Appendix A. Summaries of Literature Reviewed

Section 1. Literature Used for the Effects Review

Tide Gates: Removal

Tide Gates: Upgrade

SECTION 1. LITERATURE USED FOR THE EFFECTS REVIEW

Tide Gate Effectiveness Literature Compilation

<table>
<tr><td colspan="3">Anisfeld, S.C., M.J. Tobin, and G. Benoit. 1999. Sedimentation Rates in Flow-Restricted and Restored Salt Marshes in Long Island Sound. Estuaries 22 (2A): 231-244.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 1999</td></tr>
<tr><td>Include: Maybe</td><td>Reason: Compares sediment accretion in a restored marsh with that in reference and restricted marshes and compared all to measurements of sea-level rise.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: 6 marshes in Long Island Sound, Connecticut, sediment cores</td><td>Ecosystem(s): salt marsh</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Abstract: Many salt marshes in densely populated areas have been subjected to a reduction in tidal flow. In order to assess the impact of tidal flow restriction on marsh sedimentation processes, sediment cores were collected from flow- restricted salt marshes along the Connecticut coast of Long Island Sound. Cores were also collected from unrestricted reference marshes and from a marsh that had been previously restricted but was restored to fuller tidal flushing in the 1970's. High bulk densities and low C and N concentrations were found at depth in the restricted marsh cores, which we attribute to a period of organic matter oxidation, sediment compaction, and marsh surface subsidence upon installation of flow restrictions (between 100 and 200 years before the present, depending on the marsh). Recent sedimentation rates at the restricted marshes (as determined by t37C.s and 21~ dating) were positive and averaged 78% (lsTCs) and 50% (zloPb) of reference marsh sedimentation rates. The accumulation of inorganic sediment was similar at the restricted and reference marshes, perhaps because of the seasonal operation of the tide gates, while organic sediment accretion (and pore space) was significantly lower in the restricted marshes, perhaps because of higher decomposition rates. Sedimentation rates at the restored marsh were significantly higher than at the reference marshes. This marsh has responded to the higher water levels resulting from restoration by a rapid increase in marsh surface elevation.

NOTE: At the "restored" site, "two tidegates were allowed to fall into disrepair; they were removed and a bridge opening was widened in the mid-1970s." (from Table 1, p. 234.)

Results Summary: Vertical accretion rates (rate of increase in substrate elevation) in restored marsh was higher than those in reference sites. In both sites accretion rates were more than accomodating for sea level rise. The rates were lower in sites restricted by tide gates. Mass accumulation rates were similar among marshes, although organic material accumulation was slower at restricted sites. Organic and inorganic material input did not differ by marsh type. Marshes with high carbon had high C:N.

Broad Outcomes: The restored marsh is similar to the reference site while the restricted sites are dissimilar. The data supports the idea that there is a period of trauma immediately after restriction and then a period of recovery. The authors mention the idea that marshes should not be restored too quickly so as to avoid the area flooding and becoming open water habitat because of subsidence during the period of restriction.

Detailed Outcomes: Cs-137 profiles were good, Pb-210 profiles had some subsurface activity that was unexplained. Vertical accretion rates in reference marshes was 0.37 +/- 0.03 cm/yr (mean SE) with Cs dating and 0.36 +/- 0.07 with Pb dating, so they were more than keeping rate with sea level rise. Restricted marshes had vertical accretion rates that were 78% (0.29 +/- 0.03 Cs) to 50% (0.18 +/- 0.01 Pb) of the reference marshes - this was not a statistically significant difference. The restored marsh has much higher (178%) accretion rate than reference marshes (0.66 +/- 0.03 Cs, 0.55 +/- 0.06 Pb); p=0.002 for Cs - able to adjust to higher water levels resulting from restoration. There were no statistical differences in mass accumulation rates between the three marsh types. Inorganic material accumulated at similar rates. Organic material accumulated more slowly at restricted marshes. Pore space was largest single category in every core. It was the higher porosity in the restored marsh that allowed it to add elevation so quickly - input of organic and inorganic material did not differ among marsh types. Reference and restored marshed had similar bulk densities, which did not differ with depth. Restricted marshes had higher bulk densities that increased with depth (while C decreased with depth). There was a positive correlation between C and C:N - low C marshes had low C:N.

Effects Modifiers: The Pb profiles had varying quality and could only be used as 100-yr averages for comparisons.

Intervention: 3 restricted, 2 reference, 1 restored. In the restored marsh two dilapidated tide gates were removed and a bridge pass under was widened in the 1970s	
Conditions:	**Duration**: 1 month
Study Design: Sediment cores were removed, taken to the lab, and dried to constant weight. Dry bulk density (dry weight/volume, g/cm3) was calculated for each 1-2cm section and in 10cm aggregations. Vertical sedimentation rates were calculated using Cs-137 and Pb-210 dating. Sedimentation rates of Pb and Cs were also calculated by mass (g/m2/y). Subsamples were ashed for organic material and Loss on Ignition for C and N.	
Statistics: Accretion and accumulation rates for restored and restricted marshes were compared to reference sites using t-tests or the non-parametric equivalent. Used t-tests to compare bulk densities of 10-cm sections, maximum bulk density, minimum C, and average C:N in each core.	

Comments: It has good info on sedimentation but is on the Atlantic coast. This paper could be used in support of other studies in the PNW with similar results.

<table>
<tr><td colspan="3">Bass, A.L. 2010. Juvenile coho salmon movement and migration through tide gates. M.S. Thesis, Dep't. of Fisheries and Wildlife, Oregon State University, Corvallis, OR. 124 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: M.S. Thesis</td><td>Publication Date: 2010</td></tr>
<tr><td>Include: Yes</td><td>Reason: Data show movement of coho up and down stream through tide gates.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Coos Bay, OR
coho salmon</td><td>Ecosystem(s): freshwater and tidally influenced streams</td></tr>
<tr><td colspan="3">Reference Source: http://www.cooswatershed.org/Publications/BassArthurL2010Thesis.pdf</td></tr>
</table>

Abstract: [Excerpts from ABSTRACT:] We studied three streams, one with a top-hinged tide gate, one with a side-hinged gate, and one without any tide gates that acted as our reference site. Our study species was coho salmon...objectives were to: 1) quantify upstream and downstream sh passage occurrence at all three sites, 2) determine whether juvenile coho salmon passage is associated with a specific range of gate conditions, and 3) identify any associations between coho smolt emigration rate and environmental variables that are influenced by tide gates. Coho salmon smolts passed upstream most frequently at the non-gated channel (48% of all smolts detected at the array), next the side-hinged gate (28%), and lastly, the top-hinged gate (3%). Juvenile coho salmon passed more frequently at a specific range of gate angles and tailwater depths at both top hinged and side-hinged tide gates.

Powerpoint on this work:
http://www.dfw.state.or.us/fish/OHRC/docs/2010/Movements%20And%20Survival%20Of%20Juvenile%20Coho%20Salmon%20At%20Tide%20Gates.pdf

Results Summary: There were differences among channel types (top-hinge and side-hinge gates and ungated) in the frequency of upstream passage. For smolts the largest proportion of tagged fish migrated upstream at the ungated stream (47%), the smallest proportion at the top-hinge gate (3%) and a medium proportion at the side-hinge gate (20%). At the top-hinged and side-hinged gates smolts moved downstream more frequently at a subset of available angles and depths. At the top-hinged gate angles >20 deg were used more often. Smolts moved downstream more frequently with greater depths. At the side-hinged gate angles > 40 deg and depths >1.6m were used more often. There was no evidence for a specific subset of conditions for upstream movement at either gate. For subyearlings upstream passage dominated at both gates. At the top-hinge gate angles 7-16 were used for upstream passage and at the side-hinge gate the entire open period was utilized.

Broad Outcomes: Ch 2. 796 (top-hinged), 215 (side-hinged), 129 (ungated) unique coho smolts were detected. Top-hinged: 50% passed downstream, 3% upstream. Side-hinged: 36% downstream, 20% upstream. Ungated: 92% downstream, 47% upstream. The highest counts of upstream movement by an individual were at the ungated stream (median=2, average=4.4, maximum=27. At tide gates smolts rarely passed upstream more than once. Rejected 1st hypothesis of no difference between channel types in how frequently fish passed upstream. At the top-hinged gate 78% of subyearlilngs passed upstream and 8% downstream. Of the subyearlings detected at the side-hinged gate 31% passed downstream and 38% upstream. At the top-hinged and side-hinged gates smolts moved downstream more frequently with a distribution of angles and depths that differ significantly from the distribution of available angles and depths. At the top-hinged gate angles >20 deg were used more often. Smolts moved downstream more frequently with greater depths. At the side-hinged gate angles > 40 deg and depths >1.6m were used more often. No evidence for a specific subset of conditions for upstream movement at either gate. Rejected 2nd hypothesis. Subyearlings passed upstream at angles of 7-16 deg at the top-hinged gate. At the side-hinged gate subyearlings did not utilize any subset of conditions for upstream passage -they could utilize the entire open period. Downstream they used angles of 10-17 deg.

Detailed Outcomes: Ch 3. Salinity above the leaky top-hinged gate tracked estuary salinity, ~4-5ppt lower, but much higher than the other two creeks. T in gated creeks was higher than the bay Jul-Oct 2009, but lower during peak migration time Apr 18 - Jun 17 2009. ~50% of fish approaching tide gates emigrated in < 1min, 24% at the non-gated array. Emigration likelihood at the top-hinged gate was explained by the full model (T, FL, precipitation, tag date, salinity). At Larson the best model included only precipitation At Winchester Creek the best model included T and FL. Larger FL led to higher likelihood of passage at top-hinge and ungated. Increase in salinity = lower passage likelihood at top-hinge gate. Higher rainfall = higher passage likelihood at side-hinge gate. Higher T = increased passage likelihood at ungated channel. Rejected hypotheses that T and salinity do not affect emigration likelihood. Smolts used the reservoir most. Emigration likelihood was increased by FL, T, and later tag date. Higher salinity at the gate reduced emigration likelihood. Logistic regression showed that gate angle, tag reach, salinity best explained passage on first approach. Larger gate angle, tagging in reservoir, and lower salinity increased likelihood of passage on first approach.

Effects Modifiers:

Intervention:	
Conditions: Larsen Cr has 2 steel side-hinged doors Palouse Cr has 2 wood top-hinged doors	**Duration**: 22 months
Study Design: Ch 2. Fish were collected in screw traps and seines. Fish >60 mm were PIT tagged with 12mm tags, fish 48-60 mm with 8mm tags. PIT arrays were built and installed above and below the tide gates and at the mouth of the ungated creek. Independent passage events were recorded. Logged gate opening angle, tailwater depth, velocity. Ch 3. Salinity and T were logged and averaged daily. Recorded precipitation, FL at tagging, tag date.	
Statistics: Ch 2. Compared distributions of used and available angles and tailwaters with Kolmogorov Smirnov and Kuiper's test. Ch 3. Determined how explanatory variables influenced fish travel times in Palouse Creek reaches with Cox proportional hazard regression. Logistic regression determined which variables influenced downstream movement through the tide gate.	

Comments: This study was done on 3 streams: ungated, top-hinge gated, side-hinge gated. The sampling methods allow the author to determine which conditions are best for movement through the tide gates and to show that movement occurs in both up- and down-stream directions, and to quantify those movements.

<table>
<tr><td colspan="3">Beamer, E., R. Henderson, and K. Wolf. 2013. Juvenile salmon, estuarine, and freshwater fish utilization of habitat associated with the Fisher Slough Restoration Project in 2012. Skagit River System Cooperative, La Conner, WA. 101 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: 2012 Project Report</td><td>Publication Date: 2013</td></tr>
<tr><td>Include: Yes</td><td>Reason: Post tide gate replacement and dike setback.</td><td>Relevance: High</td></tr>
<tr><td colspan="2">Location & Species: South Fork Skagit River, WA. Chinook salmon</td><td>Ecosystem(s): tidal wetland</td></tr>
<tr><td colspan="3">Reference Source: https://salishsearestoration.org/images/5/54/Beamer_et_al_2013_fisher_slough_fish_monitoring_2012.pdf</td></tr>
</table>

Abstract: Excerpted from The Fisher Slough Restoration Project in the south fork Skagit River tidal delta is intended to help recover 6 populations of wild Chinook in the Skagit River and its estuary. Project Element 1 was to improve fish passage and tidal inundation to areas upstream of the floodgate and to protect adjacent farmland from flooding by replacing an existing floodgate with a new floodgate within Fisher Slough. Element 2 resolved a drainage conflict preventing implementation of Element 3- a dike setback to allow more of the agricultural area to be inundated by tidal and freshwater hydrology, increasing fish carrying capacity. Tidal habitat area increased from 9.8 acres to 55.7 acres. All three phases were completed before monitoring in 2012. Monitoring results related to Elements 1 and 3 are presented in this report. Our limited statistical tests and graphical trends over four years of monitoring support two tentative conclusions: (1) The new floodgate alone did not influence juvenile wild Chinook salmon as hypothesized (i.e., juvenile wild Chinook salmon abundance would increase upstream of the floodgate after its replacement) in 2010 and 2011, and (2) juvenile Chinook salmon responded as hypothesized to dike setback restoration (along with the new floodgate) in 2012.

NOTES: Full abstract too lengthy to include here. This report contains pre- and post-restoration data, and is a companion to the report below which contains pre-treatment, baseline data.

Results Summary: In 2012 sites upstream and downstream of the tide gate were 38.9% and 20.9% juvneile salmon. Chinook density was related to date, habitat strata, and their interaction up- and downstream in 2012. Before restoration there were no differences in density, after tide gate replacement density was higher downstream, and after dike setback density was higher upstream. Chinook size increased more upstream than downstream. For Coho, yearlings were mainly caught upstream, subyearlings were caught up- and downstream. Chum were collected upstream in all months sampled and downstream in May. Pinks were mainly caught downstream. Cutthroat were caught upstream in most sample months and downstream in two months. Steelhead and hatchery Chinook were present at low numbers. Water quality: Salinity was less than 0.1ppt. T was higher upstream but did not go above 15C at most sites. Dissolved oxygen was higher upstream and stayed above the stress threshhold most of the time. Water depth was >0.2m for all samples.

Broad Outcomes: Upstream sampling produced 13, 802 fish (19 spp) - 39.8% juv salmon. Salmon catch: 27.4% Chin, 66.9% coho, 0.8% cutthroat. All other spp minor. Remaining catch: 57% three-spine stickleback, 2.2% peamouth, 0.1% prickly sculpin, 0.4% pumkinseed, 0.1% starry flounder, 0.56% large scale sucker, 0.04% red-sided shiner. Downstream sampling collected 1,028 fish (14 spp) - 20.9% juv. salmon. Salmon catch: 74.9% sub Chin, 2.8% sub coho, 12.1% pink fry. Remainder were minor. Other catch: 56.7% three-spine stickleback, 17.7% peamouth, 3.7% prickly sculpin, 0.68% starry flounder, 0.1% pumpkinseed, 0.1% large scale sucker, 0.1% Pacific staghorn sculpin. Chinook density was related to date, habitat strata, and their interaction up- and downstream in 2012. Before rest (09) no diffs, 1 and 2 yr post (10 -sig and 11 -NS) higher downstream, 3 yr post tidegate & 1yr post dike setback (12 -NS) higher upstream. Connectivity explains 38-74% of variation in Chin density. Density compared to long term monitoring sites: Before - generally fall in with long term sites, 1yr and 2 yr post tide gate downstream sites similar to long term sites while upstream sites are lower, 3yr post tidegate/1yr post dike setback - downstream and upstream densities similar to long-term monitoring sites. Chin size increased more upstream than downstream. Yearling coho: more coho collected upstream, mostly in a blind channel but found at all up- sites in May. Collected at one down- site only in May. Subyearling coho: upstream density increased Apr-Jun (large catch in a blind channel after a freshet), downstream collected Apr-end - peak in June. Chum were collected up (all months) and downstream (mainly in Apr). Pink were more abundant downstream, mostly in Apr. Only found up- in blind channel 2 in Apr. Cutthroat were caught up- every month but Mar, down- Mar & Jun. Densities higher upstream. Hatchery Chinook caught upstream (8) 6CWTs, all from Marblemount on the Skagit R. Steelhead were present - 3 capture in upstream sites. Other species: Rough skinned newts and freshwater mussels were collected upstream. Numbers lower than previous years - large numbers collected at sites not utilized in 2012.

Detailed Outcomes: Water Quality and Substrate: Salinity was below 0.1ppt - essentially freshwater. T was related to site, strata and season. T increased with date, was higher above tide gates than below, and was higher in blind channel lobes than main channels ($p < 0.001$). T did not go above 15C threshhold at most sites and then only late in the season. Dissolved oxygen (DO) differed by date, site, and strata ($p < 0.001$). DO was higher above the tide gates and the difference increased with date. DO decreased with date above and below. Blind channel DO lower than main channel DO. DO below 6.5 mg/L threshhold 4.9% of the time upstream and 8.7% of the time downstream of tidegates.DO seemed to follow day/night and tidal cycles somewhat. Water depth surpassed min 0.2m at all sampling periods. Water shallowed gradually upstream. Velocity exceeded preference and presence were exceeded 10% of the sample dates (1 day) upstream and 9.7% for presence and 22.5% for preference downstream. Substrate upstream (except s5) and 2 sites downstream were mixed fines. s5 and Tom Moore were sand. Vegetation upstream moved from unvegetated to aquatic (mostly pondweed), downstream unvegetated all season. Fish: Three-spine stickleback were most abundant, Chinook subyearlings were 2nd most abundant at all sites except Fisher S1 Blind (Chinook most abundant) and Blind Ch2 (coho, stickleback, Chinook). Additional salmonids: coho, chum, pink, steelhead and hatchery Chinook subyearlings and yearlings, cutthroat, unID'd trout, and whitefish. Other spp: peamouth chub, large scale sucker, prickly sculpin, Pacific staghorn sculpin, starry flounder, redside shiner, unID'd bass, bluegill, pumpkinseed, unID'd juv sunfish, unID'd chub, lamprey, roughskin newt, freshwater mussel.

Effects Modifiers: There is more vegetation upstream but no way to determine if that was related to differences in up- and downstream catches. Tidegate operation may influence upstream densities of

Chin but this cannot be tested because operation varied around construction projects in 2010 and 2011and dike setback was completed prior to 2012 sampling.

<table>
<tr><td colspan="2">Intervention: Dike setback completed, increasing tidal habitat from 9.8 ac to 55.7ac
2 years prior: 3 paired side hinge wooden doors replaced with 3 aluminum one-piece side hinge doors. Two lower flapgates are below the middle and south doors. One opens with flow, one with adjustable arm.</td></tr>
<tr><td>Conditions: big ditch siphon culvert was relocated so that dike could be set back</td><td>Duration: 4 years but this report focuses on 2012</td></tr>
<tr><td colspan="2">Study Design: Fish collected in fyke trap and beach seine above and below the tide gate; once in Feb and then twice a month throughout season. Sites used were consistent among years - although 3 new channels created during dike setback. Fish were ID'd, measured (n=20 per species), and CWTs collected. Water T, salinity, dissolved oxygen, velocity, vegetation, substrate, water depth, water surface elevation measured.</td></tr>
<tr><td colspan="2">Statistics: Strata, site, or date differences in salinity, T, velocity, depth, dissolved oxygen were compared graphically or with ANOVA with Sheffe pair-wise testing. Calculated density and compared by strata, treatment, sampling type with ANOVA with Sheffe pair-wise testing. Calcluated average abundance, determined fish days and divided by average residence time to calculate population of Chinook using each habitat type in 2012.</td></tr>
</table>

Comments: This data is interesting because there was a time lag between replacing the tide gates and dike setback. There may be the opportunity to determine relative benefit derived from each action. The data included are different than covered in later reports, which is why both are included in the review.

<table>
<tr><td colspan="4">Beamer, E., R. Henderson, and B. Brown. 2014. Juvenile Chinook salmon utilization of habitat associated with the Fisher Slough Restoration Project, 2009-2013. Skagit River System Cooperative, LaConner, WA. 112 pp.</td></tr>
<tr><td>Keywords: flood gate replacement salmon</td><td colspan="2">Type: Report</td><td>Publication Date: 2014</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: This report should be used in conjunction with the final project report, Beamer et al. 2016, which is a brief update.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: South Fork Skagit River tidal delta. Chinook salmon, water quality (temp, dissolved oxygen)</td><td colspan="2">Ecosystem(s):</td></tr>
<tr><td colspan="4">Reference Source: http://skagitcoop.org/wp-content/uploads/2013_FisherSl_Fish_Final_061014.pdf</td></tr>
</table>

Abstract: From ABSRACT: The Fisher Slough Restoration Project, located in the S. Fork Skagit River tidal delta near the town of Conway, is intended to help recover the six populations of wild Chinook salmon present within the Skagit River and its natal estuary. The restoration project was phased in three parts. Project Element 1, completed in 2009 was to improve fish passage and tidal inundation to areas upstream of the floodgate and to protect adjacent farmland from flooding by replacing an existing floodgate with a new floodgate within Fisher Slough at the Pioneer Highway crossing. Element 2 resolved a drainage conflict preventing implementation of Element 3- completed in 2011- a dike setback to allow more of the agricultural area to be inundated by tidal and freshwater hydrology, increasing fish carrying capacity. Juvenile Chinook salmon monitoring results related to Project Elements 1 and 3 are presented in this report for all years of monitoring: 2009–2013. With five years of monitoring data and all restoration elements complete, we answer five key questions:

1. Did tidal habitat area increase following dike setback restoration at Fisher Slough? (Chapter 3)

2. Does restoration at Fisher Slough influence water temperature and dissolved oxygen? (Chapter 4)

3. Is juvenile Chinook salmon presence within Fisher Slough influenced by variable local environmental conditions, such as water temperature, dissolved oxygen, depth, and velocity? (Chapter 5)

4. How did floodgate operation vary over the juvenile Chinook salmon monitoring period for all years? (Chapter 6)

5. Did the dike setback restoration and floodgate operation influence juvenile Chinook salmon abundance, density, and size? (Chapter 7)

Results Summary: Restoration increased available habitat by 45.9 acres in Fisher Slough and increased the carrying capacity by 21,823 juvenile salmonids (mainly focused on Chinook subyearlings). Operating the tide gate in conjunction with tidal cycles has increased habitat connectivity and has had a positive benefit to Chinook smolts rearing in the estuary. Non-ebb passage opportunity was highest in 2012 and 2013 and lowest in 2009 and 2010. Chinook presence was not associated with water depth, velocity, surface temperature, surface dissolved oxygen, minimun or maximum dissolved oxygen, or maximum temperature.

Broad Outcomes: Restoration increased available habitat by 45.9 acres in Fisher Slough and increased the carrying capacity by 21,823 juvenile salmonids (mainly focused on Chinook subyearlings). Operating the tide gate in conjunction with tidal cycles has increased habitat connectivity and has had a positive benefit to Chinook smolts rearing in the estuary.

Detailed Outcomes: Water temperature: Longer floodgate closure times and warmer river T led to warmer T in Fisher Slough. Dike setback was associated with warmer surface temps upstream of the tidegate. Average logger T decreased after setback upstream but not downstream. Dissolved oxygen: longer tidegate opening times are associated with higher dissolved oxygen in Fisher Slough. Higher tributary flow and lower tributary dissolved oxygen lead to lower dissolved oxygen in Fisher Slough. Surface dissolved oxygen was higher after dike setback and was higher before Aug. Average dissolved oxygen was not influenced by any of the factors tested. Minimum dissolved oxygen was lower after dike setback and was influenced by tidegate open times (longer opening means higher dissolved oxygen) and tributary inflow and tributary dissolved oxygen in the same way as surface dissolved oxygen. Chinook presence was not associated with water depth, velocity, or surface T (except maybe in Aug), surface dissolved oxygen, minimum dissolved oxygen, and maximum dissolved oxygen, or maximum T. Non-ebb fish passage opportunity was higher in 2009 than 2010-2013. Tidegate door opening as %channel width was lower in 2011 than 2012 or 2013, which were not different. 2012 & 2013 had highest ebb passage opportunity , while 2009 & 2010 had the lowest (at <0.89 ft/s and <1.1 ft/s).

Effects Modifiers: The spot measures alone did not capture the overall decrease in average T because they were never taken at night.

Intervention: 3 wooden paired tide gates were replaced with aluminum gates in 2009. New floodgates are managed by season: fall/winter flood control, spring: salmon migration, summer: irrigation. In 2011 dike setback increased marsh area from 9.8 to 55.7 acres. Additionally, Big and Little Fisher creeks were rerouted and tidal channels were excavated.	
Conditions:	**Duration**: 5 years
Study Design: Fish were collected up and downstream of the tide gates in main channel and blind slough habitats using beach seines and fyke traps. ID'd and counted all fish, measured up to 20 of each species. Measured water elevation, T, and/or dissolved oxygen, velocity.	
Statistics: Calculated fish densities for beach seine and fyke net catches. Calculated the time and width tide gates are open when velocity is less than 0.89 ft/s (critical fatigue swim speed) and 1.1 ft/s (maximum recommended velocity for upstream migration of salmon < 60 mm) for the week prior to fish sampling. Used ANOVA to test for mixed effects on environmental variables. Scheffe pairwise testing was used to test between group comparison. Used generalized linear models to analyze juvenile Chinook abundance and density.	

Comments: This report provides information not included in the brief final project report, Beamer et al. 2016.

Beamer, E., R. Henderson, and B. Brown. 2015. **Juvenile Chinook salmon utilization of habitat associated with the Wiley Slough Restoration Project, 2012-2013.** Skagit River System Cooperative, LaConner, WA. 51 pp.		
Keywords:	**Type**: Peer-reviewed	**Publication Date**: 2016
Include: Yes	**Reason**: Fish and hydrology sampled post-replacement	**Relevance**:
Location & Species: Wiley Slough, Skagit Bay, WA. Chinook salmon, other salmonids	**Ecosystem(s)**: tidal sloughs	
Reference Source: http://skagitcoop.org/wp-content/uploads/Wiley-Slough-2012-2013-Final.pdf		

Abstract: Restoration of Skagit River delta habitat was identified as a priority to help recover Skagit Chinook salmon listed as Threatened under the ESA. The Wiley Slough Restoration Project was completed in 2009. Fish monitoring was conducted within restored habitat area of the Wiley Slough Restoration Project in 2012 and 2013. The monitoring design primarily consisted of a post-treatment (i.e., after restoration) stratified random design using beach seines to capture fish. The monitoring effort caught over 22,000 fish representing at least 23 fish species, including 7 species of salmon. Unmarked juvenile Chinook salmon dominated the catch of salmon. Unmarked juvenile Chinook salmon density varied within the Wiley Slough Restoration Project by lobe, year, and season, but not habitat type. The Wiley Slough lobe had higher densities of juvenile Chinook salmon than the Teal Slough lobe; higher densities of juvenile Chinook salmon were found in 2013 than in 2012; seasonal use of restored areas by juvenile Chinook salmon began in February, peaked from April through June, then declined afterward. Juvenile Chinook salmon density did not vary by channel and impoundment. In general, juvenile Chinook salmon are using the restored areas of both Wiley and Teal Slough lobes at seasonal density levels consistent with other long term monitoring sites in the Skagit River estuary. An estimated 88,206 (37,326-139,086, 95% CI) and 247,692 (128,973-366,412, 95% CI) unmarked juvenile Chinook salmon used restored habitat of the Wiley Slough Restoration Project in 2012 and 2013, respectively. Based on two years of monitoring the number of juvenile Chinook salmon that used the restored areas of the Wiley Slough Restoration Project: 1) exceeded the updated carrying capacity estimate based on actual restored channel habitat, and 2) exceeded the Skagit Chinook Recovery Plan's estimated benefit to juvenile Chinook salmon. However, the number of juvenile Chinook salmon that used the restored areas were somewhat less than predicted by the carrying capacity estimate that included all wetted areas (29 hectares of channel and impoundment combined). Sustainable channel conditions are reached after natural hydrologic and sedimentation processes achieve a balance at the site. Sustainable channel area is estimated at 2.03 hectares (0.50-8.25, 95% CI) suggesting total habitat area will be less than the 29 hectares currently present. Thus, actual juvenile Chinook salmon carrying capacity could change within the Wiley Slough Restoration Project based on how channel/impounded areas evolve over time. The issue of restored habitat conditions within recently restored areas using dike setback design and the long term sustainability of that habitat may be an emerging theme for estuary restoration adaptive management. This issue is of particular importance when restoration projects are intended to achieve specific goals, such as recovery of listed Chinook salmon populations. If as-built restoration conditions

are not in a sustainable state, then a false sense of restored benefits might be accepted without sufficient monitoring and adaptive management of projects.

Results Summary: Depth, velocity, temperature, salinity, and dissolved oxygen differed between the two lobes of the slough. Temperature increased with month and dissolved oxygen decreased with month in both lobes. The Wiley lobe was more tidally influenced and the Teal lobe was more influenced by the river. In the two sampling years >22,000 fish were collected including 7 species of salmonids which were mainly Chinook, chum, and pink (even years). Chinook salmon density was higher in Wiley slough, but it did not appear to be influenced by depth, velocity, or dissolved oxygen. Temperature and salinity were significant factors. The juvenile Chinook population both years was higher than estimated from tidal channel length, but lower than estimated by total wetted area.

Broad Outcomes: Depth was less in the Wiley lobe than the Teal lobe, and was lower in 2013 than 2012 but did not change with month. Velocity was lower in Wiley and did not differ with month or year. T was greater in Wiley than Teal and increased with month in both lobes and both years. Salinity was greater in Wiley and in 2013. Dissolved oxygen was less in Wiley and decreased with month. Wiley shows more tidal influence and Teal more river influence. Depth, velocity, salinity, and dissolved oxygen were not likely influencing Chinook rearing between sites but T might be. Collected >22,000 fish (7 species of salmonids, mostly juvenile Chinook, chum, and even year pink). Stickleback, starry flounder, and peamouth were the most abundant non-salmonids. Chin density was greater in Wiley, and did not vary by habitat or between channel and impoundment but did vary by year and week. Density was highest Mar-Jun. Significant factors were T (positive) and salinity (negative). Landscape connectivity explained 53-85% of Chinook density at Skagit Bay longterm monitoring sites. Wiley ('12, '13) and Teal ('13) values plotted in the long term site scatter. In both years the juvenile Chinook population was higher than the estimated carrying capacity based on tidal channel, but lower than the estimate based on wetted area.

Detailed Outcomes:

Effects Modifiers: Sustainability of impoundements as natural processes occur need to be considered.

Intervention: Dike setback with tide gate removal. New tide gate installed in the new smaller perimeter dike. Borrow ditches filled. Native plantings.	
Conditions:	**Duration**: 2 yrs
Study Design: seined fish, measured salinity, T, dissolved oxygen, velocity, depth, and classed substrate and vegetation. Results were compared to estimated expected values and to long-term monitoring sites that were used as references.	
Statistics: ANOVA: lobe, year (factors), month (covariate) for environmental variables. ANOVA: year, lobe, season, habitat type (factors) for juvenile Chinook density. T and salinity or dissolved oxygen (correlate) were covariates. Calculated cumulative Chinook density and landscape connectivity - compared to long term Skagit monitoring sites. Calculated estimated juvenile abundance and usage of each lobe each year and calculated the available habitat. Determined carrying capacity and whether it was met.	

Comments: The restoration was completed in 2009 and monitoring was carried out in 2012 and 2013.

<table>
<tr><td colspan="3">Beamer, E., B. Brown, K. Wolf, R. Henderson, and C. Ruff. 2016. Juvenile Chinook salmon and nearshore fish use in habitat associated with Crescent Harbor Salt Marsh, 2011-2015. Skagit River System Cooperative Research Program. Prepared for: U. S. Department of the Navy, Whidbey Island Naval Air Station under contracts: N44255-10-2-0006, N44255-11-2-003, N44255-12-2-0007, N44255-13-2-0005, and N44255-14-2-0005.</td></tr>
<tr><td>Keywords: N/A</td><td>Type: Report</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td>Reason: Reports water quality and fish data for 5 years post tide gate removal.</td><td>Relevance:</td></tr>
<tr><td>Location & Species: Crescent Harbor salt marsh, Whidbey Island, Puget Sound, WA</td><td colspan="2">Ecosystem(s): pocket estuaries</td></tr>
<tr><td colspan="3">Reference Source: http://skagitcoop.org/wp-content/uploads/Crescent-Harbor-Fish-Report-Final_2016-05-09.pdf</td></tr>
</table>

Abstract: [From Eric's 1/26/17 email] "This report is about fish and environmental (water quality) response to tidegate removal. Multiple years of data/analysis. Post treatment study design."

[From "Study Area and Purpose of Report", p. 4] Restoration actions mainly consisted of: a) increasing tidal connectivity within the historic marsh area, and b) replacing the system's outlet channel tide gate with a Mabey-Johnson bridge [a portable pre-fabricated truss bridge, designed for use by military engineering units] thus restoring tidal flooding and fish access to more than 200 acres of Crescent Harbor Salt Marsh...In response to the completed restoration at Crescent Harbor Salt Marsh, we monitored fish use of the restored areas and its adjacent nearshore beaches from 2011 through 2015 over the juvenile Chinook salmon rearing period for pocket estuaries (January through June). The fish monitoring design for the Crescent Harbor Salt Marsh Restoration Project is a post-treatment (i.e., after restoration) stratified (lobes within the restored area) design.

Results Summary: Prior to restoration only stickleback were caught in Crescent Marsh. After restoration 10-16 species were caught including subyearling Chinook (wild and hatchery), subyearling and yearling coho, pink, chum, yearling sockeye, cutthroat, and native char (Salvelinus sp). Pink salmon fry timing did not differ inside and outside the marsh. Chum fry abundance peaked inside the marsh earlier than the adjacent beaches but densities were similar inside and outside. Wild Chinook were collected mainly in the main marsh and adjacent beaches, but were also collected in the creek. Fish size was negatively correlated with outmigrant abundance. Density was higher in the marsh than at adjacent beaches, which follows a pattern seen at natural pocket marshes in Puget Sound but the difference was smaller.

Broad Outcomes: Prior to restoration only stickleback were caught in Crescent Marsh. Salmonid Results: Caught Chinook subyearlings (wild and hatchery), coho subyearlings and yearlings, pink, chum, sockeye yearlings, cutthroat, native char (Salvelinus sp). Pink salmon fry timing did not differ inside and outside the marsh. Chum fry abundance peaked inside the marsh earlier than the adjacent beaches. Densities were similar inside and outside. Chinook wild were collected mainly in the adjacent beaches (highest 4 yrs, peak Mar and May) and main marsh (highest 2 yrs, peak Apr), but were also collected in the creek (peak Apr). Chinook juvenile length varied with month and by year, R^2 = 0.70. Fish size is negatively correlated with outmigrant population size. Density was higher in the marsh than at adjacent beaches, this follows a pattern seen at natural pocket marshes in Puget Sound but the difference is smaller.

Detailed Outcomes: T was influenced by area and year and varied with month (+) R^2 = 0.89. T never exceeded 24.8C lethal limit but did surpass 15C stress level in May or Jun each year. The only T diff by areas was between adjacent beach and mid-marsh. Salinity differed among years but did not have any sig covariates. DO differed among areas but not years, R^2 = 0.877 with no sig covariates. DO was higher at the adjacent beach than any area in the marsh. 10% of total DO measurements were below 7.0 mg/L threshhold for juvenile salmon. Low DO mainly occurred in May and Jun. Fish Assemblage: 2011 18,959 fish (13 species), 2012 8,690 fish (10 species), 2013 5,842 fish (13 species), 2014 4,637 fish (15 species), 2015 4,928 (16 species). Aside from juvenile salmon, the 3 most abundant species were stickleback (27,410), shiner perch (5,830), and Pacific staghorn sculpin (2.752). Other species include prickly sculpin, padded sculpin, sharpnose sculpin, surf smelt, Pacific sandlance, starry flounder, English sole, and 2 non-natives: American shad, and bluegill.

Effects Modifiers:

Intervention: Removed a tide gate and replaced it with a bridge. Increased connectivity within the marsh. Completed 2009.	
Conditions:	**Duration**: 5 yrs post-restoration
Study Design: Sampled every two weeks Feb to May. Beach seining was completed in 3 distinct areas of the marsh and in adjacent nearshore waters. Electrofishing was used to sample Crescent Creek. All fish were ID'd and counted. Measured T, salinity, dissolved oxygen, velocity, set depth, vegetation, substrate type.	
Statistics: Used ANOVA to determine factor (marsh area and year) and covariate (month, T, salinity, dissolved oxygen if not autocorrelated with the test variable) influences on T, salinity, dissolved oxygen - each analyzed seperately.	

Comments: At this site the fish used the beaches, the marsh, and a tributary creek that had also been restored.

Beamer, E., R. Henderson, and C. Ruff. 2016. **Juvenile Chinook response to Fisher Slough restoration and floodgate operation: An update including 2015 results.** Skagit River System Cooperative, La Conner, WA. 21 pp.		
Keywords: N/A	**Type**: Report	**Publication Date**: 2016
Include: Yes	**Reason**: This brief update includes data from the most recently available post-restoration year.	**Relevance**:
Location & Species: Fisher Slough, South Fork Skagit River, WA Chinook salmon	**Ecosystem(s)**:	
Reference Source: http://skagitcoop.org/wp-content/uploads/2009-2015-Fisher-Slough-Chinook-Analysis-Update-Final.pdf		

Abstract: [From Eric's 1/26/17 email] "This report is about fish and environmental (water quality, area) response to tidegate (TNC insisted the structure be called a floodgates) replacement and dike setback restoration. Multiple years of data/analysis. Before/after control impact study design. This report teased out the fish and environmental effect of tidegate operation from dike setback restoration. Both were important. We also presented a conceptual model on how to think about (and statistically test) upstream chinook fry migration into tidal habitat influenced by tidegates."

Results Summary: After tide gate replacement and before dike setback the Fisher Slough sites did not follow the pattern of higher abundance with increased connectivity seen at long term monitoring sites in the Skagit River delta. However, after dike set back the Fisher Slough sites demonstrated this positive relationship. Water temperature influenced Chinook abundance only in 2015. When fish abundance was expressed as a percent of carrying capacity the 2015 data was consistent with other monitored years and all years fell close to the 1:1 line between Fisher Slough and Skagit River delta with outmigrant population as a percent carrying capacity.

Broad Outcomes: Post tide gate replacement and dike setback the sites at Fisher Slough followed the pattern of positive relationship between fish density and landscape connectivity found at the long term monitoring sitesin the Skagit delta. Post tide gate replacement but pre dike set back the Fisher slough upstream sites did not follow the expected pattern. Water T influenced Chinook presence in 2015 but no other year.

Detailed Outcomes: The population estimate for wild subyearling Chinook in the Skagit River during the 6 years of the Fisher Slough study ranged from 1.13 to 5.64 million. Non-ebb upstream opportunity varied among years but was <50% of the week except in 2015 when the tide gate was chained open. A model using month, tide gate %open, and pre-vs post dike setback did not make a good prediction of juvenile abundance in Fisher Slough in 2015 - a year with low outmigrant population and higher water T. New analyses presented in the appendices showed that 2015 was warmer with lower dissolved oxygen and that both significantly influence presence of juvenile Chinook. T had a greater effect than dissolved oxygen. Chinook density was influenced by year and strata (up- or down-stream of tide gate) and the year*strata interaction. Chinook density was only significantly different between strata in 2010. After dike setback the growth rate of juvenile Chinook was higher in the slough during spring and summer; FL was higher in Apr, May, Jun after dike setback than before dike setback. When fish abundance is expressed as a percent of carrying capacity the 2015 data is consistent with other monitored years and all fall close to the 1:1 line between 'Fisher Slough abundance as % project carrying capacity' vs 'Skagit River outmigrant population as % of Skagit delta carrying capacity'.

Effects Modifiers: Top candidate model did not accurately predict the 2015 abundance in Fisher Slough. Possible explanations: Tide gate was chained open - value outside of values used to build the model. The model does not include any measure of Skagit outmigrant population size or any local environmental data.

