injury to fishes exposed to the underwater sounds generated by impact pile driving. The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries), in its administration of the Endangered Species Act (ESA) and the essential fish habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), is using these criteria to assess potential impacts to its trust resources during consultation with Federal agencies on projects that include pile driving in, or near, aquatic environments. The new criteria use two metrics – peak sound pressure level (SPL) and sound exposure level (SEL). For the purpose of these consultations, and until new information becomes available to refine the criteria, the onset of physical injury would be expected if either the peak SPL exceeds 206 dB (re: 1 µPa)) or the SEL, accumulated over all pile strikes generally occurring within a single day, exceeds 187 dB (re: 1 µPa2•sec) for fishes 2 grams or larger, or 183 dB for smaller fishes. Here we present how NOAA Fisheries uses these criteria to assess the risk to fishes that are listed under the ESA or the essential fish habitat managed under the MSA."
- This paper describes a method to determine the distance from a pile being driven by an impact hammer that injury to fishes would be expected to occur, based on the sound levels produced by the hammer strike and the number of times the pile is struck.

Hardyniec, S, and S. Steen. 2005. Pile driving and barotrauma effects. Transportation Research Record: Journal of the Transportation Research Board. No. 1941: 184-190.

- "High-capacity driven pipe piles have recently been shown to be a viable alternative to pile groups in terms of economy and strength. A complication has emerged for the construction of bridge foundations with large diameter pipe piles, however - the injury and mortality of fish from sound pressure waves produced from pile driving, otherwise known as barotrauma. Even though this issue has been prevalent in California, regulators have started to restrict other states. This has caused confusion as to how to avoid unexpected increases in construction costs while following environmental laws.

After several trials, California Department of Transportation (Caltrans) engineers have implemented solutions to this problem, including driving windows, cofferdams, and a few different versions of air bubble curtains. This paper presents an accumulation of knowledge from engineers, biologists, and sound experts. It is to serve as an avenue for informing those who may sound be affected with pile-driving and fish barotrauma issues to minimize harmful effects and costs in the future."

Gregory T. Ruggerone, G.T., S. Goodman, R. Miner. 2008. Behavioral Response and Survival of Juvenile Coho Salmon Exposed to Pile Driving Sounds. Report by Natural Resource Consultants, Seattle, WA to the Port of Seattle. 25 pp + appendices.

- A study was conducted to examine the effects to juvenile coho salmon from the underwater sounds produced by driving 20-inch diameter hollow steel piles with an impact hammer, at Fisherman's Terminal, located on the Lake Washington Ship Canal in Seattle WA.
- Caged, hatchery-reared juvenile coho salmon were exposed to up to 1,627 pile strikes, at distances ranging from 1.8 meters to 15 meters from the pile. Received sound levels were up to 208 dB (re: 1µPa) peak pressure, 194 dB (re: 1µPa) rms pressure, and 179 dB (re: 1µPa2-sec) single strike SEL and 207 dB (re: 1µPa 2-sec) cumulative SEL.
- No mortality was observed, in either control or exposed fish, for up to 19 days post-exposure.
- Behavioral responses to pile driving were subtle, with fish responding with a startle response to the first 4-14 strikes. These were generally fish that were close to the pile (1.8 m). No avoidance response was apparent, and feeding behavior was observed on the fifth day after exposure, the first day that feeding was conducted.
- No gross internal or external injuries were observed, in either control or exposed fish, but auditory system, cellular, and stress responses were not examined.

California Department of Transportation. 2010. Mad River Bridges Replacement Project. Effects of Pile Driving Sound on Juvenile Steelhead. Prepared by ICF International, Seattle, WA. 22 pp.

- This study used caged fish deployments within the Mad River (California) to expose juvenile steelhead (*Onchorhynchus mykiss*) to a variety of peak sound pressures levels (SPLs) and cumulative sound exposure levels (SELs) from 2.2-meter-diameter (7.2-foot-diameter) cast-in-steel- shell (CISS) piles driven immediately adjacent to the Mad River.
- Four experimental trials were conducted. Each trial consisted of the driving of one pile section (20 to 24 meters [60 to 80 feet]). During each trial, cages containing fish were placed at four exposure locations at different distances from the pile driving activity (approximately 35 to 150 meters [115 to 490 feet] away) and at a control location (350 meters [1,150 feet] away).
- Underwater sound (peak and SEL) was monitored and recorded at each location during the experiments. Following cessation of pile driving, blood samples were drawn from

each fish for hematocrit (i.e., packed cell volume) and plasma cortisol level, and a necropsy was performed on each fish. Organ samples were also collected for histopathology by a highly experienced fish veterinary pathologist
- During pile driving, fish were exposed to underwater peak SPLs ranging from 69 to 188 decibels (dB) relative to 1 micropascal (re: 1 µPa).
- Cumulative SELs, ranged from 179 to 194 dB (re: 1 µPa2-sec). The cumulative SEL exceeded the interim cumulative SEL threshold of 187 dB during the last two pile driving events, both times in the two cages closest to the pile being driven (thus, four exposure groups experienced cumulative SELs in excess of 187 dB).
- On-site necropsies of all exposed and control fish conducted following each trial, as well as histopathology of the fish from the cages closest to the pile driving and control fish, showed no physical trauma that could be related to exposure to underwater noise from pile driving, and no statistically significant differences between experimental and control animals were detected.
- Hematocrit and plasma cortisol levels were not significantly related to exposure to noise generated by pile driving.
- There were no immediate significant physical effects of exposure to cumulative SELs of ≤194 dB from pile driving at the project site.

Illingworth & Rodkin. 2007. Compendium of pile driving sound data. Prepared for the California Department of Transportation, Sacramento, CA. 129 pp.
- "This appendix provides information on sound pressures resulting from pile driving measured throughout Northern California. The information provides an empirical database to assist in predicting underwater sound levels from marine pile driving projects and determining the effectiveness of measures used to control the noise. This compendium includes information on major and minor projects with a variety of different pile and hammer types that were completed within the last 6-1/2 years and were completed since work began on the pile installation demonstration project for the San Francisco-Oakland Bay Bridge in December 2000."
- The compendium covers a range of pile materials, types, and sizes, including wood, concrete, steel pipe or cast-in- steel-shell (CISS) piles, steel H-piles, and steel sheet piles. Both impact driving and vibratory driving are included.
- The compendium reports the calculated propagation loss equations, when available.
- Specific monitoring efforts for each type of pile are discussed in detail.
- The compendium is available online at: http://www.dot.ca.gov/hq/env/bio/files/pile_driving_snd_comp9_27_07.pdf

Washington State Department of Transportation. 2010. Noise impact assessment. section 7 *in:* Biological Assessment Preparation for Transportation Projects - Advanced Training Manual - Version 02-2010. Part 2: Guidance on specific biological assessment topics. Online at:

http://www.wsdot.wa.gov/NR/rdonlyres/A1F85352-90E0-457B-9A8C-B5103E097FAE/0/BA_ManualPart2.pdf.

- This guidance manual is intended to assist staff in preparing biological assessments for use by WSDOT in their Endangered Species Act and Essential Fish Habitat consultations.
- Presents important concepts of underwater sound, including metrics for measuring sound, sound propagation, sound sources, determining the extent of underwater project-related noise, and methods to estimate the potential effects to aquatic species.

WSDOT. 2010. Underwater noise monitoring plan. 6 pp. Available online at: http://www.wsdot.wa.gov/Environment/Biology/BA/BAtemplates.htm#Noise

- This is a protocol developed by the Washington State Department of Transportation for monitoring the underwater sound levels produced during pile driving activities. It describes the appropriate metrics for measuring and reporting the sound levels.

Popper, A. and M. Hastings. 2009. The effects of human-generated sound on fish. Integrative Zoology 44:43-52.

- "Findings suggest that human-generated sounds, even from very high intensity sources, might have no effect in some cases or might result in effects that range from small and temporary shifts in behavior all the way to immediate death. At this point, however, it is nearly impossible to extrapolate from results with one sound source, one fish species, or even fish of one size to other sources, species, or fish sizes."
- "To date, the concerns regarding the effects of increased background sound on fish far exceed the extent of data that is available to support such concerns. Although there is little doubt that increases in sound are likely to affect fish, we are far from understanding the extent of these effects and even further from being able to provide useful models that will enable us to predict such effects."
- "If excess particle motion significantly contributes to hearing loss and/or tissue damage, as we believe it does, then particle motion will need to be considered in risk analyses and assessments when planning sound-producing activities in the marine environment."
- "Methods must be developed that will allow for studies of behavior of "wild" animals that are not restrained in any way that examine their response, both short term and long term, to exposure to different sounds."

Hastings, M. C. and A. N. Popper. 2005. Effects of sound on fish. Admin. Rec. 151422SWR02SR6292. California Department of Transportation Contract No. 43A0139, Task Order 1.

- "It is important to note that there are no studies that have examined longer-term effects of exposure to pile driving sounds that may lead to delayed death or, perhaps, to other alteration in behavior that could affect the survival of individuals or of populations of fishes. Nor have studies examined the non-mortality responses of fishes outside of the "kill-zone" that, while not immediately apparent, may have significant effects on fish populations. Non-mortality effects may include temporary injury that heals, injury that

leads to a slow death (e.g., break down of tissues in some organ system), temporary or permanent hearing loss, movement of fish away from feeding grounds due to high signal levels, and many other possible scenarios. Thus, future investigations must not only examine immediate mortality of pile driving exposure on fish, but they must also consider longer term effects on physiology and behavior, as well as effects on fishes that are at some distance from the source."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "The type and intensity of the sounds produced during pile driving depend on a variety of factors, including, but not limited to, the type and size of the pile, the firmness of the substrate into which the pile is being driven, the depth of water, and the type and size of the pile-driving hammer. Sound pressure levels (SPLs) are positively correlated with the size of the pile, as more energy is required to drive larger piles. Wood and concrete piles appear to produce lower sound pressures than hollow steel piles of a similar size, although it is not yet clear if the sounds produced by wood or concrete piles are harmful to fishes."
- "The degree to which an individual fish exposed to sound will be affected is dependent upon a number of variables, including 1) species of fish, 2) fish size, 3) presence of a swimbladder, 4) physical condition of the fish, 5) peak sound pressure and frequency, 6) shape of the sound wave (rise time), 7) depth of the water around the pile, 8) depth of the fish in the water column, 9) amount of air in the water, 10) size and number of waves on the water surface, 11) bottom substrate composition and texture, 12) effectiveness of bubble curtain sound/pressure attenuation technology, 13) tidal currents, and 14) presence of predators.
- The following are recommended conservation measures to mitigate for woody debris removal effects:
  1. Install hollow steel piles with an impact hammer at a time of year when larval and juvenile stages of fish species with designated EFH are not present. If this is not possible, then the following measures should be incorporated to minimize adverse effects.
  2. Drive piles during low tide periods when located in intertidal and shallow subtidal areas.
  3. Use a vibratory hammer when driving hollow steel piles. Under those conditions where impact hammers are required for reasons of seismic stability or substrate type, it is recommended that the pile be driven as deep as possible with a vibratory hammer prior to the use of the impact hammer.
  4. Monitor peak SPLs during pile driving to ensure that they do not exceed the 190 dB re:1 µPa threshold for injury to fish.
  5. Implement measures to attenuate the sound should SPLs exceed the 180 dB re: 1 µPa threshold. If sound pressure levels exceed acceptable limits, implement mitigative measures. Methods to reduce the sound pressure levels include, but are not limited to, the following:

a) Surround the pile with an air bubble curtain system or air-filled coffer dam.
b) Since the sound produced has a direct relationship to the force used to drive the pile, use of a smaller hammer should be used to reduce the sound pressures.
c) Use a hydraulic hammer if impact driving cannot be avoided. The force of the hammer blow can be controlled with hydraulic hammers; reducing the impact force will reduce the intensity of the resulting sound.
6. Drive piles when the current is reduced (i.e., centered around slack current) in areas of strong current to minimize the number of fish exposed to adverse levels of underwater sound.

**Over-water Structures**

Collis, K., D.D. Roby, D.P. Craig, S. Adamany, J. Adkins, and D.E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River:
Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society: 131:537-550.

- Throughout the Columbia River basin, piscivorous birds congregate near hydroelectric dams and in the estuary near man-made islands and structures and eat large numbers of migrating juvenile salmonids.
- Hundreds of cormorants were regularly observed foraging on salmonids adjacent to the extensive system of pile dikes above Rice Island and roosting on the pile dikes between foraging bouts.
- “Smolt losses to cormorant predation may potentially be reduced by deploying bird excluders on pile dikes to prevent use by cormorants.”

Roby, D.E., K. Collis, D.P. Lyons, Y. Suzuki, J.Y. Adkins, L. Reinalda, C. Hand, N. Hostetter, A. Evans, and M. Hawbecker. 2007. Research, monitoring, and evaluation of avian predation on salmonid smolts in the lower and mid-Columbia River. Summary report to the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

- Double-crested cormorants were observed at Little Goose Dam and Lower Granite Dam on the Snake River during September-December 2007.
- At both dams, cormorants used the navigation lock walls, log booms, trash-shear walls, and spillway guide walls to roost and stage before foraging.
- Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 11.8% of the double-crested cormorant diet (by mass) at Little Goose and Lower Granite dams in 2007.

Nightingale, B., C.A. Simenstad, Jr. 2001. Overwater structures: Marine issues. White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. 133 p.

- Empirical findings support the notion that overwater structures can have measurable effects on the distribution and abundance of marine resources. Based on the existing state of the knowledge and the fact that light levels are measurable and variable with each structure and location, we conclude that light limitation assessment and mitigation in the development of overwater structures is integral to ecosystem-based resource management.
- Evidence reveals that juvenile fish, such as salmonids, feeding in shallow nearshore waters utilize ultraviolet wavelengths for prey capture. Therefore, we conclude that allowing the transmission of increasing levels of natural light to the under-dock environment to include the transmission of required ultraviolet light spectra will reduce structural interference with fish ability to capture under-dock prey.

Kahler, T., M. Grassley, D.A. Beauchamp. 2000. A summary of the effects of bulkheads, piers, and other artificial structures and shorezone development on ESA listed salmonids in lakes. Final Report to the City of Bellevue, Washington. 74 p. Available: kitsapgov.com/dcd/lu_env/cao/bas/wetlands/bellevue_bas.pdf. (January 2010).

- Shading from overwater structures may reduce prey organism abundance and the complexity of the habitat by reducing aquatic vegetation and phytoplankton abundance.

Duffy-Anderson, J.T., K.W. Able. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River estuary: a study across a pier edge. Marine Biology 133:409-418.

- Growth rates of juvenile fishes under piers had significantly lower growth rates than fishes in openwater in the Hudson Bay estuary.

Johnson, L. 2000. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. White paper from National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA. 29 p.

- Treated wood used for pilings and docks releases contaminants into saltwater environs. Poly-aromatic hydrocarbons (PAHs) are commonly released from creosote-treated wood. PAHs can cause a variety deleterious effects (cancer, reproductive anomalies, immune dysfunction, and growth and development impairment) to exposed fish.

Stehr, C.M., D.W. Brown, T. Hom, B.F. Anulacion, W.L. Reichert, T.K. Collier. 2000. Exposure of juvenile chinook and chum salmon to chemical contaminants in the Hylebos Waterway of Commencement Bay, Tacoma, Washington.

