

Quantifying Habitat Connectivity in the Lower Columbia River and Estuary

Amy B Borde, Heida L Diefenderfer, Gary E Johnson, Shon A Zimmerman, and Andre M Coleman

Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, Washington

Columbia River Estuary Conference, Astoria Oregon

11 April 2018





Acknowledgements

► PNNL

Ying-hi Ke

Jerry Tagestad

Ron Kauffman

Cailene Gunn

Lower Columbia Estuary Partnership
 Keith Marcoe

PC Trask and Associates, Inc.
 Alex McManus



Proudly Operated by Battelle Since 1965



US Army Corps of Engineers

BONNEVILLE POWER ADMINISTRATION



Columbia River Estuary Conference

Need



Columbia Estuary Ecosystem Restoration Program (CEERP) primary strategy for ecosystem restoration is to reconnect tidal wetlands to the main stem estuary.

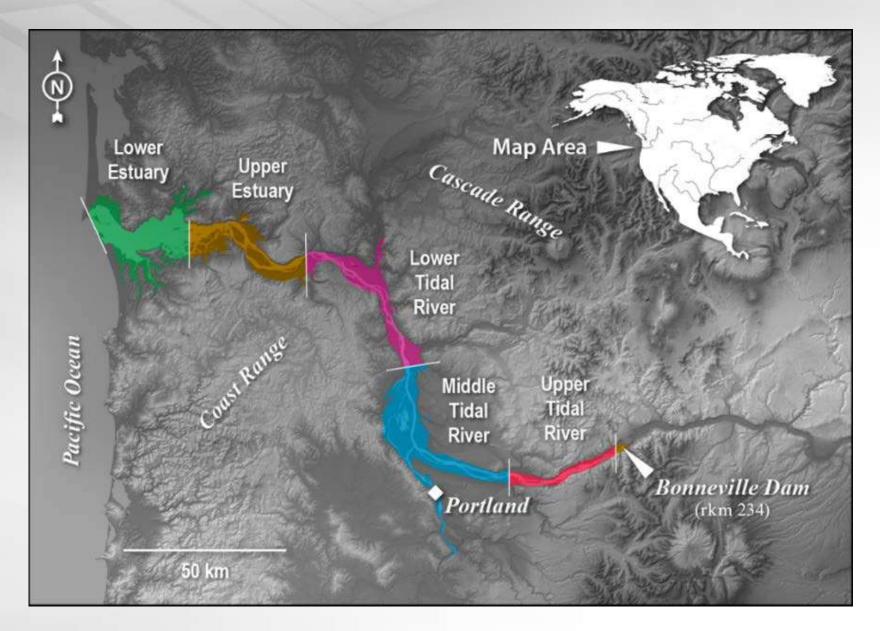
Questions:

- Quantitatively, how has habitat connectivity for juvenile salmon changed since 2000 due to reconnection restoration actions?
- How much is CEERP improving habitat connectivity by estuary zone?
- How much more potential is there for tidal hydrologic reconnection by estuary zone?

Objective: to index habitat connectivity estuary wide and by zone for 2000 (baseline), 2010 (intermediate), and 2016 (current conditions).