Intervention: 3 wooden paired tide gates were replaced with aluminum gates in 2009. New floodgates are managed by season: fall/winter flood control, spring salmon migration, summer irrigation. In 2011 dike setback increased marsh area from 9.8 to 55.7 acres. Additionally, Big and Little Fisher creeks were rerouted and tidal channels were excavated.	
Conditions:	**Duration**: 6 years
Study Design: Fish were collected up- and downstream of the tide gates in main channel and blind slough habitats using beach seines and fyke traps. ID'd and counted all fish, measured up to 20 of each species. Measured water elevation, T, and/or dissolved oxygen, velocity.	
Statistics: Calculated fish densities for beach seine and fyke net catches. Calculated the time and width tide gates were open when velocity was less than 0.89 ft/s (critical fatigue swim speed) and 1.1 ft/s (maximum recommended velocity for upstream migration of salmon < 60 mm) for the week prior to fish sampling. Used ANOVA to test for mixed effects on environmental variables. Scheffe pairwise testing was used for between group comparison. Used generalized linear models to analyze juvenile Chinook abundance and density.	

Comments: Intervention, study design, and statistics information was taken from Beamer et al. 2014, the Fisher Slough project report for 2009-2013. This report should be included as an extension and update of that report as that is the way it is intended. These two reports focus on juvenile Chinook response to restoration while Henderson et al. 2016 focuses on the hydrologic changes after restoration at Fisher Slough.

Bocker, E.J. 2015. **Restoring connectivity for migratory native fish: investigating the efficacy of Fish Friendly Gates.** M.Sc. Thesis, Massey University, Palmerston North, NZ. 89 pp.		
Keywords: flood gate replacement salmon	**Type**: M.S. Thesis	**Publication Date**: 2015
Include: Yes	**Reason**: Directly relevant to the question of modifying tide gates.	**Relevance**:
Location & Species: Bay of Plenty Region, New Zealand	**Ecosystem(s)**:	
Reference Source: http://mro.massey.ac.nz/handle/10179/7544		

Abstract: Stream connectivity and habitat diversity are key components of healthy river ecosystems. Human modification of natural flow regimes disrupts natural connectivity, and results in physical, chemical, and biological changes that impair natural river function. Such changes can be detrimental to freshwater species, particularly those which have evolved to be reliant on a variety of different habitats throughout their life cycles. Consequently, restoring connectivity has become a major restoration goal in freshwater ecology. Tide gates, a man-made coastal structure designed to protect low-land infrastructure from flooding, can negatively impact freshwater ecosystems. Through disrupting connectivity, tide gates impede the movement of aquatic biota and degrade upstream habitats. It is thought that the vast majority of tide gates in New Zealand and worldwide could be modified to enhance connectivity and fauna passage through the installation of Fish Friendly Gates (FFG's). This study is the first to investigate these claims. FFG's increased both the duration and distance that tide gates were held open over a tide cycle. These operational changes reintroduced some tidal fluctuation to upstream habitats but water levels remained within safe levels for infrastructure. FFG influence enabled upstream passage for giant bully and adult inanga, for which tide gates were otherwise impassable. Furthermore, upstream passage of whitebait (migratory galaxiid juveniles) and common bully were significantly increased when aided by FFG's. Although rapid and sustained increases in migratory species richness of resident populations were observed following FFG installation, due to small sample sizes these changes could not be regarded as statistically significant. Additionally, evidence of rehabilitation of degraded sites was limited and suggests care should be taken when restoring connectivity to poor quality habitat. Overall, this study demonstrated that FFG's can enhance upstream fish passage at tide gates while maintaining adequate flood protection. Whether FFG's can provide ecological benefits to degraded habitats requires supplementary research. Provided the limitations of FFG's are recognised and they are only installed where tide gate removal is not feasible, FFG's are an effective tool for facilitating fish passage through tide gates in New Zealand and worldwide.

Results Summary: After 'fish-friendly' modification (installing a large lever that delayed closing time) tidal fluctuation, and opening distance and duration increased. When levers were engaged the total number of species collected upstream of gates was higher. Weak-swimming species were caught only when the levers were engaged. Separately, three gated systems were retrofit with fish-friendly levers and three paired gated systems were unmodified. Prior to retrofit, species richness was significantly lower above the tide gates. One month post retrofit, differences in species richness up- and downstream were no longer significant and more diadromous species were collected upstream of gates. One year post retrofit all test sites had equal species richness up- and downstream. Although more diadromous species were found upstream of gates at test sites relative to controls, there were no significant differences in fish abundance between control and test sites for any species or group. After fish-friendly modification conductivity was higher, salt intrusion was greater, dissolved oxygen was higher at two sites and lower at one, and water T did not differ.

Broad Outcomes: Impacts of tide gates as barriers are not equal between types. FFGs increase connectivity at tide gates. FFGs facilitate upstream fish passage, especially of weak swimmers. Upstream habitat passive rehabilitation is limited.

Detailed Outcomes: Ch 3 FFG reinstated some tidal fluctuation upstream but depth increases were small. Opening duration and opening distance increased at all retrofitted gates although the increase ranged from an hour to 8 hours. Ch 4 When the FFG was engaged at least 7 species were caught: common bully (473), giant bully, shrimp (292), grey mullet, eels (long- and short- fin), whitebait species (171). The number of individuals in all species not enumerated above is <20 combined. Common bully and whitebait had significant differences in catch associated with tidal cycle. Whitebait: high on flood tides, no differences among other tide cycle parts. Common bully: fewer migrated on the low tide, no differences between flood, ebb, high. No differences for shrimp. During part tide sampling all full tide species were caught plus flounder, and goldfish. Common bully (880), whitebait (498), shrimp (354), were the 3 most abundant species again, 94% of total. Giant bully, adult inanga, grey mullet, and flounder only caught when FFG engaged. More common bully (sig), whitebait (sig), and shrimp (NS) were caught upstream when FFG was engaged. Total number of species increased, addition of weak-swimming species, with FFG. Ch 5 A total of 13 species from 10 families were collected. Species richness varied upstream of tidegates. Richness was lower upstream (sig) and pest species were abundant upstream. Estuarine species were absent at the Kaituna River sites. One month post FFG, differences in species richness up- and downstream were no longer significant. Diamdromous species increased upstream at all test sites (NS). No difference in fish abundance between control and test sites for any species. When all sites were combined, goldfish abundance decreased post FGG. Diadromous fish and species both increased at test sites relative to paired controls (NS). One year post FFG, all test sites showed equal species richness up- and downstream. Inanga abundance increased at test sites and control sites. Common bully increased at control 2 and test 2. Shortfin eel increased at all sites post FFG. No species groups showed difference in abundance after FFG retrofit, although the increase in diadromous fish at test sites relative to controls was close to significance. Water quality: T was high at all sites and were similar after a year, except test 1 which was hotter. Dissolved oxygen was low at all sites prior to FGG. Test sites 2 and 3 had higher (sig) dissolved oxygen after a year, test 1 had lower (sig) dissolved oxygen and control sites had no change. Conductivity was higher one year post FFG (sig) and salt intrusion was greater.

Effects Modifiers: Ch 3 Did not measure water velocity during opening periods to more fully estimate fish passage increase Ch 4 Sampling was only done at one site and Ch 3 showed that there could be large differences between sites.

Intervention: Ch 3 Retrofitted 5 of 6 tide gates with a fish friendly gate (FFG - a large lever that delays the gate closing time - they are adjustable and can be fit onto existing gates.) Maketu - light cast alloy

circular, Otumakoro - cast iron circular, Bell Road - square wooden on culverts (2), Awatapu Lagoon - circular cast iron on culverts (2)). Ch 4 two tide gates on culverts were FFG retrofitted. Ch 5 6 gated sites were studied, 3 FFG retrofit, 3 unmodified. FFG and control sites were paired.	
Conditions:	**Duration**:
Study Design: Ch 3 Measured water depth, gate opening width and time open before and after FFG retrofit. Ch 4 Compared fish passage through unmodified gates and with FFG retrofit. Sock nets were installed over upstream end of culverts to collect migrating fish over 5 full tide cycles and 12 flood/ebb only samples collected with the FFG engaged and 12 flood/ebb only samples with FFG disengaged. Fish were ID'd and measured. Ch 5 Pre-installation: Fish collected with fyke and minnow traps upstream (6 sites) and downstream (4 sites). Each site sampled 3 dates. Fish ID'd, measured. Vegetation (in-stream and bank), water clarity, water levels, weather were noted. Salinity, dissolved oxygen, T measured. Post-installation: Trapping was done 1 month and 1 year after FFG retrofit. Conductivity and dissolved oxygen measured on each sampling date.	
Statistics: Ch 4 Non-parametric Kruskal-Wallis rank sum tests and pair-wise differences with Tukey and Kramer tests. Wilcoxon rank sum tests were used for potential bias between nets and on part-tide samples to examine tide, FFG, and diurnal effects on the 3 most abundant species. Ch 5 Friedman's Rank Sum was used to test whether species abundance differed between sampling periods (before, 1 month, 1 year).The number of species groups (pest, marine, diadromous fish, diadromous species) were considered. Calculated daily mean environmental variables and used ANOVA to explore change in T and conductivity, and Kruskal-Wallis rank sums for dissolved oxygen.	

Comments: Although this is not in our region, this study directly links tide gate modification to the passage of weak-swimming fishes. The authors also found that simply increasing opening angle and duration did not improve all habitat metrics.

<table>
<tr><td colspan="4">Bottom, D.L., K. K. Jones, T. J. Cornwell, A. Gray, C. A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal and Shelf Science 64(1): 79–93.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td colspan="2">Type: Peer-reviewed journal article</td><td>Publication Date: 2005</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: Compared Chinook abundances before and after tide gate/dike removal.</td><td>Relevance: High</td></tr>
<tr><td colspan="2">Location & Species: Salmon River estuary, OR USA Chinook salmon</td><td colspan="2">Ecosystem(s): river delta salt marsh</td></tr>
<tr><td colspan="4">Reference Source: Full text: http://lterdev.fsl.orst.edu/lter/pubs/pdf/pub3989.pdf</td></tr>
</table>

Abstract: We examined variations in the juvenile life history of fall-spawning Chinook salmon, Oncorhynchus tshawytscha, for evidence of change in estuarine residency and migration patterns following the removal of dikes from 145 ha of former salt-marsh habitat in the Salmon River estuary (Oregon). Mark-recapture studies and abundance patterns in the estuary during 2000-2002 describe the following life-history types among Chinook salmon: (1) fry disperse throughout the estuary, and many move into restored tidal-marsh habitats in the early spring soon after emergence; (2) juveniles reside in freshwater for several months, enter the estuary in June or July, and remain for (a) a few weeks or (b) several months before entering the ocean; and (3) juveniles enter the ocean later in the fall after an extended period of rearing upriver and/or in the estuary. The absence of fry migrants in the estuary 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 April-July, 2000-2002 indicate that wetland restoration has increased estuarine rearing opportunities for juvenile Chinook salmon. Year-to-year patterns of estuarine rearing and abundance by juvenile salmon may be influenced by flood and drought conditions that affected adult spawner distribution and over-winter survival of salmon eggs. However, persistent changes in spawner distribution since 1975-1977, including the concentration of hatchery strays in the lower river, may account for the large proportion of fry that now disperse into the estuary soon after emergence in the spring. Although few of these earliest migrants survived to the river mouth, many fry and fingerlings from mid- and upper-basin spawning areas distributed throughout a greater portion of the estuary during the spring and summer and migrated to the ocean over a broader range of sizes and time periods than thirty years ago. The results suggest that wetland recovery has expanded life history variation in the Salmon River population by allowing greater expression of estuarine-resident behaviors.

NOTE: Tide gates were probably removed from study area, but this is not clear: "In the early 1960s, construction of a network of earthen dikes and tide gates converted more than 250 ha (approximately 65%) of the original salt-marsh habitat to pasture land, confining most of the estuary to a narrow ribbon of main-river channel. Subsequently, a cumulative total 145 ha of shallow wetland habitat was returned to the estuary after three successive dike-removal projects were completed in 1978, 1987, and 1996." [p.80]

Results Summary: Flow level variability and pattern were similar in the before and after periods. Juvenile salmon used the estuary and salt marsh areas earlier in the year and for a longer period after dike breaching. The increased use of the estuary after dike removal, especially by fry/fingerlings increased life history variation. Migration timing and ocean entry variation was higher post-restoration. Hatchery juveniles and adults were present after dike and tide gate removal. The contemporary spawning period was truncated relative to the historic period.

Broad Outcomes: Increased use of estuary after dike removal, especially fry/fingerlings, increased life history variation. Migration timing and ocean entry variation higher.

Detailed Outcomes: Flow level variability and pattern were similar in the before and after periods. Contemporary: Juveniles used marshes Apr - Aug, and main channel hab Apr-Oct.Mid-estuary May-Oct and lower-Estuary Jun - Nov or later. Historical: Abundance increased later and for a shorter time. Fish were not often caught in mid- or lower-estuary habs before July. Contemporary: median estuary residence time is 5 wks Spawning Contemporary: % hatchery decreases as move upstream, most spawn late Oct-Nov. Historical: no hatchery, spawn mid-Oct - mid-Jan.

Effects Modifiers: Hatchery spawners and juveniles that were not present prior to dike and tide gate implementation.

<table>
<tr><td colspan="2">Intervention: Three salt marsh areas of 22, 63, and 60 ha were restored by removal of dikes and associated tide gates in 1978, 1987, and 1996.</td></tr>
<tr><td>Conditions: The dike removal is focused on, but the tide gates were also removed.</td><td>Duration: Juveniles: 2000-2002
Adults: 1999-2001, 1975-1977</td></tr>
<tr><td colspan="2">Study Design: Monitor adult spawning and juvenile outmigration and estuary usage in 2000, 2001, and 2002 juvenile outmigration years. Monitored both restored and previously undiked areas. Three restoration events complete 4, 13, and 22 years prior to the project outset. These data were compared with data from 1975-1977, a decade or more after dikes and tide gates were constructed, but before hatchery fish first returned to spawn in the system.</td></tr>
<tr><td colspan="2">Statistics: All statistics are descriptive.</td></tr>
</table>

Comments: This paper is an early study of salmon responses to estuary restoration. It is useful to include. However, it should be noted that dikes around the marshes were removed along with the tide gates. Therefore, the results cannot be entirely attributed to tide gate removal.

Bottom, D.L., A.Baptista, J. Burke, L. Campbell, E. Casillas, S. Hinton, D.A. Jay, M.A. Lott, G. McCabe, R. McNatt, M. Ramirez, G.C. Roegner, C.A. Simenstad, S. Spilseth, L. Stamatiou, D.Teel, and J.E. Zamon. 2011. **Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary.** Final Report 2002-2008 to the to U.S. Army Corps of Engineers Portland District, Portland, OR under Contract W66QKZ20374382. Fish Ecology Division, NW Fisheries Science Center U.S. National Marine Fisheries Service, NOAA, Seattle, WA. 216 pp.		
Keywords: N/A.	**Type**: Final report	**Publication Date**: 2011
Include: Yes	**Reason**: Useful for discussion of estuary importance to juvenile salmon migrants.	**Relevance**:
Location & Species: Columbia River Estuary Chinook salmon	**Ecosystem(s)**: tidal freshwater, oligohaline, euryhaline	
Reference Source: https://www.salmonrecovery.gov/Files/Comprehensive%20Evaluation/Bottom-etal_2011_Estuarine-Habitat-Juvenile-Salmon-Linkages-LCRE-2002-2008.p**df**		

Abstract: [Excerpted from Exec Summary] Our studies in the lower 100-km of the Columbia River estuary quantified historical habitat changes and provided new information about contemporary abundance patterns, life histories, and habitat associations of Chinook salmon. In Part I, we detail our reconstruction of historical habitat opportunities and changes in the estuary as influenced by the tide, river flows, and temperature. In Part II, we depict contemporary habitat opportunities based on present-day patterns of salmon distribution and abundance and upon various physical factors that influence fish access to shallow-water rearing areas. In Part III, we compare the capacity of different wetland and nearshore habitats in supporting juvenile Chinook salmon as indicated by variations in prey availability, salmon diet, and rates of consumption. Finally, in Part IV, we examine the effects of upriver population structure and life histories on estuary rearing behavior and performance, including the genetic sources of individual Chinook salmon found within particular habitats and stock-specific patterns of residency and growth. These surveys provided new information about the present estuarine habitat associations of juvenile salmon. They also provided data for estimates of historical change in habitat conditions, estimates of historical change in salmon life histories, and analyses of food webs. Conclusions: 1) Extensive wetland loss has substantially decreased the quantity and quality of wetland habitats that support salmonid food webs and provide off-channel rearing areas for subyearling migrants with estuary-resident life histories. 2) Together, the loss of rearing opportunities and the decline of historical populations upriver have reduced life history diversity and late-season abundance of Chinook salmon in the estuary. 3) Salmon habitat use and residence times vary with fish size, but all wetland habitat types in the lower estuary are utilized by the smallest subyearling size classes, which tend to remain in the estuary for the longest periods. 4) Naturally produced subyearling salmon dominate in shallow wetland channels and may benefit most directly from restoration of wetland habitats. 5) Large releases from hatcheries have replaced diverse, naturally spawning populations with fewer hatchery stocks; these stocks are reared primarily as freshwater phenotypes with short estuary residence times. In the Columbia River estuary, contemporary patterns of abundance, stock composition, habitat use, and residency are largely driven by artificial propagation programs. 6) The response of the estuarine ecosystem to large subsidies of hatchery fish and estuary interactions between hatchery and naturally

produced salmon remain poorly understood. Such interactions may ultimately determine whether estuary restoration is an effective tool for salmon recovery. 7) Wetland-derived food webs support juvenile salmon throughout the estuary, including larger individuals that do not typically occupy wetland channels. 8) Different genetic stock groups of Chinook salmon exhibit characteristic patterns of temporal and spatial distribution in the lower estuary. 9) Most Chinook salmon Evolutionarily Significant Units (ESUs) are capable of expressing subyearling life histories. Both lower and upper Columbia River stock groups can produce subyearlings that reside in the estuary for several months. 10) The lower Columbia River estuary supports foraging and growth of juvenile migrants and contributes to the life history diversity of Chinook salmon populations.

Results Summary: Tidal amplitude has increased since 1925 in the lower Columbia River estuary; this and other factors have resulted in 75% of the shallow water habitat being lost. 273, 180 individuals of 50 species were collected. One-fifth of the total species were non-native. Chinook and chum were among the top ten most abundant species. Species presence was primarily driven by salinity. Chinook in all zones were actively foraging; mean stomach fullness was >60%. Rations were highest in the marine zone and lowest in the mixing zone. Stickleback were 86, 68, 24% of total fish in freshwater, estuarine mixing, marine sites, respectively.Stickleback diet overlapped Chinook diet in early spring but only caused lower growth in April at the highest fish densities. The daily rations were the same or higher than those reported for in-river foraging. Stock diversity increased with salinity. Otolith chemistry showed that 30-55% of the fish remained in the estuary a month or more. Size at estuary entrance increased with time and was negatively correlated with estuary residence time. Fish entering the estuary during summer had higher growth rates than those entering during winter. Estuary residence time was positively correlated with increase in fork length and rate of growth.

Broad Outcomes: Part I Tidal amplitude has increased at Astoria 0.3m since 1925. rkm 83-120 (Eagle Cliff to Kalama) 75% shallow water habitat lost during freshet and 74% during non-freshet. Water T is now 1.8-2.9 C higher from May-Dec than historic T. Reservoir manipulation (storage, withdrawal) account for >50% of the change. Feb-Mar T lower because of manipulation, but still higher than historic. Climate change caused 0.6-1 C Jun-Oct. Part II Collected 273,180 individuals of 50 species - 17 species comprised 99% of total. 20% of total species (10) non-native, including banded killifish and American shad. Chinook and chum were among the top 10 most abund. species. Others were stickleback, surf smelt, shiner perch, English sole, starry flounder, Pacific staghorn sculpin, American shad, peamouth. Species presence was primarily driven by salinity. Stickleback were 86, 68, 24% of total fish in Freshwater, estuarine mixing, marine sites, respectively. Caught 13,059 Chinook (mostly subyearlings), 2,983 chum, 250 coho, 33 steelhead, 24 cutthroat 3 sockeye. Chinook size increased with time and was 20-50 mm higher in lower estuary zones. chum size increased with time in all zones, but more quickly at marine sites. In wetland sampling collected 876,480 individuals of 22 taxa (7 confirmed non-natives). Stickleback were 91-99% at all sites between rkm 35 and 53, upstream 47 and 49%. In spring and summer Chinook were 2nd or 3rd most abundant species at all site types and rkms. 2.8% of Chinook in wetland channels were hatchery origin. Wetland channel availability should have been 60% in all survey months. Part III In all years prey were mostly Chironomid midges(39%), collembolans(28%), other dipterans(22%) and increased Mar-Jul. Annual mean densities were 551-4,365/m^2. Benthic macroinvertebrates were annelids(14%), gammarid amphipods and other crustaceans(30%), insects(42%). Chironomid emergence peaked in mid-Jun and emergent Dolichopodiae were abund in Jul&Aug. Chin in all zones were actively foraging and ~25% of stomach contents were identifiable. Mean fullness was >60%. Rations were highest in marine zone and lowest in mixing. Adult dipterans and a benthic amphipod were most important in most zones and months (except Aug when cladocerans important). In the mixing zone Mysids were also important Jan-Mar. In wetland habitats emergent chironomids dominated except for 80-90mm individuals in scrub-shrub habitat, which ate gammarid amphipods. Stickleback diet overlaps Chinook in early spring but only caused lower growth in Apr at highest densities - competition may happen before terrestrial prey is available. Feeding peaked in early morning and before dark. Diet composition did not vary with time. Daily rations same or higher than those reported for in-river foraging.

Detailed Outcomes: Part IV Genetics Samples were made up of all stocks except Mid-UpCRSp. Spring Cr (SpCr) and West Cascades Fall (WCF) groups were highest proportions. Along salinity gradient stock diversity increased with salinity. WCF was more abundant in tidal fresh, Spring Cr Fall in the marine habitats. Other stocks had different distributions in space and time. In wetland sites 55-78% of samples were WCF and SpCr Fall were 2nd highest at all but one site. Up Col R Su/F were highest at that site and minor contributors at other sites. Otolith Analysis Residence times in 2004>2003>2005, all sig, and ranged from 1-176d. 72%, 68%, 86% otoliths showed Sr increase in '03, '04, '05. 30-55% of fish stayed in the estuary a month or more. At estuary entry fish were 34-178mm. Nearly 50% were <60mm. Back-calculated size at estuary entry increased with time. Size at estuary entrance was negatively correlated with estuary residence time. Fish that entered the estuary May-Aug had higher growth rates than fish entering Jan-Apr. No year or year * season effects were found. Estuary residents were mainly SpCr Fall and WCF. Mean wetland residence times were 7d and 5d; residences ranged from 1-27d. Residence time was positively correlated size increase (sig) and rate of growth (NS).

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**:
Study Design: Part I detail historic habitat opportunities, Part II depict current habitat opportunities (distribution, abundance, access limiting physical factors) across tidal and landscape gradients. Beach seined fish, ID'd and counted, weighed and measured up to 30 individuals of non-salmonid species. Sacrificed 10 of each life-history and species of salmon (scales, otoliths, stomachs, DNA, FL), sampled (scales, FL, DNA) from 20 additional of each combo. '04-'07 kept up to 30 individuals for laboratory study, measured up to 70 additional, counted remainder. All examined for marks and tags. Determined Chinook stock origin 2002-2007. Otolith microchemistry 2003-2005. PIT tagged and tracked fish in channels of Russian Island emergent wetland. Part III Wetland habitat prey availability, consumption rates, diet. Part IV estuary rearing strategies for different life histories and stock groups (minimum probability 90%).	
Statistics:	

Comments: Looks like it summarizes a lot of research on Chinook use of estuarine habitat; provides evidence for importance of estuarine habitat, discusses reduction in extent of, and access to this habitat due to dikes and tide gates. No tide gates mentioned. Current overview of juvenile Chinook use of the shallow water habitats in the Columbia R estuary.

<table>
<tr><td colspan="6">Boumans, R.M.J., D.M. Burdick, and M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. Restoration Ecology 10(3): 543–555.</td></tr>
<tr><td colspan="2">Keywords: tide gate replacement salmon</td><td colspan="2">Type: Peer-reviewed journal article</td><td colspan="2">Publication Date: 2002</td></tr>
<tr><td colspan="2">Include: Yes</td><td colspan="2">Reason: Shows impact of incomplete restoration. Removing a tide gate but leaving a culvert: marsh vegetation and wetting level were not restored because tidal flow was still restricted.</td><td colspan="2">Relevance: Moderate</td></tr>
<tr><td colspan="3">Location & Species: New England tidal salt marshes</td><td colspan="3">Ecosystem(s): salt marsh</td></tr>
<tr><td colspan="6">Reference Source:</td></tr>
</table>

Abstract: Salt marshes continue to degrade in the United States due to indirect human impacts arising from tidal restrictions. Roads or berms with inadequate provision for tidal flow hinder ecosystem functions and interfere with self-maintenance of habitat, because interactions among vegetation, soil, and hydrology within tidally restricted marshes prevent them from responding to sea level rise. Prediction of the tidal range that is expected after restoration relative to the current geomorphology is crucial for successful restoration of salt marsh habitat. Both insufficient (due to restriction) and excessive (due to subsidence and sea level rise) tidal flooding can lead to loss of salt marshes. We developed and applied the Marsh Response to Hydrological Modifications model as a predictive tool to forecast the success of management scenarios for restoring full tides to previously restricted areas. We present an overview of a computer simulation tool that evaluates potential culvert installations with output of expected tidal ranges, water discharges, and flood potentials. For three New England tidal marshes we show species distributions of plants for tidally restricted and nonrestricted areas. Elevation ranges of species are used for short-term (5 years) predictions of changes to salt marsh habitat after tidal restoration.

FROM STUDY SITE DESCRIPTIONS: The present culvert under Drakes Island Road is 0.9 m in diameter and open. It was originally installed in the 1950s as a 1.2-m diameter flap gate culvert to exclude salt water, but inserts used to repair the pipe reduced the diameter. The flap gate fell off in March 1988, the date we consider as time 0 for this inadvertent and unplanned tidal restoration.

Results Summary: Field measurements were done to determine the relationship between water level and volume. This data populated a predictive model which accurately simulated tidal exchange. Low marsh habitat predicted was not present until 5 and 6 years after tide gate removal. At Mill Brook tidal flow is not restricted after restoration. At Drake Island water inflow and outflow were still restricted by an undersized culvert. However, restoring tidal flux is predicted to have a negative impact on salt marsh vegetation because the marsh surface has subsided.

Broad Outcomes: The model accurately simulated tidal exchange. r^2= 0.97 for DI and OK. r^2 = 0.92 for MB (tidal flow not restricted after restoration). DI: present culvert does not allow sufficient tidal inflow or outflow. MB: Vegetated areas were flooded 20% of the time. OK: 8% of upper marsh area covered 25% of tidal cycle.

Detailed Outcomes: Model predicted area of elevation in each marsh after restoration. Authors overlayed vegetation data from downstream sites on upstream sites to predict the percent occurance of high and low marsh habitat. The model predicted MB would be mostly low marsh. This was not the case in the first 2 years when high and low marsh was present but in years 5 and 6 low marsh plants dominated. The authors used the model to evaluate several restoration and flood control options to determine if they would provide the desired outcomes for stakeholders. They also used the model to predict the long term outcomes of marsh restoration because marshes may look different in the interim than at the end without moving along a clear trajectory.

Effects Modifiers: Flap gate was removed in DI but culverts remained so tidal inflow and upland water outflow was still restricted.

Intervention: Drakes Island: diked in 1848, road with water control measures replaced dike in early 1900's. Present culvert installed in 1950's with flap gate. Repair inserts have reduced pipe diameter. Flap gate fell off in 1988. (inadvertent and unplanned restoration) Mill Brook: bridge replaced with culvert and flap gate in 1960's. 1993 larger arched culvert with no gate was installed. Oak Knoll: present culvert configuration installed circa 1930. No restoration planned at the time of research	
Conditions: DI: unplanned MB: planned OK: none	**Duration**:
Study Design: Each study marsh was paired with an unimpounded marsh downstream as reference. Water depth was calculated using pressure loggers, elevations were measured with transit and rod using standard survey methods. Determined the hypsometric curve - relationship between water level and volume. Surveyed 5-6 transects across channel beginning and ending in upland vegetation. Plotted against h-curve. Field data was used to populate the model directly or estimate values for the model. Measured sediment accretion over 2 years.	
Statistics: Built a model to predict how successful a project would be in returning a site to full tidal inundation.	

Comments: This paper focuses on restoring tidal inflow and outflow and the subsequent amount of marsh that would support high and low marsh vegetation and whether that was similar to a nearby reference marsh. I would not put too much emphasis on the model output. The 'future' habitat conditions they predicted were for the same years that data was collected to calibrate the model.

<table>
<tr><td colspan="4">Boys, C.A., F.J. Kroon, T.M. Glasby, and K. Wilkinson. 2012. Improved fish and crustacean passage in tidal creeks following floodgate remediation. Journal of Applied Ecology 49: 223-233.</td></tr>
<tr><td>Keywords: Cited in: Flood mitigation structures transform tidal creeks from nurseries for native fish to non-native hotspots. http://summit.sfu.ca/item/15346</td><td colspan="2">Type: Peer-reviewed journal article</td><td>Publication Date: 2012</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: Changes in tide gate structure or operation were analyzed.</td><td>Relevance: High</td></tr>
<tr><td colspan="2">Location & Species: Macleay & Clarence River systems & estuaries, New South Wales, Australia. Functional groups [of species]: Estuarine–marine (E-M)- saltwater species that require access to estuarine or ocean waters; Freshwater-estuarine (F-E) - euryhaline species that can occupy both freshwater and saltwater; Freshwater (F) species - confined to freshwater tributaries of estuaries.</td><td colspan="2">Ecosystem(s): Rivers/Estuaries</td></tr>
<tr><td colspan="4">Reference Source: http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2011.02101.x/full</td></tr>
</table>

Abstract: Dispersal is a critical ecological process in which individuals move within and between populations, as well as colonising new habitat. Habitat fragmentation, in combination with habitat loss, detrimentally affects dispersal success with associated impacts on biodiversity. Within New South Wales (NSW) alone, there are over one thousand floodgates which fragment important coastal habitats and have had negative impacts on fish and crustacean assemblages. Importantly, 99% of all these floodgates are considered modifiable to enhance connectivity. When such works occur, however, they are rarely accompanied by rigorous monitoring of fish and crustacean responses. In collaboration with managers and land holders, tidal flushing and connectivity was restored through opening of floodgates at three tidal creeks in the Macleay and Clarence Rivers in northern NSW. Changes in fish and crustacean assemblages were evaluated by regular sampling over a two-year period. Changes in assemblages in managed creeks were compared to those in reference creeks (i.e., without floodgates) and control creeks (with closed floodgates). Following floodgate opening, managed creeks showed an immediate shift in assemblage composition to closely resemble those in reference creeks, which was sustained for the duration of the study in at least two out of the three creeks. This change was driven primarily by an increase in the number of estuarine-marine species (including commercially important fish and prawn species) and was clearly a result of floodgate opening, as similar shifts were not observed in (un-gated) reference and (gated) control creeks in either estuary. Our study demonstrates that restoration of connectivity in tidal creeks through regular and frequent opening of floodgates leads to strong, rapid and sustained recolonisation of habitats. Hence, implementation of management solutions associated with improving connectivity, particularly those that consider differences in the dispersal capabilities of animal, will significantly benefit coastal aquatic biodiversity and fisheries production. Our study

strengthens the case for robust experimental design of restoration studies to ensure that ecological objectives are being achieved and success (or otherwise) is quantified.

Results Summary: In Macleay Creek there was a significant shift in fish assemblage making it similar to reference creeks after treatment. The number of species increased, especially estuarine-marine species. In Clarence Creek active tide gate management resulted in more species upstream, again driven by estuarine-marine species. This brought the treatment sites closer to reference conditions. However, one of the Clarence creeks diverged again over time. There were not temporal differences in fish assemblage for reference or control creeks. Tide gate management did not affect salinity or pH.

Broad Outcomes: Macleay: MG1 had a significant shift in assemblage, making it similar to reference creeks after treatment. Treatment effect on pH, but not on salinity or DO. Clarence: MG2 and MG3 assemblages shifted after treatment and became closer to the reference creeks.

Detailed Outcomes: Macleay: The number of species increased to become similar to the reference creeks - increases were due to more estuarine-marine species being present. However, there were temporal differences noted at MG1 - one post-treatment sample was similar to some pre-treatment samples. Clarence: MG3 became closer to Reference creeks shortly after treatment, but over time diverged again. In MG2 and MG3 treatment resulted in more species upstream, which was driven by estuarine-marine species. Treatment did not affect salinity or pH. Both: there were not temporal (treatment) differences in fish assemblage for reference or control creeks. When open, MG creeks resembled reference creeks most in spring and early summer. The authors noted that to have the largest effect, the tide gate opening should correspond to marine larvae settlement events so coastal floodplain habitats are available.

Effects Modifiers: MG1 and MG2 creeks were directly connected to the main river channel. MG3 was at the end of a large lake, was shallower and more removed from potential recruits, upstream habitat was more degraded, and its floodgate type (pipe culvert) differed from MG1 and MG2 (box culverts).

Intervention: Manage gated creeks by retrofiting with a small flap gate (structural) or intermittent opening with manual winching (operational)	
Conditions:	**Duration**: Macleay: 20 months 2007-2008 Clarence: 21 months 2000, 2001, 2002
Study Design: Monitor and compare faunal taxa in managed-gated creeks with faunal taxa in referance (ungated) creeks (Macleay and Clarence), and control (gated, unopened) creeks (Clarence). The focus was on fish and crustacean samples.	
Statistics: Nonparametric permutation analysis of variance was used. They tested for changes in the managed creeks over time relative to reference and control creeks.	

Comments: The species assemblage in the managed creeks differed after treatment. These changes can be attributed to tide gate management because no differences were noted in the references or controls. This study also points out the important consideration of in-stream habitat degradation and distance of the stream from the river or source of potential resident organisms.

<table>
<tr><td colspan="4">Boys, C.A. 2015. Changes in fish and crustacean assemblages in Hexham Swamp following the staged opening of the Ironbark Creek floodgates. NSW DPI – Fisheries Final Report Series No. 145. 50 pp.</td></tr>
<tr><td>Keywords: Cited in: Boys et al. 2012.</td><td colspan="2">Type: Agency report</td><td>Publication Date: 2015</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: Changes in tide gate structure or operation were analyzed.</td><td>Relevance: High</td></tr>
<tr><td colspan="2">Location & Species: Ironbark Creek and Hexham Swamp, a wetland system in the Hunter River, NSW, Australia. Estuarine-marine species, including commercially important school prawn, Eastern king prawn, yellowfin bream, flat-tail mullet, and silver biddy.</td><td colspan="2">Ecosystem(s): Rivers/Estuaries</td></tr>
<tr><td colspan="4">Reference Source:</td></tr>
</table>

Abstract: [Non-technical summary clips] The Hunter River has experienced intensive flood mitigation over the past century, with 175 floodgates and hundreds of kilometers of levee banks and drainage canals being constructed. These developments have reduced the extent and biodiversity of the adjacent coastal wetlands such as Hexham Swamp. This Ramsar-listed wetland, located in the Hunter River estuary, was degraded by the installation of floodgates on Ironbark Creek in the early 1970s.
The Hexham Swamp Rehabilitation Project was established to promote the long-term rehabilitation of this important estuarine wetland ecosystem. The project has involved the staged opening of eight floodgates at the downstream end of Ironbark Creek to increase tidal flushing of the swamp and inundate low-lying lands with saline water. This involved three stages: one gate opened (Stage 1), three gates opened (Stage 2), six to eight gates opened (Stage 3).
This report documents the changing assemblage of aquatic fauna (fish and crustaceans) in Hexham Swamp over an 11-year period, between April 2004 and April 2014. It also outlines which of those changes, if any, may be attributed to the staged opening of the Ironbark Creek floodgates. To investigate the changes, seine netting was used to sample fish and crustaceans in tidal creeks above and below the Ironbark Creek floodgates. The catches were compared to nearby natural, un-gated reference creeks and a control creek that remained closed by a floodgate throughout the entire study.
After the floodgates were opened, significant recovery was noted in the upper site, which was more degraded than the lower site. Recovery was observed in both water quality and assemblage composition; by the end of the study, the upper site resembled the un-gated reference creeks. Most importantly, this response was not seen in the control creek where the floodgates remained closed. This provides strong evidence for the recovery being related to the opening of the floodgates. The recovery did not occur until all eight floodgates were opened in Stage 3.

Results Summary:

Broad Outcomes: Overall, 54 fish and 14 decapod species were collected. Two-thirds were mainly estuarine-marine dwellers and one-third moved between freshwater and estuary conditions. Nearly a third were juveniles of commercially important species. The restored creek assemblage changed from similar to the control gated creek to the ungated reference creeks after stage 3 completion. Species richness doubled, many species had significantly greater abundance, and water quality improved, especially in the upper reaches.

Detailed Outcomes: Species assemblage shifted from similar to control to similar to reference and below gate sites after stage 3 and persisted for the duration. The control site remained distinct throughout. Eight new species were seen in upper Ironbark, mostly estuarine-marine but also freshwater-estuarine, including several commercially important species. 25 species explained 92% of the post-stage 3 change. Abundance increased for estuarine-marine species but decreased for half of the freshwater-estuarine species. pH and dissolved oxygen improved with each opening stage; salinity did not improve until after stage 3 (10-15 ppt to ~25 ppt). Lower Ironbark remained similar to lower reference reaches. Because there were no differences before gate opening the gates were likely leaky or had been opened in the past. Temperature changes in the managed creek followed estuary-wide patterns. Habitat degradation may also have contributed to faunal assemblage changes. Restricting fish movement limits the export of their productivity. Tide gate opening also resulted in decreased abundance of Mosquitofish (invasive), which can alter food webs and impact nutrient cycling, and whose prey includes eggs and tadpoles of endangered frogs. Two commercially important prawn species received special interested because the Hexham Swamp was considered a historical nursery area.

Effects Modifiers:

<table>
<tr><td colspan="2">Intervention: Floodgates at the downstream end of Hexham Swamp were opened in three stages to increase inundation and tidal flushing.</td></tr>
<tr><td>Conditions: Nursery habitat functions of the estuary were degraded by the presence of the tide gates.</td><td>Duration: 11 years</td></tr>
<tr><td colspan="2">Study Design: Compared samples taken in Hexham Swamp to samples taken in reference creeks and in control creeks that remained gated. Samples were collected above and below each tide gate and in upper reaches of each restored and control creek and in upper and lower reaches of ungated reference creeks (18 samples - 2x9sites - per time). Fish and crustaceans were seined before (3 yrs), during (3 yrs) and after (2 yrs) staged gate opening. Individuals were identified to species and measured. Surface and bottom pH, dissolved oxygen, and salinity were measured at each site.</td></tr>
<tr><td colspan="2">Statistics: Multivariate analyses on fourth-root transformed data. Fish and crustacean assemblage changes visualized with NMDS; PERMANOVA was used to determine if site changes were significant at each stage of gate opening. If main effects showed response, pairwise comparisons were done among stages. For largest response, SIMPER determined relative contribution of species groups (estuarine-marine, freshwater-estuarine, freshwater). Calculated species richness for species groups, total species, and commercially important species and plotted by site and project stage. Water quality measures plotted by site and stage.</td></tr>
</table>

Comments: The fact that significant assemblage change did not occur until after all 8 gates were open, is evidence for a threshold response. For restoration projects, ecosystem processes or faunal assemblages may not respond until an appropriate restoration threshold is met (such as inundation or tidal flushing).

Brophy, L. S., S. van de Wetering, M.J. Ewald, L. A. Brown, and C.N. Janousek. 2014. **Ni-les'tun Tidal Wetland Restoration Effectiveness Monitoring: Year 2 Post-restoration (2013)**. Corvallis, Oregon: Institute for Applied Ecology.		
Keywords: tide gate removal coho	**Type**: Report	**Publication Date**: 2014
Include: Yes	**Reason**: Directly focused on review questions.	**Relevance**: High
Location & Species: Ni-les'tun tidal wetland restoration site, Bandon National Wildlife Refuge, Coquille River Estuary, Oregon. Monitoring focused on tidal hyrdology and plant communities.	**Ecosystem(s)**: tidal wetland	
Reference Source: http://appliedeco.org/wp-content/uploads/ Nilestun_Year2_EM_report_FINAL_20140730-3_bkmks.pdf NOTE: OWEB-FUNDED.		