- The results of Stehr et al. (2000) show that juvenile chum and chinook salmon from the Hylebos Waterway take up a wide range of chemical contaminants, compared to fish from hatcheries or reference estuaries. These contaminants include high and low molecular weight polycyclic aromatic hydrocarbons (PAHs).
- Concentrations of contaminants in juvenile chinook and chum salmon from the Hylebos Waterway are comparable to levels previously shown to be associated with biological injury in juvenile Chinook salmon, such as impaired growth, suppression of immune

function as demonstrated by reduced B cell function, and increased mortality following pathogen exposure.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- "Overwater structures create shade which reduces the light levels below the structure. The size, shape and intensity of the shadow cast by a particular structure depends upon its height, width, construction materials, and orientation. High and narrow piers and docks produce narrower, more diffuse shadows than do low and wide structures. Increasing the numbers of pilings used to support a given pier increases the shade cast by pilings on the under-pier environment. In addition, less light is reflected underneath structures built with light-absorbing materials (e.g., wood) than from structures built with light-reflecting materials (e.g., concrete or steel). Structures that are oriented north-south produce a shadow that moves across the bottom throughout the day, resulting in a smaller area of permanent shade than those that are oriented east-west."
- "Fishes rely on visual cues for spatial orientation, prey capture, schooling, predator avoidance, and migration. The reduced-light conditions found under an overwater structure limit the ability of fishes, especially juveniles and larvae, to perform these essential activities."
- "Wave energy and water transport alterations from overwater structures can impact the nearshore detrital foodweb by altering the size, distribution, and abundance of substrate and detrital materials. Disruption of longshore transport can alter substrate composition and can present potential barriers to the natural processes that build spits and beaches and provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning."
- "Treated wood used for pilings and docks releases contaminants into saltwater environs. Poly-aromatic hydrocarbons (PAHs) are commonly released from creosote-treated wood. PAHs can cause a variety of deleterious effects (cancer, reproductive anomalies, immune dysfunction, and growth and development impairment) to exposed fish. Wood also is commonly treated with other chemicals such as ammoniacal copper zinc arsenate (ACZA) and chromated copper arsenate. These preservatives are known to leach into marine waters for a relatively short period of time after installation, but the rate of leaching is highly variable and dependent on many factors. Concrete or steel, on the other hand, are relatively inert and do not leach contaminants into the water."
- The following are recommended conservation measures to mitigate for overwater structures effects:
  1. Use upland boat storage whenever possible to minimize need for overwater structures.
  2. Locate overwater structures in sufficiently deep waters to avoid intertidal and shade impacts, to minimize or preclude dredging, to minimize groundings, and to avoid

displacement of submerged aquatic vegetation, as determined by a pre-construction survey.
3. Design piers, docks, and floats to be multi-use facilities in order to reduce the overall number of such structures and the nearshore habitat that is impacted.
4. Incorporate measures that increase the ambient light transmission under piers and docks. These measures include, but are not limited to, maximizing the height of the structure and minimizing the width of the structure to decrease shade footprint; grated decking material; using solar tubes to direct light under the structure and glass blocks to direct sunlight under the structure; illuminating the understructure area with meta halide lamps and use of reflective paint or materials (e.g., concrete or steel instead of materials that absorb light such as wood) on the underside of the dock t reflect ambient light; using the fewest number of pilings necessary to support the structures to allow light into under-pier areas and minimize impacts to the substrate; and aligning piers, docks and floats in north-south orientation to allow arc of sun to cross perpendicular to structure and reduce duration of light limitation.
5. Use floating breakwaters whenever possible and remove them during periods of low dock use. Encourage seasonal use of docks and off-season haul-out.
6. Use waveboards to minimize effects on littoral drift and benthic habitats.
7. Locate floats in deep water to avoid light limitation and grounding impacts to the intertidal zone, and maintain at least one foot of water between the substrate and the bottom of the float.
8. Conduct in-water work during the time of year when EFH-managed species and prey species are least likely to be impacted.
9. Avoid use of treated wood timbers or pilings to the extent practicable. Use of alternative materials such as untreated wood, concrete, or steel is recommended.
10. Fit all pilings and navigational aids, such as moorings and channel markers, with devices to prevent perching by piscivorous bird species.
11. Orient night lighting such that illumination of the surrounding waters is avoided.
12. Mitigate for unavoidable impacts to benthic habitats that is adequately provided, properly monitoried, and adaptively managed.

Williams, G. D., R. M. Thom, J. A. Southard, L. K. O'Rourke, S. L. Sargeant, V. I. Cullinan, D. K. Shreffler, R. Moursund, and M. Stamey. 2003. Assessing overwater structure-related predation risk on juvenile salmon: field observations and recommended protocols. Pacific Northwest National Laboratory, Sequim, Washington.

- "Large overwater structures have often been cited as potential migratory barriers and areas of increased predation for juvenile salmon migrating along shallow shoreline habitats, although conclusive evidence has not been demonstrated to date in situ. To help resolve this issue, Washington State Ferries (WSF) sponsored directed research to determine whether WSF terminals affect predation on juvenile salmon."
- "We used a combination of standardized surveys, stomach content analyses, and new observational technologies to assess fish, avian, and mammal predation on salmon fry at

ferry terminals and paired reference sites during periods of pre- (early April) and peak (May) outmigration."

- "We observed no significant aggregation of potential bird or mammal predators at six ferry terminal study sites. Few potential fish predators were documented in SCUBA surveys, beach seines, or with a Dual frequency IDentification SONar (DIDSON) camera at Mukilteo, our single underwater study location. Only one instance of salmon predation by fish (staghorn sculpin –Leptocottus armatus) was confirmed, and this was at the corresponding reference site."
- "A tiered protocol (Minimum/ Recommended/ Preferred actions) was developed for assessing potential predation at other overwater structures. Likewise, recommendations were developed for incorporating design features into WSF terminal improvement projects that could minimize future impacts."

**Alternative Energy**

McMurray, G. 2007. Wave energy ecological effects workshop ecological assessment briefing paper. Wave energy ecological effects workshop, Hatfield Marine Science Center, Oregon State University.

- Assesment of environmental effects of wave energy generation showed minimal effects to marine life. The following potential issues affecting marine life were examined and found to only have minor effects:
  - Wave energy devices will necessarily remove some energy from the wave train, and thus, the littoral system. Resultant effects may include alterations in currents and sediment transport.
  - The deployment of structures in a previously clear area brings the risk of collision and/or entanglement of animals; primarily the larger fish, the seabirds and the marine mammals.
  - Wave energy arrays will provide a matrix of hard structures in areas previously devoid of any hard structure: this will include buoys at the surface and through much of the water column, subsea pods (see fig. 2.4), and anchors on sedimented substrates. This will likely have ecological consequences from the fouling community up through the highest levels of trophic structure.
  - Wave energy devices will create the potential for chemical effects from a variety of sources, including toxins in antifouling paints, metals including lead and zinc, and organics, such as those used for hydraulic fluids.
  - Wave energy devices will necessarily generate electrical (E fields) and magnetic (B fields) fields (EMF) as they produce and transmit electrical currents. At issue is the sensitivity of particular groups of the biota, especially the potential responses of elasmobranchs (attraction, repulsion, or other behavioral taxis), and the effectiveness of mitigation, primarily through shielding.

- Wave energy devices will have acoustic signatures, from the impingement of waves on above-water structures to generators and switching systems. Fish and seabirds are sensitive to sounds and many marine mammals are dependent on sound for life processes from feeding to mating.
- The lighting required by the US Coast Guard to address safety considerations may attract biota, especially seabirds, to the generation devices.

U.S. Department of Energy. 2009. Report to Congress: potential environmental effects of marine and hydrokinetic energy technologies. Prepared in response to the Energy Independence and Security Act of 2007, Section 633(b).

- Wave energy facilties will create pilings or mooring cables and may acts as fish aggregation devices (FADs). The aggregation of predators near FADs may adversely affect juvenile salmonids or Dungeness crabs moving through the project area.
- Four species of Pacific salmon were found to have of magnetite within them and it is believed that these crystals serve as a compass orients to the earth's magnetic field (Mann et al. 1988; Walker et al. 1988). Because some aquatic species use the Earth's magnetic field to navigate or orient themselves space, there is a potential for the magnetic fields created by the numerous electrical cables associated with offshore power projects to disrupt these movements.

Wilson, B., R. S. Batty, F. Daunt, and C. Carter. 2007. Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scotttish Executive. Scottish Association for Marine Science, Oban, Scotland.

- A fish aggregation device (FAD) is a floating device placed in the water to attract fish (Dempster & Taquet 2004) and may closely parallel many of the designs of wave energy devices. This fishing method has arisen from a phenomenon where natural aggregations of fish form under and around floating objects.
- Pelagic fishes that live in a uniform environment are attracted by any physical anomaly, e.g. an object, bottom discontinuity, steep gradients etc, and fishermen have used these associations to increase their catch, as the fish occur in bigger schools and are easier to catch (Freon & Dagorn 2000). There have been many possible reasons suggested to explain why these floating structures attract marine life. It is thought that wave and tidal devices may also act as FADs, the difference being that these devices will have moving parts. It is possible that the presence of fish will also attract predators (such as marine mammals and birds) to these areas.

**LNG Facilities**

FERC. 2009. Biological assessment: Bradwood Landing Project. Federal Energy Regulatory Comission, Office of Energy Projects, Washington, DC.

- The purpose of the Bradwood Landing Project is to import and store liquefied natural gas (LNG) to provide a new source of natural gas to the Pacific Northwest. LNG is natural gas cooled to about -260 degrees Fahrenheit (127 degrees Celsius) to reduce its volume so that it can be transported long distances across oceans in specially designed ships from its point of origin to foreign markets. NorthernStar proposes to provide up to 1.3 billion cubic feet (ft3) (3.7 million cubic meters (m3)) per day of natural gas to the region through interconnects at two industrial facilities, an intrastate pipeline, and an interstate pipeline system.
- The Biological Assessment of the Bradwood Landing Project examined the project effects to Pacific salmon essential fish habitat. The following effects were described:
    - Designated critical habitat used by migrating juvenile Columbia River salmon for forage and rearing and adult salmon for upmigration would be permanently filled in at the LNG terminal.
    - Access by LNG carriers would be made possible by dredging a deep draft maneuvering area at the LNG terminal site. Dredging can lead to significant impacts on EFH including: removal or burial of fish or their prey items; turbidity/siltation effects; release of contaminants deposited in the sediment; release of oxygen consuming substances leading to decreased dissolved oxygen availability; fish entrainment; noise; and other alterations to hydrodynamic regimes and physical habitat.
    - The Bradwood Landing LNG terminal would include overwater structures. Overwater structures can lead to modified predator-prey interactions by providing ambush. Opportunities for larger fish and perching opportunities for piscivorous birds.
    - Construction of the ship berth and other overwater structures would require the installation of pilings. The primary adverse effect of this action is intense sound pressure waves that have been shown to harm fish and may affect the ecological functioning of EFH for groundfish and Pacific salmon.
    - The intake from and subsequent discharge of water to the Columbia River for facility operations can lead to adverse effects to EFH and its ecological function through entrainment of fish species and their prey (early life stages are especially susceptible) due to inadequate screening, impingement of fish and prey species, and increased water temperatures adjacent to and downstream of outfalls.
    - The operation of vessels associated with the Bradwood Landing Project may adversely affect EFH throughout the marine and riverine portions of the action area. Impacts could include: shoreline erosion from wake generation; increased turbidity and suspended contaminants from vessel propeller wash; degraded water quality from vessel discharge, engine operation, and bottom paint sloughing; introduction of nonnative invasive species in ballast water or on hulls; and accidental spills.

- Installation of pipelines can lead to the destruction of organisms and habitat, increased turbidity, and resuspension of contaminants. The new infrastructure and proposed pipeline required for project operations would only affect Pacific Salmon EFH (in the freshwater and tributary habitats).
- The Bradwood Landing Project would include habitat preservation, restoration, and enhancement activities, including both compensatory mitigation and the SEI (described in Biological Assessment). The long-term effects of these projects are expected to provide a benefit to the ecosystem and to EFH for groundfish and Pacific salmon.

**Desalination**

Danoun, R. 2007. Desalination plants: potential impacts of brine discharge on marine life. The University of Sydney, Australia.

- "Salinity, temperature and total alkalinity fluctuations, as a consequence of the brine discharge of the desalination plant, can play a considerable role in determining the abundance and distribution of flora and fauna's species."
- "Long term monitoring of the conditions proposed in relation to temperature, salinity and alkalinity at the site of the desalination discharge outlet vicinity during the desalination process is recommended. This would allow the verification of the appropriate distribution of the discharge plume into the seawater and the impact of the above factors on the aquatic organisms could be better understood."

**Power Plant Intakes**

Kock, T. J., S. D. Evans, T. L. Liedtke, D. W. Rondorf and M. Kohn. 2009. Evaluation of strobe lights to reduce turbine entrainment of juvenile steelhead at Cowlitz Falls Dam, Washington. Northwest Science 83: 308-314.

- Kock et al. (2009) conducted a radiotelemetry evaluation to determine if strobe lights could be used to decrease turbine entrainment of juvenile steelhead as Cowlitz Falls Dam, Washington.
- They found that radio-tagged juvenile steelhead approached and entered two spillways (one lighted, one unlighted) in equal proportions.
- However, the presence of strobe lights was associated with decreased spillbay residence time of juvenile steelhead.
- "Our results suggest that factors such as deployment location, exposure, and flow are important variables that should be considered when evaluating strobe lights as a potential fish-deterring management tool."

Ferguson, J. W., B. P. Sandford, R. E. Reagan, L. G. Gilbreath, E. B. Meyer, R. D. Ledgerwood, N. S. Adams.  2007.  Bypass system modification at Bonneville Dam on the Columbia River improved the survival of juvenile salmon.  Transactions of the American Fisheries Society 136:1487-1510.

- The survival of subyearling Chinook salmon Oncorhynchus tshawytscha released into the Bonnevile Dam Powerhouse fish bypass system ranged from 0.774 to 0.911 and was significantly lower than the survival of test fish released into turbines and the area immediately below the powerhouse where bypass system flow reentered the river. Yearling and subyearling Chinook salmon and yearling coho salmon O. kisutch released into the bypass system were injured or descaled.
- This original system was then extensively modified using updated design criteria, and the site where juvenile fish reentered the river was relocated 2.8 km further downstream to reduce predation on bypassed fish by northern pikeminnow Ptychocheilus oregonensis.
- Based on studies conducted from 1999 to 2001, the new bypass system resulted in high fish survival, virtually no injuries to fish, fish passage times that were generally similar to water travel times, and mild stress responses from which fish recovered quickly. The mean estimated survival of subyearling Chinook salmon passing through the new bypass system was 0.946 in 2001, which was an unusually lowflow year.
- Survival, physical condition, passage timing, and blood physiological indicators of stress were all useful metrics for assessing the performance of both bypass systems and are discussed.
- The engineering and hydraulic criteria used to design the new bypass system at the Bonnevile Dam  that resulted in improved fish passage conditions are described in the paper.

NMFS.  2003.  Non-fishing impacts to essential fish habitat and recommended conservation measures.  National Marine Fisheries Service.

- “Adverse impacts to EFH from water intake structures and effluent discharges can interfere or disrupt EFH functions in the source or receiving waters by 1) entrainment, 2) impingement, 3) discharge, 4) operation and maintenance, and 5) construction-related impacts.”
- “Entrainment is the withdrawal of aquatic organisms along with the cooling water into the cooling system.  These organisms are usually the egg and larval stages of managed species and their prey. Entrainment can subject these life stages to adverse conditions resulting from the effects of increased heat, antifouling chemicals, physical abrasion, rapid pressure changes, and other detrimental effects. Consequently, diverting water without adequate screening prevents that portion of the EFH from providing important habitat functions necessary for the early life stages of managed living marine resources and their prey.”

- "Impingement occurs to organisms that are too large to pass through in-plant screening devices and instead become stuck or impinged against the screening device or remain in the forebay sections of the system until they are removed by other means."
- "Other impacts to aquatic habitats can result from construction related activities (e.g., dewatering, dredging, etc.) (see Section 4.1) as well as routine operation and maintenance activities. There is a broad range of impacts associated with these activities depending on the specific design and needs of the system. For example, dredging activities can cause turbidity, degraded water quality, noise, and substrate alterations. Many of these impacts can be reduced or eliminated through the use of various techniques, procedures, or technologies, but some may not be fully eliminated except by eliminating the activity itself."
- The following are recommended conservation measures to mitigate for overwater structures effects:
  1. Locate facilities that rely on surface waters for cooling in areas other than estuaries, inlets, heads of submarine canyons, rock reefs or small coastal embayments where EFH species or their prey concentrate. Discharge points should be located in areas that have low concentrations of living marine resources. They should incorporate cooling towers to control temperature and employ sufficient safeguards to ensure against release of blow-down pollutants into the aquatic environment in concentrations that reduce the quality of EFH.
  2. Design intake structures to minimize entrainment or impingement. Velocity caps that produce horizontal intake/discharge currents should be employed and intake velocities across the intake screen should not exceed 0.5 foot per second.
  3. Design power plant cooling structures to meet the "best technology available" requirements (BTAs) as developed pursuant to Section 316(b) of the Clean Water Act. Use of alternative cooling strategies, such as closed cooling systems (e.g., dry cooling) should be used to completely avoid entrainment/impingement impacts in all industries which require cooling water. When alternative cooling strategies prove infeasible, other BTAs may include but are not limited to fish diversion or avoidance systems, fish return systems that convey organisms away from the intake and mechanical screen systems that prevent organisms from entering the intake system, and habitat restoration measures.
  4. Regulate discharge temperatures (both heated and cooled effluent) such that they do not appreciably alter the temperature that could cause a change in species assemblages and ecosystem function in the receiving waters. Strategies should be implemented to diffuse the heated effluent.
  5. Avoid the use of biocides (e.g., chlorine) to prevent fouling where possible. The least damaging antifouling alternatives should be implemented.
  6. Mitigate for impacts related to power plants and other industries requiring cooling water. Mitigation should compensate for the net loss of EFH habitat functions from placement and operation of the intake and discharge structures. Mitigation should be provided for the loss of habitat from placement of the intake structure and delivery

pipeline, the loss of fish larvae and eggs that may be entrained by large intake systems, and the degradation or loss of habitat from placement of the outfall structure and pipeline as well as the treated water plume.
7. Treat all discharge water from outfall structures to meet state water quality water standards at the terminus of the pipe. Pipes should extend a substantial distance offshore and be buried deep enough to not affect shoreline processes. Buildings and associated structures should be set well back from the shoreline to preclude the need for bank armoring.