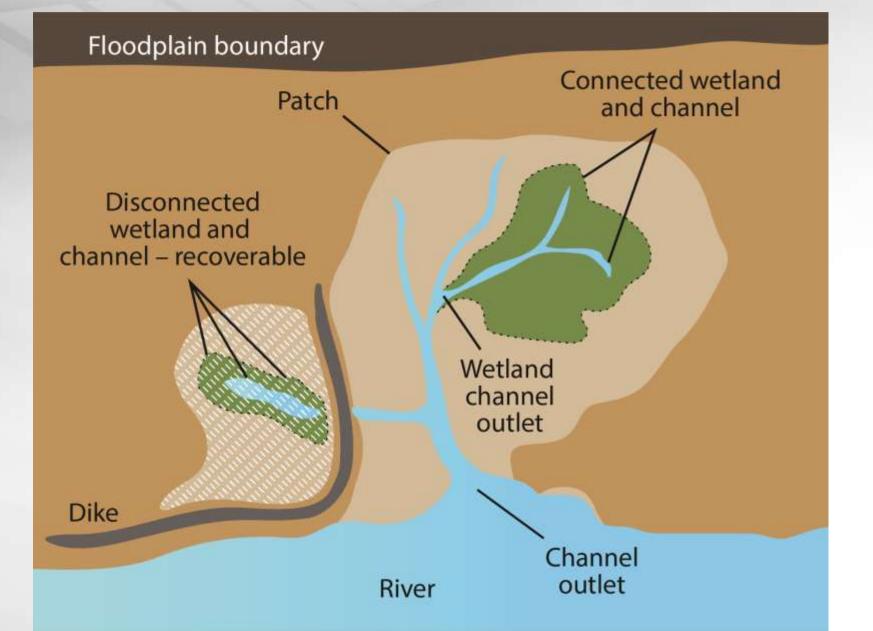
Spatial Scale





Defining Connectivity

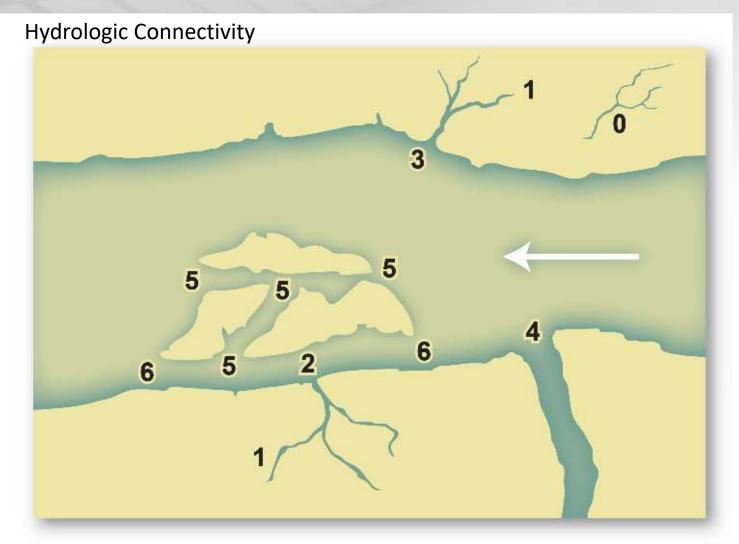




Defining Connectivity



Proudly Operated by Battelle Since 1965



Based on Lasne et al. 2007. Rank connectivity of river floodplain habitats. *Biological Conservation* 139.

Columbia River Estuary Conference



- Utilize existing estuary-wide spatial datasets
- Modify as needed to create connectivity-related datasets
- Quantify the metrics of connectivity
- Calculate an Index of Connectivity
- Calculate change in Index over time with restoration

Data Sources and Metrics

Pacific Northwest NATIONAL LABORATORY Proudly Operated by Battelle Since 1965

Ecosystem Classification (UW/USGS 2011) Patch Area Land cover (LCEP/Sanborn 2009) Structure **Recoverable Area** Historical floodplain (USGS 2012) Natural Area Recoverable Area (LCEP/Marcoe) Diking and Barriers (LCEP/Mattison 2013) Proximity Opportunity Landscape Planning Framework (UW/Trask Open 2014) **Outlets** Direct fish habitat catenae Confluences 2-year flood extent (USACE 2011) Patch Size **PNNL** delineated outlets Channel Edge Length Capacity National Hydrography Dataset Hydrologic boundaries (HUC12) Connected Flow lines Wetland Area Restoration Site Data (ERTG/Trask)

What is a Patch??



Proudly Operated by Battelle Since 1965

- A Patch includes the following:
 - Tidally influenced wetland area
 - Contiguous upland or non-tidal wetland area
 - Within a hydrologic boundary

Why is it important??

- The relatively undisturbed, natural area surrounding tidal wetlands provides the following:
 - Buffer for disturbance
 - Source of allochthonous material
 - Increased resiliency by allowing potential for wetland migration