Abstract: Purpose, approach, presentation and results are all similar to Brown et al. 2016, which includes these results and results for the 2 subsequent years.

Results Summary: Post-restoration tidal exchange was restored and tide height closely resembled mainstem. Channel morphology changed slightly - channels deepened, fine sediment increased, downcutting began in lower reaches. Percent total cover and non-native cover and species richness decreased. Pasture grass had died back and plant community was moving toward reference site. Soil salinity and percent C increased. Mean peak CPUE in the restoration site was lower than reference pre-removal and higher post-removal for Chinook, staghorn sculpin, and was higher in the restoration site pre- and post-removal for stickleback. Restoration significantly affected sculpin, and wood significantly affected Chinook and sculpin.

Broad Outcomes: Mean daily maxiumum water level was higher after restoration. Tidal exchange was restored and tide height closely resembled mainstem. Transect elevations were 1.5 -2.5 m, avg 2.1 m in 2010 with no significant changes in 2013. Channel morphology changed slightly - channels deepened, fine sediment increased, downcutting had begun in lower reaches. Percent cover and percent non-native cover and species richness decreased. Soil salinity and %C increased at the restored site. Groundwater levels and amplitude of tidal amplification of groundwater level increased at the restoration site. Groundwater levels were higher than at the reference site and tidal influence was similar to the reference site (subsidence evidence). Salinity increased at the restoration site - increases were highest farthest from channel mouths. T (mean and daily maximum) was lower in upper channel reaches after restoration. Soil salinity, shallow groundwater duration, prevalence index, and plant species richness were correlated with percent inundation - soil salinity was higher where brackish flows inundated more frequently, groundwater related to inundation frequency, prevalence index higher in wet frequently inundated areas, species richness lower in harsh (brackish/very wet) conditions. Restoration increased fish access (2% pre, 27% post). Fish access at channel mouth was higher in the restored site. Periods of time at >18C were reduced. Wooded reaches had higher channel morphology complexity. Benthic macroinvertebrate richness increased in the mid and upper sections but decreased in the lower (Sig). Shannon-Weiner diversity index decreased (Sig), community index decreased (Sig)and abundance increased (NS) in all sections. Data suggest that all restored sub-basins had higher taxa richness than adjacent river sites. There was little difference between restoration and reference sites. S-W index and abundance differences were driven by Corophium, which is a preferred prey of age-0 Chinook and staghorn sculpin, the two most abundant fish species. This increased the restoration site fish capacity (and likely increased survival and production in the system). Chinook occupancy post restoration increased in all months in 2 subbasins and increased in some months in the third. Staghorn sculpin occupancy increased after restoration. Stickleback occupancy increased at two of three restoration sub-basins post-restoration and decreased in the third. Mean peak CPUE in the restoration site was lower than reference pre-restoration and higher post-restoration for Chinook, staghorn sculpin, and was higher in the restoration site pre- and post-restoration for stickleback. BACI showed significant effects of restoration on sculpin and significant effects of wood on Chinook and sculpin. Peak migration increased in the 3 restoration subbasins, but not in the reference site.

Detailed Outcomes: Tidal maximum increased from 1.29 m (2009) to 2.09 m (2013). Restoration daily MHHW was within 9 cm of river mainstem. Tidal inundation was higher in winter. Channel deepened 12-24 cm in most channels. Fine sediment was 5-23 cm in excavated channels, 38-60 cm in pre-existing. Percent bare ground increased - pasture grass died back and not yet replaced. NMDS suggested that plant community was moving toward reference community composition. Abundance of specific plant species did not show a clear pattern with restoration - not yet equilibrated with new salinity/hydro scape. 2013: restoration site 86.2 ha native dominated, 103.0 ha non-native dominated; reference site - 81.4 ha native, 9.5 ha non-native.

Effects Modifiers: Restoration site historically was high marsh so used high marsh transects at reference site but restoration site has undergone subsidence and is currently in the low marsh elevation range. Non-excavated (natural) channels at restoration site were not sampled prior to restoration. Changes in individual channel cross-sections are not testable. Pre-and post: channel width and width:depth could not be compared b/c field methods differed.

<table>
<tr><td colspan="2">Intervention: Dikes and tide gates removed. Major ditches filled, minor ditches disked. Tidal channels excavated.</td></tr>
<tr><td>Conditions: Final removal of tide gates and dikes was Aug 2011</td><td>Duration: 1 year pre and 1 year post restoration (2 years subsequent to removal)</td></tr>
<tr><td colspan="2">Study Design: Water level was logged every 15 minutes and was used to calculate tide height maxima and inundation.Surface inundation was logged in groundwater wells. Wetland surface elevations were measured. Channel cross-sections measured (depth, fine sediment, longitudinal flow path profile - wood and no wood placements). Physical/biological metrics measured: plant community composition and extent, soil carbon, salinity, pH, groundwater levels, surface water salinity and T. Estimated amount of habitat available to juvenile salmonids using tidal elevation data. Benthic macroinvertabrates were sampled (abundance by taxon, taxon richness, S-W diversity index, community structure index) at one restoration sub-basin. Determined juvenile fish habitat use by counting fish present during low tide (multiday residents) and determining migration movement into and out of the estuary.</td></tr>
<tr><td colspan="2">Statistics: BACI (2-way ANOVA) with site and year as independent variables: tested if restoration</td></tr>
</table>

affected maximum tide height; with wood presence and channel reach as fixed effects: tested channel depth differences and fine sediment thickness. Plant community variables (cover - total, natives, non-natives, species richness) and Soil metrics (salinity, organic matter, carbon, pH) were compared seperately with restoration vs reference site and year as categorical variables. Restoration effect on groundwater daily maximum was tested with a 3-way ANOVA with site, year and season as independent categorical variables. Linear regression on inundation vs soil C, soil salinity, shallow groundwater duration, prevalence index (proportion wetland tolerant species), total plant cover, native cover, plant species richness. Benthic macroinvertebrates: general linear mixed model with pairwise comparisons of means. CPUE was analyzed with a hurdle model (binomial and count models incorporated), BACI for month effects with covariates of time (pre/post), month, sub-basin, treatment (reference/restoration). Linear model for effects of year, location, and interaction on fish abundance of age-0 salmon, shiner perch, three-spine stickleback, sculpin.

Comments: Data are presented from before and after dike and tide gate removal - tidal inundation, plant community cover and mapping, fish utilization - abundandance and timing. We should use this report for the fish data. The Brown et al. 2016 paper has plant community and hydrology data from an additional sampling year. The authors recommend using simple wood placements meant to develop scour pools for low tide refuges instead of the complex log jams used in stream restorations.

Brown, L.A., M.J. Ewald, and L.S. Brophy. 2016. **Ni-les'tun tidal wetland restoration effectiveness monitoring: Year 4 post-restoration (2015)**. Corvallis, Oregon: Estuary Technical Group, Institute for Applied Ecology.		
Keywords: tide gate removal coho	**Type**: Report	**Publication Date**: 2016
Include: Yes	**Reason**: Directly focused on review questions.	**Relevance**: High
Location & Species: Ni-les'tun tidal wetland restoration site, Bandon National Wildlife Refuge, Coquille River Estuary, Oregon. Monitoring focused on tidal hyrdology and plant communities.	**Ecosystem(s)**: salt marsh, tidal wetland	
Reference Source: **Full text**: http://appliedeco.org/wp-content/uploads/ Nilestun_Year4_EM_report_20160221_FINAL.pdf NOTE: OWEB-FUNDED.		

Abstract: PURPOSE: This report describes results of effectiveness monitoring of tidal hydrology, plant community composition, and plant community extent (vegetation mapping), at the Ni-les'tun tidal wetland restoration site, Bandon NWR, Coquille River Estuary, Oregon. Parameters monitored are a subset of the full suite of parameters that have been monitored at Ni-les'tun during baseline and post-restoration periods. Monitoring described in this report was conducted during 2015, the 4th year after the site's dikes and tide gates were removed, restoring tidal flows to the site. Effectiveness monitoring was designed to determine whether the project is meeting its goals, and to provide information to help guide other restoration projects. Results and "lessons learned" through monitoring at this landmark project are already helping to advance restoration science at many projects in Oregon, the PNW, and beyond.

APPROACH and PRESENTATION: To determine project effectiveness, we used a BACI approach, comparing 2015 and 2013 data to baseline (pre-restoration) data collected in 2010-2011(or earlier) at Ni-les'tun and the Bandon Marsh Unit reference site. Year 4 post-restoration monitoring of tidal hydrology was conducted from late winter/early spring through summer 2015 (March-September); vegetation was monitored during August 2015. This report provides summaries, representative results, and interpretation of the 2015 monitoring. Additional data are available from the Estuary Technical Group upon request. Throughout this report, we focus on year 4 post-restoration monitoring results, highlighting key comparisons to pre-restoration and year 2 post-restoration conditions. Further details on pre-restoration conditions are contained in the baseline monitoring report (Brophy and van de Wetering 2012), and details on year 2 post-restoration monitoring (which included the full suite of parameters) can be found in Brophy et al. (2014).

SUMMARY OF RESULTS: Post-restoration monitoring in 2015 showed a consistent trajectory towards full recovery of tidal wetland functions at Ni-les'tun. Tidal hydrology was completely restored to the site, with daily maximum tides matching precisely between Ni-les'tun and the adjacent Coquille River. Plant communities remain very dynamic in response to reintroduction of tidal hydrology and salinity, with salt-tolerant early colonizers spreading across the site and pasture grasses continuing to decline. Plant community changes observed between 2013 and 2015 indicate that plant communities are far from stabilization and can be expected to continue to change substantially for a number of years.

Results Summary: Daily maximum water levels were similar inside and outside and inundation and exchange were restored at even the two highest elevation transects in the restoration site by 2015. Surface elevations were higher in the restored and reference marsh in 2015 (post) than in 2011 (pre). Elevation change was similar between marshes. Species richness was lower at the restoration site and did not change at the reference site post-restoration.Percent cover (total, native, non-native) did not differ between sites or among years. However, salt-tolerant plants were increasingly present. Native-dominated communities increased and non-native-dominated communites decreased from 2013 to 2015. The large changes in specific salt-tolerant early colonizers suggest that the plant community is not yet close to a stable state. Additional evidence: spatial distribution seemed based on individual plant tolerances rather than clear zonation.

Broad Outcomes: Daily maximum water levels were similar inside and outside the restoration site in 2015 for periods of sampling overlap in all 3 yrs (Mar 1 - Jul 8, Aug 29 - Oct 1). Tidal inundation and exchange was restored at even the two highest elevation transects by 2015. Surface elevations were higher in the restored and reference marsh in 2015 (post) than in 2011 (pre). Elevation change was similar between marshes. Species richness was lower at the restoration site and did not change at the reference site post-restoration. Percent cover (total, native, non-native) did not differ between sites or among years. However, salt-tolerant plants were increasing present. Bare ground increased immediatedly after restoration but decreased slightly and did not differ from pre-restoration by 2015. Plant community is moving toward low salt marsh composition. Native-dominated communities increased and non-native-dominated communites decreased from 2013 to 2015. The large changes in specific salt-tolerant early colonizers suggest that the plant community is not yet close to a stable state. Additional evidence: spatial distribution seemed based on individual plant tolerances rather than clear zonation.

Detailed Outcomes: In 2009 water levels were lower inside, in 2013 they were higher than pre-restoration but lower than outside, in 2015 they were not significantly different inside and outside the restoration site. Tidal inundation at the two lowest elevation transects increased from negliglibe (3.9% and 0.6%) in 2009 (leaky tide gate) to 28% and 19% in 2015 and the two highest were inundated 0.2% and 0.9% of the time. Elevations at specific transects increased an average of 4.9 cm (restored) and 3.6 cm (reference) post-restoration. Non-native salt-tolerant plants that have colonized are not expected to be obstacles to restoration - they are often out-competed by later colonizing native salt-tolerant plants. NMDS showed that restoration plant community was moving toward low salt marsh found at the reference site. Broad spatial patterns were visible at the 'alliance' level but at the higher-resolution 'association' level there were a large number of associations shifting gradually making mapping difficult at this resolution.

Effects Modifiers: Elevation increases could have been caused by measurement or equipment differences, accretion, or a combination (if only accretion it would be more than twice as high as other reference marshes along the coast). Low salt marsh was not sampled in the reference marsh because transects were designed to be similar elevation to the original high marsh at the restoration site prior to diking.

Intervention: Dike and tide gates removed - completed 2011	
Conditions:	**Duration**: 2010, 2013, 2015
Study Design: Measured tidal hydrology with a electric water level logger at 15 minute intervals for 1 year in 2010-11, 2012, 2013, and 7 months in 2015. These data were compared to 2009 pre-restoration data. Calculated % inundation and daily water level maximum for 2009, 2013, 2015. Sampled plant community composition 1 time each in 2010, 2013, and 2015. Measured % cover by species randomly within 30x150 ft permanent plots (14 restoration, 4 reference). Mapped area of each plant community over the entire restoration site using high resolution aerial photography and field truthing. *mapping was not done at the reference site in 2015 because field reconnaissance showed no changes since 2013. Elevations along transects were measured in 2011 and 2015.	
Statistics: Water level analyses completed in R with daily maximum water level as dependent variable. Elevation change with mean transect elevation modeled with regression in R. Plant community: species richness, total % cover, and native & non-native percent cover were analyzed using BACI (2-way ANOVA) with site (restoration vs reference) and year (2010, 2013, 2014) as categorical independent variables. NMDS summarized plant community composition differences among transects pre- and post-restoration. Linear regression was used for the relationship between elevation and species richness at reference and restoration sites. R was used for all analyses - dependent variable was % cover per transect.	

Comments: This paper includes data before and after dike and tide gate removal, specifically tidal inundation, plant species percent cover and community mapping.

<table>
<tr><td colspan="3">Diefenderfer, H.L., G.E. Johnson, R.M. Thom, A.B. Borde, C.M. Woodley, L.A. Weitkamp, K.E. Buenau, and R.K. Kropp. 2013. An Evidence-Based Evaluation of the Cumulative Effects of Tidal Freshwater and Estuarine Ecosystem Restoration on Endangered Juvenile Salmon in the Columbia River. PNNL-23037. PNW National Laboratory, Marine Sciences Laboratory, Sequim, WA. Prepared for U.S. Army Corps of Engineers, Portland District, under Interagency Agreement w/ U.S. DOE Contract DE-AC05-76RL01830. 98 pp.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td>Type: Final report</td><td>Publication Date: 2013</td></tr>
<tr><td>Include: Yes, with careful inclusion of novel data</td><td>Reason: Several of the papers they evaluated are studies we have also included in our review. We don't want to duplicate the data, but this paper does include original data from historically breached wetlands that should not be disregarded.</td><td>Relevance: Only a small portion of the analysis was focused on tide gate replacement. The rest of the paper was focused on dike breaching restoration.</td></tr>
<tr><td colspan="2">Location & Species: Lower Columbia River estuary, all ESA listed species: Chinook, coho, chum, and sockeye salmon, steelhead</td><td>Ecosystem(s): tidal estuary</td></tr>
<tr><td colspan="3">Reference Source: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23037.pdf</td></tr>
</table>

Abstract: [CLIPS FROM ABSTRACT]...The purpose of the research reported herein was to evaluate the effect on listed salmon of the restoration effort currently being conducted under the auspices of the federal Columbia Estuary Ecosystem Restoration Program (CEERP). Linking changes in the quality and landscape pattern of tidal wetlands in the lower Columbia River and estuary (LCRE) to salmon recovery is a complex problem because of the characteristics of the ecosystem, the salmon, the restoration actions, and available sampling technologies. Therefore, we designed an evidence-based approach to develop, synthesize, and evaluate information to determine early-stage (~10 years) outcomes of the CEERP...Our evidence-based approach to evaluate the primary hypothesis incorporated seven lines of evidence, most of which are drawn from the LCRE, and included: spatial and temporal synergies, cumulative net ecosystem improvement, estuary-wide meta-analysis, offsite benefits to juvenile salmon, landscape condition evaluation, and evidence-based scoring of global literature...We concluded that all five lines of evidence from the LCRE indicated positive habitat-based and fishbased responses to the restoration performed under the CEERP, although tide-gate replacements on small sloughs were an exception.

Results Summary: All three historically reconnected sites are now emergent marshes. Water temperatures were similar to reference sites and were suitable for juvenile salmon for most of the year. Data and observations show no barrier to accessibility. Water depth is a minimum of 50 cm in 95-100% of all slough channels. At the more recent restoration site (with no tide gate present) the habitat and fish measures are trending toward reference site values. In 2008 at Karlson Island small numbers of Chinook were caught in May, Jun, Sep; chum were also caught in May. No juvenile salmonids were collected at Haven Island in 2009. Each site was sampled once and the amount of available data did not allow for strong conclusions on the benefit of dike breach and tide gate removal for juvenile salmon. However, no evidence was found to contradict the hypothesis.

Broad Outcomes: Data and observations show no barrier to accessibility. Minimum depth of 50 cm present 100% (H), 99.7%(FC), and 95.4(K)%. Main wetland channel depth was 2.3 m - 4.2 m (mean 3.4 m). Mean width:depth ratio was 8.6. Water temperature variation patterns were similar to nearby reference sites and are suitable for juvenile salmon for most of the year but exceed 17.5C 7DADM in May or Jun (the WA State criterion for favorable salmon rearing). Salmon presence: FC - not sampled, H - none, K - 83 Chinook and 2 chum, 20 Chinook, 3 Chinook in May, Jun, Sep. Complete habitat metrics results were reported in Diefenderfer 2013 PNNL-22667 %TOC floodplain - averaged 4.86, 4.84-4.88, n=2; channel - averaged 3.25, 1.34-5.16, n=2 * More complete data is available in Diefenderfer 2013 PNNL-22667.

Detailed Outcomes: Accessibility of juvenile salmon to reconnected wetlands is positively related to the degree to which natural hydrologic function is restored. All three historically reconnected sites are now emergent marshes. At more recent restoration site (with no tide gate present) the habitat and fish measures are trending toward reference site values. The amount of data available did not allow for a strong conclusion of benefit for juvenile salmon, but no evidence was found to contradict that hypothesis. Secondary production in restored marshes is exported to nearby areas and can benefit juvenile salmon, albeit likely for only a short time, even when they do not enter the marshes.

Effects Modifiers: Field sites were not sampled multiple times

<table>
<tr><td colspan="2">Intervention: Some data were collected at historically breached dikes that had never been repaired. Haven Island, Fort Clatsop, Karlson Island.</td></tr>
<tr><td>Conditions: The breaching occurred without human action (weather, flooding, erosion…?)</td><td>Duration: 2007, 2008</td></tr>
<tr><td colspan="2">Study Design: Evaluated fish presence - beach seine? (2replicate hauls at Haven Island Jun and Aug 2009, 3 hauls at Karlson Island May, Jun, and Sept 2008), channel morphology - ground survey or photo , frequency 50 cm depth - depth logger set at 1-hr intervals and channel cross sections survey transects at data logger locations, %total organic C in upper 10cm sediment - I can't find this methodology. Data collection methods followed protocol described in Roegner et al. 2009. No paired reference sites were available, and an evaluation of published reference sites found no suitable comparisons so the authors reported their findings with no reference comparisions.</td></tr>
<tr><td colspan="2">Statistics: Used descriptive statistics. Did not have paired reference sites. Did not sample each site more than once.</td></tr>
</table>

Comments: The data summarized above are novel. Other syntheses are not summarized because three of the primary sources that this data was drawn from are included in our review and synthesis (J. Johnson et al. 2008, 2009, 2011); the other is a section of an earlier report from this meta-project (Thom et al. 2012). In three sloughs tide-gate replacement did not substantially improve habitat or salmon presence. In all but two instances, data is either not supportive of a benefit to salmon, or is inconclusive.

<table>
<tr><td colspan="3">Diefenderfer, H.L., G.E. Johnson, R.M. Thom, K.E. Buenau, L.A. Weitkamp, C.M. Woodley, A.B. Borde, and R.K. Kropp. 2016. Evidence-based evaluation of the cumulative effects of ecosystem restoration. Ecosphere 7(3) :e01242.</td></tr>
<tr><td>Keywords: tide gate replacement coho</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td>Reason: This paper evaluates several lines of evidence to determine if restoration in the lower Columbia River Estuary is benefitting juvenile salmon, especially individuals from ESA-listed interior basin stocks.</td><td>Relevance: moderate</td></tr>
<tr><td colspan="2">Location & Species: Columbia River estuary coho, Chinook, sockeye, and chum salmon, steelhead</td><td>Ecosystem(s): emergent marsh, forested, shrub-dominated and restored (marsh)</td></tr>
<tr><td colspan="3">Reference Source: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1242/pdf</td></tr>
</table>

Abstract: This study adapts and applies the evidence-based approach for causal inference, a medical standard, to the restoration and sustainable management of large-scale aquatic ecosystems. Despite long-term investments in restoring aquatic ecosystems, it has proven difficult to adequately synthesize and evaluate program outcomes, and no standard method has been adopted. Complex linkages between restorative actions and ecosystem responses at a landscape scale make evaluations problematic and most programs focus on monitoring and analysis. Herein, we demonstrate a new transdisciplinary approach integrating techniques from evidence-based medicine, critical thinking, and cumulative effects assessment. Tiered hypotheses about the effects of landscape-scale restorative actions are identified using an ecosystem conceptual model. The systematic literature review, a health sciences standard since the 1960s, becomes just one of seven lines of evidence assessed collectively, using critical thinking strategies, causal criteria, and cumulative effects categories. As a demonstration, we analyzed data from 166 locations on the Columbia River and estuary representing 12 indicators of habitat and fish response to floodplain restoration actions intended to benefit culturally and economically important, threatened and endangered salmon. Synthesis of the lines of evidence demonstrated that hydrologic reconnection promoted macrodetritis export, prey availability, and juvenile fish access and feeding. Upon evaluation, the evidence was sufficient to infer cross-boundary, indirect, compounding, and delayed cumulative effects, and suggestive of nonlinear, landscape-scale, and spatial density effects. Therefore, on the basis of causal inferences regarding food-web functions, we concluded that the restoration program is having a cumulative beneficial effect on juvenile salmon. The lines of evidence developed are transferable to other ecosystems: modeling of cumulative net ecosystem improvement, physical modeling of ecosystem controlling factors, meta-analysis of restoration action effectiveness, analysis of data on target species, research on critical ecological uncertainties, evidence-based review of the literature, and change analysis on the landscape setting. As with medicine, the science of ecological restoration needs scientific approaches to management decisions, particularly because the consequences affect species extinctions and the availability of ecosystem services. This evidence-based approach will enable restoration in complex coastal, riverine,

and tidal-fluvial ecosystems like the lower Columbia River to be evaluated when data have accumulated without sufficient synthesis.

[Systematic review portion] 2 searches (2012) in Web of Science: 1) salmon AND (dike* OR dyke* OR levee* OR tidegate* OR tide gate*); and 2) salmon AND (restoration* OR creat*) AND (estuar* OR river* OR floodplain* OR tid* OR slough). 27 of 709 papers returned by searches appeared to meet three criteria: 1) included original data on juvenile Pacific or Atlantic salmon; 2) pertained to tidal ecosystems including tidal freshwater and estuaries; and 3) concerned an anthropogenic action for restoring aquatic habitat connectivity or an analogous habitat change.

Results Summary: The mean above ground biomass values for restored marshes were about three-quarters those of the emergent reference marshes. Chironomids were typically the most abundant prey and their densities at restored sites were half those at emergent marshes. Therefore, the reconnection of ~3% of the recoverable area was estimated to have resulted in substantial increases in plant biomass and prey production in the Lower Columbia River Estuary. Significantly more juvenile salmon were actively feeding in the Columbia River Estuary than in the reaches above the 2 lowermost dams. Fish sampled at rkm 15 included individuals from the Willamette R, lower, mid, and upper Columbia R, and Snake R basins; those sampled in shallow-water areas as far downstream as rkm 4 included fish from the Snake R, Deschutes R, and mid and upper Col R basins (all interior stocks - this relates to the question of whether upriver stocks utilize the estuary habitats or simply pass through quickly to reach the ocean). Landscape change: in contributing watersheds - net loss of 189 km^2, cumulative loss of 642.7 km^2; on the floodplain - net loss of 13.3 km^2, cumulative loss of 17.7 km^2.

Broad Outcomes: The mean above ground biomass values for restored marshes were about three-quarters those of the emergent marshes. Chironomids were typically the most abundant prey and their densities at restored sites were half those at emergent marshes. Therefore, the reconnection of ~3% of the recoverable area was estimated to have resulted in substantial increases in plant biomass and prey production in the Lower Columbia River Estuary. Hydrodynamic modeling of the Gray's River estimated that half of the particulate organic matter exported from the study site would travel 7-8 km to the mainstem Columbia R. It also indicated that wetted area was affected by dike breach configuration, and that the increase in the amount of wetted area per dike breach decreased after about a quarter of the dikes were breached. Of 24 restored sites, 3 were supportive and 10 suggestive that condition is moving toward reference. 6 sites had inadequate evidence and 6 (all tide-gate replacements) showed no trend. Because of this, tide gate replacement projects have been deprioritized in the Lower Columbia River Estuary.

Detailed Outcomes: Significantly more juvenile salmon were actively feeding in the Columbia River Estuary than in the reaches above the 2 lowermost dams. Fish sampled at rkm 15 included individuals from the Willamette R, lower, mid, and upper Columbia R, and Snake R basins; those sampled in shallow-water areas as far downstream as rkm 4 included fish from the Snake R, Deschutes R, mid, and upper Columbia R basins (all interior stocks - this relates to the question of whether upriver stocks utilize the estuary habitats or simply pass through quickly to reach the ocean). Landscape change: in contributing watersheds - net loss of -189 km^2, cumulative loss of -642.7 km^2; on the floodplain - net loss of -13.3 km^2, cumulative loss of -17.7 km^2.

Effects Modifiers: When calculating future prey and vegetation biomass production in restored sites the authors assumed that there would be uniform distribution and used the mean densities present in reference sites although prey is known to be patchy. Restoration project areas were estimated in some cases.

Intervention:	
Conditions:	**Duration**:
Study Design: meta-analysis with 7 restoration/reference paired sites and incorporating before-after-reference-restoration design; aggregated PIT-tag and GSI data to document presence of juvenile salmon in shallow-water habitats; sampled for stomach fullness at John Day and Bonneville dams and near the mouth (rkm 15); modeled net ecosystem improvement; evidence-based literature review; examined landscape cover change; cumulative effects evaluation using causal criteria synthesis	
Statistics:	

Comments: There is novel data on 3 sites that were reconnected to the tidal floodplain a decade or several before the study takes place. There is also some limited data on tide gate replacement, however, this seems to be from papers we are including in our analysis. We don't want to include the same studies twice (directly and indirectly). However, we may want to mention that these authors also reviewed them and concluded that they should deprioritize tide gate replacement projects. This paper is essentially the same as the Diefenderfer 2013 project annual report. I would lean toward using this one because it is more recent so analysis should be most complete and it has undergone peer review, however the original data is presented in more detail in the annual report.

<table>
<tr><td colspan="6">Ennis, S. 2009. Effects of Tide Gate Replacement on Water Temperature ina Freshwater Slough in the Columbia River Estuary. Master of Environmental Management Project Reports. Paper 12. Portland State University, Portland, OR. 70 pp.</td></tr>
<tr><td colspan="2">Keywords: tide gate replacement coho</td><td colspan="2">Type: M.S. thesis</td><td colspan="2">Publication Date: 2009</td></tr>
<tr><td colspan="2">Include: Yes</td><td colspan="2">Reason: Directly addresses review questions.</td><td colspan="2">Relevance: High</td></tr>
<tr><td colspan="3">Location & Species: Lower Columbia River estuary - Tenasillahe Island (rkm 56,restoration/impact, warm water invasive spp), and Welch Island (rkm 55, control, native spp, including salmonids)</td><td colspan="3">Ecosystem(s): Island sloughs/marshes, tidally influenced, above salt gradient</td></tr>
<tr><td colspan="6">Reference Source:
http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1016&context=mem_gradprojects</td></tr>
</table>

Abstract: Dramatic declines in salmon populations in the Pacific Northwest have brought new attention to the importance of estuarine rearing habitats. Levees and tide gates used to convert estuarine wetlands into farmland have reduced available habitat by more than half of historical levels. Recent efforts to restore estuarine habitats include tide gate replacement, though this method has been poorly studied. As a key indicator of salmon habitat suitability, temperature was used to evaluate the effects of tide gate replacement in a tidally influenced freshwater slough in the Lower Columbia River estuary. Three tide gates in the largest slough on Tenasillahe Island were replaced in 2007 with side-hinged aluminum gates. As managed during the data collection periods, the new tide gates did not allow tidal inflow into the slough. The study employed a Before-After, Control-Impact (BACI) approach, collecting data seasonally two years before and after replacement at the impact site and at the control site, a relatively unaltered slough on nearby Welch Island. Randomized Intervention Analysis and Monte Carlo tests revealed no significant difference in slough water temperatures after tide gate replacement, although minimum temperatures dropped up and downstream of the tide gates. Although the new tide gates did not have a significant effect on water temperature, the lower minimum temperatures may have been caused by a slight increase in tidal circulation. This result suggests that slough temperatures would decrease if the tide gates were managed to increase tidal inflow, and thus improve the quality of salmon rearing habitat.

Results Summary: Tide gate replacement had no significant effect on the mean water temperature or on the difference between the control sites and the section upstream of the tide gate. Mean temperature and minimum tempurature decreased at all sites after replacement. The number of days in which water temperature exceeded EPA limits decreased in all sections after replacement. This may have been due to La Nina conditions present in 2008. The main change caused by replacement was an 'increase in frequency, duration and width of tide gate openings during ebb tides'. More Chinook salmon juveniles were detected (PIT tag array) moving upstream of tide gates after replacement.

Broad Outcomes: Tide gate replacement had no significant effect on the mean water T. No change in the T difference between the control and the section upstream of the tide gate was caused by tide gate replacement. However, the change in difference between the downstream T and the control T was significant. Main change caused by replacement was 'increase in frequency, duration and width of tide gate openings during ebb tides'. More Chinook salmon juveniles were detected (PIT tag array) moving upstream of tide gates after replacement. The new gates may have increased drainage, including warm surface waters - the old gates mostly drained cooler water at depth because they were top-hinged.

Detailed Outcomes: Mean and minimum T decreased at all sites after replacement. T upstream of tide gates were higher than in other sites, downstream T were lower, and control T lowest (natural variation). T at all sites followed a similar pattern over time. T in 2008 differed from all other years, no other pairs were significantly different.Water T variation at a specific site was most explained by waterT of nearby water bodies and by air T. Discharge and precipitation had very low correlation with other variables. Salmonid habitat via T: Daily range did not increase with replacement. In general, T increased as depth decreased. The number of days in which water temp exceeded EPA limits decreased in all sections after replacement.

Effects Modifiers: In 2008 there was a La Nina during data collection which affected all sites equally. The analysis used the difference between sites. Therefore, the La Nina did not bias the results because all sites were influenced evenly. Upstream site is affected by cattle grazing, which has a net warming affect. Downstream site is influenced by Clifton Channel and outflow. LWS influenced by Clifton Channel and Columbia River, and is unimpeded. Only one control site was available, so natural range of variability was not known - high variability among sites and years may have obscured any effect of replacement on temp.

Intervention: August 2007 Tenasillahe Island - 3 top-hinge cast-iron tide gates replaced with side-hinged aluminum tide gates with a manually operated fish orifice (this could allow upstream inflow and fish passage, but they were closed during data collection) Seperately, in 2007 2 culverts (one on each branch of the slough ~3km upstream of the fork) were replaced with bridges	
Conditions: marsh habitat nonexistent, water table lowered, grazing/upland habitat present	**Duration**: 4 years
Study Design: water T and depth, daily discharge, daily precipitation data measured seasonally for 2 years before and 2 years after tide-gate replacement at the impact site and a nearby similarly sized slough that had minimal impacts. Calculated daily T range, relationship between T and depth, number of days T exceed EPA standards	
Statistics: BACI study design. Monte Carlo and Randomized Intervention Analysis (RIA) were used to determine if tide gate replacement affects water T. Also used Spearman Rank Correlation to get correlation values for water T up- and downstream, in CVS, in Clifton channel, air T, precipitation, Columbia R discharge. Also used for hourly T and depth at all sites.	

Comments: This thesis focused entirely on water quality and connectivity. The Johnson et al. 2008 report was more comprehensive and included data on gate opening, fish presence and movement, and chemical and physical habitat metrics. It seems that the data presented by Ennis is not represented in the Johnson et al. report, She reports on differences before and after replacement while Johnson et al. 2008 report on differences between restored and reference conditions.

Franklin, P.F. and M. Hodges. 2015**. Modified tide gate management for enhancing instream habitat for native fish upstream of the saline limit.** Ecological Engineering 81: 233-242.		
Keywords: tide gate removal	**Type**: Peer-reviewed journal article	**Publication Date**: 2015
Include: Yes	**Reason**: Details management action on existing gates.	**Relevance**:
Location & Species: Kurere Stream, Waihou River, New Zealand North Island	**Ecosystem(s)**: tidal freshwater (limited by tidegates)	
Reference Source: http://ac.els-cdn.com/S0925857415001147/1-s2.0-S0925857415001147-main.pdf?_tid=c38beea4-e342-11e6-a7d5-00000aab0f6c&acdnat=1485378837_447cbb9494e89e8d631ffcbcb3ff8458		

Abstract: Tide and flood gates are used widely throughout the world to facilitate drainage of lowland areas and provide flood protection to valuable agricultural land and human infrastructure. However, these structures can impact on aquatic communities by disrupting connectivity and altering physical habitat conditions. Complete removal is rarely feasible in the short-term because of the competing flood mitigation and land use interests. However, in many cases it is likely that the structure and/or its operation can be modified to enhance connectivity for migratory species and reduce the severity of impacts on instream habitats. This study describes the results of a short-term trial investigating the effects of modified tide gate management on instream habitat and fish communities in a small tidal stream in the North Island of New Zealand. The study site was located upstream of the saline limit and thus does not directly address this potential limitation on managing the effects of some tide gates. The main objective of the study was to understand whether improvements in tidal flushing could mitigate the negative effects of tide gates on upstream habitats, thus improving their suitability for native fish communities. The trial demonstrated that in impacted lowland river reaches, the reintroduction of limited tidal exchange upstream of tide gates reduced negative impacts on instream habitat by restoring hydrological variability, increasing minimum dissolved oxygen concentrations and potentially also reducing water temperatures. However, it was also shown that the recovery may not be uniform and can be dependent on interactions with other stressors. The trial illustrated the potential for using modified tide gate management to mitigate the environmental effects associated with their operation, and to restore habitat conditions so that they are more favourable for the persistence of native fish species.

Results Summary: Opening one tide gate reintroduced tidal inundation in the lower reaches and improved instream habitat characteristics. Mean daily temperature and mean daily maximum temperature decreased at all sites after gate opening. Macrophyte cover decreased in upstream areas closest to the tide gates. Dissolved oxygen was stable at sites below the tide gates and above tidal reach. At the two upstream sites nearest the tide gates dissolved oxygen increased after gate opening. However, dissolved oxygen at the next two sites upstream decreased. Above the tide gates all but one native species were diadromous. All native species were found in the lower reaches of the stream. Even so, they comprised just over half of the species collected. Total species richness averaged 7.6 whereas species richness of native species averaged 4.1.

Broad Outcomes: Instream habitat characteristics were improved with gate opening management action. T and dissolved oxygen improved. Macrophyte cover decreased in upstream areas closest to the tide gates. Responses were not uniform throughout the study area. Diamdromous species were found in sites upstream of the tide gate - however the upstream migration opportunity is likely limited.

Detailed Outcomes: Water Quality Pre action daily water level only varied with tidal activity at K1. Water level increased at K2-K5 after gate opened and tidal inundation was reintroduced. Water stayed within the banks of the channel with limited riparian inundation. Prior to gate opening dissolved oxygen above the tide gates was lower than the threshhold for faunal protection. No difference in dissolved oxygen at K1 (below gate), K6, K7 (above tidal influence). Dissolved oxygen increased (sig) at K2 and K3 and decreased (sig) at K4 and K5. Water T was above preferred T for most native species and approached lethal levels for some. Mean daily T decreased at all sites post gate opening (sig at K1, K2, K3). Mean daily max T reduced at all sites (sig at K1, K2, K4, K5). Fish Community 14 species collected, 8 natives. At K1-K7 species richness averaged 7.6. Native species richness averaged 4.1. K7 had the most native species. K6 was the only lower-reach site with no non-natives. No non-natives were found at K8-K11. All native species above the tide gates were diadromous except Cran's bully (only at K11). Inanga used as an indicator species. Juveniles at K1 peaked in Dec - upstream migration timing. Adults found in Feb and Mar at K1, K6, K7 and in Mar only at K5.

Effects Modifiers: Dissolved oxygen levels dropping could be caused by high nutrient sediment in K4 and K5 being resuspended by increased tidal inundation. It is difficult to determine if species are not using habitat because it is degraded or because the tidegates represent a physical barrier.

<table>
<tr><td colspan="2">Intervention: triple 1.5 m diameter twin-pipe double-hinge, top-hung wooden tide gates (6 gates). Modification: manually open one tide gate.</td></tr>
<tr><td>Conditions: A summer storm forced closure of the gate for one week midway through the trial for storm protection.</td><td>Duration: 6 months</td></tr>
<tr><td colspan="2">Study Design: BACI design. Stream conditions and fish communities were monitored at 7 sites: 1 below tidegate, 2-5 above and within expected tidal influence, 6-7 above tidegates and expected tidal influence. Sites 8-11 were only sampled for use by adults of diadromous species. Logged water level, T, dissolved oxygen. Collected fish via trap, fyke net, electrofishing. All fish were ID'd, counted, measured.</td></tr>
<tr><td colspan="2">Statistics: Analyses were limited to the 10-d period before tide gate opening and the 10-d immediately following commencement of the trial (to avoid impact of flood(flushing) and season). Shapiro-Wilk tests determined normality of pre and post T and dissolved oxygen. Dissolved oxygen was analyzed with Kruskal-Wallis rank sum test, T analyzed with ANOVA. CPUE calculated as total catch/set by site.</td></tr>
</table>

Comments: This study found that active management of a tide gate can have a positive impact on water temperature, dissolved oxygen, and fish community composition. The gate was manually held open, not retrofit with a mechanism.

Frenkel, R.E. and J.C. Morlan. 1990. **Restoration of the Salmon River salt marshes: retrospect and prospect.** Department of Geosciences, Oregon State University. Prepared for the US Environmental Protection Agency. 160pp.		
Keywords:	**Type**: Report	**Publication Date**: 1990
Include: Yes	**Reason**:	**Relevance**:
Location & Species: Salmon River estuary	**Ecosystem(s)**: estuary salt marsh	
Reference Source: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/21150/CompressedRestorationSalmonRiverSalt.pdf?sequence=1		

Abstract: We assessed restoration of a 21 ha diked pasture in the Salmon River estuary to a naturally functioning estuarine salt marsh in 1988, eleven years after partial dike removal in 1978. Diane Mitchell (1981) collected base line data, established an intensive sampling system of permanent plots in the diked pasture and flanking 'intact' control marshes, and analyzed restoration progress from 1978 to 1980. Our report continues Mitchell's earlier research by evaluating the composition, structure, function, and long term prospects for the restored wetland.

Results Summary: Immediately after restoration upland species died back in both the 1978 and 1987 marshes. In the 1978 marsh resultant bare ground was colonized quickly by mainly annual species whose presence was ephemeral and were replaced by later arriving permanent colonizers. Restoration and control sites displayed vegetative zoning. The restoration area elevations had increased 2-7 cm between 1979 and 1988. One of the control sites also increased in elevation 6-10 cm. Elevation increased more in areas of lower elevation and in areas with greater inundation. Mean biomass decreased after restoration as upland species died back but had increased to more than double the control sites by 1988. Communities showing a stronger increase were dominated by colonizing rather than residual species. Creeks with high connectivity and tidal exchange narrowed and deepened. Creeks with low connectivity and limited tidal exchange had slight downcutting or sedimentation.