**Pesticides**

Baldwin, D. H., J. A. Spromberg, T. K. Collier, N. L. Scholz. 2009. A fish of many scales: extrapolating sublethal pesticide exposures to the productivity of wild salmon populations. Ecological Applications 19:2004-2015.

- Because pesticide exposures are typically sublethal, a key question is whether toxicological effects at (or below) the scale of the individual animal ultimately reduce the productivity and recovery potential of wild populations.
- Baldwin et al. (2009) examined how the sublethal impacts of pesticides on physiology and behavior can reduce the somatic growth of juvenile chinook salmon (Oncorhynchus tshawytscha) and, by extension, subsequent sizedependent survival when animals migrate to the ocean and overwinter in their first year.
- "Our results indicate that short-term (i.e., four-day) exposures that are representative of seasonal pesticide use may be sufficient to reduce the growth and size at ocean entry of juvenile chinook. The consequent reduction in individual survival over successive years reduces the intrinsic productivity (lambda) of a modeled oceantype chinook population."

Weinhold, B. 2009. Synergy for Salmon: Study Spawns Insight into Pesticide Mixtures. Environmental Health Perspectives 117:A117.

- The researchers evaluated the effects of diazinon, malathion, chlorpyrifos, carbaryl, and carbo furan—which are among the most extensively used pesticides in California and the Pacific Northwest—in the brains of juvenile coho salmon. These chemicals inhibit the enzyme acetylcholinesterase (AChE), resulting in an accumulation of acetylcholine, which in turn can affect behavior and, ultimately, survival.
- For each of 10 pairings of the 5 pesticides, concentrations were designed to elicit AChE reductions of 10%, 29%, or 50% (assuming the chemicals acted additively) for a total of 30 possible exposures. Other fish were exposed to single pesticides; none were tested for combinations of 3 or more chemicals.
- Nearly every pairing inhibited AChE activity after the salmon were exposed over a 96-hour period. Synergistic inhibition was observed in 20 of the 30 combinations,

producing anywhere from about 20% stronger inhibition than predicted by additive activity alone to more than 90% inhibition in 5 combinations. For 3 combinations, the salmon died within 24 hours. In contrast, there were no deaths among fish exposed to individual pesticides only.
- If synergistic effects occur at concentrations found in habitats supporting salmon stocks, which often include species designated as threatened or endangered, regulators may need to consider multichemical effects when setting exposure standards.

NMFS. 2008c. Biological Opinion: Environmental Protection Agency registration of pesticides containing Chlorpyrifos, Diazinon, and Malathion. National Marine Fisheries Service, Silver Spring, Mo.
- "A significant risk to threatened and endangered ESUs/DPSs is pesticide drift and runoff to salmonid aquatic habitats."
- "Given the species' life history, salmonids may be exposed to chlorpyrifos, diazinon, and malathion through direct contact with contaminated surface water or pore water. Of particular concern are small streams and off-channel habitats used by salmonids that have a lower capacity to dilute pesticide contaminants. These habitats are frequently in floodplain areas that overlap with agricultural, residential, and urban land uses. Dietary consumption via salmonid prey is a likely route of exposure and is significant exposure for chlorpyrifos. Chlorpyrifos accumulates in tissues of aquatic organisms and may be consumed by other fish and animals throughout the food chain. Salmonid prey items include dead or dying aquatic terrestrial insects that have been exposed to the three active ingredients."
- "Monitoring studies indicate that detection of chlorpyrifos, diazinon, and malathion occurs frequently throughout the action area in freshwater and nearshore environments associated with urban, agricultural or mixed land use watersheds. However, there is a limited amount of monitoring data available for streams and off-channel habitats. The available monitoring data are not adequate to define exposure at the ESU/DPS level."
- "We expect surface waters that contain chlorpyrifos, diazinon, and malathion to affect individuals and prey by additive toxicity as a result of the cumulative impairment of AChE activity and all AChE-associated physiological functions. Additionally, we also expect to see additive toxicity in the form of AChE inhibition in salmonids and their prey in surface waters containing other OPs and carbamates. Similarly, synergism occurs with certain combinations and specific concentrations of chlorpyrifos, diazinon, and malathion. This interaction translates into increased rates of mortality among exposed salmonids. While we have no predictive models for this phenomenon, we expect to see synergistic effects where these three pesticides co-occur in specific levels."

Johnson, L. L., G. M. Ylitalo, M. R. Arkoosh, A. N. Kagley, C. Stafford, J. L. Bolton, J. Buzitis, B. F. Anulacion and T. K. Collier. 2007. Contaminant exposure in outmigrant juvenile salmon from Pacific Northwest estuaries of the United States. Environmental Monitoring and Assessment 124:161-194.

- "To better understand the dynamics of contaminant uptake in outmigrant juvenile salmon in the Pacific Northwest, concentrations of polychlorinated biphenyls (PCBs), DDTs, polycylic aromatic hydrocarbons (PAHs) and organochlorine pesticides were measured in tissues and prey of juvenile Chinook and coho salmon from several estuaries and hatcheries in the Pacific Northwest."
- Of the two species sampled, Chinook salmon had the highest whole body contaminant concentrations, typically 2-5 times higher than coho salmon from the same sites.
- In comparison to estuarine Chinook salmon, body burdens of PCBs and DDTs in hatchery Chinook were relatively high, in part because of the high lipid content of the hatchery fish.
- Concentrations of PCBs were highest in Chinook salmon from thw Duwamish Estuary, the Columbia River and Yaquina Bay, exceeding the NOAA fisheries' estimated threshold for adverse health effects of 2400 ng/g lipid.
- Juvenile Chinook salmon are likely absorbing some contaminants during estuarine residence through their prey, as PCBs, PAHs, and DDTs were consistently present in stomach contents, at concentrations significantly correlated with contaminant body burdens in fish from the same sites.

Fulton, M. H., D.W. Moore, E.F. Wirth, G.T. Chandler, P.B. Key, J.W. Daugomah, E.D. Strozier, J. Devane, J.R. Clark and others. 1999. Assessment of risk reduction strategies for the management of agricultural nonpoint source pesticide runoff in estuarine ecosystems. Toxicology and Industrial Health 15:200-213.

- Incorporating integrated pest management (IPM) and best management practices as part of the authorization or permitting can help ensure the reduction of pesticide contamination in estuarine ecosystems.

DeLorenzo, M.E., G.I. Scott, P.E. Ross. 2001. Toxicity of pesticides to aquatic microorganisms: A review. Environmental Toxicology and Chemistry 20(1):84-98.

- "Microorganisms contribute significantly to primary production, nutrient cycling, and decomposition in estuarine ecosystems; therefore, detrimental effects of pesticides on microbial species may have subsequent impacts on higher trophic levels."
- "There is a great deal of variability in the toxicity of even a single pesticide among microbial species. When attempting to predict the toxicity of pesticides in estuarine ecosystems, effects of pesticide mixtures and interactions with nutrients should be considered. The toxicity of pesticides to aquatic microorganisms, especially bacteria and protozoa, is an area of research requiring further study."

Moore, A., C.P. Waring. 2001. The effects of a synthetic pyrethroid pesticide on some aspects of reproduction in Atlantic salmon (Salmo salar L). Aquatic Toxicology 52:1-12.

- The synthetic pesticide cypermethrin, a known contaminant of tributaries supporting spawning salmonid fish, had a significant sublethal impact upon the endocrine system in mature male Atlantic salmon parr, disrupting the reproductive fitness of the population.

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- Current environmental conditions in the Columbia River estuary indicate the presence of contaminants in the food chain of juvenile salmonids including DDT, PCBs, and polyaromatic hydrocarbons. This data also indicates that juvenile salmonids in the Columbia River estuary have contaminant body burdens in the range where sublethal effects may occur.
- The sources of exposure are not clear but may be widespread. Several pesticides and heavy metal contaminants have been sampled in Columbia River sediments (ODEQ 2007). In field studies, juvenile salmon from sites in the Pacific Northwest have demonstrated immunosuppression, reduced disease resistance, and reduced growth rates due to contaminant exposure during their period of estuarine residence.

**Flood Control**

WSCC. 2001b. Habitat limiting factors: Yakima River Watershed. Washington State Conservation Commision. Available: http://www.scc.wa.gov/index.php/287-WRIA-37-38-39-Yakima-River-Watershed/View-category.html. (October 2009).

- There are two major types of human impacts to floodplain functions. First, channels are disconnected from their floodplain. This occurs both laterally as a result of the construction of dikes and levees, which often occur simultaneously with the construction of roads, and longitudinally as a result of the construction of road crossings. This has: 1) eliminated off-channel habitats such as sloughs and side channels; 2) increased flow velocity during flood events due to the constriction of the channel; 3) reduced subsurface flows and groundwater contribution to the stream; and 4) simplified channels since LWD is lost and channels are often straightened when levees are constructed. Channels can also become disconnected from their floodplains as a result of down-cutting and incision of the channel from losses of LWD, decreased sediment supplies, and increased high flow events.
- Elimination of off-channel habitats results in the loss of important habitats for juvenile salmonids. Sloughs and backwaters that are protected from flood flow impacts function as prime spawning habitat for chum, pink, and coho, and rearing and over-wintering habitat for spring chinook and coho juveniles.

- The second major type of impact is loss of natural riparian and upland vegetation. Riparian forests are typically reduced or eliminated as levees and dikes are constructed. Loss of vegetation on the floodplain reduces shading of water in floodplain channels, eliminates LWD contribution, reduces filtering of sediments, nutrients and toxics, and results in increased water energy and loss of bank stability during flood flows.

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009)

- Large portions of the Tucannon, Touchet and Walla Walla rivers have been channelized and confined by levees and dikes to protect nearby fields and farms that have been repeatedly damaged by floods. The cumulative impact of these projects destabilizes the rivers by increasing their erosive power. As a consequence, the Tucannon River is now actively degrading its banks and bed and causing serious problems with regard to fine sediment deposition and habitat complexity.

Ziemer, R. R. and T. E. Lisle. 2001. Hydrology. In River Ecology and Management, Lessons from the Pacific Coastal Ecoregion. Edited by Naiman, R. J. and R. E. Bilby. Springer- Verlag New York, Inc. 175 Fifth Avenue, New York, NY 10010. Pages 43-68.

- Confining streamflow through channelization and diking increases stream energy (and the potential for serious flooding downstream) by negating the benefits of water dispersing onto the floodplain.
- Functional floodplains moderate instream flow peaks by substantially increasing the area available for water storage. Water seeps into the groundwater table during floods, recharging wetlands, off-channel areas and shallow aquifers. Wetlands and aquifers in turn release water to the stream during the summer months through a process called hydraulic continuity. This maintenance of flow ensures adequate flows for salmonids during the summer months, and reduces the possibility of high energy flood events that can destroy salmonid redds during the winter months.

U.S. Fish and Wildlife Service. 2000. Impacts of riprapping to ecosystem functioning, lower Sacramento River, California. U.S. Fish and Wildlife Service, Sacramento Field Office, Sacramento, California. U.S. Fish and Wildlife Service, Sacramento Field Office, Sacramento, California. Prepared for US Army Corps of Engineers, Sacramento District.

- Like many large rivers, the lower Sacramento River exhibits fragmentation and disconnection from ecological processes. Much of the degradation results from river meandering and erosion being Over half (more in certain reaches) of the Sacramento River's banks within the lower 194 miles have been riprapped, mainly from 4 decades of work by the Corps of Engineers' Sacramento River Bank Protection Project (SRBPP).
- Riprapping prevents the recruitment of new LWD along the armored banks, and it reduces the retention of LWD inputted from nonarmored areas. The cumulative loss of

LWD functioning for the lower river is now at least 67-90 percent, or more, compared to pre-SRBPP conditions.
- The use of set-back levees to achieve bank protection goals offers the best mitigation solution. Set-back levees allow both site- and reach-level impacts to be fully avoided, and they maximize habitat enhancement opportunities.

Williams, G.D., R.M. Thom. 2001. Marine and estuarine shoreline modification issues. White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. Available: wdfw.wa.gov/hab/ahg/finalsl.pdf. (January 2010).
- Armoring of shorelines to prevent erosion and maintain or create shoreline real estate simplifies habitats, reduces the amount of intertidal habitat, and affects nearshore processes and the ecology of a myriad of species.
- Hydraulic effects to the shoreline include increased energy seaward of the armoring, reflected wave energy, dry beach narrowing, substrate coarsening, beach steepening, changes in sediment storage capacity, loss of organic debris, and downdrift sediment starvation.
- Installation of breakwaters and jetties can result in community changes from burial or removal of resident biota; changes in cover and preferred prey species; and predator attraction. As with armoring, breakwaters and jetties modify hydrology and nearshore sediment transport as well as movement of larval forms of many species.

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).
- Puget Sound has been heavily altered by human development, with 33% of shorelines modified with bulkheads or other armoring and 73% of wetlands in major deltas of Puget Sound rivers have been lost in the last 100 years.

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).
- With changes in the Columbia River flow regime, the availability of shallow (between 10 cm and 2 m depth), low-velocity (less than 30 cm/s) habitat in the Columbia River Estuary now appears to decrease at a steeper rate with increasing flow than during the 1880s, and the absorption capacity of the estuary appears to have declined.

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.
- "Dikes, levees, ditches, or other water controls at the upper end of a tidal marsh can cut off all tributaries feeding the marsh, preventing freshwater flushing and annual flushing, annual renewal of sediments and nutrients, and the formation of new marshes. Water

controls within the marsh proper intercept and carry away freshwater drainage, block freshwater from flowing across seaward portions of the marsh, increase the speed of runoff of freshwater to the bay or estuary, lower the water table, permit saltwater intrusion into the marsh proper, and create migration barriers for aquatic species. In deeper channels where reducing conditions prevail, large quantities of hydrogen sulfide are produced that are toxic to marsh grasses and other aquatic life. Acid conditions of these channels can also result in release of heavy metals from the sediments."

- The following are recommended conservation measures to mitigate for Estuarine Alteration effects:
  1. Minimize the loss of riparian habitats as much as possible.
  2. The diking and draining of tidal marshlands and estuaries should not be undertaken unless a satisfactory compensatory mitigation plan is in effect and monitored.
  3. Wherever possible, "soft" approaches (such as beach nourishment, vegetative plantings, and placement of large woody debris) to shoreline modifications should be utilized.
  4. Include efforts to preserve and enhance EFH by providing new gravel for spawning areas; removing barriers to natural fish passage; and using weirs, grade control structures, and low flow channels to provide the proper depth and velocity for fish.
  5. Construct a low-flow channel to facilitate fish passage and help maintain water temperature in reaches where water velocities require armoring of the riverbed.
  6. Replace in-stream fish habitat by providing rootwads, deflector logs, boulders, rock weirs and by planting shaded riverine aquatic cover vegetation.
  7. Use an adaptive management plan with ecological indicators to oversee monitoring and ensure mitigation objectives are met. Take corrective action as needed.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "The armoring and revetment of stream banks tends to narrow rivers, reducing the amount of habitat per unit channel length. As a result of river narrowing, benthic habitat decreases and the number of macroinvertebrates, such as stoneflies and mayflies, per unit channel length decreases, affecting salmonid food supply."