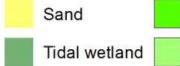
Delineation of a Patch



Proudly Operated by Battelle Since 1965

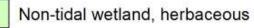


Landcover classification



Non-tidal wetland, deciduous forest

Non-tidal wetland, shrub-scrub

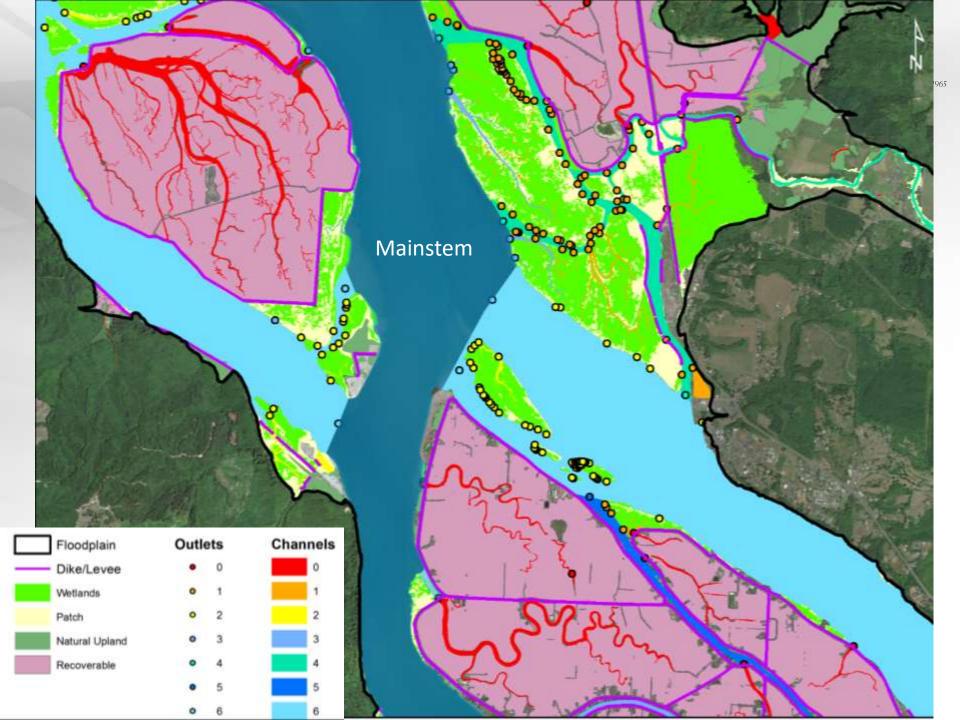




Upland shrub-scrub

Upland deciduous forest





Habitat Connectivity Variables

Equation

Description

Variable

Variable	Description
n _t	total number of outlets for all patches combined for time t
0	Proportion of open outlets
0	total number of open channel outlets

	1 — A measure of patch area connected hydrologically to the mains patch area out of all non-developed area at time t	tem, expressed as the proportion of
4	Proportion of connected patch area to all non-developed area	$A = \frac{L}{L + R + M}$
L,	Total area of less-disturbed connected patches (ha)	
R	Total recoverable area, i.e., not currently connected but potentially could be in the future (ha)	
М	Total area of remaining natural habitats that are not wetland nor connected (ha)	
	I — Measures of the <u>opportunity</u> for juvenile salmon to access habit ological advantages for juvenile salmon	ats and the <u>capacity</u> of those habitats to
Opportunit	y, involves three elements: proximity, open outlets, and open outlet	ts weighted by channel class
D _i	Proximity is the average normalized distance from wetland outlets to the main stem river for time t	$D_{t} = \left(1 - \overline{d_{t}}\right)$ $\overline{d}_{t} = \frac{\sum_{i=1}^{N} \sum_{j=1}^{J_{t}} \left(\frac{d_{y} - d_{\min}}{d_{\max} - d_{\min}}\right)}{2}$
\overline{d}_t	mean normalized outlet distance to main stem for time t	
d_{δ}	distance of the j^{th} outlet in the i^{th} wetland to main stem	
d_{\min}	the minimum distance of a wetland outlet to the main stem over all times	
d _{max}	the maximum distance of a wetland outlet to the main stem over all times	$\vec{d}_t = \frac{\vec{n} \cdot \vec{n} \cdot \vec{n} \cdot \vec{n}}{n_t}$
d_{max} J_i	이 이 것 같아요. 이 것 같아요. 이 것 이 이 것 같아요. 가지 않는 것 것 같아요. 이 것 이 것 같아요. 이 것 같아요. 이 것 같아요. 이 것 같아요. 것 같아요. 이 것	$\overline{d}_t = \frac{\overline{\operatorname{int} (j-1)} (d_{\max} - d_{\min})}{n_t}$