Broad Outcomes: Immediately after restoration upland species died back in both the 1978 and 1987 marshes. In the 1978 marsh resultant bare ground was colonized quickly by mainly annual species whose presence was ephemeral and were replaced by later arriving permanent colonizers. Subsidence during the diked period that 11 years after breaching the restoration site elevation was 34.9 cm below that of the control sites. Elevation increased more in areas of lower elevation and in areas with greater inundation. The marsh productivity was similar to the control marshes before restoration. Immediately after breaching productivity decreased but then increased substantially and was >2x that of the controls. The authors argue that the goal of restoring areas to a 'pristine', unaltered condition are unrealistic. Some reasons provided include the inabilatiy to alter some upland and hydrologic changes, the difficulty in knowing what pre-alteration conditions were, and not having unaltered controls for comparison.

Detailed Outcomes: Upland species have not returned.The two major residual species decreased from ~40% to ~8% cover. Soon after restoration some colonizers established in bare ground but by 1988 these were gone (ephemeral) and other colonizers had established themselves (permanent). The proportion of bare ground, which increased after restoration and was present in 1984, was gone by 1988. The current study described 8 plant communities in the restored and control areas. Five of these communities are present in both restoration and control sites although at differing levels. One intertidal community is only present in the restoration site and both extratidal communities are only present in the control areas. Restoration and control sites displayed vegetative zoning. The restoration area elevations had increased 2-7 cm between 1979 and 1988. One of the control sites also increased in elevation 6-10 cm. Accretion was negatively correlated with elevation in the restoration site. Most plant communities had significantly different mean elevations and the two that were similar had different substrates. Plant species on the leveled dikes in 1980 were still present in 1988 but high salt marsh communties had formed at the most elevated and least inundated sites. Creeks with high connectivity and tidal exchange narrowed and deepened. Creeks with low connectivity and limited tidal exchange had slight downcutting or sedimentation. Immediately after restoration salinity increased from 0 to 18-33 ppt. In 1988 salinity was 22-44 ppt and averaged 31.5 ppt. The amount of organic material increased with elevation and salinity increased with percent sand. Mean biomass decreased after restoration as upland species died back but had increased to more than double the control sites by 1988. Communities showing a stronger increase were dominated by colonizing rather than residual species.

Effects Modifiers:

Intervention: In 1978 the dike was partially removed, a tide gate was removed, and tidal creeks were reconnected at the dike breach and through the dike, where necessary. In 1987 dikes were removed from a 63 ha marsh on the opposite river bank.	
Conditions:	**Duration**: 1 year
Study Design: Plots from Mitchell 1989 were sampled and new plots were created where needed. At each plot they measured percent cover of vascular plants, above-ground biomass, soil salinity, soil texture and organic content, accretion since 1978, and elevation. Soil metrics were collected from cores.	
Statistics:	

Comments: This paper summarizes Mitchell's 1981 results and includes an additional 3 years of data collected by Mitchell (1981, 1982, 1984) and one year of data these authors collected (1988). It describes changes in a restored marsh over a decade relative to more undisturbed sites. However, the authors do point out that the 'control' sites are dynamic as well.

<table>
<tr><td colspan="3">Goertler, P. 2014. Juvenile Chinook salmon (Oncorhynchus tshawytscha) life history diversity and growth variability in a large freshwater tidal estuary. M.S. Thesis, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. 97 pp.</td></tr>
<tr><td>Keywords: N/A</td><td>Type: M.S. Thesis</td><td>Publication Date: 2014</td></tr>
<tr><td>Include: Yes</td><td>Reason: Data shows variable subyearling growth trends in the freshwater tidal portion of the Columbia R estuary. Demonstrates greater variability in usage/growth than recognized in mangament.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Columbia River Estuary
Chinook salmon</td><td>Ecosystem(s): freshwater tidal estuary
backwater channel, mainstem, tributary confluence</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Abstract: [Clips from ABSTRACT]…thesis focuses on juvenile Chinook salmon and their use of estuarine wetlands as nursery habitat. ..used otolith microstructural growth estimates and prey consumption to measure rearing habitat quality...sampling was designed to target as much genetic diversity as possible...individual assignment to regional stocks of origin was used to describe diversity of juvenile Chinook salmon groups inhabiting the estuary. …addresses how juvenile salmon growth changes among a range of wetland habitats in the freshwater tidal portion of the Columbia River estuary and how growth variation describes and contributes to life history diversity. …incorporated otolith microstructure, individual assignment to regional stock of origin, GIS habitat mapping and diet composition, in three habitats (mainstem river, tributary confluence and backwater channel) along ~130 km of the upper estuary. Employed a generalized linear model to test three hypotheses: juvenile Chinook growth was best explained by 1) temporal factors, 2) habitat use, or 3) demographic characteristics, such as stock of origin or the timing of seaward migration...variation in growth was best explained by habitat type and an interaction between fork length and month of capture. Juvenile Chinook salmon grew faster in backwater channel habitat and later in the summer. …mid-summer and late summer/fall subyearlings had the highest estuarine growth rates. …survival studies from the system elucidated a possible tradeoff between growth and survival in the Columbia River basin...findings [illustrate] the complexity in understanding the influences of the many processes that generate variation in growth rate for juvenile anadromous fish inhabiting estuaries. …used otolith microstructure and growth trends produced in a dynamic factor analysis (DFA, a multivariate time series method only recently being used in fisheries) to identify the life history variation in juvenile Chinook salmon caught in the Columbia River estuary over a two-year period (2010-2012). DFA estimated four to five growth trends were present in juvenile Chinook salmon caught in the Columbia River estuary.

Results Summary: Juvenile Chinook growth rate increased with month and was higher in backwater than mainstem habitat. Mid-size juveniles caught in mid to late summer had the fastest growth rates. The volumetric percentage of planktonic prey decreased with month while emergent prey increased.

Emergent prey were especially important in backwater habitats. Juvenile salmon were present year round with a consistent stock composition pattern. All month/year capture groups were characterized by 4 or 5 growth pattern trends. These trends were not grouped by stock in any capture period. However, in May of both years hatchery fish grouped tightly. Therefore, hatchery fish may not experience the same breadth of growth rate patterns as wild fish.

Broad Outcomes: Ch 1. 1 86 prey items found in stomach contents. The model that best explained growth included habitat, length, month, year, and length x month – but habitat has less support. Growth rate increased with month and was higher is backwater habitat. Mid-size juveniles caught in mid to late summer had the fastest growth rates. Planktonic prey volume decreased with month while emergent prey increased. Fish from backwater habitat had more emergent prey by number, weight, Index of relative importance. Chinook did not get terrestrial flux from flood events. Ch 2. Juveniles were present year round with consistent pattern in stock composition. Upper Columbia Spring, Snake Spring and Fall, Deschutes stocks much less frequently caught. 40% of all fish had a 'growth check' that may show habitat transition. The check was most often at ~1 month age but a 50-100 d check was also common. DFA: All month/year groups were best explained with 4 or 5 growth pattern trends. In 2010 and 2011 May growth fit 4 trends and Jul and Sep fit 5 trends – fish did not group by stock in any capture period. Hatchery fish grouped tightly in May of both years - hatchery fish may not experience the same breadth of growth rates as wild fish.

Detailed Outcomes: Ch 1 The interaction between length and month for growth rate is interpreted as an idicator of life-history type/strategy being present in the Columbia R estuary.

Effects Modifiers: DFA models took a long time to converge - may not be appropriate for otolith growth because of large sample size. The author was not able to catalog and quantify life-history diversity.

<table>
<tr><td colspan="2">Intervention: None</td></tr>
<tr><td>Conditions:</td><td>Duration: 2 yrs</td></tr>
<tr><td colspan="2">Study Design: Beach/pole seined 18 sites. Up to 100 Chinook measured, weighed, scanned for CWT/PIT/marks. Up to 30 DNA sampled for genetic origin (used fish with probability >/= 80% in analyses). All fish subyearling. Measured T. Obtained USGS discharge and T data. Ch 1. otolith microstructure analysis to determine estuarine growth rates (mean increment width, 14 d prior to capture), diet composition (preserved and sorted). Ch 2. otolith analysis (emergence to capture) to reconstruct growth history and infer habitat transitions</td></tr>
<tr><td colspan="2">Statistics: Ch 1. Generalized linear models to determine if demographic factors, habitat, temporal factors most important driver of growth rates. Ch 2. evaluated DFA (dynamic factor analysis) to estimate predictable growth patterns - shared temporal trends and determine use of proxy variables for LH type. Determined growth check where average ring width of previous ten rings increased by 25% over the following five rings.</td></tr>
</table>

Comments: The growth data for the Columbia River estuary is very interesting. Also of noteis that the different life-history strategies identified by DFA did not cluster by genetic stock. I don't know if this is because fish in each stock are employing multiple strategies, if more than one stock is employing each strategy, or both. I would suspect that although we tend to generalize about the life-history strategies of different stocks that there is a great deal of overlap.

<table>
<tr><td colspan="3">Gordon, J., M. Arbeider, D. Scott, S. Wilson, and J. Moore. 2015. When the Tides Don’t Turn: Floodgates and Hypoxic Zones in the Lower Fraser River, British Columbia, Canada. Estuaries and Coasts 38: 2337 - 2344.</td></tr>
<tr><td>Keywords: tide gate upgrade salmon</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 2015</td></tr>
<tr><td>Include: Yes</td><td>Reason: Direct data of environmental difference caused by tide gates.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lower Fraser River, BC, Canada. Metro Vancouver.</td><td>Ecosystem(s): tidal fresh streams</td></tr>
<tr><td colspan="3">Reference Source: http://link.springer.com/article/10.1007/s12237-014-9938-7</td></tr>
</table>

Abstract: Floodgates are common flood control structures in coastal river systems, which allow tributary drainage into river main stems and decrease flooding risk of land upstream of diking systems. Floodgates have been shown to impact upstream aquatic habitats and alter organismal community structures in some systems by impounding water and acting as a physical barrier to migratory species; their impacts on water quality have been less well described. This study investigated water quality in tidal creeks with and without floodgates on the lower Fraser River, British Columbia, Canada. There are an estimated 500 floodgates in this region. Water quality measurements were taken upstream and downstream at three floodgate sites and three reference sites across a 10-day period in July/August. The average dissolved oxygen (DO) concentration upstream of floodgates was 2.47 mg/L and fell as low as 0.08 mg/L, which was significantly lower than the comparable region of reference sites (8.41 mg/L) during this sampling period. In contrast, the average DO concentration downstream of floodgates was 7.38 mg/L and in reference sites 8.35 mg/L. All DO concentration measurements upstream of floodgates in July and August fell below the 6-mg/L minimum set by the Canadian Council of Ministers of the Environment. These hypoxic zones extended at least 100 m upstream of floodgates. Thus, floodgates may be facilitating the occurrence of local hypoxic zones in summer months in these locations. Floodgate-induced hypoxia may not only cause local exclusion of sensitive native fishes but may also act as a chemical barrier that decreases connectivity among aquatic systems. Understanding these environmental impacts associated with floodgates can inform floodgate design and post-installation management, which is an increasingly important issue as coastal municipalities across the world deal with aging floodgate infrastructure and sea level rise.

Results Summary: Dissolved oxygen was lower in gated streams than reference streams and dissolved oxygen concentrations were lower above tide gates than below. Upstream dissolved oxygen was always below the 6 mg/L water quality threshhold. The model that best predicted dissolved oxygen included temperature, depth, and an interaction between stream type and distance from the tidegate. Water temperature did not differ between site types. Reference sites had lower salinity and conductivity and higher pH.

Broad Outcomes: Dissolved oxygen concentrations were lower above tidegates than below and were lower above tidegates than in reference streams. Upstream dissolved oxygen was always below the

6mg/L minimum quality threshhold. Dissolved oxygen downstream of tidegates was slightly lower than reference streams. Agriculture and other human use covered the majority of the areas sampled of both types.

Detailed Outcomes: The best predictive model included water T, depth, the interaction between stream type and distance from tidegate. Those variables plus distance from tidegate were highly significant. Dissolved oxygen comparisons between site type at each distance relative to tidegate showed that dissolved oxygen was lower in gated streams at all relative distances except 100 m below the gate. There were no trends in water T between locations or site types. Salinity and conductivity were lower in reference sites and downstream reaches than upstream of gates. pH was lower at gated streams.

Effects Modifiers: Only sampled during summer. Tide gates likely did not open for the duration because the Fraser River freshet held the gates closed.

Intervention: None	
Conditions:	**Duration**: < 1 month
Study Design: Dissolved oxygen, T, conductivity, salinity, pH measured dusk and dawn 5, 10, 25, 50, and 100 m up and downstream of tide gates or reference points. Hourly weather and precipitation data were collected from weather stations. Determined area and land uses for watersheds.	
Statistics: Linear mixed effects model examined relationship between dissolved oxygen and site type. Co-variables: conductivity, salinity, pH, air T were related to water T. Water T, depth, sample time, site type and either distance from gate or reference point or upstream/downstream location included as fixed effects and creek as random effect in model testing. Also included an interaction term between site type and either distance or location relative to gate. Used AICc to determine most parsimonious model. Tukey's planned contrasts examined interaction effect.	

Comments: This paper provides an example of an issue not often focused on - basically non-functional tide gates. It focused on water quality differences between sites with and without tide gates. However, the authors point out that the gates might not open during the entire study period because the spring freshet is high enough to keep them closed. Therefore there is no drainage or interchange.

<table>
<tr><td colspan="3">Gray, A., C.A. Simenstad, D.L. Bottom, and T.J. Cornwell. 2002. Contrasting Functional Performance of Juvenile Salmon Habitat in Recovering Wetlands of the Salmon River Estuary, Oregon, U.S.A. Restoration Ecology, 10(3): 514-526.</td></tr>
<tr><td>Keywords:</td><td>Type: Peer-reviewed</td><td>Publication Date: 2002</td></tr>
<tr><td>Include: Yes</td><td>Reason: Three marshes were restored over a period of 23 years.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Salmon River estuary, Chinook salmon</td><td>Ecosystem(s): emergent salt marsh</td></tr>
<tr><td colspan="3">Reference Source: https://doi.org/10.1046/j.1526-100X.2002.01039.x</td></tr>
</table>

Abstract: For an estuarine restoration project to be successful it must reverse anthropogenic effects and restore lost ecosystem functions. Restoration projects that aim to rehabilitate endangered species populations make project success even more important, because if mis-judged damage to already weakened populations may result. Determining project success depends on our ability to assess the functional state or 'performance' and the trajectory of ecosystem development. Mature system structure is often the desired 'end point' of restoration and is assumed to provide maximum benefit for target species; however, few studies have measured linkages between structure and function and possible benefits available from early recovery stages. The Salmon River Estuary, Oregon, U.S.A., offers a unique opportunity to simultaneously evaluate several estuariene restoration projects and the response of the marsh community while making comparisions with a concurring undiked portion of the estuary. Dikes installed in three locations in the estuary during the early 1960s were removed in 1978, 1987, and 1996, creating a 'space-for-time substitution' chronosequence. Analysis of the marsh community responses enables us to use the development state of the three recovering marshes to determine a trajectory of estuarine recovery over 23 years and to make comparisons with a reference marsh. We assessed the rate and pattern of juvenile salmon habitat development in terms of fish density, available prey resources, and diet composition of wild juvenile Oncorhunchus tshawytscha (Chinook salmon). Results from the outmigration of 1998 and 1999 show differences in fish densities, prey resources, and diet composition among the four sites. Peaks in Chinook salmon densities were greatest in the reference site in 1998 and in the youngest (1996) site in 1999. The 1996 marsh had higher densities of chironomids (insects; average $864/m^2$ and lower densities of amphipods (crustaceans; average $8/m^3$) when compared with the other sites. Fauna differences were reflected in the diets of juvenile Chinook with those occupying the 1978 and 1996 marshes based on insects (especially chironomids), whereas those from the 1987 and reference marshes were based on crustaceans (especially amphipods). Tracking the development of recovering emergent marsh ecosystems in the Salmon River estuary reveals significant fish and invertebrate response in the first 2 to 3 years after marsh restoration. This pulse of productivity in newly restored systems in part of the trajectory of development and indicates some level of early functionality and the efficacy of restring estuarine marshes for juvenile salmon habitat. However, to truly know the benefits consumers experience in recovering systems requires further analysis that we will present in forthcoming publications.

Results Summary: Important insect prey species density was negatively correlated with recovery age but important benthic invertebrate density was positively correlated with recovery age. If fish diet composition is generally similar to prey community composition then fish growth will differ among sites with prey energetic content. In this study, metrics for capacity, opportunity, and fish performance differed between recovery sites and the reference site even after two decades. Foraging opportunities may still exist for juvenile salmonids during early restoration but the benefits may be modulated by lower quality habitat.

Broad Outcomes: Pacific staghorn sculpin and three-spine stickleback were the most abundant fish species and the sculpin densities were an order of magnitude higher than juvenile Chinook densities. Juvenile Chinook salmon were most abundant in the REF marsh and second most abundant in the 1996 marsh. There were no differences among sites in total density of invertebrates collected in fall traps but there were important differences in community composition. Chironomids and certopogonids, which are important Chinook prey items, were negatively correlated with marsh recovery age. This may point to differences in marsh function as relating to foraging and prey availabiltiy. Benthic macroinvertebrates were most dense in the REF marsh with no differences among the recovery marshes. Community composition differed among marshes. Corophium and Eogammarus species (amphipods) were rare in the 1996 marsh and amphipod density was positively correlated with marsh recovery age. Differences among sites in the biotic structure may lead to differences in fish growth if fish diet reflects available prey and there are differences in the energetic content of prey.

Detailed Outcomes: In 1998 and 1999 Pacific staghorn sculpin was the most abundant speciesin the REF, 1978, and 1987 marshes. Three-spine stickleback were most abundant in the 1996 marsh. Chinook salmon were similarly abundant in the REF, 1987, and 1996 marshes, and less abundant in the 1978 marsh. Peak density and timing differed between years. No pattern was found for overall density of insects among marshes in 1998, however in 1999 the 1987 hi marsh had lower abundances. Chironomidae and Ceratopogonidae dipteran families were most abundant and were assessed futher. In both years chironomidae were most abundant in the 1996 marsh. In 1998 there were no differences in density of ceratopogonids among marshes but in 1999 their density was significantly greater in the 1996 marsh. Chironomids were negatively correlated with marsh age in both years and ceratopogonids were in 1999. Ceratopogonids were not correlated with recovery age in 1998 and total insect density was not correlated with recovery age in either year. For benthic invertebrates a positive relationship between density and recovery age was only found for one species in one year. When two amphipod species from both years were considered together there a slight positive trend was indicated. Juvenile Chinook diets were most similar between the REF and 1987 marshes (they consisted mostly of crustaceans). Diets from the 1978 and 1996 marshes were mainly insects. Chinook were preying selectively on trichoptera, corophium spp, chironomid larvae, and dipterans. The average percent similarity between diet and available prey was 38%.

Effects Modifiers: Long term monitoring has not been completed. Changes in marsh habitat, prey production, or foraging have not been documented. Bioenergetic sampling was not done - similarity in diets between sites does not necessarily translate to similar energetic benefits.

Intervention: Dikes and associated tide gates removed from three marshes in 1978, 1987, and 1996.	
Conditions:	**Duration**: 2 6-mo sampling

	seasons
Study Design: The 3 restoration sites and a reference site were sampled Mar-Jul. Fish were collected twice monthly by fyke net with pole seine. Fork length and wet weight were collected for all salmonids. A subsample of juvenile Chinook were kept for stomach analysis. Fullness and digestion stage were rated. Prey was sorted and each category was counted and weighed (frequency of occurance and gravimetric composition). Marsh insects and benthic invertebrates were sampled monthly. Insects were collected in fallout traps and benthic invertebrates in sediment cores with five replicates taken at each sample site. Individuals were identified and counted.	
Statistics: Fish abundance was standardized to the estimated surface area sampled and reported as average density per m^2. Insect and benthic invertebrate abundances were standardized to sample area or core volume and reported as inverts per m^2 or m^3. Kruskal-Wallis comparison of means was used to test intergroup differences at each site. Linear regression was used to test relationship between density of groups to recovery time in restored sites. Index of relative importance was calculated for prey types, percent similarity index determined diet similarity among areas and overlap between diet and available prey. Standardized forage ratios were used to determine selectivity of certain prey. Stomach fullness was used as a measure of relative consumption rate among marshes.	

Comments: This paper is interesting becasue the marshes were restored over two decades, which allows some investigation of restoration over time. Even though it is three different marshes, their close proximity makes comparisons possible. The two sites with freshwater input had higher densities of insects and insects were more important in the Chinook diets. Perhaps it is not just the recovery age, but also the connection to upland habitats that is important for the prey types available to juvenile salmonids. This study does not determine if insects or benthic invertebrates are more beneficial energetically to juvenile salmonids.

<table>
<tr><td colspan="3">Greene, C., J. Hall, E. Beamer, R. Henerson, and B. Brown. 2012. Biological and Physical Effects of "Fish-Friendly" Tide Gates. Final Report for the Washington State Recreation and Conservation Office, January 2012.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td>Type: Final report</td><td>Publication Date: 2012</td></tr>
<tr><td>Include: Yes</td><td>Reason:</td><td>Relevance:</td></tr>
<tr><td>Location & Species: Samish and Padilla Bay, Swinomish Channel, Skagit River tidal delta, Chehalis River, and Young's Bay</td><td colspan="2">Ecosystem(s):</td></tr>
<tr><td colspan="3">Reference Source:
https://salishsearestoration.org/images/4/4a/Greene_et_al_2012_effects_of_tidegates_on_fish.pdf</td></tr>
</table>

Abstract: [From SUMMARY] Findings indicate that self-regulating tide gates (SRTs) vary substantially based on design and operation and consequently vary in performance, depending upon the metric of interest. For estuarine-dependent species in general and juvenile Chinook salmon in particular, SRTs support habitat use above gates much less than natural channels and a little better than traditional flap gates. For other anadromous salmon species that may spawn in creeks above tide gates, SRTs do not appear to strongly inhibit passage or juvenile rearing density. These findings suggest that estuary restoration with SRTs will have limited benefits for juvenile Chinook salmon and other estuarine-dependent species, but can result in some improvement in connectivity and rearing habitat quality compared to traditional flap gate designs. SRT designs and operation standards that maximize connectivity, and site selection criteria that focus on reconnection of large amounts of habitat may overcome some of the limitations of reduced habitat use associated with SRT installation. These potential reductions can successfully be evaluated by comparing the benefits of SRT installation with those of other estuary restoration techniques (e.g., dike breaching or setback).

Results Summary: Time open at side-hinged self-regulating tide gates (SRT's) was half that of reference sites and top-hinge flap gates were more restrictive. SRT's had twice the connectedness of flap gates and half that of reference sites. Water elevations at flap gate systems were 2-6 times lower than reference sites, and 1/3 to 5 times lower than at SRT's. Chinook salmon densities were more than 4 times greater at reference sites than at SRTs or flap gates (which were similar). Stickleback densities were higher at flap gates than reference sites; densities at SRT's were similar to flap gates. Cumulative densities at all tide gates were at least 8 times lower than at reference sites.

Broad Outcomes: Time open at SRT's was half of reference sites; flap gates were more restrictive. SRT's had twice the connectedness of flap gates and half that of reference sites. Connectedness, leakiness, and mean surface elevation, varied with site type. Elevation was lower above tide gates. Salinity and T varied with site type but also with visit (time) and system. Water elevations at flap gate systems were 2-6 times lower than reference sites, and 1/3 to 5 times lower than at SRT's. SRT water levels were 50% of reference levels. Chinook salmon densities were >4x greater at reference sites than at SRTs or flap gates (which were similar). Chinook also differed by system and time, and their interaction. Stickleback densities were higher at flap gates than reference sites; SRT densities similar to flap gates. Species groups did not show systematic variation among site types, except estuarine-dependent species. Densities were an order of magnitude greater at reference sites than SRT's or flap gates. At Fornsby after installation of SRT, door opening % and % time upstream movement possible increased.Tidal muting decreased after SRT installation. Cumulative densities at all tide gates were at least 8 times lower than reference sites. Post SRT installation cumulative densities increased at Fornsby but decreased at Fisher. At McElroy cumulative densities were low (no pre SRT data).

Detailed Outcomes:

Effects Modifiers:

Intervention: Fisher: 3 door side-hinged self-regulating tide gates (SRTs) with 2 small submerged flap gates replaced passive side-hinged system with manual opening during spring McElroy: post-treatment monitoring of a side-hinged SRT and 3 flap gates replacing 3 flap gates Fornsby: side-hinged SRT replaced a flap gate, channel modification, revegetation	
Conditions:	**Duration**: 3 2-week data collection periods
Study Design: 1) investigate physical and ecological characteristics of SRT's (10) vs flap gates and reference sites. (spatially extensive) 2) describe Chinook density thru rearing season at 3 SRT's in multiple years surrounding tide-gate change compared to open channel reference sites. (temporally extensive). Measured salinity, water level, water T up- and downstream, tide-gate tilt, water velocity with data loggers. Collected biological samples with beach seine, fyke nets, neuston traps. All fish were counted and up to 25% were measured. Densities were calculated from counts and net areas. Invertebrates >500 µm categorized as estuarine/marine or freshwater.	
Statistics: Tilt data classified gate open/closed, and with elevation determined connectedness. Calculated leakiness index. Calculated density of each species. Focused on Chinook, 3-spine stickleback, all anadromous fish, estuarine-dependent species, non-native species, % neuston that are estuarine. Log- transformed data to reduce variation among systems. Effects of site type on connectedness, water level, salinity, T, and fish indicator groups were examined with general linear models. Leakiness and velocity were examined with ANOVA. Temporal study analyzed SRT function in Chinook habitat over time. Focused on variation in measures of connectivity and surface water elevation. Calculated cumulative density up- and downstream, divided above by below for a comparable ratio across sites. Used Pearson correlations among physical metrics describing connectivity and water elevation, determined if these are correlated with logRatio of cumulative density.	

Comments: This report investigated side-hinged self-regulating gates in comparison to traditional flap gates and reference sites. The summary conclusions of relative impacts or benefits to juvenile salmon are useful and relevant to our questions. One caveat is that we have included reports focused specifically on Fisher Slough. We should be careful to include the data from the other systems but not to double count Fisher.

<table>
<tr><td colspan="4">Greene, C., E. Beamer, and J. Anderson. 2016. Skagit River Estuary Intensively Monitored Watershed Annual Report April 2016. NOAA Northwest Fisheries Science Center, Skagit River System Cooperative, and Washington Dep't. of Fish and Wildlife. 25 pp.</td></tr>
<tr><td>Keywords: flood gate replacement salmon</td><td colspan="2">Type: Annual Report</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: Comparison of restoration types and juvenile Chinook abundance plus adult returns.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Skagit Bay and Skagit River tidal delta</td><td colspan="2">Ecosystem(s): intertidal and tidally-influenced freshwater river delta</td></tr>
<tr><td colspan="4">Reference Source: http://skagitcoop.org/wp-content/uploads/EB2918_Greene-et-al_2016.pdf</td></tr>
</table>

Abstract: The goal of the Skagit River Intensively Monitored Watershed (IMW) Project is to understand changes in population characteristics (primarily abundance, productivity, and life history diversity) of wild Chinook salmon in response to reconnection and restoration of estuarine habitat. To accomplish this goal, we are monitoring the Skagit River Chinook salmon population at four stages of their migration: the mainstem Skagit River near estuary entry, the tidal delta, nearshore, and offshore. These monitoring programs allow us to examine changes in body size, abundance, and life history variation as fish migrate out of the estuary. The long time series of monitoring data allows us to examine the effects of large restoration projects in the tidal delta, which commenced in 2000 and will continue in future years. Additional status and trends monitoring of adults returning to the Skagit River provides a further reference to evaluate whether the cumulative amount of restoration can improve production. Our study plan and summary of results highlights the hypotheses, restoration projects, methodologies, and results of the Skagit system-wide monitoring. In doing so, we address how our methodologies are answering two general questions relevant to monitoring the population response of Chinook salmon to estuary restoration:

1) do salmon exhibit limitations during estuarine life stages related to capacity and connectivity, and

2) has estuary restoration resulted in population-or system-level responses?

This report is primarily a summary of previous knowledge gained about Chinook use of estuarine habitats in the Skagit River estuary and delta, and study plan for future post-restoration monitoring, but also includes some post-restoration results. Results are not presented for individual tide gate projects, but rather for the larger system and restoration effort as a whole which includes several different kinds of actions. Does include some discussion of "what works, what doesn't".

Results Summary: Almost 290 hectares were restored in the Skagit River South Fork between 2000 and 2012. Density decreased and residence increased after restoration. Each restored hectare provided habitat for ~690 daily residents at high outmigrations. Additionally, cohort residency would increase by 15 days for each 200 ha restored. Fry migrant abundance and the smolt-to-adult ratio did not seem to be influenced by restoration. Additionally, average length did not increase with restoration. Different types of projects provided different restoration results. Projects associated with dike setback, dike breach, and fill removal had juvenile Chinook densities comparable to reference sites. Self-regulating tide gate sites had Chinook densities an order of magnitude lower than reference sites although they did perform about twice as well as traditional flap gates. Individual projects are contributing to the overall estuary goal. Data from systems in which abundannce has been quantified and carrying capacity estimated show that Chinook are more abundant than project design estimates.

Broad Outcomes: Projects associated with dike setback, dike breach, fill removal had juvenile Chinook densities comparable to reference sites. Self-regulating tide gate sites had an order of magnitude lower Chinook densities than reference sites although they did perform about twice as well as traditional flap gates. Individual projects are contributing to overall estuary goal. Systems in which abundannce has been quantified and carrying capacity estimated, Chinook are more abundant than project design estimates. Density decreased and residence increased after restoration.

Detailed Outcomes: Between 2000 and 2012, nearly 290 hectares were restored to tidal inundation in the Skagit River South Fork. Post-restoration densities decreased and residencies increased. The added capacity translated into approximately 690 daily residents per restored hectare at high outmigrations. Residency significantly increased as a function of restoration ($R^2 = 0.25$, $p < 0.05$), such that a 200 ha restoration effort would result in an average increase in cohort residency of 15 days within the tidal delta. Fry migrant abundance and SAR did not seem to be influenced by restoration. Additionally, average length did not increase with restoration.

Effects Modifiers:

<table>
<tr><td colspan="2">Intervention: Various</td></tr>
<tr><td>Conditions:</td><td>Duration: Sampling has been done for 14-23 yrs on different segments of the study</td></tr>
<tr><td colspan="2">Study Design: Collect fish with downstream migrant trap, fyke net (tidal delta), beach seine (nearshore), townet (offshore), adult returns. Measure FL, calculate density and cumulative density, migrant timing, and recruits per spawner.</td></tr>
<tr><td colspan="2">Statistics:</td></tr>
</table>

Comments: This paper summarizes results from several restoration projects in one large river delta and estuary. The authors can make comparisons about outcomes based on the type of restoration completed (dike setback or removal, tide gate replacement) and compare to reference and traditionally gated marshes.

<table>
<tr><td colspan="6">Guimond, E. 2010. Courtenay River Estuary (Dyke Slough) Biophysical Assessment 2009–2010. Prepared For Living Rivers – Georgia Basin/Vancouver Island and BC Conservation Foundation, Nanaimo, BC. 39 pp.</td></tr>
<tr><td colspan="2">Keywords: tide gate upgrade salmon</td><td colspan="2">Type: Report</td><td colspan="2">Publication Date: 2010</td></tr>
<tr><td colspan="2">Include: Yes</td><td colspan="2">Reason: Docmented 'nomad' LH, conditions in estuary utilized by juvenile salmon.</td><td colspan="2">Relevance:</td></tr>
<tr><td colspan="3">Location & Species: Courtenay River estuary, BC. Dyke Slough - 2 tributariess: Glen Urquhart (4.7 km^2) and Mallard (2.8 km^2) creeks</td><td colspan="3">Ecosystem(s): marsh</td></tr>
<tr><td colspan="6">Reference Source:</td></tr>
</table>

Abstract: Paraphrased EXECUTIVE SUMMARY: Dyke Slough on the Courtenay River estuary receives inflows from 2 main tributaries – Glen Urquhart and Mallard creeks, and discharges to the estuary through floodboxes under Comox Road. Connectivity of this habitat to the estuary and its value as estuarine wetland habitat for juvenile salmonids is influenced by operation of 2 side-hinged and 1 top-hinged tide gate on the floodboxes. In 2009 a biophysical assessment of this habitat was initiated to establish baseline water quality conditions and seasonal utilization by juvenile salmonids and to guide future conservation and rehabilitation activities in the estuary. Five water quality sampling sites were monitored Aug 2009-Sept 2010. Two were located in the marsh (lower & middle), one in each of two tributaries (Mallard & Glen Urquhart Creeks) at their confluence with the marsh, and one downstream of Comox Road in the estuary. Temp was monitored using continuous recording instruments (15-30 min intervals) installed at 4 sites. Other environmental parameters were monitored during monthly (or 2X monthly) visits to each site including temp, DO, conductivity, salinity and pH. Discharge was measured periodically in tributaries further upstream from their confluence with the marsh, whereas discharge from Dyke Slough was calculated from measurements taken at the two lower elevation floodboxes (circular concrete culverts) at Comox Road. Water samples were collected at two sites in Oct 2009 and monthly from March-Sept 2010 for analysis of nutrients. Daily average water temperatures at all sites ranged from 0.7C to 28C. The warmest temperatures were recorded during summer at Site 3, located in the middle of the marsh, while Site 5 (Mallard Creek) had the coolest temperatures throughout the year. DO values at all sites averaged 5.98-9.64 mg/l with Site 5 lowest. It is suspected that groundwater seepage into Mallard Cr contributes to the cooler temps and lower DO, particularly during low summer flows which are predominantly groundwater sources. Site 3 had the greatest diurnal DO variation due to photosynthesis/ respiration of aquatic flora and fauna, reaching oxygen saturation values of 160% in summer. Water level recorders were installed downstream and upstream of the floodboxes at Comox Road to evaluate operation of the tide gates. Tide gates operate automatically as a result of water level differences upstream and downstream of the gate, closing during incoming tides and opening during ebb tides. By design, side-hinged tide gates require less force to open, thus remain open for longer periods. Water level data, recorded every 15 min, indicates that on average, duration of an OPEN cycle is ~6-8 hrs. However, tidal cycle and magnitude, and inflows upstream of the gates influence the hydraulic head differential, and therefore duration and frequency of the OPEN cycle. Water velocity and

depth through the culverts will determine suitability of conditions for upstream fish passage. Based on fish passage criteria in culverts in the literature, the opportunity for juvenile passage at the Comox Road floodboxes is generally limited to brief periods when the tide is flooding upstream through the floodboxes, before the gates close. Results from catch data (Gee trapping) indicate juvenile salmonid abundance was greatest in the lower tributaries of the slough with the highest catches occurring in Feb. No salmonids were captured at Site 3. Average length and weight of all coho captured in Gee traps was 93mm (range 46–144 mm) and 9.42g (range 0.9 – 32.1 g), respectively. High numbers of coho juveniles were captured in pools downstream and upstream of the floodboxes at Comox Road in Oct 2010. The presence of one adipose clipped coho fry (2010 hatchery release) upstream provides evidence of successful passage through the floodboxes.

Results Summary: Both Glen Urquart and Mallard creeks had measureable flow all year. Water temperature was generally between 5°C and 16°C Oct to Jun. Dissolved oxygen varied but was above the optimum survival threshhold of 8mg/L at all but one site. Salinity decreased with distance upstream. Nitrogen was below the threshhold for aquatic and animal protection. Phosphorus was higher than threshhold criteria at two sites. The tide gates only open if the low tide passes below a certain point. Between Oct 2009 and Jun 2010 the gates were open ~44% of the time. Gate open time was 0.5 to 18.75 hours per open cycle. This may influence juvenile migration but not likely adult migration. Most salmonids were collected at sites 4 and 5. None were caught at site 3. From Sep 2009 to Sep 2010 98 coho and 1 steelhead were collected. Condition factor was near or above 1 for all fish. During Oct 2010 nomad sampling more than 65 coho fry were collected below the gates and 32 were collected above. Fulton's condition factor was 0.8 to 1.64 for all fry and did not differ above and below the gates.

Broad Outcomes: Habitat Both tributaries had measurable flow all year. Flows were highest Nov - Apr in tributaries and Oct-May in Dyke Slough. T was similar at all sites mid-Oct to early Jun. Site 3 was warmest in Aug-Sep and Jun-Aug. Site 5 was coolest throughout the year with biggest differences Aug-Oct and Jul-Sep. T was generally between 5°C and 16°C Oct-Jun. Dissolved oxygen samples ranged from 1.8 to 12 .74. Average dissolved oxygen was above optimum survival threshhold (8 mg/L) at all sites except 5. Site 5 groundwater likely influenced cool T and low dissolved oxygen. Sites 1-3 were saline or brackish (conductivity 18,900 - 41,660) and 4-5 were freshwater (conductivity <266). pH ranges overlapped at all sites. Salinity decreased with distance upstream, ending in the middle marsh. Nutrients: No measure of nitrogen was higher than threshhold criteria for fish and aquatic animal protection. Phosphorus was 0.028-0.134 mg/L at site 3 and 0.02-0.051mg/L at site 4, higher than the threshhold criteria of 0.005-0.015. Discharge and velocity: The tide gates only open if the low tide passes below a certain point not reached on all tides. Oct 2009 - Jun 2010 the gates had 43 open and close cycles per month and gates were open ~44% of the time. Gate open time was 0.5 to 18.75 hours per open cycle. Means for all months were > 6 hours. However, it is not clear what proportion of that time would be suitable for juvenile migration. Adult migration is not likely to be impacted. Fish: Most salmonids were collected at sites 4 and 5. None were caught at site 3. Stickleback dominated at all sites. Prickly sculpin and Pacific staghorn sculpin were found at site 2. 98 coho and 1 steelhead were collected Sep 2009 - Sep 2010. Coho FL ranged from 46 to 144 mm, weight from 0.9 to 32.1 g, and condition factor was >1 for most fish (min 0.92) showing fish were adequatley nourished. Oct 2010 nomad sampling: collected >65 coho fry below and 32 coho fry above (1 ad marked - migrated upstream) tide gates. Nomad size and condition: Below - FL 62-107 mm, weight 2.1-13.7 g, K 0.84-1.64, Above - FL 79-113 mm, weight 5.6-17.0 g, K 0.80-1.42.

Detailed Outcomes:

Effects Modifiers:

Intervention:	
Conditions: the slough is regulated with 2 side-hinged and 1 top-hinged tide gates at the junction with Comox Road	**Duration**: 1 year
Study Design: Habitat: Logged water surface elevation and T, measured stream discharge, dissolved oxygen, conductivity, salinity, pH at all sites. At tributary outflows measured total nitrogen, ammonia, nitrate, total phosporus, ortho-phosphate, pH. Juvenile fish were collected in 15-30 minnow traps (baited, 24 hr soak) at sites 2, 3, 4, 5 bimonthly Sep - Nov 2009, monthly Feb - Sep 2010 excluding Jul. Fish were ID'd, salmonids were measured (mm) and weighed (g). Scale samples collected in Mar, Apr, Jun 2010 for age composition. Fish: Fish were beach seined at sites 1 and 2 (up and down stream of tide gates) in Oct 2010 with focus on coho nomads. All fish were ID'd and counted and all coho were inspected for marks and a subset were measured and weighed.	
Statistics: Calculated Fulton's condition factor K=(W/L3)x100,000.	

Comments: This paper provides additional evidence of the nomad life-history in juvenile coho. It also extensively documents physical characteristics of an estuary used by juvenile salmonids.