**Culvert Construction**

Castro, J. 2003. Geomorphologic impacts of culvert replacement and removal: avoiding channel incision. Portland, OR: U.S. Fish and Wildlife Service - Oregon Fish and Wildlife Office.

- Channel incision can often occur downstream of a culvert and generally moves upstream, potentially affecting fish habitat and impeding fish passage. An existing culvert can act as a grade control, halting the upstream progression of a headcut and causing further channel regrade.

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- "In light of the heavy road development within much of the HSA, impaired fish passage at road crossings is commonly a bottleneck to migrating coho salmon. Many roads administered by the California Department of Transportation have faulty or poorly designed culverts that block upstream and downstream migration."
- "Problem culverts should first be inventoried and ranked in order to optimize use of limited funding resources."

NMFS. 2003. Non-fishing impacts to essential fish habitat and recommended conservation measures. National Marine Fisheries Service.

- The following is a recommended conservation measure to mitigate for road building: 3. Build bridges when possible. If culverts are to be used, they should be sized, constructed, and maintained to match the gradient and width of the stream, so as to accommodate 100-year flood flows, but equally to provide for migratory passage of adult and juvenile fishes. Utilize guidelines provided in the document: "Guidelines for Salmonid Passage at Stream Crossing," NOAA Fisheries, Southwest Region, October 2001 (http://swr.nmfs.noaa.gov/hcd/NMFSSCG.PDF).

Flanders, L.S., J. Cariello. 2000. Tongass road condition survey report. Technical Report 00-7. Douglas, AK: Alaska Department of Fish and Game, Southeast Regional Office of the Habitat and Restoration Division.

- "Velocity is the most common cause of fish passage restriction in culverts. If a culvert is installed at too steep a gradient or the culvert width is significantly narrower than the streambed width, the water velocity will be increased within the culvert. Very slight changes in the slope of the culvert and the roughness of the substrate within the culvert may significantly change velocity and the ability of fish to pass through the culvert during all of the times of year when they normally move upstream or downstream. Other frequent causes of fish passage problems include perching of the culvert outlet above the water surface, blockage by excessive substrate or woody debris within the culvert and structural damage to the culvert. In most cases, multiple factors interact to restrict fish passage."

Chestnut, T.J. 2002. A review of closed bottom stream crossing structures (culverts) on fish-bearing streams in the Kamloops forest district, June 2001. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2602.

- "A review of closed bottom culverts was conducted to assess whether the fish and fish habitat provisions of the Fisheries Act were being achieved. A total of 31 culverts, installed on fish-bearing streams, in the Kamloops Forest District, B.C., were assessed."

- "At each culvert site the likelihood of juvenile fish passage and the maintenance of fish habitat was assessed. Only one of the thirty-one culverts assessed met Fisheries and Oceans objectives for juvenile fish passage and maintenance of fish habitat."
- "Fisheries and Oceans fish passage and fish habitat protection objectives associated with closed bottom stream crossing structures are rarely being achieved in the Kamloops Forest District. It is recommended that clear span, open bottom structures, i.e. bridges, be used on all fish bearing streams."

NMFS. 2001. Guidelines for salmonid passage at stream crossings. NOAA Fisheries, Southwest Region, Long Beach, CA.

- This document provides guidelines for design of stream crossings to aid upstream and downstream passage of migrating salmonids. It is intended to facilitate the design of a new generation of stream crossings, and assist the recovery of threatened and endangered salmon species. These guidelines are offered by the National Marine Fisheries Service, Southwest Region (NMFS-SWR), as a result of its responsibility to prescribe fishways under the Endangered Species Act, the Magnuson-Stevens Act, the Federal Power Act, and the Fish and Wildlife Coordination Act. The guidelines apply to all public and private roads, trails, and railroads within the range of anadromou salmonids in California.
- The following are the alternative methods for designing or replacing culverts. The document describes them in detail:
    - Active Channel Design Method
        - The Active Channel Design method is a simplified design that is intended to size a culvert sufficiently large and embedded deep enough into the channel to allow the natural movement of bedload and formation of a stable bed inside the culvert.
    - Stream Simulation Design Method
        - The Stream Simulation Design method is a design process that is intended to mimic the natural stream processes within a culvert. Fish passage, sediment transport, flood and debris conveyance within the culvert are intended to function as they would in a natural channel.
    - Hydraulic Design Method
        - The Hydraulic Design method is a design process that matches the hydraulic performance of a culvert with the swimming abilities of a target species and age class of fish. This method targets distinct species of fish and therefore does not account for ecosystem requirements of non-target species.

Sylte, T.L. 2002. Providing for stream function and aquatic organism passage: An interdisciplinary design. Stream Notes: January 2002. Stream Systems Technology Center, Rocky Mountain Research Station, Fort Collins, CO.

- "Despite many standards and guidelines that address the importance of fish movement, the number of culverts either partially or fully impeding passage is high…Although the impact of any one culvert in most cases is not substantial, cumulatively, impacts can be significant."
- "Four primary issues explain the large number of existing inadequate culverts:
    - Former design approaches,
    - Lack of cross-disciplinary communication and understanding,
    - Salmo- and adult-centric knowledge and application, and
    - New knowledge and awareness."
- "Culverts commonly impede fish movement by one of the following mechanisms:
    - Excessive velocities,
    - Excessive outlet perch heights,
    - Inadequate depths for fish migrating during lower flow conditions, or
    - Debris blockage at the inlet."
- "…culverts should provide passage whenever fish are present…Generally, weaker swimming fish are the limiting factor in passage considerations…Properly designed culverts do not produce water velocities that exceed fish swimming abilities. Properly designed culverts also accommodate stream structure and function, which in most cases means at least spanning the active channel width…Spanning the active channel width and simulating a channel bottom through the culvert will satisfy most biological and hydrological concerns."
- "For the engineer, planner, and manager, the initial costs of designing for aquatic passage will likely increase because the culvert will be larger and thus more expensive. However, failure risks will be reduced and structure life will be optimized. Maintenance levels and replacement frequency will decrease creating more economic opportunities with limited budgetary resources."

Wheeler, A.P., P.L. Angermeier, and A.E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Reviews in Fisheries Science 13(3):141-164.

- "The presence of culverts destabilizes stream channels by interrupting the downstream transport of woody debris, sediment, substrate, and waters…Unlike dynamic natural stream channels, culverts are rigid and un-accommodating to changes in channel morphology. In addition, the stream channel is often widened above the culvert, reducing current velocities and forming a sediment trap. Although downstream sediment flow is reduced above the culvert, it continues or accelerates below the culvert causing channel downcutting and resulting in an elevation drop, even if initial construction put the pipe at stream level. Typically, culverts are sized to accommodate rare flood flows but are too small to allow passage of woody debris. Accumulations of woody debris near the inlet can starve downstream areas of this important component of stream habitat and may plug the culvert, causing failure of road fill during floods and increasing the risk of catastrophic debris torrents."

- "Culverts provide poor internal habitat due to low-bottom complexity and uniformly high-flow velocities…they are notorious fish movement barriers. The effects of highway crossings on stream fish movement depend on the swimming speed and behavior of individual species. Fish passage is obstructed by high current velocities and shallow depths inside culverts, as well as vertical drops at the culvert outflow."
- Overall fish movement may be an order of magnitude lower through culverts when compared to other crossing types or natural channels
- "Culverts throughout a tributary network can reduce production of species that require spawning migrations…by preventing adults from reaching spawning habitat. Barriers can isolate populations, resulting in reduced genetic diversity and increased probability of extinction due to demographic instability and impeded recolonization…importance of movement and movement barriers to nongame fishes and fish communities is poorly understood…engineers designing passable culverts may narrowly focus on the effects of singular parameters…and not consider the cumulative effects of multiple passage inhibiting features."

Vaughan, D.M. 2002. Potential impact of road-stream crossings (culverts) on the upstream passage of aquatic macroinvertebrates. U.S. Forest Service Report, U.S. Forest Service, Portland, OR.

- To minimize the impact of culverts on upstream dispersal and the overall effect on the hydro-geomorphology of a stream:
  - Make culverts as wide as possible or use a bridge to allow lateral movement of stream
  - Culvert bottoms should be at least 20cm below the surface of stream's substrate
- Little data available on ability of aquatic macroinvertebrates to pass through culverts – suggest species-specific impacts need to be studied for each culvert placement – insects with flight generally not a problem – culverts may pose more of a problem for non-insects (i.e., mollusks and crustaceans) – upstream movement of parasitic macroinvertebrates may be blocked by culverts that block upstream movement of hosts
- Actual effect of culverts on upstream passage of threatened and endangered species will need to be assessed on a case-by-case basis
- In limited number of cases, culverts may block upstream dispersal of invasive species – if true barriers are needed, culverts cannot be considered reliable
- Channelization and subsequent erosion and sedimentation that accompanies culverts likely has a much greater negative impact on macroinvertebrate communities than the culvert itself.

Wargo, R.S., and R.N. Weisman. 2006. A comparison of single-cell and multicell culverts for stream crossings. Journal of the American Water Resources Association 42(4):989-995.

- "Single-barrel culverts are a common means of roadway crossings for smaller streams. While this culvert design provides an economical solution for a crossing, the adverse effects of conveying the stream through a single opening can be far reaching. The single-barrel culvert is typically sized for a design storm much greater than the channel forming discharge. This oversizing causes an interruption of the normal flow patterns and sediment transport for the system. Shallow depths at low flow in the pipe and perching at the outlet can impede fish passage."

- "Multicell culverts (where the main culvert at the channel invert is sized for bankfull discharge, and additional pipes are placed at the floodplain elevation to convey overbank flow up to the design discharge) have been recommended as a best management practice to minimize erosion and improve fish passage."
- Authors used flumes and scaled prototype single-barrel and multicell culverts to compare outlet scour and flow depths between the two designs
- Depths in the multicell design were higher than the single-barrel design at all three test flows and the single-cell scour pool was larger and perched higher than the multicell design at all flows – suggests that multicell designs are better for fish passage at all flows
- Authors only recommend using multicell designs in channels that are not incised and do not carry large debris loads – also need to evaluate economic costs and ecological benefits before installation as multicell designs are more expensive

**Climate Change**

National Wildlife Federation. 2005. Fish Out of Water: A Guide to Global Warming and Pacific Northwest Rivers. National Wildlife Federation, Western Natural Resource Center. Seattle, WA.

- Increase in stream temperatures due to climate change can contribute to a reduction in the preferred species of insects that are used for food by salmon

Climate Impacts Group. 2004. Overview of Climate Change Impacts in the U.S. Pacific Northwest. University of Washington. Seattle,WA

- Although the impacts of global climate change are less clear in the ocean environment, early modeling efforts suggest that, warmer temperatures are likely to increase ocean stratification, which in the past has coincided with relatively poor ocean habitat for most Pacific Northwest salmon, herring, anchovies, and smelt populations.

Schindler, D.E., X. Augerot, E. Fleishman, N. J. Mantua, B. Ridell, M. Ruckelshaus, J. Seeb, and M. Webster. 2008. Climate change, ecosystem impacts, and management for Pacific salmon. Fisheries 33:502-506.

- Shindler et al. identify the following study areas that can reduce key uncertainties about climate change impacts on pacific salmon and improve salmon-climate policy:
    - Developing quantitative models that allow projections for temperature, precipitation, and hydrologic conditions to be reliably downscaled to the watershed level.

- Exploring the extent to which salmon and co-occuring organisms might adapt to ongoing climate change, thus affecting the direction and magnitude of overall ecosystem response.
- Improving understanding of how climate change affects the metapopulation processes important to salmon evolutionary and ecological dynamics.

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 104:6720-6725.

- Using a series of linked models of climate, land cover, hydrology, and Chinook salmon population dynamics in the Snohomish River Basin, Washington, Battin et al. found a large negative impact of climate change on freshwater salmon habitat.
- River basins that span the current snow line appear especially vulnerable to climate change, and salmon recovery plans that enhance lower-elevation habitats are likely to be more successful over the next 50 years than those that target the higher-elevation basins likely to experience the greatest snow-rain transition.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western north america under a 'business as usual' climate change scenario. Climatic Change 62:217-232.

Under21st

- Under 21$^{st}$ century warming trends predicted by the Parallel Climate Model under business-as-usual greenhouse-gas emissions, springtime snowmelt is predicted to occur earlier than observed to date.
- The strongest changes in streamflow timing are expected to occur in the Pacific Northwest, Sierra Nevada, and Rocky Mountains, where many rivers are projected to run 30-40 days earlier.
- A one-month advance in the timing of snowmelt runoff would increase the length of the summer drought that occurs in much of western North America, affecting habitat availability for rearing or migrating juvenile pacific salmon.

Mote, P. W., E. A. Parson, A. F. Hamlet, W. S. Keeton, D. Letternmaier, N. Mantua, E. L. Miles, D. W. Peterson, D. L. Peterson, R. Slaughter, and A. K. Snover. 2003. Preparing for climate change: the water, salmon, and forests of the Pacific Northwest. Climate Change 61:45-88.

- Using output from eight climate models, Mote et al. project a further warming of 0.5–2.5 ◦C (central estimate 1.5 ◦C) by the 2020s, 1.5–3.2 ◦C (2.3 ◦C) by the 2040s, and an increase in precipitation except in summer. The foremost impact of a warming climate will be the reduction of regional snowpack, which presently supplies water for ecosystems and human uses during the dry summers.

Miles, E. L., A. K. Snover, A. F. Hamlet, B. Callahan, and D. Fluharty. 2000. Pacific northwest regional assessment: the impacts of climate variability and climate change on the water resources of the Columbia River Basin. Journal of American Water Resources Association 36:399-420.

- Climate change projections suggest exacerbated conditions of conflict between users as a result of low summertime streamflow conditions. An understanding of the patterns and consequences of regional climate variability is crucial to developing an adequate response to future changes in climate.
- Miles et al. identify four elements necessary for an effective response to climate variability: centralized management of the resource, managerial flexibility and the ability to incorporate new information, development of institutional memory, and coordination.

Northwest Power and Conservation Council (NPCC). 2004. Draft Columbia River Basin research plan. Northwest Power and Conservation Council, Portland, OR.

- The risks of global climate change are potentially great for Upper Columbia stocks because of the sensitivity of salmon stocks to climate-related shifts in the position of the sub-arctic boundary, the strength of the California Current, the intensity of coastal upwelling, and the frequency and intensity of El Nino events.

ISAB (Independent Scientific Advisory Board). 2007. Climate change impacts on Columbia River basin fish and wildlife. ISAB, Report 2007-2, Portland, Oregon.

- The ISAB (2007c) identified the following list of likely effects of projected climate changes on Columbia basin salmon:
    - Anticipated water temperature increases, and the subsequent depletion of cold water habitat, could reduce the areal extent of suitable inland salmon habitats.
    - Variations in intensity of precipitation may alter the seasonal hydrograph and water available for salmon.
    - Eggs of fall and winter spawning fish, including Chinook, coho, chum, and sockeye salmon, may suffer higher levels of mortality when exposed to increased flood flows.
    - Earlier snowmelt and earlier, higher spring flows, warmer temperatures, and a greater proportion of precipitation falling as rain rather than snow, may cause spring Chinook and steelhead yearlings to smolt and emigrate to the estuary and ocean earlier in the spring.
    - Within the Columbia estuary, increased sea levels in conjunction with higher winter river flows could cause the degradation of estuary habitats created by increasing wave damage during storms.
    - Changes in the intensity and timing of coastal upwelling. These changes will alter primary and secondary productivity, the structure of marine communities, and, in turn, the growth, productivity, survival, and migrations of salmonids.

Cramer, S.P., J. Norris, P. Mundy, G. Grette, K. O'Neal, J. Hogle, C. Steward, and P. Bahls. 1999. Status of Chinook salmon and their habitat in Puget Sound, volume 2. Final report. S.P. Cramer and Associates, Gresham, Oregon.

- Evidence suggests that marine survival of salmonids fluctuates in response to the PDO's 20 to 30 year cycles of climatic conditions and ocean productivity.

Zabel, R. W., M.D. Scheuerell, M.M. McClure, and J.G. Williams. 2006. The interplay between climate variability and density dependence in the population viability of Chinook salmon. Conservation Biology 20 (1):190-200.