OProportion of open channel outlets $O = \frac{o}{o+c}$ ctotal number of closed channel outlets $K = \frac{o}{0+c}$ Kproportion of open channel outlets $K = \frac{o}{0+c}$ $r = 0-4$ $r = 0.4$ $K = \sum_{i=1}^{i} (i+o_i)$ $v = 0$ total number of open channel outlets $K = \sum_{i=1}^{i} (i+o_i)$ $r = 0.4$ $r = 0.4$ $K = \sum_{i=1}^{i} (i+o_i)$ $v = 0$ total number of open channel outlets $K = \sum_{i=1}^{i} (i+o_i)$ $r = 0.4$ $r = 0.4$ $K = \sum_{i=1}^{i} (i+o_i)$ $r = 0.4$ $r = 0.4$ $K = \sum_{i=1}^{i} (i+o_i)$ $r = 0.4$ <td< th=""><th>0</th><th>Proportion of open outlets</th><th>0 0</th></td<>	0	Proportion of open outlets	0 0			
Kproportion of open channel outlets weight by class of outlet (1 = 0-4) $K = \sum_{l=1}^{L} \binom{l * o_l}{o * 4}$ r total number of open channel outlets $K = \sum_{l=1}^{L-1} \binom{l * o_l}{o * 4}$ l^* weighted outlets $K = \sum_{l=1}^{L-1} \binom{l * o_l}{o * 4}$ Capacity, involves four elements: patch size, channel class 5 edge length, channel class 0-4 edge length, and connected weiland area. S_t S_tmean normalized patch size for time t S_t S_ssize of the in patch $S_t = \sum_{n=1}^{T} \binom{S_t - S_{min}}{P_t}$ S_mmmaximum patch size over all times (ha) P_t S_mmmaximum patch size over all times (ha) P_t S_mm maximum patch size over all times (ha) P_t f_t class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch P_t f_t class 5 channel edge length not adjacent to patches (m) $F = \frac{f_a}{f_a + f_n}$ f_c class 5 channel edge length not adjacent to patches (m) $F = \frac{e_a}{e_a + e_n}$ e_a edge length of channel classes 0-4 (m) $E = \frac{e_a}{e_a + e_n}$ e_a edge length of channel classes 0-4 (m) $E = \frac{e_a}{e_a + e_n}$ X proportion of wetland area connected to the mainstem X x_a area of the kth wetland in the in patch (ha) $X = \frac{\sum_{i=1}^{i} \frac{k_i}{Z}}{Z}$ K total number of patches Z $E = \frac{e_a}{e_a + e_n}$ Z total number of patches Z Z X proportion of wetlands in the in patch (ha) $Z = \frac{\sum_{i=1}^{i} \frac$	0	total number of open channel outlets	$O = \frac{1}{o+c}$			
$ \begin{array}{c c c c c c } \hline & = 0.4, \\ \hline & & = 0.4, \\ \hline & & & & & & & \\ \hline & & & & & & & \\ \hline & & & &$	с	total number of closed channel outlets				
l^*o weighted outlets $U = U = U$ Capacity, involves four elements: patch size, channel class 5 edge length, channel class 0-4 edge length, and connected wetland area.Srmean normalized patch size for time tSisize of the i th patchSmarmaximum patch size over all times (ha)Smarmaximum patch size over all times (ha)Pitotal number of patches for time tFproportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patchf,class 5 channel edge length adjacent to patches (m)f,class 5 channel edge length not adjacent to patches (m)f,class 5 channel edge length not adjacent to patches (m)f,class 5 channel edge length not adjacent to patches (m)f,class 5 channel edge length of channel classes 0-4 (m)e,edge length of channel classes 0-4 (m)e,edge length of wetland area connected to the mainstemx _a area of the kth wetland in the i th patch (ha)Xproportion of wetlands in the i th patch (ha)X,total number of patchesZtotal area of historical floodplain not including developed areas (ha) (Z=L+R+M)HConlhabitat connectivity indexY,value of the vth variable (A, D, O, K, S, F, E, X)w,weighting factor for the vth variable (= 1 for all variables)	K		$\sum_{l=0}^{4} (l * o_l)$			