<table>
<tr><td colspan="4">Henderson R., G. Hood, E. Beamer, and K. Wolf. 2016. Fisher Slough tidal marsh restoration 2015 monitoring report. Prepared for The Nature Conservancy, contract # WA-S-150106-034-1-2. Skagit River System Cooperative, LaConner, WA. 201 pp.</td></tr>
<tr><td>Keywords: Skagit River System Cooperative website
http://skagitcoop.org/documents/</td><td colspan="2">Type: Report</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: Most recent report from this restoration site.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Fisher Slough, South Fork Skagit River, WA Chinook salmon</td><td colspan="2">Ecosystem(s): freshwater tidal wetland</td></tr>
<tr><td colspan="4">Reference Source: http://skagitcoop.org/wp-content/uploads/2015MonitorReport_Final_062316.pdf</td></tr>
</table>

Abstract: [Paraphrased from introduction] The Nature Conservancy's Fisher Slough Tidal Marsh Restoration Project has been monitored to document conditions in the original and restored freshwater tidal habitats following reintroduction of tidal hydrology and reconnection of stream floodplains on the site in order to evaluate success of restoration efforts. This monitoring report compares established baseline (pre-project) conditions with changing-project conditions, to test hypotheses derived from project objectives....In 2009, existing floodgates at the Pioneer Highway crossing were replaced with new self-regulating floodgates to allow greater tidal exchange and fish access upstream of the floodgate, while still providing flood protection to adjacent farmland. The new floodgate is designed and operated to maximize tidal exchange (i.e. open for a longer timeframe during the year) and also to improve fish access during spring migration for Chinook salmon. At the same time, a small flapgate located below the south floodgate was retrofitted with a gate that can be propped open to allow fish passage in summer when water levels drop below the floodgate sill. [The project also included ditch realignment and excavation, a levee setback and plantings. All work was completed in 2011.] Data in this report are presented for the fourth water year after restoration construction was completed.

Parameters measured include water elevations, tidal amplitudes, water temps, dissolved oxygen, vegetation cover, sediment accretion, Chinook density.

Results Summary: Tidal amplitude increased upstream of tide gates post restoration. Area inundated at MHHW increased and the inundation curves up and downstream became more similar. However, 55.7 acres were inundated instead of the expected 60 acres. The plant community changed to freshwater tidal composition covering 99.6% of the tidal floodplain. Species richness of native vegetation increased and transitioned to late succession plants - however, it remained distinct from the reference site. The area covered by reed canary grass (RCG) decreased, but at bit more was observed in 2015 than 2012 and the density of RCG did not decrease at all elevations as targeted. Total channel length, channel area, channel density, and channel depth increased.

Broad Outcomes: Tidal amplitude increased upstream of tide gates post restoration. Tidal amplitude immediately upstream of gates matched that below gates. MHHW at Nav88 >/= 8.88 ft and immediately upstream of tide gate >/= 9.5 ft. Dissolved oxygen was below 8mg/L in all years, fell below the critical level in late spring or early summer (the goal of >8mg/L may be unrealistic because tidal inundation might not be the driving force). 7-DADM T goal was exceed every year. The area inundated at MHHW increased and the inundation curves up and downstream became more similar. 55.7 ac were inundated instead of the expected 60 ac. The percent of time wetland is inundated and the area inundated at 9.5 ft NAVD88 increased. Mean sedimentation rates were positive and more pins showed accretion than erosion by 2015. Plant community changed to freshwater tidal composition covering 99.6% of the tidal floodplain. Species richness of native plants increased and transitioned to late succession plants - however it remained distinct from the reference site. Vegetation elevation ranges in 2015 were similar to target. The area covered by reed canary grass (RCG) decreased, however at bit more was observed in 2015 than 2012. RCG density did not decrease at all elevations, as targeted. Percent cover of RCG was not measured in 2015. Total channel length, area, channel density, and channel depth increased. Relative Chinook juvenle density above floodgates increased. Density and connectivity were within the scatterplot of long-term monitoring sites by 2015. Floodgate doors were open 5 deg once a day on most but not all days Oct-Feb. After sill removed at Big Ditch the channel was deeper with a more natural profile. Flood storage increased by 245 acre-feet.

Detailed Outcomes:

Effects Modifiers: Sedimentation rates may not be accurate because not all stakes stayed upright.

Intervention: Replaced tide gates with self-regulating gates. Re-routed big ditch, filled old ditch channel. Built new dike farther back, removed old dike. Excavated new tidal channels.	
Conditions: goal is to evaluate success of restoration treatment	**Duration**: 12 months
Study Design: Measured surface and ground water levels, dissolved oxygen, T, vegetation, marsh elevation, channel cross-section. Monitored fish.	
Statistics:	

Comments: Earlier reports suggest that the dike setback had more positive influence than gate replacement, but new gate is self regulating and does remain open longer. This report focuses on tidal amplitude, inundation, and plant community composition. Beamer et al. 2016, which also reports on the Fisher Slough restoration, focuses on juvenile Chinook population abundance and response to environmental factors.

<table>
<tr><td colspan="4">Hering, D.K. 2010. Growth, residence, and movement of juvenile Chinook salmon within restored and reference estuarine marsh channels in Salmon River, Oregon. M.S. Thesis, Department of Fisheries & Wildlife, Oregon State University, Corvallis, OR 164 pp.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td colspan="2">Type: M.S. thesis</td><td>Publication Date: 2010</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: Directly focused on review questions.</td><td>Relevance: Moderate</td></tr>
<tr><td colspan="2">Location & Species: Salmon River estuary, Oregon; Chinook</td><td colspan="2">Ecosystem(s): blind tidal channel (generally no subsurface water - dries in between tidal cycles or has distinct wetted pools)</td></tr>
<tr><td colspan="4">Reference Source: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/14097/HeringDavidK2010.pdf?sequence=1</td></tr>
</table>

Abstract: Tidal wetland channels provide rearing habitat for juvenile Chinook salmon as they emigrate from freshwater habitat and prepare to enter the ocean. Widespread diking and drainage of estuarine marshes for agricultural and urban development may have contributed to a decline in salmon abundance in the Pacific Northwest, prompting efforts to restore estuarine salmon habitat in the region. I investigated the growth and residence patterns of age-0 Chinook salmon in two blind tidal channels in the Salmon River estuary, Oregon. One channel drained a natural high salt marsh in "reference" condition, and the other channel was in an adjacent salt marsh, restored to tidal inundation in 1996 after being diked and controlled by a tide gate for thirty five years. Recapture of individually marked fish indicated salmon growth rates were similar in the two channels, though growth rates varied more seasonally in the restored site. Average minimum residence times of individual fish were approximately ten days in each channel, and individual salmon were observed up to 79 and 117 days after initial marking in the reference and restored channels, respectively. To characterize movement of age-0 salmon within tidal channels, I tested the feasibility of stationary Passive Integrated Transponder (PIT) detection within a small (approximately 8m wide) tidal channel within the natural marsh system. I found that a stationary PIT detector was an effective tool for monitoring tagged fish movement in a brackish water channel network. Salmon movements in the channel were asymmetrical about high slack tide, with peak movement frequency occurring late during both flood and ebb tide periods. Most movements were in the direction of tidal currents, but 20% of individuals entered the channel against the ebbing tide. Individuals occupied the intertidal channel for a median 4.9 hours and as long as 8.9 hours per tidal cycle, and few were detected moving when water depth was <0.4m. Some individuals used the channel on multiple successive tidal cycles, and others entered intermittently over periods up to 109 days. This research used individual-based fish marking methods to quantify juvenile Chinook salmon behavior and performance within tidal marsh channels, assessing functional equivalence of natural and restored sites and demonstrating the value of such habitats for conservation and restoration of salmon populations.

Results Summary: Peak CPUE was late May/early Jun 2003 and late Jun/early Jul 2004, before peak temps and increased salinities for both reference and restored channels, although Chinook were collected into the fall in both sites. Growth, condition, and residence time did not differ significantly between the channels. Density was higher closer to the tidal refuge of the mainstem. 7-9 years after dike breaching and tide gate removal the marsh seemed to be functionally equivalent to the reference marsh in terms of growth, residence and density. However, with lower abundance smaller fish. In 2004 fish growth was modeled using bioenergetics. Measured growth was lower than modeled growth. The authors argue that models are good for comparing growth potential but not realized growth and may not make accurate predictions of growth.

Broad Outcomes: Peak CPUE was late May/early Jun and late Jun/early Jul in 2003 and 2004. Both before peak temps and increased salinities although Chinook were collected into the fall in both channels. Growth, condition, and residence time did not differ significantly between the channels. Density was higher closer to the tidal refuge of the mainstem. 7-9 years after dike breaching and tide gate removal the 1996 marsh seemed to be functionally equivalent to the reference marsh in terms of growth and residence. However, abundance was lower (smaller size too though), the fish were smaller in one year but densities were similar. ****in 2004 fish growth was also modeled using bioenergetics. The actual measured growth was lower than modeled growth. Therefore, models may be good for comparing actual growth potential but not realized growth and may not make accurate predictions of growth.

Detailed Outcomes: Chinook were present Apr/May - Aug/Sep but CPUE was low after mid-Jul (water temp peaked then). CPUE was negatively correlated with the distance from the main stem river during peak abundance. In 2004, peak abundance and density were estimated as 1812 fish and 0.09 (95% CI 0.01 - 0.16) fish/m^2 in the reference and 563 fish and 0.04 (95% CI 0.01 - 0.07) fish/m^2 in the 1996 marsh. Water temperature increased throughout the sampling season. Reference: surface T ranged from 10.5 to 23 C at all sites and bottom T ranged from 9.2 to 18.9 C at high tide. Difference between surface and bottom generally greater. 1996: surface temps ranged from 9.5 to 23 C, bottom temps were 10.8 to 21.1 C. Salinity varied with the tidal cycle and rainfall, and generally increased through the summer but not consistently greater than 10 C until early Jul. Salinity was often 2 to 3 PSU greater in the reference marsh - likely because it was closer to the ocean. Fish were almost always recaptured in the channel where they were tagged (3 fish, <0.01%, switched) so growth attributed to channel. Growth was not significantly different between channels or among years but in 2004 (the best sampled) FL averaged 6.5 mm less. Individual PIT growth ranges: -1.31 - 2.10 mm/d; biomass growth -2%/d to 4.2%/d (1996marsh) and to 11%/d (reference). Condition was similar between channels in all years. Median measured residence in the reference marsh were 3d, 10d, and 8d in the 3 years. 1996 only measured in 2004 - 10d median residence. Longest residence: reference - 79d, 1996 - 117d (both 2004).

Effects Modifiers: Abundance estimates were likely postively biased because the populations were not closed as assumed; however, effect should be same in both channels. Growth calculations excluded recaptures after </= 48 hours. CPUE was positively correlated with abundance estimators. Differences in capacity or rearing potential are influenced by landscape position and land use/restoration history. Rearing capacity may be additive at the estuary level with additional marsh restoration creating habitat for additional cohorts.

Intervention: tide gate removal some years prior, compared to a reference never gated marsh	
Conditions: the restored marsh was diked for 35 years but by the time the study was undertaken a native salt marsh plant	**Duration**: 3 years

community was forming.	
Study Design: Sites within each channel were beach seined at high tide. Sampling frequency was highest and most even in 2004. Fish (naturally-produced) were collected and counted. 2003: 195 >/= 60mm in reference were weighed, measured, and PIT-tagged; 2004: all fish weighed and measured, 671 in reference and 319 in restored PIT-tagged; 2005: all reference fish weighed and measured, 569 PIT-tagged. Surface temperature, and salinity were recorded at each seining site at each sampling. Water temp was logged continuously in each channel.	
Statistics: CPUE=relative abundance - spatial and temporal distribution. Abundance estimates: maximum likelihood Lincoln-Peterson estimator (program NOREMARK). Population level growth was calculated as the slope of the regression of length or weight on time and the change in size from first to last capture of PIT-tagged fish. Fish condition was estimated as the slope of the regression of logWeight on logLength. PIT data was used to calculate growth rates in length (mm/d), weight (g/d), and specific growth rate (%biomass/d). In 2004 growth was estimated for 2-wk intervals also. The median minimum residence time in a channel was used as an index of residence time. Report maximum time between first and last capture in each channel.	

Comments: No data before restoration except the plant community description. Chapters 2 and 3 of this thesis are individual papers. Only chapter 2 includes data from a previously diked and gated marsh and contains the data I have summarized here.

<table>
<tr><td colspan="3">Johnson, J. and T.A. Whitesel. 2012. Julia Butler Hansen National Wildlife Refuge: Post-Construction Assessment of Fishes, Habitats, and Tide Gates in Sloughs on the Mainland. Draft 2011 Annual Report. U.S. Fish and Wildlife Service Columbia River Fisheries Program Office, Population & Habitat Assessment Program, Vancouver, WA. 30 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: Annual report. (Copy on file is listed as "draft".)</td><td>Publication Date: 2011</td></tr>
<tr><td>Include: Yes</td><td>Reason: Directly relevant to question of tide gate replacement.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Mainland sloughs at Julia Butler Hansen NWR, lower Columbia River; juvenile Chinook, coho and chum salmon</td><td>Ecosystem(s): Columbia River estuary</td></tr>
<tr><td colspan="3">Reference Source: https://www.salmonrecovery.gov/Files/2011%20APR%20files/
New%20Folder%203/Johnson_and_Whitesel_2012_JBH_NWR_2011Monitoring.pdf</td></tr>
</table>

Abstract: GOAL: The primary goal of this study is to assess the effect of habitat restoration on fish, fish communities and aquatic habitat at Julia Butler Hansen National Wildlife Refuge. Habitat restoration is focused on replacement of traditional style tide gates with side-hinged, self-restrained tide gates and installation of these new style tide gates at sloughs without connection to the Columbia River.

OBJECTIVES

1. Assess the periods, frequency, and duration that tide-gates (as presently configured, after modifications, and newly installed) are conducive to passage by juvenile and adult salmonids, specifically during October-June.

2. Describe presence, distribution, and biological characteristics (e.g., species, size) of fish inhabiting mainland sloughs at Julia Butler Hansen NWR (pre-and-post construction) and compare to that observed at reference sloughs.

3. Characterize habitats of mainland sloughs at Julia Butler Hansen NWR and compare to that observed at reference sloughs (pre-and post-construction).

4. Quantify changes in fish community and habitat quality with the re-introduction and/or improvement of the return of tidal exchange.

Results Summary: Juvenile salmonids: Chinook, coho, chum, cutthroat, were collected in all reaches of all sloughs except mid Indian Jack, which was previously closed. More juvenile salmon were collected in a greater number of reaches of previously closed sloughs after tide gates reconnected access. The similarity index increased in previously closed sloughs relative to both control and reference sloughs. However, for sloughs with replacement tide gates the similarity indices did not increase relative to reference or control sloughs. There were no differences in dissolved oxygen among individual sloughs, but when grouped dissolved oxygen was higher in reference sloughs than in either treament. Dissolved oxygen was above critical levels in all sloughs.

Broad Outcomes: Passage: 532 juvenile coho and Chinook were caught entering a gated previously closed and a reference slough. Stickleback most abundant, juvenile Chinook 2nd. Community: 5710 fish in 25 taxa collected. Juvenile salmon (including Chinook, coho, chum, cutthroat trout) were collected in all reaches of all sloughs except mid Indian Jack (prev closed) and 3 of 5 reaches in closed control. More juvenile salmon were collected and in more reaches of previously closed sloughs post-contruction. The similarity index increased post-construction in previously closed compared to reference and control sloughs. There was no similarity index increase in previously gated sloughs compared to reference or controls. Habitat: Dissolved oxygen did not differ among individual sloughs; when grouped dissolved oxygen was higher in reference sloughs than treatment. Dissolved oxygen was not below critcal levels in any slough.

Detailed Outcomes:

Effects Modifiers: All gated and closed sloughs were on the mainland and all ungated sloughs were on islands. Data are from 2 years pre and 2 years post restoration. Variable catches and weather make it difficult to make conclusions about treatments.

Intervention: Replaced top-hinge tide gates with side-hinged self-restrained aluminum tide gates at 3 sloughs. Installed side-hinged self-restrained aluminum tide gates at 3 closed sloughs with no current connection to the Columbia River. One gated and one closed slough had no treatment, and 2 reference sloughs were monitored.	
Conditions:	**Duration**: 4 months
Study Design: Compare habitat conditions, fish communities in treatment sloughs to control and reference sloughs before and after treatment. Each slough was divided into 50- or 25-m reaches. Sampling order randomized, all surveyed twice. Passage was determined with hoop nets. Community and distribution measured with beach seine. Fish ID'd, counted; salmonids weighed, measured, examined for marks, scanned for PIT-tags. Measured dissolved oxygen, conductivity.	
Statistics: Calculated Sorensen Similarity Index for seine data 2007-2011 to compare fish community among sloughs grouped by slough type.	

Comments: This is an interesting study because it looks at tide gate replacement and tide gate insertion. Replacement of top-hinge gates with side-hinge self-restrained gates did not provide positive benefit for fish or habitat. However, positive results were seen in sloughs with newly installed gates that had been previously completely disconnected.

<table>
<tr><td colspan="3">Johnson, J., S. Ennis , J. Poirier, and T.A. Whitesel. 2008. Lower Columbia River Channel Improvement: Assessment of Salmonid Populations and Habitat on Tenasillahe and Welch Islands. 2008 Project Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Population & Habitat Assessment Program, Vancouver, WA. 40 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: 2008 Project Report</td><td>Publication Date: 2008</td></tr>
<tr><td>Include: Yes</td><td>Reason: Directly relevant to question of tide gate replacement.</td><td>Relevance: High</td></tr>
<tr><td colspan="2">Location & Species: Lower Columbia River estuary, rkm 56, Welch (reference) and Tenasillahe (diked and gated) Islands</td><td>Ecosystem(s): tidal estuary wetland Tenasillahe: 2 interior sloughs connected to Columbia R with tide-gated channels Welch: pristine wetland habitat, no evidence of human alteration</td></tr>
<tr><td colspan="3">Reference Source:
https://www.fws.gov/columbiariver/publications/Johnson_Tenasillahe_Welch_2008.pdf</td></tr>
</table>

Abstract: [From introduction] In an attempt to improve conditions for fish, in 2007 the U.S. Army Corps of Engineers (USACOE) replaced the three top-hinge steel tide gates controlling tidal action on the largest Tenasillahe Island slough with side-hinge aluminum gates equipped with a manually controlled fish orifice. This action was to improve aquatic habitat conditions and to improve fish passage for juvenile salmonids while balancing the needs of the endangered white-tailed deer found on the island. It is unclear whether these modifications will result in improved fish passage into and out of the sloughs or in changes to aquatic habitat conditions. The U. S. Fish and Wildlife Service, Columbia River Fisheries Program Office (CRFPO) is evaluating this project with the goal of assessing the effects of the USACOE restoration actions at Tenasillahe Island. This project will compare slough conditions in Tenasillahe Island sloughs before and after restoration and among treatment and reference sites in Welch Island sloughs. Pre-construction assessment began in 2005. Activities associated with this assessment provided insights into logistical constraints such as access to sample sites and fish sampling methods amenable to conditions within the sloughs. Data collected March through June 2006 and March through May 2007, before gates were replaced, show elevated gated slough water temperatures, more non-native species present in gated sloughs, and limited opportunity for juvenile salmonids to enter gated sloughs. Activities in 2008 focused on collecting post-construction data needed to assess effects of the new tide gates. The following objectives were addressed during 2008 field season: 1. Assess fish passage conditions; 2. Describe fish distribution among treatment and reference sloughs; 3. Characterize aquatic habitats of treatment and reference sloughs; 4. Measure juvenile salmonid growth rate and residence time in treatment and reference sloughs.

Results Summary: Replacement side-hinged tide gates opened on 64% of the low tides and were open an average of 3.4 hour per opening. No salmon were collected entering Large Tenasillahe Slough, however juvenile Chinook and coho were caught exiting the slough. PIT-tagged fish released in LTS remained throughout the summer and grew well. Water quality differed for some factors and was similar for others. Gated sloughs had higher water temperature, lower percent dissolved oxygen, and more emergent aquatic vegetation. However, pH was similar in all sloughs and turbidity and transparency ranges overlapped. Conductivity was similar among sloughs except Large Tenasillahe Slough, which had much higher values. The reference sloughs on Welch Island had larger proportions of native species.

Broad Outcomes: Passage: 12 species entered LTS (no salmonids). 13 species exited LTS (including Chinook and coho). Community structure: 48,879 fish, 20 species collected. 99.4% of fish were native species. 255 salmonids captured - 231 Chinook (85% not ad-clipped), 23 chum, and 1 steelhead 7-DADM reached 16C twice in all sloughs between Mar 20 and Jul 10 (with decrease between - remained above for total of 47d in LTS and STS, 26d in LWS and 24d in SWS. 65.6% of PIT-tagged fish released were detected leaving LTS. Gated sloughs have higher water T, lower dissolved oxygen, and more emergent aquatic vegetation. PIT-tagged fish released in LTS remained throughout the summer and grew well.

Detailed Outcomes: Replacement tide gates opened 64% of the low tides and were open an average of 3.4 hr/opening. (Avg of 1.3 opening/d, 4.4hrs open/d). 3-spine stickleback dominated species entering LTS (78.6% and 89% of two traps) and no salmon. 3-spine stickleback comprised 92% fish exiting LTS, 27 Chinook (12 PIT-tagged) and 1 coho exited. Community: Native species - LWS: 8/10, SWS: 8/9, LTS: 5/12, STS: 3/8. Water Quality: LTS and STS (gated) had smaller T ranges than LWS and SWS (reference). LTS also had a smaller T range than STS (but not sig). Percent dissolved oxygen ranges overlapped in gated and reference sloughs. Conductivity was higher in LTS (2700 uS) than in other sloughs (128.9 uS - 167.2 uS). pH was 6.19-8.04 in all sloughs. Turbidity was higher in LTS (10-40 JTU), but overlapped other sloughs (5-10). Transparency was slightly higher in reference sloughs but all ranges overlapped. Habitat: Silt dominated all reaches. Reference sloughs predominantly shrub and forb-grassland. STS was shrub and trees, LTS was grassland-forb and shrub. LTS and STS cover dominated by aquatic veg. LWS and SWS cover provided by overhanging trees/shrubs and woody debris. Residence was 1-119d, median 41d to 45d for 4 release groups, 64-67% were detected leaving. 43% of total had one detection. Time between 1st and last detection ranged from 1 to 61.5d. 150 fish had detections >24hrs apart. 10 recaptures were in culvert fyke traps and growth rate was 1.29 - 1.62 mm/d and 0.51 - 0.79 g/d. Growth rates of penned fish were lower (-0.07-0.12 mm/d in LWS and 0.02-0.26 in LTS - sig higher in LTS).

Effects Modifiers:

Intervention: Tenasillahe: Replaced three top-hinge steel tide gates on the larger slough with side-hinge aluminum tide gates with a manually controlled fish opening. The smaller slough retains its single top-hinged steel tide gate	
Conditions: Attempt to improve fish passage and habitat while maintaining habitat for endangered Columbia white-tailed deer	**Duration**: 3years
Study Design: 25-m transects in a large and small slough on each of Tenasillahe and Welch Islands. Large Tenasillahe Slough (LTS): 8, Small Tenasillahe Slough (STS): 3, Large Welch Slough (LWS): 5, Small Welch Slough (SWS): 2 Calculated water level differential needed to open the gates, then used to estimate total openings and durations. Fyke nets were installed to capture incoming (2 gates) and outgoing (1 gate) fish in LTS. Fish were identified and counted, and salmonids were measured. Fyke nets and beach seines were used in all reaches of all sloughs to determine fish community composition. Seine area size was estimated to quantify effort. All fish were identified and counted. Salmonids were measured and weighed and those >60mm were scanned for a PIT-tag. Habitat data	

(water T, atmospheric pressure, dissolved oxygen, specific and relative conductivity, pH, turbidity, water transparency, wetted width, mean depth, substrate, riparian vegetation, percent shade, and physical channel cover) were recorded for each site once Mar-Apr and once May-Jun. In reference and gated sloughs water temp and depth were recorded hourly in lowest and highest reach and temp only was recorded in the middle reach. 7-DADM for temperature were calculated. Residence time was determined by releasing 1500 (LWS) and 1000 (LTS) PIT-tagged sub-yr fall Chinook, which were recaptured with seining, fyke traps, and PIT antennas. To compare growth rates and survival PIT-tagged fish were held in enclosures in 3 reaches each of LWS and LTS for 1.5 months (50 fish/reach).
Statistics: BACI, tested for sig diff in mean percent dissolved oxygen using ANOVA with Bonferroni multiple comparisons.

Comments: This report describes one of the few tide gate replacement projects in the Columbia River Estuary. It is also useful because it does not include other restoration actions. The effects are all related to the tide gate treatment. This is an example of other 'uses' requiring less change - the Columbia White tail deer habitat on the island needs to be maintained and protected.

Johnson, G.E., N.K. Sather, A.J. Storch, J. Johnson, J.R. Skalski, D.J. Teel, T. Brewer, A.J. Bryson, E.M. Dawley, D.R. Kuligowski, T. Whitesel, and C. Mallette. 2013. **Multi-Scale Action Effectiveness Research in the Lower Columbia River and Estuary, 2012.** PNNL-22481, final annual report submitted to U.S. Army Corps of Engineers, Portland District, Portland, OR, by Pacific Northwest National Laboratory, Richland, WA. 172 pp.			
Keywords: N/A	**Type**: Final report		**Publication Date**: 2013
Include: Yes	**Reason**: Salmon presence and water T data from several sloughs after replacement with two types of side-hinge gates.		**Relevance**:
Location & Species: Columbia River estuary		**Ecosystem(s)**:	
Reference Source: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22481.pdf			

Abstract: The study reported herein was conducted for the U.S. Army Corps of Engineers, Portland District by researchers at the Pacific Northwest National Laboratory (PNNL), National Marine Fisheries Service (NMFS), Oregon Department of Fish and Wildlife (ODFW), University of Washington (UW), and U.S. Fish and Wildlife Service (USFWS). The goal of the study was to evaluate the ecological benefits of restoration actions for juvenile salmon in the lower Columbia River and estuary (LCRE; rkm 0–234). This multi-year study (2011–2018) addresses the ecological benefits of restoration actions at multiple spatial scales over time. The spatial scales include the 1) site scale as a result of an individual project, 2) landscape scale as a result of multiple restoration actions located within a ~50-km segment of the LCRE, and 3) estuary scale as a result of the cumulative effects of multiple restoration actions estuary-wide. 2012 Objectives: Objective 1, Site Scale – a) Continue pre-restoration action effectiveness research to evaluate effects of the upcoming dam removal/rechannelization at the Sandy River delta; b) continue post-restoration action effectiveness research to evaluate effects of the tide gate replacements at the Julia Butler Hansen National Wildlife Refuge (JBHNWR) mainland and Tenasillahe Island.Objective 2, Landscape Scale – a) Estimate juvenile salmon density in shallow water habitats between St. Helens and Longview (rkm 110–141); b) estimate residence time for tagged juvenile Chinook salmon during winter 2012 in Carroll's Channel behind Cottonwood Island.Objective 3, Estuary Scale – Prepare a compendium of tag release-recapture technologies to inform planning for future action effectiveness studies.

[TIDE GATE RELATED FINDINGS] Comparison of the presence and distribution of fish inhabiting mainland and Tenasillahe Island sloughs at JBHNWR to those observed at reference sloughs showed that 1) juvenile salmon had increased access to sloughs after installation of self-regulating tide gates at JBHNWR, and 2) juvenile salmon were captured in more treatment sloughs after self-regulating tide gates were installed. Water temperatures of sloughs at JBHNWR were similar to reference sloughs with 7-DADM exceeding 18°C in the same months and at similar cumulative days.

Results Summary: Installation of side-hinged, self-restrained tide gates improved fish passage and distribution, and water quality at Julia Butler Hanson National Wildlife Refuge. Juvenile salmon were collected in all reaches in all reference, gated, and control sloughs after hydrologic connectivity was restored. Pre-restoration, juvenile salmon were only caught in reference sloughs. At Tenasillahe Island replacement of top-hinged gates with side-hinged tide gates with manual fish orifices did not improve fish passage or water quality. There were no differences in temperature pre- and post- replacement. No juvenile salmon were collected in gated sloughs.

Broad Outcomes: Side-hinged, self-restrained tide gate installation improved fish passage and distribution, and water quality at JBHNWR. Side-hinged tide gates with manual fish orifice did not improve fish passage or water quality at Tenasillahe Island.

Detailed Outcomes: Ch 3 JBH: 26,004 fish (21 taxa) were collected. 22,832 (87.8%) were stickleback. In reference 82% of species were native, in gated sloughs 50% were native, at control sites 47% were native. Juvenile salmon were collected in all reaches in all reference, gated, and control sloughs. Mostly Chinook (684), and coho (126), but some chum (3) were collected in May. 7-DADM T was below 18°C threshhold until May in all sloughs, Jun in Winter, and Jul in Indian, South Hunting, and Ellison. T remained high through Aug and Sep in all sloughs and into Oct for Winter, South Hunting, and Steamboat. Tenasillahe: 10,930 fish (18 taxa) collected, 9947 (91%) stickleback. In reference 80% of species were native, in gated 38% were native. No juvenile salmon were collected in gated sloughs. In Welch reference sloughs Chinook (121) and coho (1) were collected. Appendices - pre-and post-restoration data: JBH Pre-restoration water T surpassed 18°C later in the season in reference sloughs. In 2007 reference sloughs had more salmon species (chum not collected in closed or gated sloughs). Reference: 66 Chinook, 1 chum, 3 coho; Gated: 87 Chinook, 12 coho; Closed: 1 Chinook, 1 coho. Gated and closed had more species, especially non-natives. 2010 fish community: 3430 fish caught in Control (22 Chinook, 2 chum, 9 coho), 6773 fish caught in gated (314 Chinook, 2 chum, 41 coho), 4590 fish collected in Reference (62 Chinook, 18 coho). Tenasillahe: Pre-restoration water T surpassed 18°C earlier in May at Tenasillahe than Welch. Relative abundance and %native species were higher in Welch sloughs. Salmon were never collected in Large Tenasillahe when tide gate was operating. In Welch sloughs 270 Chinook, 6 chum, and 1 coho were collected. Post-restoration no difference in water T. 2008 fish community: Large Tenasillahe: 475 fish (2 Chinook), Small Tenasillahe 447 fish (0 salmon). Large Welch 35,428 fish (175 Chinook), Small Welch 12,529 fish (54 Chinook, 1 Sthd). Large Tenasillahe gate only opens when water is higher in slough (~20% of time) and fish have to swim against the flow.

Effects Modifiers:

<table>
<tr><td colspan="2">Intervention: JBHNWR: In 2009 two sloughs were reconnected to the Columbia River with culverts and side-hinged gates, one top-hinge aluminum gate at Brooks was replaced with a side-hinge aluminum gate. Tenasillahe: in 2007 three top-hinge steel gates were replaced with three side-hinge aluminum gates in Large Tenasillahe Slough.</td></tr>
<tr><td>Conditions:</td><td>Duration: 10 months</td></tr>
<tr><td colspan="2">Study Design: Ch 3 Fish were collected in beach seines, counted, measured, and weighed (stickleback not measured and weighed). Recorded T and calculated 7-day maximum daily average.</td></tr>
<tr><td colspan="2">Statistics:</td></tr>
</table>

Comments: Chapter 3 is pertinent to our questions. Data from Tenasillahe and Welch are in Johnson et al. 2008 but the data presented here was collected in 2012 and 2013. The other chapters are not summarized here.

Jones, K.K., T.J. Cornwell, D.L. Bottom, L.A. Campbell, and S. Stein. 2014. **The contribution of estuary-resident life histories to the return of adult *Oncorhynchus kisutch*.** Journal of Fish Biology 85(1): 52-80.		
Keywords:	**Type**: Peer-reviewed	**Publication Date**: 2014
Include: Yes	**Reason**: Indirectly related to our study questions. In an estuary we included already.	**Relevance**:
Location & Species: Salmon River and estuary, coho salmon	**Ecosystem(s)**: stream tributary, mainstem river, estuary	
Reference Source: http://onlinelibrary.wiley.com/doi/10.1111/jfb.12380/abstract;jsessionid=F1DAF908C95B8AF1D9C2226CB2FA329D.f02t04		

Abstract: This study evaluated estuarine habitat use, life-history composition, growth and survival of four successive broods of coho salmon Onchorynchus kisutch in Salmon River, Oregon, U.S.A. Subyearling and yearling *O. kisutch* used restored and natural estuarine wetlands, particularly in the spring and winter. Stream-reared yearling smolts spent an average of 2 weeks in the estuary growing rapidly before entering he ocean. Emergent fry also entered the estuary in the spring, and some resided in a tidal marsh throughout the summer, even as salinities increased to >20. A significant portion fo the summer stream-resident population of juvenile *O. kisutch* migrated out of the catchment in the autumn and winter and used estuary welands and adjacent streams as alternative winter-rearing habitats until the spring when they entered the ocean as yearling smolts. Passive integrated transponder (PIT) tag returns and juvenile life-history reconstructions from otoliths of returning adults revealed that four juvenile life-history types contributed to the adult population. Estuarine-associated life-history strategyies accounted for 20-35% of the adults returning to spawn in the four brood years, indicating that a sizable proportion of the total *O. kisutch* production is ignored by conventional estimates based on stream habitat capacity. Juvenile *O. kisutch* responses to the reconnection of previously unavailable estuarine habitats have led to greater life-history diversity in the population and reflect greater phenotypic plasticity of the species in the U.S. Pacific Northwest than previously recongnized.

Results Summary: Overwinter habitat was generally low except in a few areas in the same sections of high spawner abundance. Spawning, freshwater rearing, and quality overwinter habitat were concentrated in the upper Salmon and Little Salmon rivers and Bear Creek. Summer juvenile abundance and density increased with spawner abundance. Juvenile size was similar among years and did not vary with abundance. Juveniles demonstrated 4 migrant patterns and these 4 patterns were present in the adult spawners that returned (all as 3 year olds). Three of the rearing patterns included estuary residence: fry migrants, fry-nomad migrants, and parr migrants. These three life history strategies together comprised 20-35% of the returning spawner population. Based on PIT detections survival rates could be calculated for some groups: fry migrants - 1.5%, parr migrants - 3.2%, yearling migrants - 4.4%. Growth rates in the estuary were high compared to the freshwater habitats. The authors argue that estuarine habitat restoration has increased the productivity of the population by increasing off-channel rearing opportunities which the coho population has responded to by expressing estuarine-dependent life-history strategies. The authors also mention that production models that do not consider the contributions of estuarine rearing may be missing a portion of the population. Multiple life-history strategies also increase the resilience of a population.

Broad Outcomes: Spawning, freshwater rearing, and quality overwinter habitat were concentrated in the upper Salmon and Little Salmon rivers and Bear Creek. Juvenile size was similar among years and did not vary with abundance. Juveniles demonstrated 4 migrant patterns and these 4 patterns were present in the adult spawners that returned (all as 3 year olds). Three of the rearing patterns included estuary residence: fry migrants, fry-nomad migrants, and parr migrants. These three life history strategies together comprised a fifth to a third of the returning spawner population. Based on PIT detections survival rates could be calculated for some groups: fry migrants - 1.5%, parr migrants - 3.2%, yearling migrants - 4.4%. Growth rates in the estuary were high compared to the freshwater habitats. The authors argue that estuarine habitat restoration has increased the productivity of the population by increasing off-channel rearing opportunities which the coho population has responded to by expressing estuarine-dependent life-history strategies. The authors also mention that production models that do not consider the contributions of estuarine rearing may be missing a portion of the population. Multiple life-history strategies also increase the resilience of a population.

Detailed Outcomes: Adults: Spawning occurred mid-Sep to early Jan and peaked in Nov. Most spawning was in upper main-stem Salmon and Little Salmon rivers and Bear Creek. Juveniles: Summer juvenile abundance and density increased with spawner abundance. Juvenile abundance was high in the upper Salmon River and Bear Creek, two of the spawning concentrations. Freshwater fork length was 42-109 mm in all years and mean size was 70.6 0 76.7 mm. Juveniles were significantly larger in 2008, the year with lowest densities, and smaller in 2011, although density was not much higher in that year and years with higher densities also had larger mean sizes. Overwinter habitat was generally low except in a few areas in the same sections of high spawner abundance. Juvenile Outmigration: Age 0 migrated Mar-Jun and late-Sep. Age 1 outmigration began in Mar and peaked in Apr or May. Age 1 migrants were 63 -151 mm, averaging 104mm. Up to 40% of the summer coho population may have moved to the estuary in the winter when the trap was not operated. Estuary Rearing and Growth: Age 0 spring migrants resided in the estuary 31 - 147 d. Age 0 fall migrants were detected for 6 days but some were detected again in spring, evidence of overwintering. Nearly all Age 0 were caught in the upper and mid estuary. Fish growth was higher in the estuary than upriver and this difference was significant in winter. Age 1 migrants were collected in all areas of the estuary. Their estuary residence was 2 - 34 d, average 13 d. 27% were detected in the marsh outfitted with a PIT array. Life-History Diversity: PIT and juvenile otolith data showed 4 migrant types: yearling, fry, fry-nomad, parr. 18% of the otoliths were fry-nomad and parr migrants. Nomads estuary entry size was 60mm median and parr migrants entered at median 97 mm and resided for up to 101 d. Juvenile Rearing Patterns of Returning Adults: yearling migrants comprised 65-80% of the spawner population and combined Age 0 migrants contributed 20-35%.Fry, fry-nomad, and parr migrants were represented. Survival rates: fry migrant - 1.5%, parr-migrant - 3.2%, yearling - 4.4%.

Effects Modifiers:

Intervention: >175 ha total of estuary habitat have been restored. Over 35 years > 2/3 of diked welands were restored with dikes and tide gates removed.	
Conditions: USFS manages the estuary as part of the Cascade	**Duration**: 4 yrs

Head Scenic Research Area and spearheaded the first restoration	
Study Design: Spawning surveys were conducted at sites in 15-20% of available habitat at least every 10d. Otoliths were collected from natural origin spawners. A PIT antenna recorded tagged adult and juvenile migrants. Juveniles were sampled with backpack electrofishers, abundance was standardized to fish per m or km. Coho were counted, measured, and weighed. Individuals >65 mm (71-79%) were PIT tagged. Downstream migrants were screwtrapped and those > 65 mm were PIT tagged. Rearing capacity was estimated for summer and winter periods. Estuary residents were beach seined in mainstem and wetland channel habitats twice monthly. Separate sampling was done to monitor ocean entry Apr - Nov.	
Statistics: Spawner abundance was estimated for the entire available habitat using AUC. Age 0 rearing abundance was determined with the LNB estimator then expanded to spawning and rearing habitat in the basin. Fish size and timing at trapping were representative of estuary entry because of the nearness to the estuary. PIT detections were used to determine residence time, growth, migration time, juvenile to adult survival, and spawner age. Size and growth differences by year and location were analyzed with ANOVA and Dunnett-Tukey-Kramer pairwise multiple comparisons. Juvenile migration histories of spawning adults were determined using otolith Sr:Ca. Juvenile sizes and timing of ocean entry were calculated from juvenile otoliths collected at the estuary mouth. Sr:Ca increase relative to annulus formation was used to determine season of estuary/ocean entry. Spawner age was determined from scale analysis.	

Comments: This paper describes the presence and contribution of 4 life-history strategies. Three of them are estuary dependent and are expressed in response to estuary restoration. This restoration was described in other studies we included. This study is especially helpful because it describes the life-history variation in the juveniles and then demonstrates the existence of all 4 strategies in the returning adult population.

<table>
<tr><td colspan="4">Koski, K.V. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society 14(1): 4.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td colspan="2">Type: Peer-reviewed journal article</td><td>Publication Date: 2009</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason:</td><td>Relevance: Low</td></tr>
<tr><td colspan="2">Location & Species: Review summary, coho salmon</td><td colspan="2">Ecosystem(s):</td></tr>
<tr><td colspan="4">Reference Source: http://www.ecologyandsociety.org/vol14/iss1/art4/</td></tr>
</table>

Abstract: 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. Chinook and sockeye salmon have developed the ocean-type life-history strategy to exploit the higher productivity of the estuarine environment and migrate to the ocean at age 0. 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.

Results Summary: Nomads (age-0 coho migrants) migrate downstream and use the estuary similarly to age-0 Chinook and sockeye but overwinter in freshwater tributaries including non-natal streams. Coho cannot survive direct migration to ocean salinities but do survive and grow in some estuarine salinities. Nomad migration increases the available rearing area, food, and growth potential for coho populations and increases overall productivity. However, it is difficult to determine nomads' contribution to the population because freshwater and estuarine growth are not readily distinguishable in scales. Recommends reconnecting freshwater/estuarine habitats by removing tide gates and dikes to allow these kinds of up and downstream migrations.