- Population viability analysis of Snake River Chinook salmon supports the premise that climate conditions can have extreme effects on the viability of natural populations.
- "Our results also emphasize that the impacts of climate go beyond just good or bad climate conditions. The autocorrelation associated with climate conditions leads to a greater tendency for populations to grow or decline exponentially, which clearly has important implications for population viability."

Luce C. H. and Z. A. Holden. 2009. Declining annual streamflow distributions in the Pacific Northwest United States, 1948-2006. Geophysical Research Letters, Volume 36.

- Luce and Holden (2009) tested for trends in the distribution of annual runoff using quantile regression at 43 gages in the Pacific Northwest.
- Seventy-two percent of the gauging stations showed significant (a = 0.10) declines in the 25th percentile annual flow, with half of the stations exceeding a 29% decline and a maximum decline of 47% between 1948 and 2006.
- "The driest 25% of years are becoming substantially drier. Reliance on tests of trends in the mean alone has promoted a view that only shifts in flow timing caused by temperature increases are occurring in snow dominated watersheds. This view could result in management adaptations that are locally inappropriate and may also lead to misinterpretation of ecological process. Because many aspects of managed and natural systems operate without impairment within some range of the mean, trends in less central parts of the distribution may be more important than trends in the mean. The decreasing trends in the lowest quartile, in particular, represent increasing challenges for land and water managers who must cope with water scarcity and its ecological consequences on more frequent and acute basis."

Mote, P.W. 2006. Climate-driven variability and trends in mountain snowpack in western North America. Journal of Climate 19: 6209-6220.

- Widespread declines in springtime snow-water equivalents (SWE) have occurred in much of the North American West since the 1920s, especially since mid-century. This decrease in SWE can be largely attributed to a general warming trend in the western United States since the early 1900s.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18: 1136-1155.

- Climactic changes have resulted in earlier onsets of springtime snowmelt and streamflow across western North America, as well as lower flows in the summer.
- The projected runoff-timing trends over the course of the 21st century are most pronounced in the Pacific Northwest, Sierra Nevada, and Rocky Mountain regions, where the eventual temporal centroid of streamflow (i.e. peak streamflow) change amounts to 20–40 days in many streams.
- A 1-month advance in timing centroid of streamflow would also increase the length of the summer drought that characterizes much of western North America, with important consequences for water supply, ecosystem, and wildfire management.

Vicuna, S., E. P. Maurer, B. Joyce, J. A. Dracup, and D. Purkey. 2007. The sensitivity of California water resources to climate change scenarios. Journal of the American Water Resources Association 43:482-498.

- Using the latest available General Circulation Model (GCM) results Vicuna et al. (2007) present an assessment of climate change impacts on California hydrology and water resources.
- Our results show greater negative impacts to California hydrology and water resources than previous assessments of climate change impacts in the region. These impacts, which translate into smaller streamflows, lower reservoir storage and decreased water supply deliveries and reliability, will be especially pronounced later in the 21st Century and south of the San Francisco bay Delta.

Crozier, L.G., R.W. Zabel, and A.F. Hamlet. 2008. Predicting differential effects of climate change at the population level with life-cycle models of spring Chinook salmon. Global Change Biology 14(2):236-249.

- Crozier et al. (2008) linked predicted changes ion air temperature and precipitation from several General Circulation Models to a local hydrological model to project streamflow and air temperature under two climate-change scenarios. Using a stochastic, density-dependent life-cycle model, they found that mean abundance decreased 25-50% and the probability of quasi-extinction increased dramatically for all populations in response to climate change.
- Results demonstrate that detailed population models can usefully incorporate climate-change predictions, and that global warming poses a direct threat to freshwater stages in these fish, increasing their risk of extinction.

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available:

http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (December 2009).

- “Current climate change information suggests that the Central Valley will become warmer, a challenging prospect for Chinook salmon and steelhead – both of which are coldwater fish at the southern end of their distribution.”
- “To recover Central Valley salmon ESUs and the steelhead DPS, some populations will need to be established in cooler, high elevation areas now blocked by dams or insufficient flows.”

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- “Climate change, both natural and induced, could have significant effects on Chinook salmon and other salmonids in the Puget Sound region and beyond. Possible effects include alteration of the hydrologic cycle resulting in changes in low and high flow patterns, changes to habitat forming processes, changes in terrestrial and riparian vegetation that affect habitat forming processes, changes in erosion patterns, and impacts to water quality. Significant research on this topic is being conducted in the region, however none of the watershed plans have proposed means of monitoring climate change or its impacts. This is a significant uncertainty in the Puget Sound Recovery Plan and should be addressed through the detailed watershed and regional adaptive management plan.”

Osgood, K. E. 2008. Climate impacts on U.S. living marine resources: National Marine Fisheries Service Concerns, activities and needs. NOAA Technical Memorandum NMFS-F/SPO-89.

- “Altered freshwater systems, due to increased air temperatures and changes in the timing, amount and type (i.e. rain vs. snow) of precipitation, are a major climate induced ecosystem concern for the California Current Ecosystem. The focus is on anadramous fish such as salmon that use river systems and coastal regions for habitat. The primary concerns center on altered stream flows and warmer temperatures affecting survival and passage through tributaries, and changes in coastal ocean habitat quality and productivity due to altered freshwater input. Changes to freshwater input are also important in other regions where species depend upon coastal habitat or coastal currents which are influenced by freshwater input.”

Scheuerell, M.D., J.G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (Oncorhynchus tshawytscha). Fisheries Oceanography 14(6):448-457.

- “While numerous retrospective analyses show a strong correlation between past changes in the ocean environment and salmon production within the north Pacific, these correlations rarely make good predictions. Using a Bayesian timeseries model to make successive 1-yr-ahead forecasts, we predicted changes in the ocean survival of

Snake River spring/summer chinook salmon (O. tshawytscha) from indices of coastal ocean upwelling with a high degree of certainty (R2=0.71). Furthermore, another form of the dynamic times-series model that used all of the available data indicated an even stronger coupling between smolt-to-adult survival and ocean upwelling in the spring and fall (R2=0.96). This suggests that management policies directed at conserving this threatened stock of salmon need to explicitly address the important role of the ocean in driving future salmon survival."

## Task 4. Salmon Life History

### Chinook Salmon

*Eggs and Spawning*

Montgomery, D.R., E.M. Beamer, G.R. Pess, & T.P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Science 56:377-387.

- Adult Chinook salmon tend to spawn in stream reaches characterized as low-gradient pool-riffle reaches.

Moyle, P.B. 2002. Inland fish of California, 2nd edition. University of California Press, Berkeley, California.

- The optimal water temperature for Central Valley Chinook salmon egg incubation ranges from 41$^{o}$F to 55.4$^{o}$F.

Merz, J. 2001. Association of fall-run Chinookk salmon redds with woody debris in the Lower Mokelumne River, Califronia. California Fish and Game 87:51-60.

- Surveys in the lower Mokelumne River during 1994-1995 indicated that fall-run chinook salmon, Oncorhynchus tshawytscha, redds associated with woody debris (WD) had smaller substrate and greater mean depths. Also, the proportion of redds associated with WD was negatively related to stream gradient. Female chinook salmon selected spawning sites containing WD in some instances. Woody debris may make less desirable habitats more suitable for spawning and may allow greater concentrations of redds on suitable sites.

Bratovich, P. M., G. W. Link, B. J. Ellrot, and J. A. Pinero. 2005. Impacts on lower American River salmonids and recommendations associated with Folsom Reservoir operations to meet Delta water quality objectives and demands. Surface Water Resources, Inc., Sacramento, CA.

- "The dewatering redds in the main channel, or isolation of redds in the river side channels in the American River, can result from flow reductions from levels at which spawning initially occurred. Redd dewatering can affect salmonid embryos and alevins by impairing development and causing direct mortality due to desiccation, insufficient

oxygen levels, waste metabolite toxicity, and thermal stress… The primary period of concern for redd dewatering and isolation extends from about mid October through May, corresponding to fall-run Chinook salmon and steelhead spawning and incubation period in the lower American River."

Connor, E.J. and D. E. Pflug. 2004. Changes in the distribution and density of Pink, Chum, and Chinook salmon spawning in the Upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24:835-852.

- "Densities of spawning salmon were compared among three contiguous reaches of the upper Skagit River before and after the implementation of flow management measures in 1981. The measures were intended to minimize redd dewatering during the spawning and incubation periods and fry stranding during the emergence and outmigration periods.
- "Field monitoring confirmed that increasing the minimum incubation flows created improvements in redd protection levels… Spawner abundance of all three species progressively increased in an upstream direction following implementation of flow measures; increases were greatest in the reach immediately below the hydroelectric project. The upstream shift in spawner abundance was highly significant based on factorial analyses of variance. The greatest increases in spawner abundance for Chinook salmon and chum salmon were observed during even years, when pink salmon did not spawn. Mean spawner abundance in the upstream-most study reach increased from 311 to 1,169 carcasses/mi (odd years) for pink salmon, from 6 to 115 fish/mi (odd years) or 58 to 462 fish/mi (even years) for chum salmon, and from 48 to 49 redds/mi (odd years) or 59 to 65 redds/ mi (even years) for Chinook salmon."
- "These increases were substantially greater than those observed concurrently in other areas of the Skagit River basin and in other northern Puget Sound rivers. The average number of Chinook salmon spawners remained unchanged in the study area after 1981, while substantially declining in other unregulated Skagit River subbasins and most Puget Sound rivers. The study area now possesses the greatest percentage of pink, chum, and Chinook salmon spawners within the Skagit River basin. The Skagit River presently supports the largest run of native Chinook salmon in the Puget Sound region and the largest runs of pink and chum salmon in the coterminous United States."

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009).

- Preferred habitat for spawning spring and summer Snake River Chinook includes Pool or glides with a minimum velocity of 3 ft./sec., depth of 20-36 inches, and temperatures between 42$^{o}$F and 51$^{o}$F.

USBR. 2008. Central Valley Project and State Water Project operations criteria and plan biological assessment. U.S. Bureau of Reclamation Mid-Pacific Region, Sacramento, California.

- "Central Valley spring-run Chinook salmon spawning timing occurs from mid to late August through early October, with peak spawning times varying among locations. For instance, in Deer Creek, spawning begins first at higher elevations, which are the coolest reaches… Water temperatures between 42 F and 58 F are considered most suitable for spawning."

*Juveniles(Freshwater)*

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia spring Chinook salmon and steelhead recovery plan. Upper Columbia Salmon Recovery Board. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Upper-Columbia/upload/UC_Plan.pdf. (October 2009).

- Juvenile Chinook salmon in the Upper Columbia Basin are most often associated with streams that contain large woody debris (LWD) and pools in low-gradient alluvial valleys. In higher-gradient fluvial canyons, large boulders provide habitat complexity.

Gregory, R.S. & C.D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127:275-85.

- Gregory and Levings (1998) compared predation on salmonids by potential predators caught by beach seine and by the rate of predator attack on tethered juvenile chinook salmon O. tshawytscha in the Harrison River and Frasier River, British Columbia.
- During their seaward migration in the Fraser River system, age-0 Chinook salmon were less likely to encounter and be consumed by fish piscivores in turbid water than in clear water.
- Juvenile Chinook salmon use low-velocity areas where substrate irregularities and other habitat features create velocity refuges and they may increasingly rely on turbidity as cover.
- Juvenile salmon losses to predators may be reduced at least 45 percent in turbid-water stream reaches relative to clear-water reaches.

Marine, K.R. & J.J. Cech, Jr. 2004. Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook salmon. North American Journal of Fisheries Management 24:198-210.

- For Central Valley Chinook salmon, sublethal impairment of predator avoidance, smoltification, and disease begins in the range of about 64 to 68$^{o}$F.

Sommer, T. R., M. L. Nobriga, W. C. Harrel, W. Batham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325-333.

- Sommer et al. (2001) found evidence that the Yolo Bypass, the primary floodplain of the lower Sacramento River (California, U.S.A.), provides better rearing and migration habitat for juvenile chinook salmon (Oncorhynchus tshawytscha) than adjacent river channels.
- During 1998 and 1999, salmon increased in size substantially faster in the seasonally inundated agricultural floodplain than in the river, suggesting better growth rates. Similarly, coded-wire tagged juveniles released in the floodplain were significantly larger at recapture and had higher apparent growth rates than those concurrently released in the river.
- Improved growth rates in the floodplain were in part a result of significantly higher prey consumption, reflecting greater availability of drift invertebrates. These findings support the predictions of the flood pulse concept and provide new insight into the importance of floodplain habitat for juvenile salmon.

Brandes, P.L. and J S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. California Department of Fish and Game Fish Bulletin 179:39-136.

- Analyses of the lower river and Delta beach seine data and the trawl data at Sacramento and Chipps Island, indicates that many juveniles Chinook salmon enter the Sacramento-San Joaquin Delta as fry in wet years and that overall, juvenile production leaving the Delta is higher in wet years.
- Increased river flows appeared to increase fry survival upstream, but likely caused a greater proportion of them to migrate to the estuary where fry survival appears lower than upriver in the higher flow years.
- The survival of marked fry and smolts in the Central Delta appeared lower than in the North Delta, especially in the drier years. Both fry and smolts in the Central Delta may be more vulnerable to exports than those released in the North Delta in drier years.

Martin, C.D., P.D. Gaines, and R.R. Johnson. 2001. Estimating the abundance of Sacramento River juvenile winter Chinook salmon with comparisons to adult escapement. Red Bluff Research Pumping Plant Report Series, Volume 5. U.S. Fish and Wildlife Service, Red Bluff, California.

- Similar to adult movement, juvenile salmonid downstream movement in California's Central Valley is crepuscular. The daily migration of juvenile Chinook salmon passing RBDD is highest in the 4-hour period prior to sunrise.

Beckman, B. R., B. Gadberry, P. Parkins, K. Cooper amd K. D. Arkush. 2007. State-dependent life history plasticity in Sacramento River winter-run chinook salmon (Oncorhynchus tshawytscha): interactions among photoperiod and growth modulate smolting and early male maturation. Canadian Journal of Fisheries and Aquatic Sciences 64: 256-271.

- Beckman et al. (2007) examined the relative effects of photoperiod at emergence and growth rate on smolting pattern and early male maturation in Sacramento River winter-run Chinook salmon.
- "Male maturation was growth dependent, with high feed groups maturing at a rate double that found in low feed groups. Male maturation was also photoperiod dependent with a linear relation found between emergence date and rate of male maturation. These resilts demonstrate that individual life history pattern was variable and dependent on emergence timing and growth rate."

Sykes, G. E., C. J. Johnson and J. M. Shrimpton. 2009. Temperature and flow effects on migration timing of Chinook salmon smolts. Transactions of the American Fisheries Society 138: 1252-1265.

- Sykes et al. (2009) used an information-theoretic model comparison analysis to investigate the roles of daily mean temperature, temperature experience (accumulated thermal units [ATU]), photoperiod, and flow on the timing of the downstream migration of Chinook salmon O. tshawytscha smolts from the Nechako River in central British Columbia.
- "The analyses identified a combination of temperature experience, flow, and the number of spawners as best able to describe the observed migration patterns. In addition, increasing ATU had a positive influence on migration, while increasing flow had a negative influence. "
- "Based on the results of this study, flow manipulations that change the timing, duration, or magnitude of temperature and flow in the spring could affect the migration of Chinook salmon. Both temperature and river flow should be considered when one is managing flow-controlled watersheds for salmon productivity."

Geist, D. R., C. S. Abernathy, K. D. Hand, V. I. Cullinan, J. A. Chandler and P. A. Groves. 2006. Survival, development, and growth of fall Chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. Transactions of the American Fisheries Society 135:1462-1477.

- Geist et al. (2006) found that exposure to water temperatures up to 16.58C will not have deleterious effects on survival or growth of Chinook salmon from egg to emergence if temperatures decline at a rate of 0.28C/d or more after spawning.
- "Although fall Chinook salmon survived low initial dissolved oxygen levels, the delay in emergence could have significant long-term effects on their survival. Thus, an exemption to the state water quality standards for temperature—but not oxygen—may be warranted for the portions of the Snake River where fall Chinook salmon spawn."

Jeffres, C. 2006. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Master's thesis. University of California - Davis, Davis, CA.