Capacity involves four elements: patch size, channel class 5 edge length, channel class 0-4 edge length, and connected wetland area. S_t mean normalized patch size for time t S_i size of the i th patch S_{min} minimum patch size over all times (ha) S_{min} maximum patch size over all times (ha) S_{min} maximum patch size over all times (ha) P_i total number of patches for time t F proportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch f_s class 5 channel edge length adjacent to patches (m) f_s class 5 channel edge length in patches e_a edge length of channel classes 0-4 (m) e_a edge length of channel classes 99 (altered) (m) X proportion of wetland area connected to the mainstem x_{ik} area of the kth wetland in the i th patch (ha) K_i total number of patches Z total number of patches Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat Connectivity index K_i value of the vth variable (A, D, O, K, S, F, E, X) w_i weighting factor for the vth variable (= 1 for all variables)	0	total number of open channel outlets	$K = \frac{1-1}{\alpha * 4}$			
connected wetland area.Srmean normalized patch size for time tSrsize of the i th patchSmainminimum patch size over all times (ha)Smainminimum patch size over all times (ha)Smainminimum patch size over all times (ha)Prtotal number of patches for time tFproportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patchf_aclass 5 channel edge length adjacent to patches (m)f_aclass 5 channel edge length adjacent to patches (m)Fproportion of total classes 0-4 (m)e_aedge length of channel classes 0-4 (m)e_aedge length of channel classes 0-4 (m)e_aedge length of channel classes 0-4 (m)Kitotal number of wetlands in the i th patchXproportion of wetlands in the i th patchXiproportion of wetlands in the i th patchXiproportion of wetlands in the i th patchXitotal number of patchesZitotal number of writing at connectivity indexYivalue of the vth variable (A, D, O, K, S, F, E, X) </td <td><i>l</i>*o</td> <td>weighted outlets</td> <td>-</td>	<i>l</i> *o	weighted outlets	-			
S_tsize of the i th patch $\overline{S}_t - S_{min}$ S_{min} minimum patch size over all times (ha) $\overline{S}_t = \frac{\sum_{i=1}^{t-1} \left(\frac{S_t - S_{min}}{S_{max}} - S_{min} \right)}{P_t} \right)}{P_t}$ F proportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch $F = \frac{f_a}{f_a + f_n}$ f_a class 5 channel edge length adjacent to patches (m) $F = \frac{e_a}{e_a + e_n}$ f_a class 5 channel edge length or adjacent to patches (m) f_n class 5 0 + channel classes 0.4 (m) e_n edge length of channels class 99 (altered) (m) X proportion of wetland area connected to the mainstem x_{ik} area of the kth wetland in the i th patch P total number of patches Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat connectivity index Y_i value of the vth variable (A, D, O, K, S, F, E, X) W_i W_i weighting factor for the v th variable (= 1 for all variables)			nnel class 0-4 edge length, and			
S_{max} maximum patch size over all times (ha) I_{t} P_{t} total number of patches for time t T_{t} F proportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch $F = \frac{f_{a}}{f_{a} + f_{n}}$ f_{a} class 5 channel edge length adjacent to patches (m) $F = \frac{e_{a}}{f_{a} + f_{n}}$ f_{n} class 5 channel edge length not adjacent to patches (m) $F = \frac{e_{a}}{e_{a} + e_{n}}$ e_{a} edge length of channel classes 0-4 (n) $E = \frac{e_{a}}{e_{a} + e_{n}}$ e_{n} edge length of channels class 99 (altered) (m) $E = \frac{e_{a}}{e_{a} + e_{n}}$ X proportion of wetland area connected to the mainstem $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_{i}} x_{ik}}{Z}$ K_{i} total number of patches Z Q total area of historical floodplain not including developed areas (ha) $(Z=L+R+M)$ Z Habitat Connectivity index $\sum_{i=1}^{p} (Y_{v} * 100 * w_{v})$ Y_{v} weighting factor for the v th variable (= 1 for all variables) $HabConI = \frac{\sum_{v=1}^{p} (Y_{v} * 100 * w_{v})}{V$	St	mean normalized patch size for time t	$\sum_{i=1}^{P_i} (S_i - S_{min})$			