Broad Outcomes: Nomads (age-0 coho migrants) likely migrate downstream in response to carrying capacity being met. They use the estuary similarly to age-0 Chinook and sockeye but overwinter in freshwater tributaries. Coho may overwinter in non-natal streams (moving upriver or downriver to get there). Coho cannot survive direct migration to ocean salinities but do survive and grow in some estuarine salinities (some describe as tidal-fresh to tidal-brackish transition zone) - habitat for osmoregulatory change. Estuaries increase rearing area, food available, growth potential for coho populations and increase overall productivity - may also allow recovery of depressed populations or repopulate streams whose runs had been extirpated. It is difficult to determine contribution to the population because freshwater/estuarine growth is not readily distinguishable in scales. Recommends reconnecting freshwater/estuarine habitats by removing tide gates and dikes to allow these kinds of up and downstream migrations.

Detailed Outcomes:

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**:
Study Design: Review recent papers, examine unpublished data, and discuss a case study on the subject of coho juvenile migration patterns and life-history diversity.	
Statistics:	

Comments: This does not focus on our questions but does describe a relatively recently recognized life-history variant of coho that benefits from greater connectivity between freshwater and estuarine portions of watershed. The paper synthesizes data from the coasts of Oregon, British Columbia, and Alaska - a wide geographic area.

Lyons, B. and M. Ramsey. 2013. **Program Report: Summary and synthesis of comments on a study of the "Biological and Physical Effects of 'Fish-Friendly' Tide Gates."** WA Department of Fish & Wildlife, Estuary and Salmon Restoration Program. March 2013.		
Keywords: N/A	**Type**: Report	**Publication Date**: 2013
Include: Yes	**Reason**:	**Relevance**:
Location & Species: Samish and Padilla Bay, Swinomish Channel, Skagit River tidal delta, Chehalis River, and Young's Bay	**Ecosystem(s)**:	
Reference Source:		

Abstract: Paraphrased from SUMMARY: This paper summarizes and translates, into less technical language, a scientific report: Biological and Physical Effects of 'Fish-Friendly' Tide Gates (in the PNW). This work was commissioned in 2009 by the WA Estuary and Salmon Restoration Program (ESRP) and completed by NOAA's Fisheries Science Center via an Interagency Agreement with the WA Recreation and Conservation Office. The final product was a technical report (Appendix B). This investigation was a first step toward comprehensive evaluation of the effectiveness of tide gates in providing benefits to fish. We expect the results of this study will be of interest to the broader restoration community. During review and early circulation of this report a number of important questions were raised provoking a useful dialogue about the current state of knowledge and remaining data gaps. Much of this dialogue is preserved in Appendix A as a technical Question and Answer (Q&A) session between authors, reviewers and ESRP staff. We have provided this information to help answer common questions, to clarify some uncertainties presented in the report and to identify priority data gaps need to better inform policy and restoration practice.

Contents of this document:

• Background and context on the tide gate study, including description of the study objectives

• Summary of findings, policy implications and recommendations on future inquiries and applications

• Appendix A: Q & A section in which the study authors address questions about the study design, findings, and interpretation of results. Also included are recommendations on future monitoring and research needs

• Appendix B: The final report on tide gates delivered to ESRP by NOAA as a contract deliverable

Results Summary: Summary: Site type (type of gate, reference) had a larger influence on juvenile Chinook density than habitat water quality characteristics. However, habitat characteristics are important when they are above or below threshholds for stress or survival (likely leading to avoidance before mortality). Dike setback is more beneficial to juvenile salmon than tide gate replacement by increasing the amount of habitat available without traversing any obstacles.   Recomendations: Maximize gate opening width and time and maximize culvert width, and increase upstream depth at high tide. Additionally, perform studies to tease apart the limiting factors of connectivity and habitat quality, and evaluate benthic conditions, riparian cover, and prey availability.

Broad Outcomes: Direct measurements of door openness angle and gate type. Site type (type of gate, reference) was a larger influence on juvenile Chinook density than habitat water quality characteristics. However, habitat characteristics are important when they are above or below threshholds for stress or survival (likely leading to avoidance before mortality). The authors suggest a suite of sites that experimentally vary the operation of several tide gates types to determine the influence of operation and design on fish usage. The authors present some general operation considerations to maximize benefit for juvenile salmon. 1) maximize gate opening width and time 2) maximize cumulative width of culverts 3) keep the culvert low in the channel (minimize the height of culvert invert) 4) increase upstream depth at high tide (trade-off between drainage and rearing hab) 5) gate operation and design should be adjustable. Collect habitat data using loggers up and down stream. Sample fish community biweekly up and downstream. Recommend performing studies to tease apart the limiting factors of connectivity and habitat quality. The report demonstrates that dike setback is more beneficial to juvenile salmon than tide gate replacement - increases the amount of habitat available without traversing any obstacles. Recommend considering rearing habitat characteristics 1)connectivity 2)maximum production possible from restored area (using some expected density level) 3) habitat quality. Additional habitat measures to evaluate are benthic conditions, riparian cover, prey availability.

Detailed Outcomes:

Effects Modifiers: The study was unable to address the question of how much tide gate functionality can be influenced by design and operation - what are the limits or expected levels of change with this approach?

<table>
<tr><td colspan="2">Intervention:</td></tr>
<tr><td>Conditions: study designed to evaluate the relative benefits of different types of tide gates compared to natural reference conditions</td><td>Duration:</td></tr>
<tr><td colspan="2">Study Design: This paper summarized the Greene et al. 2012 report and provided question and answer correspondence that occurred after the report was submitted. The authors also provide information on data gaps and suggest ways to collect the data necessary to fill them.</td></tr>
<tr><td colspan="2">Statistics:</td></tr>
</table>

Comments: This paper should be included as a companion to and extension of Greene et al. 2012. I have noted the main technical questions and answers and data gaps listed in this report.

<table>
<tr><td colspan="3">Mitchell, D.L. 1981. Salt Marsh Reestablishment Following Dike Breaching in the Salmon River Estuary, Oregon. PhD Thesis, Oregon State University, Corvallis, OR. 187 pp.</td></tr>
<tr><td>Keywords:</td><td>Type: Thesis</td><td>Publication Date: 1981</td></tr>
<tr><td>Include: Yes</td><td>Reason: Very early study on changes after tide gate removal.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Salmon River estuary (45d 03min N 124 d 00min W) vegetation and soils</td><td>Ecosystem(s): diked pasture to salt marsh</td></tr>
<tr><td colspan="3">Reference Source: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/7748/Mitchell_Diane_L_1981.pdf?sequence=1</td></tr>
</table>

Abstract: A 22 ha, 15-year old, diked permanent pasture in the Salmon River estuary in Lincoln County, Oregon, was chosen for a study to determine the potential for natural salt marsh restoration with dike breaching. Two undiked fragments of relatively undistrubed sal marsh, one at each end of the study site, were used as 'control' marshes. A permanent plot-permanent transect system was set up for vegetation and soils sampling before and after dike breaching. Three pasture communities, the Potentilla pacifica community, the Agrostic alba-Holcus lanatus community, and the Holcus lanatus community, were described before dike breaching. Elevational means for each community were not significantly different, and spatial distribution appeared to be most influenced by cultural practices. Vegetative cover in 49-1.0m^2 permanent plots was also recorded for comparison with post-dike breaching data. Half the dike was leveled in September 1978 and tidal creeks reopened. Vegetation resampling in 1979 and 1980 has shown that upland pasture-type species suffered close to 100% mortality by 1979. Somewhat salt-tolerant residual species, mainly Agrostis alba and Potentilla pacifica, either expanded into areas previously occupied by upland species or died back depending on degree of flooding and/or drainage within a local area. Permanent plots were grouped into four persistence classes (P.C.) based on cover of residual species. They ranged from P.C. I with 100% cover in 1979 and 1980 to P.C. IV with 30% mean cover of residual species by 1979. P.C. I permanent plots average 10-15 cm higher than P.C. IV plots, and are furthest from tidal creeks and/or locally better drained. Intensive sampling of colonizing species was done in 1979 and 1980 on over 3000 m^2 using the permanent plot system. By 1980, in areas of high residual species cover (P.C. I and II), the most successful colonizers were Atriplex patula (up to 18% cover locally), Hordeum brachyantherum (11%), and Carex lyngbei (to 6%). In P.C. III and IV areas, where there was mostly bare mud, Spergularia marine (to 11%) and Salicornia virginica (to 12%) have colonized most rapidly. Because of 0.30-0.40 m subsidence of the diked site below the elevation of the 'control' marshes, intertidal to low-transitional salt marsh is expected to develop. Future net primary productivity is projected to be in the 1200-1800 g/m^2/yr range, compared to 800-1200 g/m^2/yr for the higher transitional marshes on undisturbed Salmon River sites. Soils changes on the study site include increase in interstitial soil water salinity from zero on the diked site to 18 to 30 ppt summer salinity (5-10 ppt higher than 'control' marshes). Soil pH which was lower (4.7) on the diked site than the 'control' marshes (5.5) has returned to the level of the 'control' marshes. Higher concentrations of NH4 on the breached site indicate more anaerobic conditions with increased flooding and poorer drainage.

Results Summary: After restoration Upland species cover decreased from 85% in 1978 to near 0% in 1979 and remained low in 1980. Residual species cover decreased somewhat, colonizing species increased cover to ~20% and bare ground increased from near zero to ~45%. For residual species, those that persisted after breaching and tide gate removal, the percent cover decreased in areas that flooded most and increased in areas with less flooding. After dike breaching the proportion of biomass represented by residual species increased from about 50% to 97% and 80% in 1979 and 1980. The percent cover of residual species is related to elevation, distance from a tidal channel, and drainage efficiency because they cannot tolerate flooding. Colonization occured more in persistence classes with a greater degree of flooding. The colonizing species differed with the degree of flooding as well. In areas with the most bare ground plant vigor was lowest. Concentrations of several extractable bases (K, Ca, Mg, Na, B) and ammonia increased after breaching while nitrate and Potassium decreased. After breaching the study site had higher ammonium and sodium compared to control sites and Potassium and Magnesium had increased to control site levels. Organic material is high 25-40% over the site with very little stratification.

Broad Outcomes: For residual species, those that persisted after breaching and tide gate removal, the percent cover decreased in areas that flooded most and increased in areas with less flooding. After dike breaching the proportion of biomass represented by residual species increased from about 50% to 97% and 80% in 1979 and 1980. The percent cover of residual species is related to elevation, distance from a tidal channel, and drainage efficiency because they cannot tolerate flooding. Concentrations of several extractable bases and ammonia increased after breaching while nitrate and P decreased. After breaching the study site had higher ammonium and sodium compared to control sites and Potassium and Magnesium had increased to control site levels. Organic material is high 25-40% over the site with very little stratification.

Detailed Outcomes: Within the study areas there were three plant community types: those dominated by Patentilla pacifica (silverweed), Agrostis alba (black bent/redtop) / Holcus lanatus (velvet grass), and Holcus lanatus. The P. pacifica community sections had 75-100% cover and 99-100% frequency of the dominant species. The A. alba / H. lanatus community had patches of Ranunculus repens, Alopecurus geniculatus and Trifolium repens. These shorter grasses may have been maintained by cattle grazing. The H. lanatus community included tall weed species such as Senecio jacobea, Epilobium watsonii, and Cirsium vulgare and was patchier - indicative of its use as horse graze land. H. lanatus, A. alba, and P. pacifica had overall frequencies of 90%, 74%, and 65% respectively. The three plant communities had overlapping elevational means ranging from 1.08 m to 1.14 m above MLLW. Upland species cover decreased from 85% in 1978 to near 0% in 1979 and remained low in 1980. Residual species cover decreased somewhat, colonizing species increased cover to ~20% and bare ground increased from near zero to ~45%. The crop biomass in 1979 and 1980 was 59% and 28% that of 1978. Biomass decreased less quickly than cover, mostly driven by residual species. 1978 biomass was about half upland and half residual species but after dike breaching residual species made up 97% and 80% of the biomass. Residual species had complete mortality in areas flooded often, some mortality and low vigor in areas of moderate flooding, and increased cover in areas flooded infrequently. Colonization occured more in persistence classes with a greater degree of flooding. The colonizing species differed with the degree of flooding as well. In areas with the most bare ground plant vigor was lowest.Percent cover of colonizers was 30% in two intertransect types by 1980. Pre-restoration sampling found more colonizing species in creek samples than in transect samples. Post-restoration upland species had high mortality except along the highest creek banks. After breaching three of the 8 tidal creeks experienced downcutting erosion. Two years after restoration the net primary productivity was ~50 - 33% of that of the natural marshes. Soil salinity pre-breaching was 0 ppt in all areas except near the leaky tide gate. Post restoration soil salinity ranged from 11 to 39 ppt and averaged 25 ppt over the entire site. Control site soil salinities were lower. Soil pH increased after dike breaching to a value near that of the control sites. Concentrations of K, Ca, Mg, Na, B, and ammonium increased. Nitrate and phosphorus decreased.

Effects Modifiers:

<table>
<tr><td colspan="2">Intervention: The tide gate and half of the dike around the pasture was leveled in Sep 1978. Additional material was removed to restore connectivity of tidal creeks where they intersected with the leveled or intact dike.</td></tr>
<tr><td>Conditions: The study site was diked ~1963. It was bordered on either side by areas of relatively intact salt marsh.</td><td>Duration: 3 yrs</td></tr>
<tr><td colspan="2">Study Design: Vascular plant species cover was sampled along a total of 20 permanent transects in in the study site in 1978 (pre) and 1979-1980 (post), and in one year in each of the control sites (1 in 1978 and 1 in 1979), in 102 permanent plots created along the transects (minimum of 3 plots per transect), and along the permanent profiles. Permanent profiles were created across tidal creeks. Plant species mean height was also recorded within plots. In 1979 1-m wide belts were sampled every 10 m between plots on adjacent transects or between a plot and another permanent marker. Above ground biomass was measured in permanent plots once each summer. Water elevation in the river upstream of the study site was recorded May 1979 to Aug 1980. Elevations were determined for all permanent transects, plots, and profiles. Soils were sampled for salinity, pH, strata delineation, and from each strata: bulk density and organic matter measurements.</td></tr>
<tr><td colspan="2">Statistics: 1978 study sites were classified into clusters by the dissimilarity of vegetative species cover. Mean cover of each species was calculated across all samples, and within upland species, residual species, colonizing species, and bare ground categories for each year. Permanent plots were assigned to persistence classes based on the timing and degree to which the pre-restoration vegetation broke up and exposed bare ground. Mean cover of residual species and frequency of colonizing species were calculated by persistence class. Intertransect belts were classified by persistence class and mean cover and frequency of colonizing species was calculated. Standing crop biomass and net primary productivity were determined for the control sites. Monthy averages were calculated for 5 tide height categories and reduced to the Metonic cycle using Garibaldi tide data. Radiocarbon dating was performed on samples of seaside arrowgrass found in the soil samples.</td></tr>
</table>

Comments: This is the first of several studies on restored marshes in the Salmon River delta. It is nice to have papers that examine the effects of restoration at different points in time. One side note: It seems odd to classify the colonization and species of occurrence by persistence class because the persistence classes are defined by the amount of bare ground and colonization.

<table>
<tr><td colspan="3">Nordholm, K.E. 2014. Contribution of subyearling estuarine migrant coho salmon (Oncorhynchus kisutch) to spawning populations on the southern Oregon coast. M.S. Thesis, Dep't. of Fisheries and Wildlife, Oregon State University, Corvallis, OR. 81 pp.</td></tr>
<tr><td>Keywords: "tide gate" salmon
Supplementary search; GS search parameters set to "sort by date, since 2013". (Earlier searches were sorted by relevance, the default setting.)</td><td>Type: M.S. Thesis</td><td>Publication Date: 2014</td></tr>
<tr><td>Include: Yes</td><td>Reason: Definitive data for fry and parr emigrants contributing to the spawning population for coho.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Larson Creek and Palouse Creek, Coos Bay coho salmon</td><td>Ecosystem(s): tidally influenced streams</td></tr>
<tr><td colspan="3">Reference Source: Note: This is OWEB Funded.</td></tr>
</table>

Abstract: The typical coho salmon life history has been characterized by juvenile fish that spend their entire first year in freshwater habitats before migrating into estuaries as smolts. However, reports of early migrating coho fry (age 0), including migration downstream to estuarine habitats, date back to the 1960s. Until a few years ago, these individuals were considered to be displaced surplus fish with low chances of survival. Recent studies have suggested that subyearling estuarine migrating coho salmon could be an alternative life history in coastal populations, but their return as jacks or mature adults needed to be documented for this life history to be considered a viable strategy. The goal of our study was to track the return of spawning coho salmon that had been individually tagged in either estuarine or riverine nursery habitats, and determine return percentages for each life history strategy as well as independently verify the presence of subyearling estuarine migrating coho salmon through otolith analysis on spawning populations. We used Passive Integrated Transponder (PIT) tags to identify individual fish as they passed through a series of antennas deployed in two coastal lowland streams on the southern Oregon coast. Percentage return of estuary tagged parr (fish ≥ 60 mm tagged in spring and summer of their first year) was variable between years and streams. For the 2010 return year, subyearling estuarine migrants was 2.5 times higher than stream residents in Palouse Creek. Fork length at estuary entrance was reconstructed for one return year of spawning fish based on otolith Sr:Ca and Br:Ca. Four main life history strategies were identified based on their fork length at time of estuary/ocean entrance: early migrating fry (< 60 mm fork length), early migrating parr (60 - 70 mm fork length), early migrating parr that returned to freshwater before migrating as yearlings ("nomads"), and yearling migrating smolts (> 70 mm fork length). Overall, 30% (Larson Creek) to 42% (Palouse Creek) of the 2009 spawning run was made up of fish that displayed evidence of estuarine residence during their first year. This study confirms that subyearling estuarine migrating coho salmon survive to reproductive age and contribute to subsequent generations. The survival of this life history type likely varies between years with changing ocean and stream conditions. It is hypothesized that their life history serves as a "bet hedging" strategy that supports coastal populations in years of poor stream conditions. In the face

of rising sea levels, this life history may represent a key to the future viability of coho salmon stocks in coastal watersheds.

Results Summary: In this system the Sr:Ca in the estuary was distinguishable from that in the ocean. Three subyearling estuarine life-histories were identified: estuarine fry migrants, estuarine parr migrants, estuarine nomads (migrated to estuary as fry, migrated back to freshwater as parr and overwintered before returning to estuary as smolts). Return rates by life-history type were 2.81%, 1.81%, and 0.78% for smolts, estuary subyearlings (fry and parr migrants and nomads), and stream parr. Stream resident smolt migrants were also identified. Of the adults spawning in Palouse and Larson creeks, 58 and 69% had been yearling smolts, 21 and 16% were estuary parr, estuary fry were 15 and 13%, nomads were 6 and 2%.

Broad Outcomes: Estuary Sr:Ca distinguishable from ocean ratio. Return rates by life-history type: smolts (2.81%), estuary parr (1.81%), stream parr (0.78%). Three subyearling estuarine life-histories were identified - estuarine fry migrants, estuarine parr migrants, estuarine nomads (migrated to estuary as fry, migrated back to freshwater as parr and overwintered before returning to estuary as smolts). Stream resident smolt migrants were also identified. Of the adults spawning in Palouse and Larson creeks, yearling smolts were 58 and 69%, estuary parr were 21 and 16%, estuary fry were 15 and 13%, nomads were 6 and 2%.

Detailed Outcomes:

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**:
Study Design: Fish collected via screw trap, seine, electrofishing - all trapped and subsample of other YOY and smolts PIT-tagged. PIT arrays set in double rows to determine directionality. Adults were recovered as antenna detections and as carcasses on the spawning grounds. Water samples were collected to predict the elemental ratios expected in the otoliths.	
Statistics: Return rate, odds of returning calculated for each creek. Odds ratios were used to determine if subyearling estuarine migrants differed significantly from stream residents. Calculated detection efficiencies for each array. Used regressions to determine relationship between otolith width (OW) and FL, then back-calculated fish length at estuarine entry.	

Comments: These tide gates had no modifications; one is top-hinged and one is side-hinged. However, this study presents conclusive evidence for the contribution of at least four life-history types to the coho spawning population.

<table>
<tr><td colspan="4">Poirier, J., S. Lohr, T.A. Whitesel, and J. Johnson. 2009. Assessment of Fishes, Habitats, and Fish Passage at Tide gates on Deer Island Slough and lower Tide Creek. USFWS, Columbia River Fisheries Program Office, Population & Habitat Assessment Program, Vancouver, WA. 41 pp.</td></tr>
<tr><td>Keywords: N/A.</td><td colspan="2">Type: 2009 Project Report</td><td>Publication Date: 2009</td></tr>
<tr><td>Include: Yes</td><td colspan="2">Reason: For discussion of estuary usage by juvenile salmon.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Deer Island, Lower Columbia River, Deer Island Slough and Lower Tide Creek</td><td colspan="2">Ecosystem(s):</td></tr>
<tr><td colspan="4">Reference Source: https://www.fws.gov/columbiariver/publications/Deer_Island_Report_2009.pdf</td></tr>
</table>

Abstract: Deer Island is located at river kilometer 125-130 along the south shore of the lower Columbia River near the town of St. Helens in Columbia County, Oregon. The area encompasses over 1,821 hectares within the Columbia River floodplain, which historically consisted of tidally influenced backwater and slough habitats (i.e., Deer Island Slough), as well as stream habitats in relatively small tributaries adjacent to the area (e.g., Tide and Merrill creeks). Presently, the value of these habitats for anadromous salmonids has been reduced by such activities as dike construction, tide gate installation, and stream channelization, resulting in restricted access by fish and degraded habitat conditions. However, anadromous fish continue to use the area....In spring 2009, the USFWS, Columbia River Fisheries Program Office (CRFPO), contributed to these efforts by monitoring biological and physical attributes of Deer Island Slough and lower Tide Creek for the preparation of this biological assessment. The ultimate goal of this assessment was to provide information concerning fish presence, aquatic habitat conditions, and fish access to habitats that would assist with the identification and prioritization of future restoration actions intended to improve juvenile salmonid habitats and access to habitats, as well as providing information useful for describing baseline conditions prior to implementing restoration actions. Our monitoring efforts occurred during the time when juvenile salmonids were likely to be in the area, March-June.

Results Summary: Water elevation was higher inside the gates. The gates were perched 46% of the time during adult migration and 5% of the time during juvenile migration. 73 juvenile salmon were captured during fish passage trials: 83.6% in Apr. Chinook comprised 98.6%. In Apr 29.4% were captured upstream and in Jun 41.7%. Juvenile salmonids entered the slough only in Apr. Length frequencies suggest subyearling and yearling Chinook and coho were present. In North Deer Island Slough 10,125 fish were collected and 4/13 species were native. No salmonids were collected. In South Deer Island Slough 4,104 fish were collected and 10/20 species were native. Chinook and coho were collected. In Tide Creek 1,250 fish were collected and 10/15 species were native. Coho, cutthroat, and steelead were collected. North Deer Island Slough had lower dissolved oxygen and higher temperature and conductivity. Tide creek had lower turbidity. Transparency and pH did not differ among systems.

Broad Outcomes: 73 juvenile salmon were captured during fish passage trials, 83.6% in Apr. 98.6% were Chinook. 29.4% were captured upstream in Apr and 41.7% in Jun. Salmonids only entered the slough during the Apr trial. Chinook were 62-141 mm in Apr and 51-104 mm in Jun. The length-frequency distribution suggests subyearlings and yearlings were present.

Detailed Outcomes: Water elev higher inside gates. During adult migration time the gate was perched 46% of the time, during juvenile migration time the gate was perched 5% of the time. Fish Community North Deer Island Slough10,125 fish in 13 taxa - 81.5% hoop netted, 18.5% in minnow/crayfish traps. Stickleback were most abundant (97.5%), oriental weatherfish were 2nd most abundant (0.7%) 4/13 species were native (97.7% total catch) - excluding stickleback native species were 9.0%. No salmonids. South Deer Island Slough 4,104 fish in 20 taxa - 74.8% hoop net, 21.2% seine, 18.5% traps. Stickleback 84.5%, sculpin 3.0%. 10/20 species were native (94.3% total). Excluding stickleback, natives were 63.0%. 71 salmonids were collected. Chinook comprised 66.2%. Of salmon 81.7% seine, 12.7% hoop nets, 5.6% traps. Chinook 71-125mm ad marked, 40-79mm unmarked, coho 39-152mm. Coho length-frequency suggests subyearlings (66.7%) and yearlings. Tide Creek 1,250 fish in 15 taxa - 92.3% hoop net, 6.7% seine, 1.0% trap. Stickleback 63.0%, coho 18.8%. 10/15 species were native (94.7%). 243 salmonids. Coho 96.7%, cutthroat 2.5%, steelhead 0.8%. 90.5% coho in hoop net, 9.5% seine. Coho were 37-142 mm, cutthroat 120-217 mm, steelhead 176, 180 mm. Coho length-frequency suggests subyearlings (55.7%) and yearlings. Habitat Substrate was silt and sand in all areas. Shrubs and trees dominated in North and South Deer Island sloughs. Grass/Forb dominated in lower Tide Cr. Percent shade 9-16%. Overhanging tree/shrub, woody debris, aquatic vegetation dominated in North and South Deer Island Slough. Reed canary grass, woody debris, overhanging tree/shrub dominated in lower Tide Cr. 7DADM in Deer Island Sloughs <16.8°C until late May. Dissolved oxygen was lower at N Deer Island Slough. T and conductivity were higher at N Deer Island Slough. Turbidity was lower at Tide Cr. Transparency and pH did not differ.

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**:
Study Design: Fish passage trials - seine in- and out-side gates, net attached to culvert upstream. Water depth and T were logged. Dissolved oxygen, conductivity, pH, turbidity, transparency, mean wetted width, mean depth, substrate, riparian veg, percent shade, physical channel cover were measured. Sampling was spatially balanced among the 3 water bodies. Fish were seined and hoop netted. Fish were ID'd, counted, salmon were also weighed, measured, checked for marks, and >60 mm scanned for PIT tag.	
Statistics: Estimated gate openings and 'perched culverts'. The T range was compared between sloughs using Kruskal-Wallis ANOVA on ranks and Dunn's multiple comparison procedure. Mean daily T compared with Kruskal-Wallis ANOVA with Holm-Sidak multiple comparison. Dissolved oxygen compared with ANOVA and Holm-Sidak, conductivity compared with ANOVA on ranks and Dunn's multiple comparison.	

Comments: This paper reported on physical conditions in sloughs with salmon present and absent. Data novel to this paper were the proportions of time when the gate was 'perched', i.e. when the culvert was above the water level, that adult and juvenile salmonids were able to successfully pass upstream.

<table>
<tr><td colspan="3">Rebenack, J.J., S.Ricker, C. Anderson, M. Wallace, and D.M. Ward. 2015. Early Emigration of Juvenile Coho Salmon: Implications for Population Monitoring. Transactions of the American Fisheries Society 144(1): 163 - 172.</td></tr>
<tr><td>Keywords: "tide gate" salmon</td><td>Type: Peer-reviewed</td><td>Publication Date: 2015</td></tr>
<tr><td>Include: Yes</td><td>Reason: Useful for describing juvenile coho life history strategies and estuary use</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Freshwater Creek, Humboldt County, CA coho salmon</td><td>Ecosystem(s):</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Abstract: Salmon monitoring programs often measure juvenile production by operating migrant traps downstream of spawning and rearing areas during smolt migration. However, this approach does not account for individuals that move downstream of trapping locations prior to smolt sampling. We used a mark–recapture study with passive integrated transponder tagging to estimate the proportion of coho juveniles, tagged in the fall in a N. California stream, that migrated to rearing habitat downstream of a seasonally operated trap before spring smolt sampling. Emigrants were detected by using the migrant trap, located near the upstream limit of tidal influence, and continuously operated antennas located in tidal wetlands downstream of the trap. For all three cohorts sampled (2010, 2011, 2012), we identified two distinct emigration periods (not including fry emigrants that emigrated in spring at a size too small to tag): a fall–winter period, when early emigrant parr moved into a restored tidal wetland (early emigrants); and a spring period, when smolts emigrated (smolt emigrants). There was little movement in the intervening period. Emigration timing varied depending on the location in the basin where fish were tagged; locations in the lower main stem generally produced more early emigrants, while locations in the upper basin produced more smolt emigrants. Across locations, early emigrants accounted for 2–25% of the fall-marked juveniles from 2010, 8–29% from 2011, and 7–13% in 2012. Smolt emigrants accounted for 15–49% of the fall-marked juveniles from 2010, 13–14% from 2011, and 3–35% from 2012. The consistent occurrence of early emigration in this and other recent studies brings into question estimates of smolt abundance and demographic rates (e.g., overwinter and marine survival) that do not account for this [early emigrant] life history variant.

Results Summary: Coho emigrated at two times, in winter as early emigrants and in spring as smolts. Whether larger fish were early emigrants or smolts differed by year. Early emigration imparted a growth benefit in one of the two study years. Growth rates were more variable for early emigrants.

Broad Outcomes: Early emigrants left during high flow events in late fall and winter. Smolts emigrated in April. Larger fish were more likely to be early emigrants in one year and smolt migrants in two years. Growth rates were more variable for early migrants. Wood Creek was suitable habitat for overwinter growth and survival. Early emigration had growth benefits in 2010 and deficits in 2011.

Detailed Outcomes:

Effects Modifiers:

Intervention:	
Conditions:	**Duration**: 3 years
Study Design: Fish were beach seined within stream reaches, measured, weighed, PIT-tagged. Fish were recaptured with PIT arrays (in a tributary) or at a weir migrant trap. Recaptures were measured and weighed	
Statistics: Used Cormac Jolly Seber mark recapture to estimate probability of early emigration and of smolts emigrating each year.	

Comments: While this paper describes coho early migrant life-history and growth benefits associated with this strategy in some years, it did not sample the adult population to determine what the importance of each life-history type was to the spawning population.

<table>
<tr><td colspan="3">Roegner, G.C., E.W. Dawley, M. Russell, A. Whiting, and D.J. Teel. 2010. Juvenile Salmonid Use of Reconnected Tidal Freshwater Wetlands in Grays River, Lower Columbia River Basin. Transactions of the American Fisheries Society 139 (4): 1211 - 1232.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 2010</td></tr>
<tr><td>Include: Yes</td><td>Reason: Directly focused on review questions.</td><td>Relevance: High</td></tr>
<tr><td colspan="2">Location & Species: Grays River tidal freshwater system, WA USA coho, chum, and Chinook salmon</td><td>Ecosystem(s): tidal freshwater river</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Abstract: Degraded wetland systems with impaired hydraulic connections have resulted in diminished habitat opportunity for salmonid fishes and other native flora and fauna in the Pacific Northwest. Many of these lost habitats were once intertidal freshwater marshes and swamps. Restoration of these systems is effected in part by reestablishing tidal processes that promote connectivity, with a central goal of restoring rearing habitat for juvenile Pacific salmon Oncorhynchus spp. In the Grays River tidal freshwater system of Washington, we measured hydrologic changes that resulted from the removal of tide gates from diked pastureland and we determined the subsequent time series of salmonid abundance and size frequency in the restoring marshes. Dike breaching caused an immediate return of full semidiurnal tidal fluctuations to the pasturelands. Juvenile Pacific salmonids quickly expanded into this newly available habitat and used prey items that were presumably produced within the marshes. Habitat use varied by species and life history stage. Fry of chum salmon O. keta migrated rapidly through the system, whereas populations of Chinook salmon O. tshawytscha and coho salmon O. kisutch resided from March to at least July and were composed of fry, fingerlings, and (for coho salmon) yearlings. Based on salmon size at date and the timing of hatchery releases, we concluded that most salmon sampled in restored and reference sites were the progeny of natural spawners. However, the presence of adipose-fin-clipped Chinook salmon indicated that hatchery-raised fish originating outside the Grays River system also used the restoring wetland habitat. Because of extensive mixing of stocks through hatchery practices, genetic analyses did not provide additional insight into the origins of the Chinook salmon but did reveal that out-migrating juveniles were an admixed population composed of lower Columbia River ancestry and nonindigenous Rogue River stock. Restoration of tidal wetlands in the Columbia River estuary will improve overall ecosystem connectivity and reduce habitat fragmentation and may therefore increase survival of a variety of Pacific salmon stocks during migration.

Results Summary: At the Kandoll Farm site hydraulic patterns more closely followed tidal fluctuations after removal. Fish species number and community compsition more closely matched reference sites after removal. Johnson was not sampled pre-removal. Life-history stage and size range similar at all sites: chum were fry, and coho were fry and fingerlings (2005 2006, 2007), also smolt (2007), Chinook were less abundant and were fry and fingerlings. 7d average maximum temperatures were similar among years and sites. At the downstream site T was above 16 deg earlier and for longer periods and went over 20 deg more often than upstream sites. Chinook and chum were most abundant below 16 deg but coho were most abundant at 16-18 deg. Salmonids in restoration sites had more diverse diets.

Broad Outcomes: Hydraulic patterns more closely followed tidal fluctuations after removal. Fish species number and community compsition more closely matched reference sites after removal. For Chinook: fry and fingerlings, chum: fry, coho: fry and fingerlings (2005 2006, 2007), also smolt (2007). 7DAM T were similar among years and sites but were higher downstream. Downstream sites were above 16 deg earlier and for longer periods and went over 20 deg more often. Salmonids in restoration sites had more diverse diets.

Detailed Outcomes: Kandoll: water level fluctuations changed to fully tidal pattern immediately, water levels increased within two weeks. Combined restoration and control: 93.6% of all fish were 3-spine stickleback. Of the remaining species, chum salmon were 32.7%, coho salmon were 13.4%, and Chinook salmon were 8.3%. Banded killifish, prickly sculpin, and peamouth were also nonincidental collections. Before restoration only killifish were collected at Kandoll. After treatment: 9 species including Chinook, chum, and coho were present. In 2005 and 2006 10 and 11 species were present at Johnson. Total catch and #species were lower in 2007. Salmonid catch by T varied with species: Chinook CPUE peaked between 11-15 deg, chum were not present above 16 deg and were most common between 9 and 12 deg, coho were most abundant between 16 and 18 deg but were present up to 23 deg. Insects were the most important prey at all sites. Annelids, amphipods, cladocerans, mysids, fish, and isopods were also eaten.Most Chinook were either Rogue River or West Cascades Tributary (Columbia R) stock but some had a mixture from both stocks.

Effects Modifiers: Chinook salmon numbers were very low after 2005

<table>
<tr><td colspan="2">Intervention: Kandoll Farm: two 4.2 m culverts were installed in the dike to reconnect to Seal Slough in 2004. Johnson Farm: a tide gate along the Grays River was breached in 2005. In both cases historic channel reaches were reconnected and pasture surfaces were flooded tidally.</td></tr>
<tr><td>Conditions: land aquired by conservation organizations and subsequently restored</td><td>Duration: 2005, 2006, 2007</td></tr>
<tr><td colspan="2">Study Design: Water level change showed hydraulic connectivity (Kandoll only). Used water T to determine conditions adequate for salmonid rearing. Sampled fish communities (CPUE, #species, S-W diversity index), tracked salmonid migration stage and timing (time series of relative annual abundance), tested for thermal restraints,gastric lavaged large coho and Chinook to sample diet (%IRI, and proxy for habitat use), noted ad-marks, performed genetic analysis of salmonids (2006-2007, genetic stock ID, estimated Columbia R ancestry for each fish).</td></tr>
<tr><td colspan="2">Statistics: All statistics are descriptive.</td></tr>
</table>

Comments: We should keep in mind that one of the marshes in this study had dike breaches to reconnect tidal channels, but not a tide gate treatment. The other included a tide gate removal.

<table>
<tr><td colspan="3">Scott, D.C., M. Arbeider, J. Gordon, and J.W. Moore. 2016. Flood control structures in tidal creeks associated with reduction in nursery potential for native fishes and creation of hotspots for invasive species. Canadian Journal of Fisheries and Aquatic Sciences 73(7): 1138-1148.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td>Reason: Clear difference in fish community in gated and reference channels.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lower Fraser River delta, BC</td><td>Ecosystem(s): tidal creeks</td></tr>
<tr><td colspan="3">Reference Source: http://summit.sfu.ca/item/15346</td></tr>
</table>

Abstract: Habitat connectivity is important for maintaining biodiversity and ecosystem processes yet globally is highly restricted by anthropogenic actions. Anthropogenic barriers are common in aquatic ecosystems; however, the effects of small-scale barriers such as floodgates have received relatively little study. Here we assess fish communities in ten tributaries over the spring– summer season of the lower Fraser River (British Columbia, Canada), five with floodgates and five reference sites without barriers, located primarily in agricultural land use areas. While the Fraser River supports the largest salmon runs in Canada, the lower Fraser river–floodplain ecosystem has numerous dikes and floodgates to protect valuable agricultural and urban developments. Floodgate presence was associated with reduced dissolved oxygen concentrations, threefold greater abundance of invasive fish species, and decreased abundances of five native fish species, including two salmon species. These findings provide evidence that floodgates decrease suitable habitat for native fishes, and become hotspots for non-native species. Given climate change, sea-level rise, and aging flood protection infrastructure, there is an opportunity to incorporate biodiversity considerations into further development or restoration of this infrastructure.

Results Summary: Gated and reference sites were similar in size and land use proportions. T did not differ between gated and reference sites. Salinity and conductivity were negligible at all sites. Sites above tide gates had lower dissolved oxygen, especially later in the season (Jul, Aug). 30,759 fish from 21 species were collected, including 674 juvenile salmon from 5 species.Stickleback dominated at all sites. Other abundant native species were northern pikeminnow, prickly sculpin, and peamouth chub. During summer reference sites shifted away from salmon communities to a higher abundance of minnows and prickly sculpin. Communities at gated sites transitioned to higher abundances of sunfish and brown bullhead. Juvenile salmon were collected at all reference and two gated sites but abundances were 2.5 times higher at reference sites. Abundance of other natives (exculding stickleback) was also higher at reference sites. Non-native species were 3.1 times more abundant at gated sites.

Broad Outcomes: Gated and reference sites were similar in size and land use proportions. T increased with date, but there was no affect of tide gates. Salinity and conductivity were negligible at all sites. Sites above tide gates had lower dissolved oxygen, especially later in the season (Jul, Aug - below safe min in Aug). 30,759 fish collected (21 species), 674 juvenile salmon (5 species), 29,351 'other natives' (10 species), 734 non-natives (6 species). Stickleback dominated (27,791 individuals). Other abundant native species: northern pikeminnow, prickly sculpin, peamouth chub. Non-natives included: pumpkinseed, largemouth bass, common carp, brown bullhead, black crappie, weather loach. Fish communitiy difered by date, gate presence, and interaction. During summer, reference sites shifted away from salmon communities to higher abundance of minnows and prickly sculpin. Gated site communities moved to higher abundances of sunfish and brown bullhead. Juvenile salmon were collected at all reference and two gated sites - abundances 2.5x higher at references. For individual salmon species abundance was 11.7x (coho -sig), 1.5x (chum-sig), and 2.2x (Chinook-NS) higher at reference sites. Abundance of other natives (exculding stickleback) was also lower at gated sites: Prickly sculpin (37.2x -sig) and minnows (11.7x -sig for peamouth and pikeminnow). Non-native species had 3.1x higher abundance at gated sites. Largemouth bass was the only non-native not more abundant at gated sites.

Detailed Outcomes:

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**: 5 months
Study Design: Fish were seined in first 150 m upstream of gates or confluence or were trapped overnight (avg 18 hr). Fish were ID'd and measured. Recorded salinity, T, dissolved oxygen, and conductivity. Determined watershed area and land use proportions.	
Statistics: Fish community composition among sites and sampling times and between site types was analyzed with NMDS. Used Generalized additive models to test gate presence on fish abundance by species. Salmon data were log(x+1) transformed.	

Comments: This study compared gated sites to ungated reference sites. It shows very clear differences in the fish community composition and fish density between the two types. It does not, however, include any restoration action or treatment.