- Jeffres (2006) reared juvenile Chinook salmon for two consecutive flood seasons within various habitats of the Cosumnes River and its floodplain (California) to compare growth rates of in river and newly created floodplain habitats.
- Jeffres (2006) found significant differences in growth rates between salmon rearing in floodplain and river sites. Salmon reared in seasonally inundated habitats with annual terrestrial vegetation showed higher growth rates than those reared in a perennial pond on the floodplain.
- Overall, ephemeral floodplain habitats supported higher growth rates for juvenile Chinook salmon than more permanent habitats in either the floodplain or river.

Beechie, T. J., M. Liermann, E. M. Beamer, R. Henderson. 2005. A classification of habitat types in a large river and their use by juvenile salmonids. Transactions of the American Fisheries Society, 134:717-729.

- “Densities of juvenile Chinook salmon and coho salmon were highest in bank and backwater units in winter in the Skagit River basin, WA. In summer, coho salmon densities were significantly different among edge unit types, densities being highest in banks and backwaters. Microhabitat selection (velocity, depth, and cover type) by juvenile salmonids mirrored that in small streams, most fish occupying areas with a velocity less than 15 cm/s and wood cover. Among ocean-type salmon, Chinook and chum salmon fry were captured in large numbers in all edge units and exhibited only slightly higher densities in low-velocity areas (,15 cm/s).”

Connor, E.J. and D. E. Pflug. 2004. Changes in the distribution and density of Pink, Chum, and Chinook salmon spawning in the Upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24:835-852.

- “Densities of spawning salmon were compared among three contiguous reaches of the upper Skagit River before and after the implementation of flow management measures in 1981. The measures were intended to minimize redd dewatering during the spawning and incubation periods and fry stranding during the emergence and outmigration periods.
- “Greater protection of fry from stranding was achieved by substantially reducing the annual number of downramping events and by reducing downramping during daytime, when fry are most vulnerable to stranding.”

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009).

- Preferred habitat for rearing juvenile spring and summer Snake River Chinook includes edge habitat along the main channel with a variety of cover types, maximum depth of 4 feet, and temperatures between 53°F and 60°F.

USBR. 2008. Central Valley Project and State Water Project operations criteria and plan biological assessment. U.S. Bureau of Reclamation Mid-Pacific Region, Sacramento, California.

- "For Central Valley spring-run, yearling emigration occurs from October through March and may be triggered in part by precipitation events. In some years however, under certain flow and/or water temperature conditions, greater proportions of juveniles in Mill and Deer Creeks may emigrate as fry or fingerlings soon after emergence. The bulk of Butte and Big Chico Creek may emigrate as fry or fingerlings soon after emergence."

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available: http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (January 2010).

- Winter-run and spring-run Central Valley Chinook salmon rearing fry seek streamside habitats containing beneficial aspects such as riparian vegetation and associated substrates that provide aquatic and terrestrial invertebrates for food, predator avoidance cover, and slower water velocities for resting. These shallow water habitats have been described as more productive juvenile salmon rearing habitat than the deeper main river channels.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- "The channelized, leveed, and riprapped river reaches and sloughs that are common in the Sacramento River system are much degraded, and typically have low habitat complexity, low abundance of food organisms, and offer little protection from either fish or avian predators. However, some complex, productive habitats with floodplains remain in the system [e.g., Sacramento River reaches with setback levees (i.e., primarily located upstream of the City of Colusa)] and flood bypasses (i.e., Yolo and Sutter bypasses). Juvenile life stages of salmonids are dependant on the function of this habitat for successful survival and recruitment."

Seesholtz, A., B.J. Cavallo, J. Kindopp, & R. Kurth. 2004. Juvenile fishes of the lower Feather River: Distribution, emigration patterns, and associations with environmental variables. Pages 141-166. In F. Feyrer, L.R. Brown, R.L. Brown, and J.J. Orsi (Eds.), Early life history of fishes in the San Francisco Estuary and watershed. American Fisheries Society, Symposium 39, Bethesda, Maryland.

- Rotary screw traps and beach seines in the Feather River were used to assess distribution, abundance, and emigration patterns of juvenile Chinook salmon between 1997 and 2001.
- More than 80% of Chinook salmon captured were less than 50 mm, demonstrating that most Feather River Chinook salmon emigrate before smolting. In multiple linear

regression models, Chinook salmon spawn timing and water temperature were statistically significant predictors of weekly Chinook salmon catch.

*Juveniles (Estuarine)*

Ehinger, W., T. Quinn, G. Volkhardt, M. McHenry, E. Beamer, P. Roni, C. Greene, and R. Bilby. 2007. Study plan for the intensively monitored watershed program: Skagit River estuary complex. Intensively monitored watersheds scientific oversight committee.

- Skagit River system studies indicate that the quantity of certain types of delta habitat may have a major effect on juvenile Chinook productivity

Newman, K. 2003. Modelling paired release-recovery data in the presence of surival and capture heterogeneity with application to marked juvenile salmon. Statistical Modelling 3:157-177.

- Statistical models suggest that reducing export pumping in the California Sacramento-San Joaquin Delta will increase the survival of outmigrating juvenile Chinook salmon smolts.

MacFarlane, B.R. and E.C. Norton. 2002. Physiological ecology of juvenile Chinook salmon (Oncorhynchus tshawytscha) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. California. Fisheries Bulletin 100:244-257.

- Juvenile Chinook salmon were found to spend about 40 days migrating through the Sacramento-San Joaquin Delta to the mouth of San Francisco Bay and grew little in length or weight until they reached the Gulf of the Farallones.
- Based on the mainly oceantype life history observed (i.e., fall-run), MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon show little estuarine dependence and may benefit from expedited ocean entry.

Semmens, B. X. 2008. Acoustically derived fine-scale behaviors of juvenile Chinook salmon (Onchorhynchus tshawytscha) associated with intertidal benthic habitats in an estuary. Canadian Journal of Fisheries and Aquatic Sciences 65:2053-2062.

- "A hierarchical Bayesian state–space model of movement was developed to associate the behaviors of tagged fall Chinook salmon in Willapa Bay, Washington, with characteristics of benthic habitat in the enclosure."
- "Model results indicated that smolts had a strong preference for remaining in native eelgrass (Zostera marina). Conversely, no such preference existed for other structured benthic habitats such as oyster (Crassostrea gigas) beds, non-native eelgrass (Zostera japonica), and non-native smooth cordgrass (Spartina alterniflora). There was a positive relationship between individual survivorship in the enclosure and the strength of

behavioral preference for native eelgrass, suggesting that predator avoidance may be the evolutionary mechanism driving behavioral responses of smolts to benthic habitats."

Bottom, D. L., K. K. Jones, T. J. Cornwell, A. Grey and C. A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary. Estuarine, Coastal and Shelf Science 64:79-93.

- "The absence of Chinook fry migrants in the Salmon River estruary during spring and early summer in 1975-1977 – a period that precedes restoration of any of the diked marshes - and the extensive use of marsh habitats by fry and fingerlings during April-July, 2000-2002, indicate that wetland restoration has increased estuarine rearing for juvenile Chinook salmon."

Webster, S. J., L. M. Dill and J. S. Korstrom. 2007. The effects of depth and salinity on juvenile Chinook salmon Oncorhynchus tshawytscha (Walbaum) habitat choice in an artificial estuary. Journal of Fish Biology 71:842-851.

- Webster et al. (2007) examined the energetic cost for juvenile Chinook salmon Oncorhynchus tshawytscha to forage in habitats of different salinity and depth was quantified using a behavioural titration based on ideal free distribution theory.
- Their results indicate that the preference for deep saline habitats during the stratified phase was driven by some benefit associated with residency in deeper water, rather than salinity. "The low perceived cost of low salinity might be in part due to the fish's ability to minimize this cost by only making brief forays into the alternate freshwater habitat."
- "When the food ration delivered to the more costly, shallow habitat was 50% greater than that delivered to the less costly, deep habitat, fish distributed themselves equally between the two habitats, presumably because of equal net benefits."
- "This study demonstrates that juvenile Chinook salmon prefer deep saline habitat to shallow freshwater habitats but will make brief forays into the freshwater habitat if food availability is sufficiently high."

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available: http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (January 2010).

- "Juvenile Chinook salmon movements within the Sacramento-San Joaquin estuarine habitat are dictated by the interaction between tidally-driven salt water intrusions through the San Francisco Bay and fresh water outflow from the Sacramento and San Joaquin rivers."
- The timing of migration through the Delta varies somewhat due to changes in river flows, dam operations, and water year type.

Winter-run Chinook salmon juveniles remain in the Delta until they reach a fork length ( FL) of approximately 118 millimeters (mm) and are from five to 10 months of age.

NMFS. 2009. Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region.

- “In the Sacramento-San Joaquin Estuary significant amounts of flow and many juvenile spring-run enter the Delta Cross Channel (when the gates are open), and Georgiana Slough, especially during increased Delta pumping. Mortality of juvenile salmon entering the central Delta is higher than for those continuing downstream in the Sacramento River. This difference in mortality could be caused by a combination of factors: the longer migration route through the central Delta to the western Delta, exposure to higher water temperatures, higher predation rates, exposure to seasonal agricultural diversions, water quality impairments due to agricultural and municipal discharges, and a more complex channel configuration making it more difficult for salmon to successfully migrate to the western Delta and the ocean. In addition, the State and Federal pumps and associated fish facilities increase mortality of juvenile spring-run through various means, including entrainment into the State and Federal canals, handling, trucking, and release.”
- “The current condition of the estuarine habitat in the project area has been substantially degraded from historic conditions. Over 90 percent of the fringing fresh, brackish, and salt marshes have been lost to human actions. This loss of the fringing marshes reduces the availability of forage species and eliminates the cycling of nutrients from the marsh vegetation into the water column of the adjoining waterways. The channels of the Delta have been modified by the raising of levees and armoring of the levee banks with stone riprap. This reduces habitat complexity by reducing the incorporation of woody debris and vegetative material into the nearshore area, minimizing and reducing local variations in water depth and velocities, and simplifying the community structure of the nearshore environment.”

Maier, G. O. and C. A. Simenstad. 2009. The role of marsh-derived macrodetritus to the food webs of juvenile Chinook salmon in a large altered estruary. Estuaries and Coasts 32: 984-998.

- “Using multiple stable isotope analysis, we distinguished the role of various organic matter sources in Chinook food webs in the Columbia River Estuary and interpreted the dynamics of their use both spatially and temporally within the estuary.”
- “Our results indicate that subyearling Chinook are associated with fluvial, anthropogenic, estuarine, and marine organic matter sources, with hatchery food and vascular plant detritus being the most dominant sources in juvenile Chinook food webs. Although freshwater phytoplankton is involved in many food web pathways to subyearling Chinook, increased phytoplankton production from the impounded river has not replaced the loss of autochthonous marsh production to fish.”

- "Our results indicate that large-scale ecosystem alteration may have decreased the availability and quality of food webs in the estuary and potentially diminished the ability of the Columbia to support Chinook salmon."

*Juveniles (Marine)*

Scheuerell, M.D., J.G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (Oncorhynchus tshawytscha). Fisheries Oceanography 14(6):448-457.

- Scheuerell and Williams (2005) showed that the coastal upwelling index is a strong determinant of year-class strength and subsequent smolt-to-adult return ratios for Snake River Chinook salmon.
- When winds do not blow south, the forces that create upwelling off the U.S. coast are reduced, as are nutrient inputs to the euphotic zone, reducing near-shore ocean productivity. This reduction in ocean productivity has been shown to reduce juvenile salmon growth and survival.

Lindley, S.T., C.B. Grimes, M.S. Mohr, W. Peterson, J. Stein, J.T. Anderson, L.W. Botsford, D. L. Bottom, C.A. Busack, T.K. Collier, J. Ferguson, J.C. Garza, A.M. Grover, D.G. Hankin, R.G. Kope, P.W. Lawson, A. Low and R.B. MacFarlane. 2009. What caused the Sacramento River fall Chinook stock collapse? Pre-publication report to the Pacific Fishery Management Council. March 18.

- Lindley et al. (2009) reviewed the possible causes for the decline in Sacramento River fall-run in 2007 and 2008 for which reliable data were available. They concluded that a broad body of evidence suggested that anomalous conditions in the coastal ocean in 2005 and 2006 resulted in unusually poor survival of the 2004 and 2005 broods of fallrun.
- However, Lindley et al. (2009) recognize that the rapid and likely temporary deterioration in ocean conditions acted on top of a long-term, steady degradation of the freshwater and estuarine environment.

Ruggerone, G. T., J. L. Nielsen and B. A. Agler. 2009. Linking marine and freshwater growth in western Alaska Chinook salmon. Journal of Fish Biology 75: 1287-1301.

- The hypothesis that growth in Pacific salmon Oncorhynchus spp. is dependent on previous growth was tested using annual scale growth measurements of wild Chinook salmon Oncorhynchus tshawytscha returning to the Yukon and Kuskokwim Rivers, Alaska, from 1964 to 2004.
- First year marine growth in individual *O. tshawytscha* was significantly correlated with growth in fresh water. Furthermore, growth during each of 3 or 4 years at sea was related to growth during the previous year. The magnitude of the growth response to

the previous year's growth was greater when mean year-class growth during the previous year was relatively low.

- Positive growth response to previous growth in O. tshawytscha was probably related to piscivorous diet and foraging benefits of large body size. Faster growth among *O. tshawytscha* year classes that initially grew slowly may reflect high mortality in slow growing fish and subsequent compensatory growth in survivors.

Jarrin, J. R., A. L. Shanks and M. A. Banks. 2009. Confirmation of the presence and use of sandy beach surf-zones by juvenile Chinook salmon. Environmental Biology of Fishes 85: 119-125.

- "Twenty-five years ago, subyearling Chinook salmon were hypothesized to stay close to shore (<5 km). To test this hypothesis we sampled the surf-zone of a southern Oregon dissipative sandy beach throughout the summer of 2006 (06/07–09/29) using a beach seine in 1 m of water depth."
- "We caught 48 sub-yearlings over six dates (07/22 to 09/01). Mean standard length of Chinook salmon caught in the surf-zone increased from 9.1±0.6 (07/22/06) to 11.6± 0.7 cm (09/01/06), suggesting a mean increase of 0.6 mm in standard length (S.L.) per day.
- "Early in the summer, smaller fish fed mostly on amphipods. Later in the summer, larger juveniles fed primarily on larval and juvenile fish. All prey items were common in the surfzone. Juveniles appear to migrate from the estuary to the surf-zone where they feed on the local zooplankton for up to two summer months before migrating offshore."

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available: http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (January 2010).

- "Central Valley Chinook salmon begin their ocean life in the Gulf of the Farallones, then they distribute north and south along the continental shelf primarily between Point Conception and Washington State. "

Brennan, J. S., K. F. Higgins, J. R. Cordell and V. A. Stamatiou. 2004. Juvenile salmon composition, timing, distribution, and diet in marine nearshore waters of the Central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, WA.

- Diet samples from juvenile Chinook salmon caught in marine nearshore waters of Puget Sound showed distinct seasonal patterns in diet composition. Polychaete worms dominated the <90 and 90-149 mm FL size classes of juvenile Chinook prey early in the sampling season (May) but were replaced by other prey organisms later in the season. For example, in September, insects made up over 50% of the prey weight in Chinook from 90-149 mm size class and over 80% of the >150 mm size class. There was a great deal of similarity between diets of juvenile Chinook classified as hatchery and wild.

Weitkamp, L. A. and M. V. Sturdevant. 2008. Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of Southeast Alaska. Fisheries Oceanography 17: 380-395.

- Chinook salmon from marine waters of Southeast Alaska generally consumed more and slightly larger fish prey than coho salmon, whereas coho consumed more crustacean prey (e.g., crab larvaeand hyperiid amphipods).
- …"If high fullness and low frequency of empty stomachs contribute to higher coho salmon marine survival, it is surprising that differences between Chinook and coho salmon in Southeast Alaska were not more pronounced, given the nearly order of magnitude difference in marine survival rates. The difference in fullness between the two species was only 22%, and, although proportionally far fewer coho salmon had empty stomachs, the overwhelming majority (95%) of Chinook salmon had prey in their stomachs. If diet does, indeed, play a role in survival differences between Chinook and coho salmon, the differences are quite subtle, and may be difficult to detect when survival differences are less extreme."

*Adults*

CDFG. 1998. A status review of the spring-run Chinook salmon (Oncorhynchus tshawytscha) in the Sacramento River drainage. Candidate Species Report 98-01.