<table>
<tr><td colspan="3">Seifert, R.E. 2016. Floodgate Operations and Implications for Tidal Creek Fish Communities. 2016. MRM Research Project Report No. 646, School of Resource and Environmental Management, Simon Fraser University, Vancouver, BC. 72 pp.</td></tr>
<tr><td>Keywords: tide gate replacement coho</td><td>Type: Master's thesis</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td>Reason: It may be useful for expanding on our understanding of how tide gates affect water quality and fish community.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lower Fraser River, BC Canada</td><td>Ecosystem(s):</td></tr>
<tr><td colspan="3">Reference Source: http://summit.sfu.ca/item/16240</td></tr>
</table>

Abstract: Tidal creeks represent important fish habitats that are often highly modified by human activities. Floodgates can protect developed areas but also restrict connectivity of tidal creek habitats; however, floodgate operations and their effects are not well quantified. I used time-lapse cameras to quantify the timing of gate openings for 22 tributaries of the Lower Fraser River in British Columbia, Canada, and related these operational data to dfferences in fish communities above and below floodgates. I found that floodgate operations varied substantially, with some floodgates opening daily while others opened less than 20% of the day. Where floodgates opened infrequently, I found lower upstream dissolved oxygen concentrations, greater differences in fish communities, and lower native species richness relative to sites where floodgates opened more. Thus, improvements in floodgate operation will likely benefit fish communities. These data can inform management activities to balance fish and flood protection in the region.

Results Summary: Almost half of the gates opened for less than 20% of the day and 40% opened less than 10% of the time. However, 30% of gates were open more than half the day. Opening time was not related to tide gate type. The gates opened more when mainstem flows were lower and at sites farther from the ocean. Fish communities above and below gates were more different at gates that opened less. When gates rarely opened native species richness was ~32% lower upstream. Prickly sculpin seem particularly vulnerable - where gates rarely or never open, abundance above was 1/4 of that below. Dissolved oxygen was lower above gates that opened infrequently. However, temperature, salinity, and conductivity did not differ with gate openess.

Broad Outcomes: Almost half of the gates opened for less than 20% of the day. The gates opened more when mainstem flows were lower and at sites farther from the ocean. Tide gate type was not related to openess (maybe because there were just a few top-mounted and manual gates). Fish communities were more different above and below gates than opened less. When gates rarely opened native species richness was ~32% lower above. Prickly sculpin seem particularly vulnerable - where gates rarely or never open, abundance above was 1/4 of that below.

Detailed Outcomes: 40% of floodgates opened less than 10% of the time while 30% of gates were open more than half the day - high variability. Opening patterns differed seasonally and regionally - only Fraser discharge consistently explained patterns - many gates were closed during the freshet, which could impact juvenile salmon outmigration and geographic redistribution. More than 50% fish collected were 3-spine stickleback (>4000). Next were juvenile cyprinids (>1000). Other species with >100 individuals were pumpkinseed, northern pikeminnow, prickly sculpin, and peamouth chub. Collected only 11 chum and 17 coho. Up- and downstream communities differed more where gates opened less. Gates open more had higher relative native species richness. However, neither floodgate openess nor site characteristics explained differences in fish counts, biomass, or taxonomic richness. When gates opened less, fewer prickly sculpin were collected above the gates. Dissolved oxygen was lower above gates that opened infrequently. Temperature, salinity, and conductivity did not differ based on gate openess.

Effects Modifiers: Most gates were side mounted (13), while 2 were top-mounted, and 3 were manual. When gates are open there may be barriers to fish passage (velocity, installed too high or low, opening too small for larger fish).

Intervention:	
Conditions:	**Duration**: 1 year
Study Design: Time-lapse camera of tide gate opening to compare opening time with fish communitiy composition above and below tide gates	
Statistics: Used general linear mixed-effects models to determine if site characteristics affected time open. Calculated difference between up and downstream communities using a dissimilarity matrix. Then used linear models to see if the community differences and water quality are related to gate openness.	

Comments: This is an interesting study looking at whether the amount of time tide gates are open affects fish community and water quality above relative to below. However, there were no modifications done prior to monitoring.

<table>
<tr><td colspan="3">Silver, B.P., J.M. Hudson, and T.A. Whitesel. 2015. Bandon Marsh National Wildlife Refuge Restoration Monitoring, Final Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA. 49 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: Final Report</td><td>Publication Date: 2015</td></tr>
<tr><td>Include: Yes</td><td>Reason: Tide gate removal; BACI design.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Ni-les'tun Unit within the Bandon Marsh National Wildlife Refuge in the Coquille River estuary</td><td>Ecosystem(s): intertidal and freshwater marsh, 2 creeks at rkm 5 and 8 (of the Coquille)</td></tr>
<tr><td colspan="3">Reference Source:
https://www.fws.gov/Columbiariver/publications/Bandon%202015%20Final%20Report.pdf</td></tr>
</table>

Abstract: Bandon Marsh National Wildlife Refuge (BMNWR) completed construction of a large-scale tidal marsh restoration project on the Ni-les'tun Unit within the Coquille River estuary in 2011. This monitoring project is focused on changes in the aquatic species community before and after the restoration construction. [p. 6: Construction actions included dike and tide gate removals, culvert replacements, and channel and wetland construction.] Stream sections were sampled on Fahys Creek and Redd Creek within the restoration site, reference areas in the Bandon Marsh Unit, and along the Coquille River. Fish were sampled by double hoop net, seine, and backpack electrofisher from 2007 to 2013. Invertebrates were collected and archived from the restoration area and reference area before and after construction. Biodiversity was assessed by community, species richness, distribution, relative abundance, and frequency of occurrence. The project positively benefits salmonids and juvenile estuarine fish by creating habitat and increasing access to the refuge. The overall assemblage of the fish community was not substantially different after construction; however, the number of estuarine species increased by 80% (4/5). Change in the Simpson Diversity Index differed by site, sample method, and season. Tidally influenced areas saw a decrease in richness where upper stream areas saw an increase. Salmonids were found in all areas of the refuge. Chinook (age-0), coho (age-1), and an increased number of sea-run coastal cutthroat trout were found primarily in tidally influenced areas. Newly constructed channels were occupied and used seasonally. Species found in these new channels include salmonids, introduced species, and estuarine species. Three spine stickleback and species of sculpin dominated the restoration area and reference area in abundance and capture frequency. Among salmonids, coastal cutthroat trout and coho had the highest frequency of occurrence and relative abundance before and after construction. After construction, estuarine fish increased in both abundance and frequency. Changes are likely due to improved access and changing habitat created by the reintroduced tidal regime. Future assessment of the Ni-les'tun Unit would continue to focus on changes in the aquatic species community over time for further evaluation of the success of the restoration.

Results Summary: 21 fish species were collected over all sampling events. Of these, 13 were present pre- and post-restoration, 3 pre- only, and 5 post- only. The proportion of unique species differed between restoration and reference sites pre- and post-resoration, but to a lesser degree post-restoration. Life-history diversity, as measured by size classes, did not change with restoration.

Ecological classisfications were similar in the restoration and reference sites. Greater abundance of estuarine species, subyearling Chinook, and sea-run cutthroat trout in the restored area increased the similarity post-restoration. The distribution of estuarine and salmonid species changed after restoration. Coho moved farther upstream and more estuarine species were present in the creeks.

Broad Outcomes: 21 fish species were collected over all sampling events. 13 present pre and post, 3 pre only (carp, small mouth bass, steelhead), 5 post only (anchovy, American shad, bay pipefish, starry flounder, crappie). Jaccard's similiarity coefficient not substantially different pre and post in the Ni-les'tun Unit. More estuarine species present post. Jaccard's coefficient for Ni-les'tun and Reference differed pre and post, but to a lesser degree post. Species richness index increased slightly for Fahys electrofishing, Redd double hoop, reference seine (Coquille R), decreased for Fahys double hoop (sig) and reference marsh double hoop. LH diversity Redd - 2 size classes of coho pre and post. Fahys - mult size classes cutthroat, 1 size class coho above N Bank Lane pre and post; mult size classes cutthroat, 2 size classes coho and Chinook pre and post below N Bank Lane. Reference - 2 size classes coho and Chinook pre and post. Ecological classifications were similar in reference and restoration sites. Changes post restoration were mainly due to greater abundance of estuarine species (although some no longer seen), subyearling Chinook, and sea-run cutthroat; the restoration sites became more similar to the reference site. Estuarine and salmonid distributions changed after restoration. Coho moved farther upstream. More estuarine species were present in the creeks.

Detailed Outcomes:

Effects Modifiers: channels only sampled at low tide

Intervention: removed 3 tide gates, excavated 5 km tidal channels, lowered dikes, improved culverts, filled large ditches, disrupted small ditches	
Conditions: Completed 2011	**Duration**: 7 years
Study Design: Restored creeks and reference sites sampled with double hoop nets overnight (avg 21 hrs) . Upper reaches of Fahys electrofished. REF-1 switched to seine in Fall 2009. Coquille River sites seined. Newly restored (excavated) channels seined. Measured T, conductivity, salinity at each site. All fish were ID'd and counted and up to 20 per species were measured. Salmonids were weighed (up to 20). Macroinvertebrates were netted (surface and water column) in Fahys and REF-1.	
Statistics: Jaccard's coefficient calculated the proportion of unique species pre and post restoration. Simpson's diversity index was used for species richness. ANOVA tested differences in mean Simpson Diversity Index of double hoop values between Fahys, Redd, Reference pre- and post- construction. Salmonids were categorized into age classes using length frequency histograms with 50 mm bins by species, area, construction phase. Mean FL calculated by sample area. Used % frequency of occurence and average relative abundance to classify species as dominant, common, occasional, rare by area, sampling method, construction phase. BACI design.	

Comments: The authors equate life-history diversity with the size classes present. However, this may not be the whole story. Coho distribution changed after removal. This may be evidence that life-history diversity is beginning to increase even with no change in size classes. The plant community evaluation and hydrology of the Ni-les’tun restoration project are described in Brophy et al. 2014 and Brown et al. 2016.

<table>
<tr><td colspan="3">Tryon, L. 2011. Investigation of Restoration and Protection Options for Juvenile Salmonids in the Courtenay Estuary. BC Fish and Wildlife Compensation Program Project # 10.PUN.08. Prepared for Comox Valley Project Watershed Society by Lake Trail Environmental Consulting, Cumberland BC. 149 pp.</td></tr>
<tr><td>Keywords: Found while searching for "Comox Road Dyke Slough tide gate modifications".</td><td>Type: Report</td><td>Publication Date: 2011</td></tr>
<tr><td>Include: Yes</td><td>Reason: Includes recently gathered (2010) data on coho use of estuary habitat. Also some discussion of tide gates.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Courtenay River estuary, BC. Chinook, coho</td><td>Ecosystem(s): river estuary from tidal fresh to subtidal</td></tr>
<tr><td colspan="3">Reference Source: http://a100.gov.bc.ca/appsdata/acat/documents/r40301/ 10.PUN.08_Courtenay_1386168826750_6166228483.pdf</td></tr>
</table>

Abstract: [Paraphrased from exec summary:] Study goal was to provide a foundation for future restoration and protection of important salmon habitats and their supporting food webs in the Courtenay River estuary. The study produced an ecological characterization of the estuary and developed restoration and protection options. Estuary characterization involved a field investigation of habitat requirements of juvenile salmonids from the upper to the lower estuary over the spring and summer of 2010. We used chinook and coho fry as indicator species. Fry stages were marked and monitored for recaptures, fish were identified and counted, water conditions were recorded, snorkel counts were conducted and habitats were mapped. Data from past studies were analyzed to identify changes in residency period and salmon size classes. Chinook and coho fry stages were more dependent on the estuary than smolts, which moved through the estuary quickly. Chinook and coho fry were in the estuary by early spring. Coho fry were found into December. Most chinook fry left by early July.

NOTE: Didn't find much mention of tide gates until the "Management Recommendations" (Appendix 9, p. 99-111) where tide gate impacts and mitigation actions are discussed.

Results Summary: Length frequencies indicated two age classes of both Chinook and coho were present. Subyearlings of both species stayed in the estuary longer than smolts. Most Chinook had left by Jul but coho remained in Oct and Dec. Chinook subyearlings preferred upper ecotone habitats near freshwater input. Coho subyearlings were collected in areas with good refuge and freshwater inflow. Additionally, estuary rearing coho grew faster than those that stayed in freshwater. Chinook growth rate was slower than coho growth rate in May and Jun below the tide gate. Chinook were mainly preying on insects (not prevalent) and coho were eating gammarid amphipods (prevalent). Water T increased throughout the season, surpassing optimal conditions in May but never reached lethal levels. Mark-recapture data indicated that coho subyearlings had site fidelity within the estuary.

Broad Outcomes:

Detailed Outcomes: Chinook and coho subyearlings stayed in the estuary longer than smolts. Chinook were mostly gone by Jul but coho were still left in Oct and Dec. Chinook fry preferred upper ecotone habitats near freshwater input. Coho fry were found in areas with good refuge and freshwater inflow - they grow faster than those that stayed in freshwater. In May and Jun below the tide gate Chinook growth rate was slower than coho. Chinook were mainly preying on insects (not prevalent) and coho were eating gammarid amphipods (prevalent). May CPUE was highest for Chinook and coho - sites 1-4 were the most used. Other relatively abundant species collected: chum, steelhead, sea-run cutthroat, sculpins, stickleback, perch. Two age classes of Chinook and coho were indicated by length frequency analysis in most months. Diet composition varied by species and month. Chinook selected for copepods and then insects and against amphipods, isopods, and ostracods. Coho selected for amphipods and mysids, then amphipods and insects, and against ostracods, isopods, and amphipods (in Jun). Water T increased throughout the season, surpassing optimal conditions in May but never reached lethal levels. Growth rate varied with time and site. Mark-recapture data showed that coho fry had site fidelity within the estuary. Residence times in Jun were 23, 41, and 66 days in areas 2, 4, and 5.

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**: 5 months
Study Design: Fish were collected at 20 sites with beach seine, pole seine, minnow trap, mini purse seine. Fish were ID'd, counted. Chinook and coho were measured (mm) and weighed (0.1 g), VIE marked. Diet (stomach contents from accidental mortalities) and benthic prey availability were recorded. Salinity and T recorded at the surface and 0.5 m where possible. Snorkel survey data were used to calculate density in upper ecotone. Pole seine and minnow trap collections were used to determine freshwater usage later in the year and compare fish using the river and estuary habitats. Habitats were characterized and mapped.	
Statistics:	

Comments: The estuary does have a tide gate on Dyke Slough but it is not discussed in terms of the results. However, this does detail estuarine use of the estuary and stream estuary ecotone by Chinook and coho.

Wallace, M., S. Ricker, J. Garwood, A. Frimodig, and S. Allen. 2015. **Importance of the stream-estuary ecotone to juvenile coho salmon (*Oncorhynchus kisutch*) in Humboldt Bay, California.** California Fish and Game 101(4):241-266.		
Keywords: tide gate removal coho	**Type**: Peer-reviewed journal article	**Publication Date**: 2015
Include: Yes	**Reason**: Useful for the discussion of estuary and non-natal tributary rearing.	**Relevance**:
Location & Species: Humboldt Bay tributaries, coho salmon	**Ecosystem(s)**: freshwater and tidally influenced streams	
Reference Source: https://www.researchgate.net/publication/287686888_Importance_of_the_stream-estuary_ecotone_to_juvenile_coho_salmon_Oncorhynchus_kisutch_in_Humboldt_Bay_California		

Abstract: Recent studies have shown the broad role estuaries play in juvenile coho salmon (Oncorhynchus kisutch) life history; however, most of these studies were limited to the PNW and did not include information from the southern end of its range in California. We sampled the stream-estuary ecotone (SEE) of numerous Humboldt Bay tributaries from 2003 to 2011 to document use by juvenile coho salmon. We sampled fish using seine nets and baited minnow traps and found that young-of-the-year (YOY) and yearling plus (1+) coho salmon reared primarily in freshwater or tidal freshwater habitat in the SEE. We detected three basic life history strategies employed by juvenile coho salmon regarding their use of the SEE. The first group were YOY fish that arrived in the spring and resided mostly in mainstem channel habitat in the summer and early fall; the second group of nearly 1+ fish arrived after the first large stream flow event in the fall and resided extensively in smaller tributary and off-channel habitat during the winter and spring; and finally a third group of stream-reared 1+ coho salmon emigrated through the SEE quickly during the following spring. Juvenile coho salmon resided in the SEE an average of one to two months but some individuals reared there for over a year. We found that about 40% of the coho salmon smolt production from Freshwater Creek, Humboldt Bay's largest tributary, originated from the SEE. Juvenile coho salmon rearing in the SEE were larger than their cohorts rearing in stream habitat upstream of the SEE. Our results demonstrate that juvenile coho salmon utilize portions of the Humboldt Bay SEE in ways similar to those reported in Pacific Northwest estuaries, and suggest that the SEE of Humboldt Bay provides quality rearing habitat—especially over winter rearing habitat—for those juveniles. By incorporating this knowledge into habitat eestoration plans we can design effective habitat restoration projects to improve habitat conditions and non-natal rearing for juvenile coho salmon.

Results Summary:

Broad Outcomes: Subyearling and 1+ coho reared for extensive periods on sampled sections of Humbold Bay stream-estuary ecotone. Subyearlings were mostly in upper sloughs in spring and summer. The mean residence was 1-2 months, but some individuals reared there for over a year. Age1+ used small downstream non-native tributaries mostly in winter (age classification changed at end of calendar year) and residence varied (1-9 months). Lower sloughs were mostly used in spring by both subyearlings and yearlings. Some subyearlings moved into tributaries after spending some time in the brackish water. Yearling fish in the lower sloughs were significantly larger than those in the upper sloughs. Likewise, subyearlings rearing in the SEE were larger than those rearing upstream. Juveniles rearing in the SEE tended to move more during winter than spring and summer. The authors did not comment on possible causes (two examples are life stage and seasonal habitat differences).

Detailed Outcomes:

Effects Modifiers:

Intervention: None	
Conditions:	**Duration**: 2003-2011
Study Design: Stream sections were sampled 4-8 years with seines and traps at set sites within the range of tidal influence. Fish were weighed (0.1g), measured FL (mm), and checked for tags. All untagged coho were PIT-tagged if large enough - migration and growth rates determined for recaptures. Downstream migrant traps were used to geographically partition juvenile production and PIT antennas were used to capture movement and residence data.	
Statistics: Calculated residence time in the stream-estuary ecotone (SEE), and growth rates for fish at large for >12 days. Used ANOVA for spatial and temporal differences of mean size in different areas of the SEE and between the SEE and upper reaches. Tukey-Kramer used for post-hoc comparisons.	

Comments: Tide gates were mentioned in the abstract and very briefly in the discussion but this study was not set up to evaluate effects, did not alter any stream reaches or impediments in any way, and did not discuss the habitat conditions that were most beneficial to juvenile salmon. However, it does provide additional evidence for fish moving into the lower stream reaches and mildly brackish habitats as both subyearlings and yearlings.

<table>
<tr><td colspan="3">Weybright, A.D. and G.R. Giannico. 2017. Juvenile coho salmon movement, growth and survival in a coastal basin of southern Oregon. Ecology of Freshwater Fish. 2017:1–14.</td></tr>
<tr><td>Keywords: N/A</td><td>Type: Peer-reviewed</td><td>Publication Date: 2017</td></tr>
<tr><td>Include: Yes</td><td>Reason: Useful for a discussion of current understanding of juvenile salmon use of stream and estuary habitats.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Palouse Creek, Coos Bay, OR</td><td>Ecosystem(s): freshwater and tidally influenced streams</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Abstract: Juvenile salmonids display highly variable spatial and temporal patterns of early dispersal that are influenced by density-dependent and density-independent factors. Although juvenile coho salmon (Oncorhynchus kisutch) movement patterns in streams and their relationship with body mass and growth have been examined in previous studies, most observations were limited to one season or one stream section. In this study, we monitored the movement of juvenile coho salmon throughout their period of residence in a coastal basin to identify prevalent dispersal strategies and their relationships with body mass, growth rates and survival. Our results revealed seasonally and spatially variable movement patterns. Juvenile coho salmon that dispersed to tidally affected reaches soon after emergence remained more mobile and expressed lower site fidelity than those individuals that remained in upper riverine reaches. We did not detect significantly different growth rates between sedentary and mobile individuals. Although a greater proportion of sedentary than mobile fish survived winter to emigrate from the creek in the spring, reach of residence at the onset of winter influenced these survival estimates. Hence, apparent summer-to-smolt survival for mobile individuals was greater than for sedentary fish in tidally influenced reaches, whereas in riverine reaches the sedentary strategy seemed to be favoured. Our research identified complex movement patterns that reflect phenotypic and life history variation, and underscores the importance of maintaining diverse freshwater and estuarine habitats that support juvenile coho salmon before marine migration.

Results Summary: In summer ~75% of the fish were sedentary and in the winter ~70% were mobile. In summer the mobile fish originated mainly in the lower reaches; in winter they were from all reaches. Of the 64 fish captured in both seasons, the fish sedentary in summer split about evenly between sedentary and mobile classes in winter but for those mobile in summer the majority became sedentary in winter. There was no overarching relationship between growth rate and movement pattern. Winter survival depended on collection reach and movement class in both seasons. Completely sedentary fish had higher apparent survival.

Broad Outcomes: In summer ~3/4 of the fish recovered were sedentary and in the winter ~70% of recovered fish were mobile. The summer mobile fish originated mainly in the lower reaches. The winter mobile fish were from all reaches. 64 were captured in both seasons - of these the summer sedentary split about evenly between sedentary and mobile classes in winter but for those mobile in summer the majority became sedentary in winter. Growth rate differences between sedentary and mobile fish depended on reach and season - no common pattern. Winter survival depended on movement class in summer and winter, and sample reach. Completely sedentary fish had higher apparent survival.

Detailed Outcomes:

Effects Modifiers:

Intervention:	
Conditions: 2 wood top-hinge flap-doors - last refurbished 1985 - large scour holes allow upstream movement of estuarine water	**Duration**: 2 years
Study Design: Water T and salinity recorded. BY '08, '09 coho PIT tagged and tracked. Fish collected, ID'd, counted, subsample tagged, measured (mm), weighed (0.1g). Fish were recaptured physically and by PIT array to track movement. Fish classed as sedentary or mobile by capture location relative to tagging location.	
Statistics: Calculated instaneous growth rate for recaptures. Used a t-test to determine if body size predicted movement class. Tested if growth differed between movement classes. Estimated winter survival.	

Comments: This paper includes very interesting data on coho movement within the freshwater/brackish environment prior to estuary emigration. However, the only affect of the tide gate is to create a brackish pool upstream that coho use for rearing.

<table>
<tr><td colspan="6">G.V. Wright, R.M. Wright, and P.S. Kemp. 2014. Impact of tide gates on the migration of juvenile sea trout, Salmo trutta. Ecological Engineering 71(October): 615–622.</td></tr>
<tr><td colspan="2">Keywords: tide gate removal salmon</td><td colspan="2">Type: Peer-reviewed journal article</td><td colspan="2">Publication Date: 2014</td></tr>
<tr><td colspan="2">Include: Yes</td><td colspan="2">Reason: Based on data for individual fish.</td><td colspan="2">Relevance:</td></tr>
<tr><td colspan="3">Location & Species: The River Meon, UK; juvenile sea trout, Salmo trutta</td><td colspan="3">Ecosystem(s): Tidally influenced river channel and canals</td></tr>
<tr><td colspan="6">Reference Source:</td></tr>
</table>

Abstract: As part of flood protection and land reclamation schemes, tide gates allow rivers to discharge to sea when open, and prevent salt water intrusion when closed. Their impact on diadromous fish migration between essential spawning and rearing habitats, and the effectiveness of mitigation measures, have received little consideration. The River Meon, UK, discharges to sea through four top-hung counterbalanced tide gates. In March 2012, the gates were replaced with new ones of the same design, but with an orifice installed in two of them partly to improve fish passage. Sixty downstream migrating juvenile sea trout, Salmo trutta, were trapped approximately 4.9 km upstream of the tidal limit and tagged with acoustic transmitters in April 2011 (n = 30) and 2012 (n = 30). Tagged individuals were detected by acoustic receivers placed near the tide gates before (year 1) and after (year 2) orifice installation. Of the fish that approached the tide gates, 95.8% and 100.0% successfully passed in years 1 and 2, respectively. The speed of migration at the gates was slower than for upstream and downstream reaches, and was positively related to percentage of time the gates were open. Presence of the orifices did not influence delay. Overall, top-hung tide gates delayed sea trout migration, potentially increasing the risk of predation and energy expenditure during the vulnerable juvenile life stage.

Study highlights: •First study to quantify fish passage efficiency and delay at tide gates. •Smolt passage past the tide gates was high. •Smolts migrated slower through the gates than surrounding river reaches. •In year 2, orifices were installed in 2 gates to increase connectivity. •Mean migration speed past the gates did not differ between years.

Results Summary: 25 of 30 tagged smolts survived to the study area each year. Passage efficiency at the tide gates was 95.8% and 100% in years 1 and 2. Tide gates delayed migration downstream. Orifices in the gates did not decrease the delay caused by the gates. The proportion of time the gates were closed was the most significant factor in migratory delay. Of the time that each fish spent in the tide-gated reach the proportion of time that was night was also significant.

Broad Outcomes: Tide gates delayed migration downstream. Orifices in the gates did not decrease the delay caused by the gates. The proportion of time the gates were closed was the most significant confounding factor in migratory delay.

Detailed Outcomes: 25 of 30 tagged smolts survived to study area each year. Passage efficiency at the tide gates was 95.8% and 100% in years 1 and 2.Confounding factors accounted for 19.8% above and

40.8% in the treatment reach when years were combined. In the treatment reach, the proportion of time that was night was also significant.

Effects Modifiers: River discharge was significantly lower in year 2.

Intervention: 2 of 4 tide gates (counterbalanced, top-hinge) were modified with the addition of a 300 mm diameter orifice which remains open during the full tidal cycle.	
Conditions: The 4 tide gates are deployed in a row across the culvert. The orifices were installed in the outer two (end) gates.	**Duration**: 2 years
Study Design: 30 smolts captured each year, acoustic tagged, released to migrate to the ocean. 6 acoustic recievers were set up to create 3 reaches, one above and two below the culvert and tide gates. Migration timing (delay) and efficiency were determined. Water conductivity, T, pressure, and barometric pressure were measured above (2012) and below (2011, 2012) the tide gates. Tide gate angle and upstream river discharge were also recorded. Migration time = distance between receivers/time between first detections. Mean discharge (Qfish) and T (Tempfish) in each reach, along with % time gates were open (GO%), and % night (N%) were calculated for each fish.	
Statistics: Kolmogorov-Smirnov for normal distribution, Bonferroni correction applied to Qfish and Tempfish for subsequent pairwise comparisons. Multiple regression to explored speed of migration and FL, Qfish, Tempfish, GO%, N% in reaches A & B when combined and within a year. Used t-tests to test influence of tide gate postition and time of day on migration speed, and to compare upstream and downstream conductivity and water T.	

Comments: This paper is not from the PNW, but may be helpful. It shows that fish passage orifices do not decrease the migration delay caused by tide gates for outmigrating juveniles. There is a companion paper focused on adults.

<table>
<tr><td colspan="3">G.V. Wright, R.M. Wright, B. Bendall, and P.S. Kemp. 2016. Impact of tide gates on the upstream movement of adult brown trout, Salmo trutta. Ecological Engineering 91(June): 495–505.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: Yes</td><td>Reason:</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: River Stiffkey, North Norfolk, UK; Brown trout, anadromous form called sea trout</td><td>Ecosystem(s): river</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Abstract: Tide gates, used to regulate tidal flow as part of land reclamation programmes, temporally block fish movement by closing during the flood tide. Their impact on the upstream movement of brown trout, Salmo trutta, and other fish species has received little consideration. The River Stiffkey, UK, discharges into the North Sea via three top-hung tide gates, one counterbalanced (Gate 1), and two not (collectively referred to as Gate 2). Three-hundred adult trout were caught between 0.5 and 6.0 km upstream from the gates on 20 separate days between July and December 2011 (n = 15 per day) and implanted with 23 mm half-duplex Passive Integrated Transponder (PIT) tags before being released 15 m downstream from Gate 1 where PIT antennas were located on either side. Overall, gate attraction (percentage of fish released that were detected by at least one antenna) and passage efficiencies (number of fish that passed Gate 1 reported as a proportion of those that approached) were 96.7% and 92.4%, respectively. The operation of an orifice, installed to improve connectivity for adult trout and juvenile eels, did not influence passage efficiency or delay. Of the fish that passed Gate 1 when the orifice was operational, 42.6–55.7% approached the orifice entrance and 70.6–92.3% of these passed through. Individuals that passed through the orifice were larger than those that did not. Movement past the tide gates (median duration = 6.04 h) took 6 times longer than passage through two unimpeded reaches upstream. Duration of passage through the gates was predominately related to the mean angle of gate opening during the time prior to passage, followed by water temperature. Overall, a counterbalanced top-hung tide gate delayed the upstream movement of brown trout, highlighting a need to assess and potentially mitigate the impact of gates with more restrictive opening apertures and durations.

Study highlights:

• Diadromous fish passage at tide gates has received little consideration.

• Upstream adult brown trout, Salmo trutta, passage at a tide gate was high.

• Adult trout moved 6 times slower past the gate than through unimpeded river reaches.

• An orifice modification did not improve passage or decrease delay.

• Smaller gate apertures and higher temperatures were related to longer passage times.

Results Summary: Migration speed was 6 times slower in the tide gate reach than in upstream unimpeded reaches. The orifice did not improve attraction, passage efficiency, or delay. Larger fish used the orifice when it was available. No fish passed through the orifice when the tide gate was closed. The time to pass the gate was negatively correlated with temperature downstream, temperature upstream, and discharge.

Broad Outcomes: Migration speed was 6 times slower in the tide gate reach than in upstream unimpeded reaches. The orifice did not improve attraction, passage efficiency, or delay. Larger fish, on average, used the orifice. No fish passed through the orifice when the tide gate was closed.

Detailed Outcomes: 290 of 300 PIT tagged trout were detected at least once. 251 passed through Gate 1 (91.6% efficiency). Fish had no apparent preference for passing at flood or ebb tide stage. Fish made a median of 8 approaches (no difference with orifice status). No fish returned downstream after passage. More fish passed at night. Fish that used the orifice were larger than those that passed at the gate when the orifice was open. No fish used the orifice when Gate 1 was closed. Gate angle during each fish's passage time had the most influence on passage duration when the orifice was non-operational and fish specific T had the most influence when the orifice was operational. Migration speed was lower in the impeded (tide gate) reach than in unimpeded reaches upstream. Reach A migration duration did not differ between fish that passed through the orifice and those that used Gate 1. # Gate 1 approaches was positively correlated with duration of migration through Reach A, negatively correlated with angle width. Reach A passage duration was negatively correlated with with T downstream, T upstream, discharge at release.

Effects Modifiers:

<table>
<tr><td colspan="2">Intervention: A submerged fish passage orifice with a float controlled bottom-hinged flap gate was installed under tide gate 1. Tide gate 1 is top-hinged with a counterbalance weight to increase opening time and width.</td></tr>
<tr><td>Conditions: Some of the river discharge also flows through Tide gate 2 - two paired top-hinge tide gates operated passively.</td><td>Duration: 5 months</td></tr>
<tr><td colspan="2">Study Design: Collected, measured (mm), weighed (g), and PIT tagged adult upstream migrant brown trout. The fish passage orifice was allowed to operate passively or was clamped shut - alternated on every 2nd tidal cycle. 6 PIT tag detectors installed in River Stiffkey lower reaches recorded movement up- and downstream. The orifice was monitored with a IR-LED video camera. Only fish passing through Gate 1 were included in analyses. Categorized fish behavior at the passage orifice. Logged condutivity, T, pressure, barometric pressure. Calculated water depth and salinity. Recorded gate opening angle, river discharge, dissolved oxygen, velocity at Gate 1.</td></tr>
<tr><td colspan="2">Statistics: Calculated speed of migration through each reach for each fish and determined the mean opening angle, discharge, T, % of time it was night during passage through each reach. Wilcoxon signed-rank test and Friedman's ANOVA were used to test for between reach differences in migration speed, discharge, T for each fish. Assessed the influence of orifice status and environmental variables on delay in Reach A (the location of the tide gate).</td></tr>
</table>

Comments: This study is outside the PNW and focused on adults instead of juveniles. However, I think it would be a good piece of information to include. Many of the studies on juveniles assume that adults will be able to better traverse tide gated reaches and impoundments.

<table>
<tr><td colspan="4">Beamer, E. and R. Henderson. 2013. Fisher Slough Floodgate Report for Water Year 2012. Report prepared for The Nature Conservancy under Grant Agreement # WA-S-0216-061-0. Skagit River System Cooperative, LaConner, WA. 45 pp.</td></tr>
<tr><td>Keywords: flood gate replacement salmon</td><td colspan="2">Type: Reports</td><td>Publication Date: 2013, 2014, 2015, 2016</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: The relevant water data is included in other reports with fish monitoring data.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Fisher Slough, South Fork Skagit River, WA.</td><td colspan="2">Ecosystem(s):</td></tr>
<tr><td colspan="4">Reference Source: http://skagitcoop.org/wp-content/uploads/FisherSloughFGReportWY2012Final.pdf</td></tr>
</table>

Study Description: Fisher Slough, Skagit River estuary, Washington. In 2009 barn style doors were replaced with 3 tidegates with floats to self-regulate. There are two lower submerged tidegates on the headwall.The tide gates were monitored for water velocity and depth, water surface elevation, and gate openness during water years 2012 and 2013. Monitoring results were compared to operational criteria for both flood protection and fish passage. The authors pointed out that successful floodgate operation must include monitoring of current conditions and appropriate response to achieve desired outcomes.

<table>
<tr><td colspan="6">Beamer, E. and R. Henderson. 2015. Technical Memo: Fir Island Farms before restoration fish monitoring 2015. December 16, 2015. Skagit River System Cooperative, LaConner, WA. 8 pp.</td></tr>
<tr><td colspan="2">Keywords: N/A</td><td colspan="2">Type: Technical memo</td><td colspan="2">Publication Date: 2015</td></tr>
<tr><td colspan="2">Include: No</td><td colspan="2">Reason: This is first year pre-restoration data with no summarization or data analysis.</td><td colspan="2">Relevance:</td></tr>
<tr><td colspan="3">Location & Species: Fir Island Farms, Skagit River basin</td><td colspan="3">Ecosystem(s):</td></tr>
<tr><td colspan="6">Reference Source: http://skagitcoop.org/wp-content/uploads/SRSC-Memo-FIF-2015.pdf</td></tr>
</table>

Study Description: This memo describes pre-restoration baseline fish monitoring. A dike setback was planned for the site. Fish were collected up and downstream of the tide gate, identified and counted. Water quality was measured, and substrate and vegetation classes documented.

Results Summary: A total of eleven species were caught. Five estuarine species were caught upstream (including Chinook and chum), likely passing at flood tide through leaky tide gate. Environmental data was presented in tables but not summarized or elaborated on.

<table>
<tr><td colspan="4">Beamer, E.M., W.G. Hood, and R. Henderson. 2009. Fish response to restoration of a seasonal coastal stream in Puget Sound (Washington, USA). Washington States Estuary and Salmon Restoration Program (ESRP) Project #07-64. Skagit River System Cooperative, LaConner, WA 98257 USA. 31pp.</td></tr>
<tr><td>Keywords: N/A</td><td colspan="2">Type: Report</td><td>Publication Date: 2009</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: Evaluates culvert removal, no tide gates present.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lone Tree Lagoon, Lone Tree Creek</td><td colspan="2">Ecosystem(s): seasonal non-natal stream upstream of a natural lagoon</td></tr>
<tr><td colspan="4">Reference Source:</td></tr>
</table>

Study Description: A culvert (no tide gate) was removed between Lone Tree Lagoon and stream and replaced with a bridge. The channel was deepened and several culverts were replaced with wider shorter versions. For 6 years fish were sampled with beach seine, fyke net, and electrofisher and water quality was measured. Identified and counted all fish, sub-sampled length by species. Tide gauges logged water level in the lagoon. Standardized abundances between lagoon and stream and compared pre- and post-restoration.

Results Summary: The channel and lagoon had similar species present, and included juvenile Chinook, chum, and pink (even years). The stream catches included subyearling Chinook, coho, chum, rainbow trout, and yearling coho. After culvert replacement the standardized abundance of staghorn sculpin, chum, and shiner perch in the channel increased by orders of magnitude but that of Chinook and stickleback did not change.

Beamer, E., R. Henderson, and K. Wolf. 2010. **Juvenile salmon, estuarine, and freshwater fish utilization of habitat associated with the Fisher Slough Restoration Project, Washington.** Skagit River System Cooperative, La Conner, WA. 66 pp.			
Keywords: tide gate replacement salmon	**Type**: 2009 Project Report		**Publication Date**: 2010
Include: No	**Reason**: These 2009 pre-restoration data are included in the analyses in subsequent project reports.		**Relevance**: Low
Location & Species: South Fork Skagit River, WA. Chinook salmon focus (also collected coho and chum salmon, steelhead, cuttthroat)		**Ecosystem(s)**: tidal delta slough, riverine tidal	
Reference Source: http://skagitcoop.org/wp-content/uploads/FisherSlough2009Report_Final.pdf			

Study Description: The Fisher Slough tide gate is 3 openings in a concrete sill, each with paired side-hinge doors. The gates open and close with the tide for flood control fall, winter, and spring but are tied open in summer for irrigation. Fish passage is possible only when gates are open. Collected fish up and downstream of the tide gate. Identified fish and counted by species. Measured 20 individuals per site each sampling period. Measured water quality variables and documented substrate and vegetation. Analyzed fish density and environmental variables among sites and dates with ANOVA.

Results Summary: Under normal operation water level changes upstream were less extreme than downstream, mean T was similar up and downstream, and passage opportunity (gate open, water velocity low) was 49%. During irrigation operation water level changes were similar up and downstream, mean T was ~2°C higher upstream, and passage opportunity (water velocity low) was 73%. Chinook threshholds were exceeded ~5% of the time up and downstream. Wild Chinook were present up and downstream in Feb, persisted upstream until mid-July and downstream at least until Aug 12. All upstream Chinook had passed the tide gate; there are no Chinook spawning upstream of the tide gate.

<table>
<tr><td colspan="4">Beamer, E., B. Brown, and K. Wolf. 2011. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Dugualla Heights Lagoon, 2011. Prepared for Whidbey Camano Land Trust. Skagit River System Cooperative, La Conner, WA. 13 pp.</td></tr>
<tr><td>Keywords: N/A</td><td colspan="2">Type: Report</td><td>Publication Date: 2011</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: This is pre-restoration baseline monitoring data.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Dugualla Heights Lagoon, Skagit Bay</td><td colspan="2">Ecosystem(s): tidally influenced lagoon, pocket estuary, non-natal estuary</td></tr>
<tr><td colspan="4">Reference Source: http://skagitcoop.org/wp-content/uploads/Dugualla-Heights-Fish-Report-2011-4.pdf</td></tr>
</table>

Study Description: The baseline monitoring described in this report is at a lagoon connected with a culvert. The lagoon and adjacent intertidal were beach seined. Fish were identified and counted by species. The authors also measured T, salinity, and dissolved oxygen.

Results Summary: The authors collected 13 species, including Chinook, chum, and bull trout (~3% of the total catch). Cottids, flatfish, forage fish, other estuarine or nearshore species (especially stickleback and shiner perch), and juvenile dungeness were also collected. All salmonids were caught in adjacent nearshore, none in the lagoon. Dissolved oxygen remained above critical levels, salinity was at or below levels in other pocket estuaries used by Chinook juveiles, T in the lagood reached 15°C critical temperature in May.

<table>
<tr><td colspan="6">Beamer, E., B. Brown, and K. Wolf. 2012. Juvenile salmon and nearshore fish use in shallow intertidal habitat associated with Dugualla Heights Lagoon, 2012. Prepared for Whidbey Camano Land Trust. Skagit River System Cooperative, La Conner, WA. 14 pp.</td></tr>
<tr><td colspan="2">Keywords: N/A</td><td colspan="2">Type: Report</td><td colspan="2">Publication Date: 2012</td></tr>
<tr><td colspan="2">Include: No</td><td colspan="2">Reason: This report includes only pre-restoration monitoring data.</td><td colspan="2">Relevance:</td></tr>
<tr><td colspan="3">Location & Species: Dugualla Heights Lagoon, Skagit Bay</td><td colspan="3">Ecosystem(s): tidally influenced lagoon, pocket estuary, non-natal estuary</td></tr>
<tr><td colspan="6">Reference Source:</td></tr>
</table>

Study Description: The baseline monitoring described in this report is at a lagoon connected with a culvert. The lagoon and adjacent intertidal were beach seined; the nearshore habitat was also sampled. Fish were identified and counted by species. The authors also measured T, salinity, and dissolved oxygen.