- Spring-run Chinook salmon in the Sacramento River Basin hold in pools that have moderate water velocities (0.5 to 1.3 feet per second) and cover, such as bubble curtains.
- The preferred temperature range for upstream migration of Chinook salmon in the Sacramento Basin is 38$^{o}$F to 56$^{o}$F.

Lindley, S.T., R. Schick, B.P. May, J.J. Anderson, S. Greene, C. Hanson, A. Low, D. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams. 2004. Population structure of threatened and endangered Chinook salmon ESU in California's Central Valley basin. NMFS Southwest Science Center NOAA-TM-NMFS-SWFSC-360. Santa Cruz, CA.

- Chinook salmon adult migration in California's Central Valley is blocked when temperatures reach 70$^{o}$F, and fish can become stressed as temperatures approach 70$^{o}$F.

Keefer, M. L., C. A. Perry, M. A. Jepson, and L. C. Stuehrenberg. 2004. Upstream migration rates of radio-tagged adult Chinook salmon in riverine habitats of the Columbia River basin. Journal of Fish Biology 65:1126-1141.

- Keefer et al. (2004) found migration rates of adult Chinook salmon ranging from approximately 10 kilometers (km) per day to greater than 35 km per day and to be primarily correlated with date, and secondarily with discharge, year, and reach, in the Columbia River basin.

Hughes, N.F. 2004. The wave-drag hypothesis: an explanation for sized-based lateral segregation during the upstream migration of salmonids. Canadian Journal of Fisheries and Aquatic Sciences 61:103-109.

- The wave-drag model created by Hughes (2004) predicts that larger fish will swim upstream further from the bank because the minimum cost migration corridor moves offshore as fish size increases. Fish that use this corridor optimize the trade-off between swimming in deeper faster water to reduce wave drag and swimming in shallower slower water to reduce skin friction and form drag. Compared with the traditional model, the wave-drag hypothesis predicts that fish will swim against faster water and pay higher energetic costs to migrate.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley Region of California. North American Journal of Fisheries Management 18:487-521.

- Central Valley spring-run Chinook salmon utilize mid- to high elevation streams that provide appropriate temperatures and sufficient flow, cover, and pool depth to allow over-summering while conserving energy and allowing their gonadal tissue to mature (Yoshiyama et al. 1998).

Torgensen, C. E., D. M. Price, H. W. Li and B. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in Northeastern Oregon. Ecological Applications 9:301-319.

- Torgensen et al. (1999) quantified distribution and behavior of adult spring chinook salmon related to patterns of stream temperature and physical habitat at channel-unit, reach-, and section-level spatial scales in a wilderness stream and a disturbed stream in the John Day River basin in northeastern Oregon.
- “Our observations of thermal refugia and their use by chinook salmon at multiple spatial scales reveal that, although heterogeneity in the longitudinal stream temperature profile may be viewed as an ecological warning sign, thermal patchiness in streams also should be recognized for its biological potential to provide habitat for species existing at the margin of their environmental tolerances.”

Goniea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. Bennet and L. C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook Salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society 135:408-419.

- “The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon were studied using historical counts at dams and recently collected radiotelemetry data.”
- “The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000–2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about

20oC. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2–78C cooler than the main stem. "

- "Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants."

SRSRB. 2006. Snake River salmon recovery plan for Southeast Washington. Snake River Salmon Recovery Board. Available: http://www.snakeriverboard.org/resources/library.htm. (October 2009).

- Preferred habitat for pre-spawn holding spring and summer Snake River Chinook Salmon includes deep holes and log jams, with minimum depth of 5 ft. and temperatures between 53°F and 60°F.

USBR. 2008. Central Valley Project and State Water Project operations criteria and plan biological assessment. U.S. Bureau of Reclamation Mid-Pacific Region, Sacramento, California.

- Central Valley spring-run salmon hold during summer months in pools that need to be sufficiently deep, cool (about 64 F or less), and oxygenated to allow over-summer survival. Adults tend to hold in pools near quality spawning gravel.

NMFS. 2009d. Public draft recovery plan for the Evolutionary Significant Units of Sacramento winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley Steelhead. National Marine Fisheries Service, Southwest Regional Office, Sacramento, California. Available: http://swr.nmfs.noaa.gov/recovery/cent_val/Public_Draft_Recovery_Plan.pdf. (January 2010).

- "Winter-run Chinook salmon are immature when upstream migration begins, and need to hold in suitable habitat for several months prior to spawning."
- "Because water temperatures in the lower Sacramento River below the RBDD generally begin exceeding 60°F in April, it is likely that little, if any, suitable holding habit at exists in the lower Sacramento River. It most likely is only used by adults as a migrati on corridor. Following installation of the water temperature control device on Shasta Dam in 1997, it is possible that
some deep water pool habitat may exist for a short distance downstream of the RBDD with suitable cold water temperatures for adult holding."

**Coho Salmon**

*Eggs and Spawning*

*Juveniles(Freshwater)*

CDFG. 2004. Recovery strategy for California coho salmon. Report to the California Fish and Game Commission. California Department of Fish and Game, Native Anadromous Fish and Watershed Branch, 1419 9th Street, Sacramento, CA. Available: http://www.dfg.ca.gov/nafwb.cohorecovery. (December 2009).

- Flooded riparian vegetation and oxbow channels associated with beaver ponds are critical to both winter and summer survival of juvenile coho salmon in the Klamath River.

Sutton, R., M. 2007. Klamath River thermal refugia study, 2006. U.S. Bureau of Reclamation technical memorandum no. 86-68290-01-07.

- thermal refugial studies conducted by Sutton (2007) on the mainstem Klamath River have documented the persistence of small numbers of coho salmon young-of-the-year near select tributary confluence habitat throughout the summer period.

National Research Council (NRC). 2002. Scientific evaluation of biological opinions on Endangered and Threatened fishes in the Klamath River Basin - interim report. Committee on Endangered and Threatened fishes in the Klamath River Basin - interim report. Committee on Endangered and Threatened Fishes in the Klamath River Basin. National Academy Press. Washington, D.C. 26 pp.

- The National Research Council Committee on Endangered and Threatened Fishes in the Kamath Basin (NRC) addressed the importance of mainstem Klamath River habitat to listed coho salmon in its review of NMFS' 2002 Biological Opinion regarding the effects of Klamath Project Operations on listed coho salmon.
- The NRC concluded that although the importance of tributary rearing habitats to coho salmon YOY survival is widely recognized and restoring degraded tributary habitat within the Klamath River Basin will likely be paramount to recovering the species, mainstem habitat may nevertheless play a critical role in YOY coho salmon survival in rivers such as the Klamath where tributary conditions are particularly inhospitable.

NMFS. 2007. Magnuson-Stevens Reauthorization Act Klamath River Coho Salmon Recovery Plan. Prepared by Rogers, F. R., I. V. Lagomarsino and J. A. Simondet for the National Marine

Fisheries Service, Long Beach, CA. 48 pp. Available: http://swr.nmfs.noaa.gov/salmon/MSRA_RecoveryPlan_FINAL.pdf. (November 2009).

- As part of their ongoing coho salmon overwintering study, the Yurok Tribe has documented substantial use of off-channel habitat by juvenile coho salmon within non-natal tributaries of the Klamath River estuary.
- Preliminary results from the study suggest displaced fish exhibit high fidelity with regard to this non-natal habitat, as well as a greater fitness level at the smolt stage as compared to fish that overwintered solely within their natal tributary.

Roni, P. 2002. Habitat use by fishes and pacific giant salamanders in small western Oregon and Washington streams. Transactions of the American Fisheries Society 131(4): 743-761.

- In 30 streams in western Washington and northwestern Oregon, Roni (2002) found juvenile coho salmon summer densities to be highest in backwater, dam, and scour pools and, to a lesser extent, glides. Also, coho salmon summer densities among streams were positively correlated with both site elevation and the number of pieces of large woody debris (LWD).
- During winter months, the highest coho densities were associated with backwater and dam pools.

Beechie, T. J., M. Liermann, E. M. Beamer, R. Henderson. 2005. A classification of habitat types in a large river and their use by juvenile salmonids. Transactions of the American Fisheries Society, 134:717-729.

- "Densities of juvenile Chinook salmon and coho salmon were highest in bank and backwater units in winter in the Skagit River basin, WA. In summer, coho salmon densities were significantly different among edge unit types, densities being highest in banks and backwaters. Microhabitat selection (velocity, depth, and cover type) by juvenile salmonids mirrored that in small streams, most fish occupying areas with a velocity less than 15 cm/s and wood cover. Among ocean-type salmon, Chinook and chum salmon fry were captured in large numbers in all edge units and exhibited only slightly higher densities in low-velocity areas (,15 cm/s)."

USBR. 2008. Central Valley Project and State Water Project operations criteria and plan biological assessment. U.S. Bureau of Reclamation Mid-Pacific Region, Sacramento, California.

- "Juvenile coho salmon in the Trinity River spend up to a full year in freshwater before migrating to the ocean. Their habitat preferences change throughout the year and are highly influenced by water temperature. During the warmer summer months when coho are most actively feeding and growing, they spend more time closer to main channel habitats."
- "When the water cools in the fall, juvenile coho move further into backwater areas or into off-channel areas and beaver ponds if available."

*Juveniles (Estuarine)*

Koski, K. V. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society 14: 4.

- "The downstream movement of coho salmon nomads (age 0), conventionally considered surplus fry, has been an accepted characteristic of juvenile coho salmon for the past 40 to 50 yr. The fate of these nomads, however, was not known and they were assumed to perish in the ocean."
- "Several studies and observations have recently provided new insights into the fate of nomads and the role of the stream-estuary ecotone and estuary in developing this life history strategy that promotes coho resilience."
- "Nomad coho can acclimate to brackish water, and survive and grow well in the stream-estuary ecotone and estuary, but instead of migrating to the ocean they return upstream into freshwater to overwinter before migrating to the ocean as smolts."
- "Nomads may enter the estuarine environment from natal or non-natal streams, rear there throughout the summer, and then emigrate to a non-natal stream for overwintering and smolting in the spring. These estuarine and overwintering habitats have enabled coho to develop this unique nomad life history strategy that may help to ensure their resilience."
- "Restoring estuarine habitats may be essential to the recovery of depressed populations of coho."

*Juveniles (Marine)*

Weitkamp, L. A. and M. V. Sturdevant. 2008. Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of Southeast Alaska. Fisheries Oceanography 17: 380-395.

- Weitkamp and Sturdevant (2008) found that Alaskan coho salmon achieved extremely high marine survival rates despite a diet consisting largely of small, less energetically-efficient crustacean prey. Their results suggest that diet quantity (how much is eaten) rather than diet quality (what is eaten) is important to marine survival.

Malick, M. J., M. D. Adkison and A. C. Wertheimer. 2009. Variable effects of biological and environmental processes on Coho salmon marine survival in southeast Alaska. Transactions of the American Fisheries Society 138:846-860.

- Malick et al. (2009) used correlation analyses, linear regression models, and multistock mixed effects models to examine the relationships between coho salmon Oncorhynchus kisutch marine survival and six biological and environmental covariates across 14 southeast Alaska (SEAK) stocks.

- "An index representing local hatchery pink salmon and chum salmon fry abundance was the most important variable in explaining the variation in coho salmon marine survival, having a stronger estimated effect on survival than an index of local wild pink salmon fry abundance."
- "The magnitude and sign of the hatchery pink salmon and chum salmon effect varied greatly among different localities. Our results suggest that (1) SEAK coho salmon stocks are not equally influenced by the same factors and (2) there are factors that appear to affect marine survival of SEAK coho salmon stocks at varying spatial scales."
- "This study also provides evidence that coho salmon stocks throughout SEAK experience some degree of regional concordance in the marine environment but also that local stock-specific conditions are important in fully understanding variation in marine survival."

Van Doornik, D. M., D. J. Teel, D. R. Kuligowski, C. A. Morgan, and E. Casillas. 2007. Genetic analyses provide insight into the early ocean stock distribution and survival of juvenile coho salmon off the coasts of Washington and Oregon. North American Journal of Fisheries Management 27:220-237.

- Van Doornik et al. (2007) created a database of coho salmon microsatellite allele frequencies. Using genetic distance calculations, they identified six major geographic regions and 15 smaller subregions into which the populations grouped.
- Van Doornik et al. (2007) used the database to estimate stock proportions and densities of 2,344 coho salmon sampled over eight summers in a juvenile marine ecology study conducted off the coasts of Washington and Oregon.
- "Columbia River juveniles were caught at higher densities than coastal fish throughout the summer. Fish from Columbia River and coastal sources were captured both north and south of their points of sea entry in early summer and at higher densities than in late summer. September catch of Columbia River juveniles was correlated with adult abundance in the following year, indicating that year-class strength for this stock is largely set during the first summer in the ocean."

Brennan, J. S., K. F. Higgins, J. R. Cordell and V. A. Stamatiou. 2004. Juvenile salmon composition, timing, distribution, and diet in marine nearshore waters of the Central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, WA.

- The majority of the diet of juvenile coho salmon in marine nearshore areas of Puget Sound consisted of plankton (e.g. crab larvae, copepods, amphipods). By weight, prey composition was dominated by fishes, especially larval and juvenile sand lance.

*Adults*

Roni, P., D.V. Slyke, B.A. Miller, J.L. Ebersole, and G. Pess. 2008. Adult coho salmon and steelhead use of boulder weirs in southwest Oregon streams. North American Journal of Fisheries Management 28(3):970-978.

- Compared redd and spawner densities for coho salmon and steelhead in 10 reach pairs in seven Oregon streams and additional sites in the West Fork of the Smith River – specifically looking at the effects of artificially placed boulder weirs
- In 10 reach pairs, found significantly higher coho salmon spawner numbers and peak redd counts in reaches with boulder weirs
- No differences in coho salmon or steelhead spawner counts or redd numbers were observed in the West Fork of the Smith River, but coho salmon redd densities did differ between reach types examined – highest redd densities in tributary reaches – both spawner density and redd density were positively correlated to percent gravel
- Authors suggest that placement of boulder weirs in bedrock channels leads to localized increases in spawning abundance, but other large-scale factors influence coho salmon and steelhead spawner abundance at the watershed level – also state need to consider gravel availability when placing instream structures designed to improve spawning habitat
- Boulder weirs primarily improved spawning habitat through accumulation of suitable spawning gravel immediately upstream of structure

**Pink Salmon**

*Eggs and Spawning*

Connor, E.J. and D. E. Pflug. 2004. Changes in the distribution and density of Pink, Chum, and Chinook salmon spawning in the Upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24:835-852.

- “Densities of spawning salmon were compared among three contiguous reaches of the upper Skagit River before and after the implementation of flow management measures in 1981. The measures were intended to minimize redd dewatering during the spawning and incubation periods and fry stranding during the emergence and outmigration periods.
- “Field monitoring confirmed that increasing the minimum incubation flows created improvements in redd protection levels… Spawner abundance of all three species progressively increased in an upstream direction following implementation of flow measures; increases were greatest in the reach immediately below the hydroelectric project. The upstream shift in spawner abundance was highly significant based on factorial analyses of variance. The greatest increases in spawner abundance for Chinook

salmon and chum salmon were observed during even years, when pink salmon did not spawn. Mean spawner abundance in the upstream-most study reach increased from 311 to 1,169 carcasses/mi (odd years) for pink salmon, from 6 to 115 fish/mi (odd years) or 58 to 462 fish/mi (even years) for chum salmon, and from 48 to 49 redds/mi (odd years) or 59 to 65 redds/ mi (even years) for Chinook salmon."

- "These increases were substantially greater than those observed concurrently in other areas of the Skagit River basin and in other northern Puget Sound rivers. The average number of Chinook salmon spawners remained unchanged in the study area after 1981, while substantially declining in other unregulated Skagit River subbasins and most Puget Sound rivers. The study area now possesses the greatest percentage of pink, chum, and Chinook salmon spawners within the Skagit River basin. The Skagit River presently supports the largest run of native Chinook salmon in the Puget Sound region and the largest runs of pink and chum salmon in the coterminous United States."

*Juveniles(Freshwater)*

Connor, E.J. and D. E. Pflug. 2004. Changes in the distribution and density of Pink, Chum, and Chinook salmon spawning in the Upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24:835-852.

- Mean spawner abundance of pink salmon in the upper Skagit River, Washington, increased significantly (from 311 to 1,169 carcasses/mi) following implementation of flow management measures that increased minimum incubation flows and decreased stranding events.

*Juveniles (Estuarine)*

Murphy, M.L., S.W. Johnson, and D.J. Csepp. 2000. A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska. Alaska Fishery Research Bulletin 7:11-21. http://adfg.alaska.gov/pubs/afrb/vol7/murphyv7.pdf

- Seined monthly from April to June and in September 1998 to compare fish assemblages between sites with eelgrass and sites with either kelp or only filamentous algae
- "Catch of pink salmon *Oncorhynchus gorbuscha* fry, chum salmon *O. keta* fry, and coho salmon *O. kisutch* smolts was similar at eelgrass and non-eelgrass sites, except for chum salmon in June when catch was significantly lower at eelgrass sites."
- "Juvenile salmon were not significantly associated with eelgrass."
- "Although previous authors have suggested juvenile salmon in Puget Sound use eelgrass for feeding and cover, direct evidence is lacking."
- Pink salmon fry were 84, 49, and 0% of catch in April, May, and June, respectively.

Mortensen, D., A. Wertheimer, S. Taylor, and J. Landingham**.** 2000. The relation between early marine growth of pink salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fish Bull. 98:319-335.

- Tagged juvenile pink salmon as they emigrated to the estuarine waters of Auke Bay – used four consecutive brood years – emigration period extended from late March to mid-May, with most fish emigrating during 2-3 weeks in mid- to late April
- Later emigrating juveniles spent significantly less time in the estuary
- Individual growth rates ranged from 3.1-3.7% per day – growth occurred more slowly in early April than in late April and early May – growth was significantly correlated to water temperature, but not to prey availability – early marine growth was significantly related to survival to the adult stage
- Data suggests that early emigrants encounter poor conditions for growth (i.e., low water temperatures and low zooplankton abundance) compared to later emigrants, but fish that survive are typically larger when compared to later emigrants later on in the season
- Juveniles abundant in nearshore areas in April and May, but moved offshore by late May and early June

*Juveniles (Marine)*

Moss, J. H., D. A. Beauchamp, A. D. Cross, E. V. Farley, J. H. Hellel and K. W. Myers. 2007. Spatial patterns in consumption demand and growth potential of juvenile pink salmon (Oncorhynchus gorbuscha) in the gulf of Alaska. North Pacific Anadromous Fish Commission Technical Report 7:35-36.

- Moss et al. (2007) examined if localized conditions affecting growth during the first summer in coastal shelf regions could determine the severity of over winter survival.
- Daily growth potential for juvenile pink salmon inhabiting the Coastal Gulf of Alaska increased from 2001 to 2002, as did marine survival for juvenile pink salmon Prince Willian Sound (PWS) hatchery stocks. Total returns to PWS (hatchery and wild stocks combined) were greater in 2002 relative to 2001 by a factor of 2.21. This suggests that the daily growth potential metric has the ability to describe variation in marine survival.
- A large proportion of juvenile pink salmon were concentrated in nearshore habitats, which ranked the lowest in daily growth potential relative to other habitats during 2001, and average juvenile pink salmon body size and estimated consumption rates were lower in 2001 than 2002, thus, density dependent forces may have contributed to lower survival.

Orsi, J.A., M.V. Sturdevant, J.M. Murphy, D.G. Mortensen, and B.L. Wing. 2000. Seasonal habitat use and early marine ecology of juvenile Pacific salmon in southeastern Alaska. NPAFC Bulletin No. 2:111-122.

- Monitored habitat use and early marine ecology of juvenile (age-0) Pacific salmon at inshore, strait, and coastal habitats along a seaward migration corridor in southeastern Alaska on a monthly basis from May through October 1997-1999
- Juvenile pink salmon most abundant in strait habitats throughout all sampling and most abundant in June samples
- Catches for all 5 species of juvenile salmon generally were confined to <25km from shore and declined with distance from shore – higher proportion of pink and chum salmon were captured closer to shore
- Juvenile pink salmon growth rates in June and July declined in years with lower temperatures and zooplankton indices
- Juvenile pink salmon captures were very low in all waters in May, peak captures occurred in June with the vast majority captured in strait areas, and captures steadily declined and became more evenly distributed throughout habitat types during later months

*Adults*

**Salmon (General)**

*Eggs and Spawning*

*Juveniles(Freshwater)*

*Juveniles (Estuarine)*

Collis, K., S. Adamany, D. Roby, D. Craig, and D. Lyons. 2000. Avian predation on juvenile salmonids in 22 the lower Columbia River. 1998 Annual Report to the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, OR.

- Collis et al. initiated a field study in 1997 to assess the impacts of fish-eating colonial waterbirds (i.e., terns, cormorants, and gulls) on the survival of juvenile salmonids in the lower Columbia River.
- “Diet analysis indicated that juvenile salmonids were an important part of the diet of fisheating colonial waterbirds in the Columbia River estuary. As in 1997, Caspian terns were most dependent on salmonids (74% of diet mass), followed by double-crested cormorants (21% of diet mass) and glaucous-winged/western gulls (approx. 8% of diet mass). Juvenile salmonids were especially prevalent in the diets of fish-eating waterbirds in the estuary during April and May. The diet samples from California and ring-billed gulls nesting at up-river colonies included few fish and very few juvenile salmonids.”
- “We estimated that Caspian terns in the Columbia River estuary consumed 10.8 million juvenile salmonids (range = 7.4 – 15.2 million), or approximately 11% (range = 8% - 16%) of the estimated 95 million out-migrating smolts that reached the estuary during the 1998 migration year. The best estimate the number of juvenile salmonids consumed by double-crested cormorants in the estuary was 4.6 million (range = 2.2 – 9.2 million), or approximately 5% of out-migrating smolts (range = 2% - 10%) that reached the estuary in 1998. A rough estimate of the number of juvenile salmonids consumed by glaucouswinged/western gulls in the estuary was 1.3 million (range = 0.4 – 3.9 million). Thus the estimated total consumption of juvenile salmonids by fish-eating colonial waterbirds in the Columbia River estuary was 16.7 million smolts (range = 10.0 – 28.3 million smolts), or 18% (range = 11% – 30%) of those smolts that reached the estuary in 1998.”
- “We recommend relocation of part of the Rice Island Caspian tern colony to East Sand Island in 1999 to test whether this approach will reduce smolt losses to terns. In the longer term, it would probably benefit both salmonids and terns if much of the tern population was relocated to other coastal colony sites, possibly restored former colony sites in Grays Harbor, Willapa Bay, and Puget Sound, where greater diversities of non-salmonid prey are presumably available.”

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. NOAA Tech. Memo., NMFS-NWFSC-69.

- “From the perspective of the estuary, we conclude that population viability of stream type ESUs is most affected by tern predation and flow while flow and habitat most affect ocean type ESUs. At this time, we do not know how much of a change in each factor is required to affect improvements in population responses of relevant ESUs. Based upon available information, we hypothesize that the greatest opportunity to affect ESUs in the Columbia River basin by the manipulation of estuarine factors is with restoration of shallow water habitat. These actions will primarily affect ocean type ESUs and the shallow water dependent strategies of stream type ESUs. This is because there is a strong linkage between the fry and fingerling life history strategies, which dominant ocean type ESUs, and shallow water habitat. Thus, the main affect on ocean type ESUs of making changes in habitat and flow will be realized as gains in abundance and productivity. The main affect on stream type ESUs of reducing tern predation and altering flow will be realized as gains in spatial structure and diversity."

*Juveniles (Marine)*

NMFS. 2007a. Puget Sound Salmon Recovery Plan. NMFS. Available: http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Chinook-Plan.cfm. (October 2009).

- The Pacific Decadal Oscillation (PDO) and the El Nino/Southern Oscillation (ENSO) are cycles that appear to have significant influence on salmon survival and migratory patterns. During El Nino and/or warm phase PDO cycles, higher Pacific Ocean temperatures and changes in wind patterns may reduce the upwelling of nutrients from the ocean floor, thereby affecting the entire food web in the Pacific.

National Wildlife Federation. 2005. Fish Out of Water: A Guide to Global Warming and Pacific Northwest Rivers. National Wildlife Federation, Western Natural Resource Center. Seattle, WA.

- Wind driven mixing in the ocean replenishes nutrients to rich surface waters where phytoplankton occur, thereby promoting biological productivity at the base of the food chain and working its way up to salmon and other species of fish.
- As scientific understanding of these processes has improved, fisheries managers have started to utilize information on favorable or unfavorable ocean conditions in their harvest planning forums

NMFS. 2008a. Federal Columbia River power system biological opinion. National Marine Fisheries Service. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. (October 2009).

- The Columbia River plume is that portion of the near-shore ocean environment sufficiently influenced by Columbia River energy, water quality, and biotic constituents to affect the local ecosystem. The plume is important juvenile salmonid habitat, particularly during the first month or two of ocean.

Robertis, A., C. A. Morgan, R. A. Schabetsberger, R. W. Zabel, R. D. Brodeur, R. L. Emmett, C. M. Knight, G. K. Krutzikowsky, and E. Casillas. 2005. Columbia river plume fronts II: distribution, adundance, and feeding ecology of juvenile salmon. Marine Ecology Progress Series 299:33-44.

- Robertis et al. (2005) examined the spatial distribution of juvenile Pacific salmonids Oncorhynchus spp. in and around plankton-rich frontal regions of the Columbia River

plume to test the hypothesis that juvenile salmonids aggregate at riverine plume fronts to feed.

- "Juvenile salmonids tended to be abundant in the frontal and plume regions compared to the more marine shelf waters, but this pattern differed among species and was not consistent across the 2 study years. Stomach fullness tended to be higher in the more marine shelf waters than either the front or plume areas, which does not support the hypothesis that salmonids consistently ingest more prey at frontal regions. However, the short persistence time of these fronts may prevent juvenile salmon from exploiting these food-rich, but ephemeral, features."

Hare, S. R., N. J. Mantua, and R. C. Francis. 1999. Inverse production regimes: Alaska and West Coast Pacific salmon. Fisheries 24 (1): 6-14.

- Recent evidence suggests that marine survival among salmonids fluctuates in response to 20- to 30-year cycles of climatic conditions and ocean productivity. This phenomenon has been referred to as the Pacific Decadal Oscillation.

Wells, B.K., C.B. Grimes, J.C. Field and C.S. Reiss. 2006. Covariation between the average lengths of mature coho (Oncorhynchus kisutch) and Chinook salmon (O. tshawytscha) and the ocean environment. Fisheries Oceanography. 15:1, 67-79.

- Wells et al. (2006) used the average fork length of age-3 returning coho (Oncorhynchus kisutch) and age-3 ocean-type and age-4 stream-type Chinook (Oncorhynchus tshawytscha) salmon along the northeast Pacific coast to assess the covariability between established oceanic environmental indices and growth.
- Washington, Oregon, and California salmon sizes were negatively correlated with the Multivariate El Nino-Southern Oscillation Index values indicating that ultimate fish size was affected negatively by El Nino-like events.
- Size variation of coho salmon stocks south of Alaska was synchronous and negatively correlated with warm conditions and weak North Pacific high pressure during ocean residence.

Peterson, W.T., R.C. Hooff, C.A. Morgan, K.L. Hunter, E. Casillas, and J.W. Ferguson. 2006. Ocean Conditions and Salmon Survival in the Northern California Current.

- A brief cold cycle in the California current was immediately succeeded by a 4-year period of predominantly warm ocean conditions beginning in late 2002, which appeared to have negatively impacted salmon populations in the California Current.
- There are indications that these regime shifts in ocean conditions affect the migration patterns of larger animals that prey on salmon (e.g., Pacific hake, sea birds) resulting in a "top-down" effect as well.

Wells, B.K., J.C. Field, J.A. Thayer, C.B. Grimes, S.J. Bograd, W.J. Sydeman, F.B. Schwing, and R. Hewitt. 2008. Untangling the relationships among climate, prey, and top predators in an ocean ecosystem. Marine Ecology Progress Series, 364:15-29.

- Wells et al. (2008a) developed a multivariate environmental index that can be used to assess ocean productivity on a finer scale for the central California region. This index (also referred to as the Wells Ocean Productivity Index) has also tracked the Northern Oscillation Index, which can be used to understand ocean conditions in the North Pacific Ocean in general.
- The Wells et al. (2008a) index incorporates 13 oceanographic variables and indices and has correlated well with the productivity of zooplankton, juvenile shortbelly rockfish, and common murre production along the California coast (MacFarlane et al. 2008).
- In addition to its use as an indicator of ocean productivity in general, the index may also relate to salmon dynamics due to their heavy reliance on krill and rockfish as prey items during early and later life stages. For instance, not only did the extremely low index values in 2005 and 2006 correlate well with the extremely low productivity of salmon off the central California coast in those years, but the index also appears to have correlated well with maturation and mortality rates of adult salmon from 1990-2006 in that region.

Francis, R.C. and N. Mantua. 2003. Climatic influences on salmon populations in the Northeast Pacific. In: Assessing Extinction Risk for West Coast Salmon. Proceedings of the Workshop November 13-15, 1996. NOAA Technical Memorandum NMFS-NWFSC-56.

- Analysis by Francis and Mantua (2003) demonstrate clear linear relationships between naturally occurring and large-scale changes to the physical environment and a number of salmon populations in the Northeast Pacific.
- "Of particular interest to the issue of climatic influences on salmon extinctions, interdecadal environmental fluctuations, associated with the Pacific Interdecadal Oscillation (PDO), appear to have significantly reduced the ecosystem(s) carrying capacity for West Coast coho salmon since the 1977 regime shift."
- "The overall productivity of salmon in Alaska has dramatically increased during this same time period in response to PDO-related climate changes."
- "Our results agree with those of previous studies that identify the first few months of the salmon's ocean life as the period of critical climatic influences on survival, which in turn, suggests that coastal and estuarine environments are key areas of biophysical interaction."
- Francis and Mantua (2003) point out that climate patterns would not likely be the sole cause of extinctons of salmon populations but could certainly increase the risk of extinction when combined with other factors, especially in ecosystems under stress from humans.

MacFarlane, R.B., S. Hayes, and B. Wells. 2008. Coho and Chinook Salmon Decline in California during the Spawning Seasons of 2007/08. National Marine Fisheries Service. Southwest Region. Santa Cruz, California.

- Data from across the range of coho salmon on the coast of California reveal there was a 73% decline in returning adults in 2007/08 compared to the same cohort in 2004/05. The problem extends beyond California: preliminary data from the Oregon coast show a

70% decline. The low coho salmon numbers come on the heels of the Pacific Management Council's report of exceptionally low Chinook salmon returns to California's Central Valley (and other streams in California, Oregon, Washington, and British Columbia) in the fall of 2007.
- The Wells Ocean Productivity Index (WOPI), an accurate measure of central California ocean productivity, reveals poor conditions during the spring and summer of 2006, when juvenile coho from the 2004/05 spawn entered the ocean. The WOPI also showed low productivity potential for the spring and summer of 2005, which may explain low returning Chinook salmon numbers in 2007.

Behrenfeld, M.J., R.T. O'Malley, D.A. Siegel, C.R. McClain, J.L. Sarmiento, G.C. Feldman, A.J. Milligan, P.G. Falkowski, R.M. Letelier, and E.S. Boss. 2006. Climate-driven trends in contemporary ocean productivity. Nature 444: 752-755.
- The link between the physical environment and ocean biology functions through changes in upper-ocean temperature and stratification, which influence the availability of nutrients for phytoplankton growth. The observed reductions in ocean productivity during the recent post-1999 warming period provide insight on how future climate change can alter marine food webs.

Emmett, R. L., G. K. Krutzikowsky and P. Bentley. 2006. Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998-2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. Progress In Oceanography 68:1-26.
- From 1998 to 2003, Emmett et al. (2006) observed large fluctuations in the abundance and distribution of four pelagic predatory (piscivorous) fishes off northern Oregon and southern Washington. They found that predatory and forage fish distributions respond to ocean temperatures, predator/prey interactions, and possibly turbidity.
- "A shift in ocean conditions in 1999 decreased overall predator fish abundance in the Columbia River plume, particularly for Pacific hake. Marine survival of juvenile salmon started to increase in 1999, and forage fish densities increased in 2000, lagging by one year."

*Adults*