Results Summary: The authors collected 22 species and juvenile salmonids comprised >16% of the catch. Salmon were only collected below the culvert; there was no salmon passage. Chinook, chum, and pink were only caught in the intertidal. Cottids, flatfishes, forage fish, other estuarine or nearshore species (dominated by stickleback and shiner perch) and a few juvenile dungeness were also collected.

<table>
<tr><td colspan="4">Brophy, L.S., and S. van de Wetering. 2012. Ni-les’tun Tidal Wetland Restoration Effectiveness Monitoring: Baseline: 2010-2011. Corvallis, Oregon: Green Point Consulting, the Institute for Applied Ecology, and the Confederated Tribes of Siletz Indians.</td></tr>
<tr><td>Keywords: tide gate replacement coho</td><td colspan="2">Type: Report</td><td>Publication Date: 2012</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: These data are used in the Brophy 2014 report and are compared to post-restoration monitoring data.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Ni-les’tun tidal wetland restoration site, Bandon National Wildlife Refuge, Coquille River Estuary, Oregon. Monitoring focused on tidal hydrology and plant communities.</td><td colspan="2">Ecosystem(s): tidally influenced wetland streams and tidal channels</td></tr>
<tr><td colspan="4">Reference Source: http://ir.library.oregonstate.edu/xmlui/handle/1957/35590</td></tr>
</table>

Study Description: Dikes and tide gates were removed. Major ditches were filled and minor ditches disked. Tidal channels were excavated. The plant community composition and vegetative cover were sampled.

Results Summary: In general, the plant community composition is dynamic at restoration and reference sites but the restoration site is becoming more similar to the reference site and other least disturbed sites.

<table>
<tr><td colspan="6">Calles, O. and L. Greenberg. 2009. Connectivity is a two-way street—the need for a holistic approach to fish passage problems in regulated rivers. River Research and Applications, 25: 1268–1286.</td></tr>
<tr><td colspan="2">Keywords: N/A</td><td colspan="2">Type: Peer-reviewed paper</td><td colspan="2">Publication Date: 2009</td></tr>
<tr><td colspan="2">Include: No</td><td colspan="2">Reason: This paper has data on passage through fishways around hydropower turbines, not tide gates.</td><td colspan="2">Relevance:</td></tr>
<tr><td colspan="3">Location & Species: River Emån, southeastern Sweden. Sea-run brown trout</td><td colspan="3">Ecosystem(s): freshwater river</td></tr>
<tr><td colspan="6">Reference Source:</td></tr>
</table>

Study Description: This project focused on sea-run brown trout passage around turbines on the River Emån, Sweden. Monitoring was conducted during 2 years. Upstream migrating adults were PIT-tagged, downstream migrating smolts were tagged with radio transmitters. Monitored movement with fixed telemetry stations and PIT arrays. Two-way ANOVA tested for differences in size by sex, year, tag type. Calculated fishway attraction effeciencies for spawners with radio tags and passage efficiency with radio and PIT tags.

Results Summary: Most adults stopped at spawning sites below the second turbine. Median travel time between the two turbines for adults was approximately a month in both years. Fish that had previously made the spawning migration were more likely to migrate to fishways. Approximately half of the smolts migrated downstream past both turbines in each year. Losses were from turbines, predation, desmoltification. The key points seem to be that both upstream and downstream passage issues need to be addressed and that connectivity needs to be addressed holistically.

<table>
<tr><td colspan="3">Cordell, J., J.D. Toft, A. Gray, G.T. Ruggerone, and M. Cooskey. 2011. Functions of restored wetlands for juvenile salmon in an industrialized estuary. Ecological Engineering 37(2):343-353.</td></tr>
<tr><td>Keywords:</td><td>Type: Peer-reviewed</td><td>Publication Date: 2011</td></tr>
<tr><td>Include: No</td><td>Reason: These projects were all created 'restoration' sites. None of them included tide gate removal or replacement.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Duwamish Estuary, Chinook and chum salmon</td><td>Ecosystem(s): intertidal bay, tidal creek, embayment</td></tr>
<tr><td colspan="3">Reference Source:
https://www.researchgate.net/profile/Gregory_Ruggerone/publication/229349845_Functions_of_restored_wetlands_for_juvenile_salmon_in_an_industrialized_estuary/links/53ce975f0cf24377a65dd31a.pdf</td></tr>
</table>

Study Description: Three sites were 'restored' by creating embayments or estuaries and planting riparian species. Three restoration sites and adjacent paired reference sites (linear rip-rap segments) were sampled with enclosure nets. Fish were identified and counted; salmonids were checked for hatchery origin,at least 5 of each species and origin type were measured, weighed, and lavaged (chum were preserved whole for diet). 5 additional reference sites were beach seined and fish sampled as above except all diet samples were preserved in whole fish. Measured water quality variables, analyzed diet, and modeled growth.

Results Summary: Fish densities were similar between restored and reference areas at the two upriver sites but lower in the restored site at the lower river location. At a given date chum were smaller than Chinook and consumed smaller prey species. Chinook diets differed between restored and reference sites. However, modeled growth rates did not differ systematically between restored and reference sites. Growth rate of co-occurring wild and hatchery Chinook varied with season and were highest during peak densities. Inartaneous ration and estimated growth rates were higher at the Turning Basin sites than at other locations. Location of restoration projects in the estuary is key to their success providing habitat and forage for juvenile salmon migrants. Coho, sockeye, pink, steelhead, cutthroat were present at low numbers but not included in analyses.

<table>
<tr><td colspan="3">David, A.T., C.S. Ellings, I. Woo, C.A. Simenstad, J.Y. Takekawa, K.L. Turner, A.L. Smith, and J.E. Takekawa. 2014. Foraging and growth potential of juvenile Chinook salmon after tidal restoration of a large river delta. Transactions of the American Fisheries Society 143(6):1515-1529.</td></tr>
<tr><td>Keywords:</td><td>Type: Peer-reviewed</td><td>Publication Date: 2014</td></tr>
<tr><td>Include: No</td><td>Reason: Dike removal, no mention of tide gates.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Nisqually River delta, WA (47.08N, 122.70W), Chinook (natural origin, hatchery), and chum (natural origin) salmon</td><td>Ecosystem(s): tidal marsh</td></tr>
<tr><td colspan="3">Reference Source: http://afs.tandfonline.com/doi/abs/10.1080/00028487.2014.945663</td></tr>
</table>

Study Description: Dike sections were removed in 1996, 2002, 2006, and 2009 restoring tidal inundation to 364 ha. Sampled 2006 and 2009 restored and 2 reference sites, 1 channel per site. T was logged. Fish were collected Apr-Jul, counted by species, and diet analyzed for up to 10 hatchery and 10 natural-origin Chinook. Stomach contents were weighed, and sorted by taxa (each counted and weighed). Fish density was calcuated for each site. Diet similarity was calculated and regressed against time since restoration. Stomach fullness, daily ration, diet energy density, and fish energy density were calculated. A growth potential (g/g*d) bioenergetics model was run with consumption, energy density of diet and fish, fish mass, and temperature as inputs. Of the model inputs only gastric evacuation rate was derived from literature values while the rest were based on measurements from fish collected in the sample area.

Results Summary: Chinook were the most often collected salmonid. Other salmonids were collected seasonally (chum and pink), or rarely (coho and cutthroat). Chinook density differences between restored and reference channels decreased through time but density remained higher in reference channels, especially during May and Jun. The energetic density of the diet decreased with increasing fish density. Diet similarity between restored and reference channels increased with time since restoration. Bioenergetics modeling indicated that the potential for growth was similar in the restored and reference channels after the first year post-restoration. However, the increased temperature range in the restored channels led to larger potential growth ranges and indicated that channels in the restored marshes had not reached reference conditions.

<table>
<tr><td colspan="3">Diefenderfer, H.L., A.M. Coleman, A.B. Borde, and I.A. Sinks. 2008. Hydraulic geometry and microtopography of tidal freshwater forested wetlands and implications for restoration, Columbia River, U.S.A. Ecohydrology and Hydrobiology 8(2): 339-361.</td></tr>
<tr><td>Keywords: tide gate removal coho</td><td>Type: Peer-reviewed journal article</td><td>Publication Date: 2008</td></tr>
<tr><td>Include: No</td><td>Reason: The data are presented in such a way that it is not possible to isolate the data for tide gate removal versus replacement.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Grays Bay, Columbia River. Looked at restoration of channel geometry, sediment budgets and vegetation communities after spruce swamp restoration. Some study sites had tide gates replaced. Discusses results in context of potential restoration of salmon habitat.
JRB note: Potentially relevant; may be hard to clearly differentiate and summarize relevant content.</td><td>Ecosystem(s): Historically forested tidal freshwater diked pasture restoration swamps (3) and remnant reference swamps (3) + tidal marsh mitigation site and reference marsh on Youngs Bay</td></tr>
<tr><td colspan="3">Reference Source: http://fulltext.study/download/4388250.pdf</td></tr>
</table>

Study Design: Restoration sites: culvert installation(tide gate removal) or dike breaching - intended to restore flows and forest cover. Marsh mitigation: tide gate replacement - enhance hydrologic connectivity and still control flooding for airport. Measured sediment accretion, water level, and elevations along cross-section transects. Cross-sections represented areas closest to, farthest from restoration point and a point between the two. Calculated cross sectional area. Derived contributing catchment area and total channel length in network for inundation. Calculated topgraphic roughness of the floodplain surface and area-time inundation index.

Results Summary: Hydrological reconnection immediately influences inundation frequency and area-time. Channel density was similar between restoration and reference sites. Most change in channel cross-section and incision was at the mouth. Catchment area, channel length, and cross-sectional area at outlet were correlated in reference but not restoration sites. From the analyses it is difficult to determine differences between dike breach, culvert installation (tide gate removal), and tide gate replacement (top hinge with side hinge) because restoration sites were grouped.

<table>
<tr><td colspan="4">Diefenderfer, H.L., A.B. Borde, and V.I. Cullinan. 2013. A synthesis of environmental and plant community data for tidal wetland restoration planning in the Lower Columbia River and Estuary. PNNL-22667, prepared by the Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, Washington, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.</td></tr>
<tr><td>Keywords:</td><td colspan="2">Type: Report</td><td>Publication Date: 2013</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: Discussion of tidal marsh sites but not response to tide gate removal</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lower Columbia River and Estuary and tributaries: Grays River and Lewis and Clark River</td><td colspan="2">Ecosystem(s): tidal wetlands</td></tr>
<tr><td colspan="4">Reference Source: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22667.pdf</td></tr>
</table>

Study Description: Data from 55 studies was combines and reanalyzed to describe plant community composition and hydrologic change after restoration. Summarized data on plant communities and distribution, non-native species, transect slope, hydrologic regime, sediment accretion, temperature, channel morphology and inundation. The results are organized to provide guidance to those planning restoration projects so that measures can be taken to increase project success. Determined if wetland metrics were related to disturbance level.

Results Summary: Elevation and inundation are related. Within an estuary zone elevation can serve as a proxy for inundation. Vegetation data is organized to show the horizontal and vertical distributions and to provide data on whether each species is native, its wetland status (facultative, obligate), and whether it is invasive/weedy. Transect slope did not differ among wetland types and was not related to plant community metrics. Sediment accretion did not differ with estuary zone or weland type. Water temperature differed with rkm in some years and some seasons. Morphology and inundation did not differ except between tributaries and mainstem for inundation. Marsh elevation and proportion of low marsh differed among disturbance categories. Sediment accretion and grain size did not differ among disturbance categories but total organic carbon did.

<table>
<tr><td colspan="3">Ellings, C.S., M.J. Davis, E.E. Grossman, I. Woo, S. Hodgson, K.L. Turner, G. Nakai, J.E. Takekawa, J.Y. Takekawa. 2016. Changes in habitat availability for outmigrating juvenile salmon (Oncorhynchus spp.) following estuary restoration. Restoration Ecology 24(3): 415-427.</td></tr>
<tr><td>Keywords:</td><td>Type: Peer-reviewed</td><td>Publication Date: 2016</td></tr>
<tr><td>Include: No</td><td>Reason: Dike removal, no mention of tide gates.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Nisqually River delta, WA (47.08N, 122.70W), Chinook (natural origin, hatchery), and chum (natural origin) salmon</td><td>Ecosystem(s): brackish marsh with large freshwater input (2006 restored, Nisqually Ref), salt marsh (2009 restored, Red Salmon Ref)</td></tr>
<tr><td colspan="3">Reference Source: https://walrus.wr.usgs.gov/reports/reprints/Ellings_RE24.pdf</td></tr>
</table>

Study Description: This study focused on marshes with dike removals in 2006 and 2009. Measured channel morphology, tidal inundation, and water quality variables. Fish were identified, counted, 10 individuals of each species were measured (mm). Hatchery had 95% mark rate so all unmarked fish assumed natural origin. Calculated index of fish use for each site - proportional presence - number months fish present at site relative to number of sampling months fish present in the delta for fyke net data. Calculated mean catch per set by month across all sites for beach seine data.

Results Summary: The time that marsh habitat was available increased from 30% to 75% post-restoration. Dike removal increased connectivity, accessibility for juvenile salmon, tortuosity, and, for some sloughs, the number of connection pathways. There were no changes in channel sinuosity for major or minor channels. However, channel area, length, and edge all increased after restoration. Channel depth increased at restored sites, but to a greater degree on the west side of the river and especially at seaward and midland sites. Reference sites showed little change. Water temperature was stable at reference sites while restored sites had lower temperatures. Inland sites were warmer with larger fluctuations throughout the year. Salinity was 3ppt higher at reference sites. Natural origin and hatchery Chinook and chum were caught in restored channels during the first post-restoration sampling year. Proportional use by hatchery and natural origin Chinook was highest at the Nisqually Ref and 2009 Restoration sites. Proportional use by chum was highest at the Nisqually Ref and Red Salmon Ref sites. Catch per set was generally lowest for chum at the 2009 Restoration site and for Chinook at the 2006 Restoration site. The capacity of the marshes to support foraging and growth were not estimated.

<table>
<tr><td colspan="3">Ellingson, K.S. and B.J. Ellis-Sugai. 2014. Restoring the Salmon River Estuary: Journey and Lessons Learned Along the Way 2006-2014. Report to Siuslaw National Forest, Corvallis: OR. 54pp.</td></tr>
<tr><td>Keywords: N/A</td><td>Type: Educational report</td><td>Publication Date: 2014</td></tr>
<tr><td>Include: No</td><td>Reason: This is mainly logistics and leasons learned for those preparing or planning restoration actions.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Salmon River estuary, Oregon</td><td>Ecosystem(s):</td></tr>
<tr><td colspan="3">Reference Source:</td></tr>
</table>

Study Description: This report describes restoration projects in the Salmon River estuary. It is generally non-technical and one of the aims is to share lessons learned for those condisering undertaking large complex restoration actions. The land use history of the estuary and the Cascade Head Scenic Research area designation are discussed. The Tamara Quays and Pixieland projects are included separately in Appendix B.

Flitcroft, R.L., D.L. Bottom, K.L. Haberman, K.F. Bierly, K.K. Jones, C.A. Simenstad, A. Gray, K.S. Ellingson, E. Baumgartner, T.J. Cornwell, and L.A. Campbell. 2016. **Expect the unexpected: place-based protections can lead to unforseen benefits.** Aquatic Conservation: Marine and Freshwater Ecosystems 26(Suppl 1): 39-59.		
Keywords:	**Type**: Peer-reviewed	**Publication Date**: 2016
Include: No	**Reason**: The primary sources are included in our review.	**Relevance**:
Location & Species: Salmon River and estuary	**Ecosystem(s)**:	
Reference Source: https://www.fs.fed.us/pnw/pubs/journals/pnw_2016_flitcroft001.pdf		

Study Description: This paper is basically an essay on the process of conservation, restoration, and research in the Salmon River and estuary. The authors discuss the sequence of events that led to the long term study of the area and summarize results from several studies.

<table>
<tr><td colspan="6">Gardner, C.J., J. Rees-Jones, G. Morris, P.G. Bryant and M.C. Lucas. 2016. The influence of sluice gate operation on the migratory behaviour of Atlantic salmon Salmo salar (L.) smolts. Journal of Ecohydraulics, 1:1-2, 90-101</td></tr>
<tr><td colspan="2">Keywords: N/A</td><td colspan="2">Type: Peer-reviewed paper</td><td colspan="2">Publication Date: 2016</td></tr>
<tr><td colspan="2">Include: No</td><td colspan="2">Reason: This paper describes tide gate effects – no intervention was done.</td><td colspan="2">Relevance:</td></tr>
<tr><td colspan="3">Location & Species: River Dee, North Wales. Atlantic salmon</td><td colspan="3">Ecosystem(s): freshwater river</td></tr>
<tr><td colspan="6">Reference Source: http://dx.doi.org/10.1080/24705357.2016.1252251</td></tr>
</table>

Study Description: This paper focuses on juvenile Atlantic salmon passage of sluices on River Dee, North Wales. Sluices are undershot guillotine style gates. The study was meant to ascertain local impacts of flow-control gates on behavior and survival of juveniles. Smolts were caught by fyke nets and 94 were tagged with coded acoustic tags. Six discrete receiver arrays detected tags as the fish emigrated.

Results Summary: A majority of fish (91% hatchery and 88.9% wild) successfully passed the gates. There was no difference between hatchery and wild fish in the control or gate reaches. Fish preferentially passed at night. Migration speed was positively influenced by flow and by the gate opening apertures. Fish origin and size, and temperature did not influence migration speed. Migration speed was delayed by the presence of the sluice gates.

<table>
<tr><td colspan="4">Giannico, G. and R. Cooper (eds). 2007. Proceedings of the West Coast Symposium on the Effects of Tide Gates on Estuarine Habitats and Fishes. October 31–November 2, 2006. South Slough National Estuarine Research Reserve, Charleston, OR. Publication w06001, Oregon Sea Grant, Corvallis, OR. 86 pp.</td></tr>
<tr><td>Keywords: tide gate removal coho</td><td colspan="2">Type: Conference proceedings</td><td>Publication Date: 2006</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: Insufficient detail presented.</td><td>Relevance: Hinton et al. chapter has high relevance</td></tr>
<tr><td colspan="2">Location & Species:</td><td colspan="2">Ecosystem(s):</td></tr>
<tr><td colspan="4">Reference Source:
http://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/sgpubs/onlinepubs/w06001.pdf</td></tr>
</table>

Comments: Chapter by Jon Souder mainly explains methodology for using paired transducers to determine tide gate opening times. Chapter by Hinton et al. has a BACI design but detailed data are not presented. Data from this project are included in Skagit River estuary reports that we have reviewed.

<table>
<tr><td colspan="4">Greene, C.M. and E.M. Beamer. 2012. Monitoring Population Responses to Estuary Restoration by Skagit River Chinook salmon. Intensively Monitored Watershed Project Annual Report 2011. Fish Ecology Division, Northwest Fisheries Science Center and Skagit River System Cooperative.</td></tr>
<tr><td>Keywords:</td><td colspan="2">Type: Report</td><td>Publication Date: 2012</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: The focus is broadly on restoration, not on tide gate removal or replacement.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Skagit River delta and Skagit Bay; Chinook salmon</td><td colspan="2">Ecosystem(s): tidal delta, shoreline, nearshore (subtidal neritic)</td></tr>
<tr><td colspan="4">Reference Source:
https://www.nwfsc.noaa.gov/assets/11/7388_06272014_140450_Greene.and.Beamer.2012.pdf</td></tr>
</table>

Study Description: A large-scale effort to restore Skagit delta habitat was begun in 2000. These 7 projects represent >750 acres restored. They have fulfilled ~10% of the restoration called for in the Skagit Recovery plan. Juvenile Chinook were sampled in freshwater, blind channel, shoreline, and subtidal habitats. Estimated abundance and density for resident and migrant fish. Investigated 3 density-dependent relationships: tidal delta density vs total migrants, delta fry size vs total migrants, shorline cumulative density vs delta density. Calculated connectivity index based on distance from mainstem and channel width at sample site; compared with local density.

Results Summary: Fry size, outmigrant abundance, and cumulative density were density dependent. Fish density was dramatically higher and relatively stable at sites closer to the mainstem and with wider channel mouths. Local densities increased after restoration actions at two sites. At sites with low connectivity indices fish densities were low but at connectivity indices above ~0.02 fish density was relatively stable around 10,000 fish/ha. The South Fork Skagit cumulative density decreased relative to the North Fork Skagit after South Fork restoration actions, evidence of increased rearing capacity. However, the density of juvenile Chinook in the shoreline of Skagit Bay and the fry to adult return rate remained density dependent. Additional restoration efforts are needed to increase recruitment.

Greene, C., E. Beamer, and J. Anderson. 2015. **Study Plan and Summary of Results for the Skagit River Estuary Intensively Monitored Watershed Project**. August 2015. National Marine Fisheries Service, Northwest Fisheries Science Center, Skagit River System Cooperative, Washington Department of Fish and Wildlife. 29 pp.		
Keywords:	**Type**: Report	**Publication Date**: 2015
Include: No	**Reason**: The more recent report, Greene et al. 2016, is included in the review.	**Relevance**:
Location & Species: Skagit Bay and Skagit River tidal delta	**Ecosystem(s)**: intertidal and tidally-influenced freshwater river delta	
Reference Source: http://www.rco.wa.gov/doc_pages/other_pubs.shtml#salmon		

Study Description: The Skagit River is an Intensively Monitored Watershed, which means that several of its tributaries, sloughs, and river sections are sampled each year. Systems had been sampled for 14-23 years. Depending on the sampling area fish were collected by downstream migrant trap, fyke net (tidal delta), beach seine (nearshore), or townet (offshore). The authors calculated density and cumulative density, measured FL, and documented migrant timing. They aimed to determine the effectiveness of different restoration designs by summarizing data from projects throughout the watershed.

Results Summary: Projects associated with dike setback, dike breach, and fill removal had juvenile Chinook densities comparable to reference sites. Self-regulating tide gate sites had much lower Chinook densities than reference sites although they did perform better than traditional flap gates. Individual projects are contributing to overall estuary goal. As capacity increased after restoration, densities decreased and residency time increased.

<table>
<tr><td colspan="4">Hill, G. 2013. Comox Road Dyke Slough Tide Gate Modifications Numerical Modelling and Conceptual Design Report (DRAFT) Project #300174. Northwest Hydraulic Consultants, Ltd., Nanaimo, BC. 13 pp.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td colspan="2">Type: Report</td><td>Publication Date: 2013</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: The modeling is likely not transferrable to other systems. Several other studies have found that data post-restoration do not match predicted or expected levels (water, habitat, fish usage…).</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Comox Slough, Courtenay, British Columbia</td><td colspan="2">Ecosystem(s): tidal freshwater slough</td></tr>
<tr><td colspan="4">Reference Source: http://projectwatershed.ca/wp-content/uploads/2010/10/300174-Comox-Road-Tide-Gates-Modelling-Update-DRAFT.pdf</td></tr>
</table>

Study Description: Modeled hydrologic effects of increasing tailrace riffle elevations downstream to -0.6 or -0.4 m and installing permanent holes 40x80mm or 200x300 mm in one of three tide gates. Used graphical comparison and calibration of modelled and actual water levels.

Results Summary: At high flow conditions there were no differences among model simulations. At low flow conditions model outputs differed. Higher water elevations were achieved with the 200x300mm hole and were not strongly influenced by the riffle tailwater increase although the -0.4 m tailwater and 200x300 mm combination produced the highest water elevation during low water conditions. 200x300 mm hole is also large enough for juveniles and adults to pass through.

<table>
<tr><td colspan="3">Johnson, J., J. Poirier, R. Horal, and T. Whitesel. 2007. Lower Columbia River Channel Improvement: Assessment of Salmonid Populations and Habitat on Tenasillahe and Welch Islands 2006 Project Report. USFWS, Columbia River Fisheries Program Office, Population & Habitat Assessment Program, Vancouver, WA. 43 pp.</td></tr>
<tr><td>Keywords: tide gate replacement coho</td><td>Type: 2006 Project Report</td><td>Publication Date: 2007</td></tr>
<tr><td>Include: No</td><td>Reason: Subsequent reports include these pre-restoration baseline data in their analyses.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Tenasillahe Island (tide gates) and Welch Island (reference), Columbia River estuary</td><td>Ecosystem(s): freshwater tidal sloughs</td></tr>
<tr><td colspan="3">Reference Source: https://www.fws.gov/Columbiariver/publications/Johnson_Tenasillahe_2007.pdf</td></tr>
</table>

Study Description: Sampled one large and one small slough each on Tenasillahe and Welch islands. Determined tide gate opening. Recorded water T, dissolved oxygen, conductivity, pH, turbidity, water transparency. Described physical attributes of each reach. Fish were collected in fyke nets, minnow traps, crayfish traps, and beach seines. They were then identified, weighed, measured, examined for marks, and scanned for PIT tag if >60mm.

Results Summary: Of 100 tides, 42% failed to open the tide gate at Large Tenasillahe and the Small Tenasillahe gate was blocked shut by debris twice. Maximum daily temperature was similar in the two sloughs, but the daily minimum was lower in Welch sloughs. Dissolved oxygen was higher in Welch sloughs (always above 6 mg/L). Cover in Tenasillahe sloughs changed from woody debris and trees early to aquatic vegetation later. Welch sloughs were dominated by woody debris throughout study. Substrate was silt and sand for all sloughs throughout. Three-spine stickleback comprised >97% of the catch. 279 Chinook, chum, coho were collected. No salmon were collected in Tehasillahe sloughs, which had higher non-native percentages and lower abundances than Welch sloughs.

<table>
<tr><td colspan="4">Johnson, G.E. (ed.) 2007. Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, Annual Report 2006. PNW National Laboratory, PNNL-16561. Report to the U.S. Army Corps of Engineers, Portland District. 118 pp.</td></tr>
<tr><td>Keywords: tide gate removal salmon</td><td colspan="2">Type: Annual report
(3rd annual report of 6-year project)</td><td>Publication Date: 2007</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: These data are either in primary sources included in our review, or the analyses are incomplete.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Columbia River estuary</td><td colspan="2">Ecosystem(s): Vera Slough, Young's Bay, OR - brackish marsh; Kandoll Farm, Gray's River, WA - freshwater swamp;both tidally influenced</td></tr>
<tr><td colspan="4">Reference Source: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-16561.pdf</td></tr>
</table>

Study Description: At Vera Slough tide gates were replaced and at Kandoll Farm tide gates were removed. Surveyed plant community composition and cover. Measured water depth, velocity, salinity, organic carbon, inorganic nutrients, chlorophyll a, and chlorophyll fluorescence. Collected fish and prey (insects, benthos, neuston). Measured fish, checked for tags, and lavaged a subset.

Results Summary: Plant species increased from 27 to 41 from 2005 to 2006. Six species had cover >10% while 51% had cover <1%. Velocity did not differ with tidal cycle or water column strata. Treatment and elevation influenced plant species composition. Chinook diet was mainly insects and amphipods. Chum and coho ate mostly insects. Salmon were collected inside and outside tide gates and at reference sites. Chum were present only at small sizes early in the season. Coho were present during all sampling dates outside tide gates and at reference sites. Chinook were collected upstream of tide gates Apr-Jun. More salmon were upstream of Kandoll tide gates post restoration. Dissolved nutrients were higher at Vera than Kandoll and nitrogen:phosphate at Vera was closer to reference levels.

<table>
<tr><td colspan="3">Johnson, J., J. Poirier, S. Ennis, and T. Whitesel. 2009. Julia Butler Hansen National Wildlife Refuge: Assessment of Fishes, Habitats, and Tide gates in Sloughs on the Mainland 2007, 2008 Progress Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Population & Habitat Assessment Program, Vancouver, WA. 64 pp.</td></tr>
<tr><td>Keywords: tide gate replacement coho</td><td>Type: Report</td><td>Publication Date: 2009</td></tr>
<tr><td>Include: No</td><td>Reason: These baseline data are in later post-restoration reports.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lower Columbia River estuary, Julia Butler Hansen NWR</td><td>Ecosystem(s): 8 tidally-influenced sloughs, 4 gated, 4 with dikes closing them off from the Columbia R, and 2 pristine reference sloughs on nearby islands</td></tr>
<tr><td colspan="3">Reference Source: https://www.fws.gov/columbiariver/publications/jbh_2009.pdf</td></tr>
</table>

Study Description: Sloughs were divided into 50- or 25-m reaches. Sample closest to the mouth, tidegate, or historic connection to Columbia R. was sampled. All slough reaches were seined. Additional reaches were selected to be spatially balanced and representative of all habitats. Fish passage potential was measured by sampling up and downstream of tide gates. Reference streams were sampled at the mouth. All fish were counted by species. Salmonids were measured, weighed, and checked for marks. Those >60mm were scanned for PIT tags. In each slough and reach environmental variables were recorded.

Results Summary: Reference sloughs had only native species in both years. Gated sloughs had 5/10 and 8/13 native species and closed sloughs had 6/13 and 3/9 native species in the two years. In reference, gated, and closed sloughs juvenile salmon were 19.1%, 25.8%, and 1.5% of the total catch, respectively, in 2007 and 1.5%, 5.1%, and 0%, respectively, in 2008. Temperature passed 16°C in May in most sloughs and remained high. Dissolved oxygen was lower in closed sloughs in 2008; otherwise, it was similar among slough types. In both years Chinook, coho, and chum were present. In 2008 steelhead were also collected. Reference sloughs contained 72% and 92% of the juvenile salmonids in the two years. Reference sites had more woody shrubs and woody debris both years.

<table>
<tr><td colspan="3">Lohr, S., J. Poirier, S. Castle, B. Silver, G. Silver, J. Johnson, J.M. Hudson, J. Jolley, D. Allard, A. Hortsman, M.L. Koski, and T.A. Whitesel. 2012. Presence, distribution, movement, and biological characteristics of select aquatic species in Tide Creek, Merrill Creek, and Deer Island Slough, Columbia County, Oregon, 2010 Annual Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA. 38 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: Annual Report</td><td>Publication Date: 2012</td></tr>
<tr><td>Include: No</td><td>Reason: The entirety of sampling was done above tide gates and their impact was not measured or discussed.</td><td>Relevance: Low</td></tr>
<tr><td colspan="2">Location & Species: Tide Creek and Merrill Creek on Deer Island, Columbia River - rkm 125-130 cutthroat, coho salmon, Pacific lamprey, western brook lamprey, western pearlshell mussel</td><td>Ecosystem(s): stream and slough</td></tr>
<tr><td colspan="3">Reference Source:
https://www.fws.gov/columbiariver/publications/2010_Deer_Island_%20Report.pdf</td></tr>
</table>

Study Description: Habitat was described, and T and conductivity were recorded. Lamprey nests were surveyed. Cutthroat and coho collected and PIT-tagged. Cutthroat DNA and scale samples taken. PIT-array detections were used to describe residency and movement.

Results Summary: No Pacific lamprey carcasses or nests were found. Coincidental western brook lamprey were found. Coastal cutthroat were captured in 76% (32/42) of reaches sampled and 19 reaches had 2 or more size classes (criteria to label a reach occupied). Coho that entered the sloughs in fall remained 156d while those entering in spring and summer stayed 7d and 1d (medians). PIT-arrays also detected fish from outside the system in South Deer Island Slough. Western pearlshell mussels were found and sedimentary evidence of spawning was found although no inspected individuals showed signs of reproduction.

<table>
<tr><td colspan="3">Love, M., R. Shea, A. Llanos, and S. Allen. 2015. Martin Slough Enhancement Project Eureka, California Project Design Report. Prepared for: Redwood Community Action Agency. Michael Love & Associates, Arcata, CA. 198 pp.</td></tr>
<tr><td>Keywords: tide gate replacement, salmon</td><td>Type: Report</td><td>Publication Date: 2015</td></tr>
<tr><td>Include: No</td><td>Reason: This is a pre-restoration 'basis-of-design' report. It is stated to be the 65% plan.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species:</td><td>Ecosystem(s):</td></tr>
<tr><td colspan="3">Reference Source:
http://www.naturalresourcesservices.org/sites/default/files/Martin%20Slough%2065%25%20BODR%20%20Aug2015.pdf</td></tr>
</table>

Study Description: A new tide gate structure was constructed in 2014 to replace the existing undersized tide gate structure where Martin Slough drains into Swain Slough. The project had flood protection, habitat availability, and passage objectives. This report includes a thorough description of the intended restoration project but does not include any monitoring or data collection aside from a geologic report on soil type and wetness as regards excavation and construction and possible settlement of permenent structures. It appears that the design is going through a series of design and feasibility reviews before implementation.

<table>
<tr><td colspan="4">Mierau, D. 2005. Rocky Gulch Salmonid Access and Habitat Restoration Project: Phase I Restoration Final Report. Prepared for California Dept. of Fish and Game and US Fish and Wildlife Service. McBain & Trush, Inc. 980 7th St. Arcata, CA 95521, December 7, 2005.</td></tr>
<tr><td>Keywords: tide gate upgrade salmon</td><td colspan="2">Type: Final Report</td><td>Publication Date: 2005, 2002</td></tr>
<tr><td>Include: No</td><td colspan="2">Reason: No monitoring data available. The end of this report says it was to be done by CDFG but I could find no reports with post-restoration monitoring.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: 6 miles N of Eureka, CA Tributary to Humboldt Bay Historically had coho salmon, steelhead, and anadromous cutthroat spawning populations</td><td colspan="2">Ecosystem(s): freshwater stream, borders tidal zone, tidal inundation in first 1700 ft. Tide gate at 600 ft is leaky so seawater moves farther upstream but all anadromous fish passage is blocked.</td></tr>
<tr><td colspan="4">Reference Source: http://www.coastalwatersheds.ca.gov/portals/0/humboldtbay/monitor/docs/Hydro_McBTrush_rocky_4.pdf</td></tr>
</table>

Study Description: This project was meant to improve passage for anadromous fish, especially naturally producing salmonid populations (coho and steelhead) while still providing flood protection. The top-hinged wooden tide gate at Rocky Gulch, Humboldt Bay, CA was replaced with a side-hinged aluminum tide gate with an adjustable 'guillotine' auxillary door, mounted on the existing wingwalls. The restoration also included excavation of aggraded fines, reconstruction/rerouting of 2,800 ft of channel, relocating some dikes and rehabbing others, installing riparian fencing, and planting native species. The report includes a fairly detailed description of the tide gate that was subsequently replaced, and evidence and reasoning for concluding that it effectively blocked passage for migrating salmonids.

Results Summary: The tidal portion of Rocky Gulch was surveyed as part of a larger survey of Humboldt Bay that found coho and steelhead. However because they did not survey higher reaches they could not determine if they were produced in the system or nearby watersheds. There is a blurb about the project on the USFWS site that says coho and steelhead were found in Rocky Gulch within a year of the project completion.

<table>
<tr><td colspan="3">Thom, R., N. Sather, G. Roegner, and D. Bottom. 2013. Columbia Estuary Ecosystem Restoration Program: 2012 synthesis memorandum. Pacific Northwest National Laboratory Report # PNNL-21477 FINAL.</td></tr>
<tr><td>Keywords: tide gate replacement coho</td><td>Type: Final report</td><td>Publication Date: 2013</td></tr>
<tr><td>Include: No</td><td>Reason: The tide gate removal and replacement studies here are all included in our review.</td><td>Relevance:</td></tr>
<tr><td colspan="2">Location & Species: Lower Columbia River; coho salmon (among other species)</td><td>Ecosystem(s): tidally influenced shallow river, side channels, and peripheral embayments</td></tr>
<tr><td colspan="3">Reference Source: http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p16021coll3/id/94</td></tr>
</table>

Study Description: This is a literature review of the Lower Columbia River Estuary with 3 questions focused on juvenile salmon (migration patterns by habitat and salmon species, facors limiting salmon recovery, restoration and salmon performance) and one question focused on the estuary status holistically. It discusses the effects of a number of restoration actions in particular locations in the LCRE, including several tide gate projects.

Results Summary: In general, yearling coho use main channel habitat during spring and have longer residence in side channels and tributaries in winter (24-34 d) and subyearling coho used lower sections of tributary rivers. Coho did not frequent wetland channels and were only abundant in the main channel but did use side channels and tributaries in winter. Chinook were found in all habitats sampled and abundance generally increased after restoration. Increased access does not guarantee increased use. Upstream sources differ and use by migrants is often determined by proximity to the migration channel (mainstem or tributary). Tide gate replacement with more 'fish friendly' gates and systems increase water quality, inundation, and fish presence, but not to the level of ungated systems.

<table>
<tr><td colspan="3">Warren, R.S., P.E. Fell, R. Rozsa, A.H. Brawley, A.C. Orsted, E.T. Olson, V. Swamy, and W.A. Niering. 2002. Salt marsh restoration in Connecticut: 20 years of science and management. Restoration Ecology 10(3): 497–513.</td></tr>
<tr><td>Keywords: flood gate replacement salmon</td><td>Type: Peer-reviewed</td><td>Publication Date: 2002</td></tr>
<tr><td>Include: No</td><td>Reason: There were no pre-restoration data presented and this study was outside the PNW.</td><td>Relevance: Low</td></tr>
<tr><td colspan="2">Location & Species: Six marsh systems along Long Island Sound: Mumford Cove (MC), Great Meadows (GM), Great Creek (GC), Long Cove (LC), Hammock R (HR), Barn Island (BI) (9 sites)</td><td>Ecosystem(s): salt marsh</td></tr>
<tr><td colspan="3">Reference Source:
http://www.edc.uri.edu/nrs/classes/nrs555/assets/readings_06/CR_RestEcol_warren.pdf</td></tr>
</table>

Study Description: Marshes were diked between 1900 and 1954 and restored between 1978 and 1991. Surveyed plant community composition, cover density, and shoot height. Measured soil water and surface salinity, surface elevation. Sampled macroinvertebrates, fish, macrocrustaceans, and birds. Not all restoration sites had paired or nearby reference sites. One reference site was used for 4 restored sites.

Results Summary: Marshes were recovering quickly or slowly (order of magnitude difference in rate). There was no relationship between recovery rate and time since restoration. Fast recovery marshes had higher water tables. Salinity did not differ among marshes. Typical fish assemblages are present soon after restoration but abundances are lower for a number of years. For birds, generalists return first while specialists return longer periods after restoration. Restoration to complete parity with reference sites may take decades and different functions and attributes have independent trajectories and rates.

<table>
<tr><td colspan="3">Weybright, A.D. 2011. Juvenile coho salmon movement, growth and survival in a coastal basin of southern Oregon. M.S. Thesis, Dep't. of Fisheries and Wildlife, Oregon State University, Corvallis, OR. pp. 127 pp.</td></tr>
<tr><td>Keywords: tide gate replacement salmon</td><td>Type: M.S. Thesis</td><td>Publication Date: 2011</td></tr>
<tr><td>Include: No</td><td>Reason: These data were subsequently published in Weybright and Giannico 2017.</td><td>Relevance: Note: this is OWEB funded monitoring project.</td></tr>
<tr><td colspan="2">Location & Species: Palouse Creek, Coos Bay, OR</td><td>Ecosystem(s): freshwater and tidally influenced streams</td></tr>
<tr><td colspan="3">Reference Source: http://www.cooswatershed.org/Publications/WeybrightAdamD2011Thesis.pdf</td></tr>
</table>

Study Description: Over two years the authors seined fish in stream sections/habitat units. Sampling sites were described and environmental variables measured. Fish were identified and counted – a subset of the coho were PIT tagged, measured, and weighed. PIT recaptures were by seining and array readings. Movement was characterized by season and fish were classified as sedentary or mobile based on movement between reaches. Survivorship was based on PIT detections. Logistic regression examined association between winter survival and winter movement, late summer location, active channel width, late summer size, density. All models evaluated with AIC.

Results Summary: Most fish (>70%) were sedentary in summer, mobile in winter. Sedentary fish in summer or winter had higher winter survival. Winter survival was related to late summer distance from tide gate, late summer FL, Rkm*FL. Dispersal was not likely associated with competition or discharge. Most reach1 (tide gate) fish moved upstream in late summer (avoiding salinity or temperature?). Growth rates higher in early summer and near the estuary.