S_{max} maximum patch size over all times (ha) I_{t} P_{t} total number of patches for time t T_{t} F proportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch $F = \frac{f_{a}}{f_{a} + f_{n}}$ f_{a} class 5 channel edge length adjacent to patches (m) $F = \frac{e_{a}}{f_{a} + f_{n}}$ f_{n} class 5 channel edge length not adjacent to patches (m) $F = \frac{e_{a}}{e_{a} + e_{n}}$ e_{a} edge length of channel classes 0-4 (n) $E = \frac{e_{a}}{e_{a} + e_{n}}$ e_{n} edge length of channels class 99 (altered) (m) $E = \frac{e_{a}}{e_{a} + e_{n}}$ X proportion of wetland area connected to the mainstem $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_{i}} x_{ik}}{Z}$ K_{i} total number of patches Z Q total area of historical floodplain not including developed areas (ha) $(Z=L+R+M)$ Z Habitat Connectivity index $\sum_{i=1}^{p} (Y_{v} * 100 * w_{v})$ Y_{v} weighting factor for the v th variable (= 1 for all variables) $HabConI = \frac{\sum_{v=1}^{p} (Y_{v} * 100 * w_{v})}{V$	Si	size of the i th patch	$\sum_{i=1}^{n} \left(\frac{-i}{S_{i}} - S_{i} \right)$			
P_i total number of patches for time t F proportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch $F = \frac{f_a}{f_a + f_n}$ f_a class 5 channel edge length adjacent to patches (m) F f_n class 5 channel edge length not adjacent to patches (m) F E proportion of total classes 0-4 channel edge length in patches E e_a edge length of channel classes 0-4 (m) E e_n edge length of channel classes 0-4 (m) E x_n proportion of wetland area connected to the mainstem X_{ak} X_{ak} area of the kth wetland in the i th patch (ha) $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_i} x_{ik}}{Z}$ K_i total number of patches Z Z total area of historical floodplain not including developed areas (ha) $(Z=L+R+M)$ $Habitat$ connectivity index Y_v HConIhabitat connectivity index Y_v Y_v sulue of the vth variable (J, D, O, K, S, F, E, X) W_v $HabConI = \frac{\sum_{v=1}^{V} (Y_v * 100 * W_v)}{V$	Smin	minimum patch size over all times (ha)	$S_t = \frac{1 - 1}{P}$			
Fproportion of total class 5 channel edge length adjacent to or within patches; these are off channels and may be outside the patch $F = \frac{f_a}{f_a + f_n}$ f_a class 5 channel edge length adjacent to patches (m) $F = \frac{e_a}{f_a + f_n}$ f_n class 5 channel edge length not adjacent to patches (m) E E proportion of total classes 0-4 channel edge length in patches e_a e_a edge length of channel classes 0-4 (m) $E = \frac{e_a}{e_a + e_n}$ e_n edge length of channels class 99 (altered) (m) $E = \frac{e_a}{e_a + e_n}$ X proportion of wetland area connected to the mainstem $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_i} X_{ik}}{Z}$ K_i total number of wetlands in the i th patch $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_i} X_{ik}}{Z}$ P total number of patches Z Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M) $Habitat$ connectivity index Y_i value of the vth variable (A, D, O, K, S, F, E, X) W_V $HabConI = \frac{\sum_{v=1}^{V} (Y_v * 100 * W_v)}{V}$	Smax	maximum patch size over all times (ha)	± t			
within patches; these are off channels and may be outside the patch $F = \frac{J_a}{f_a + f_n}$ f_a class 5 channel edge length adjacent to patches (m) $F = \frac{d_a}{f_a + f_n}$ f_n class 5 channel edge length not adjacent to patches (m) E E proportion of total classes 0-4 channel edge length in patches $E = \frac{e_a}{e_a + e_n}$ e_a edge length of channel classes 0-4 (m) $E = \frac{e_a}{e_a + e_n}$ w_n edge length of channel classes 0-4 (m) $E = \frac{e_a}{e_a + e_n}$ w_n edge length of channel classes 0-4 (m) $E = \frac{e_a}{e_a + e_n}$ X proportion of wetland area connected to the mainstem $X = \sum_{i=1}^{p} \sum_{k=1}^{K_i} X_{ik}$ X_{ik} area of the kth wetland in the i th patch (ha) $X = \sum_{i=1}^{p} \sum_{k=1}^{K_i} X_{ik}$ P total number of patches Z Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M) Z Habitat Connectivityindex $\sum_{i=1}^{V} (Y_v * 100 * w_v)$ W_v weighting factor for the v th variable (= 1 for all variables) $HabConI = \frac{\sum_{v=1}^{V} (Y_v * 100 * w_v)}{V$	P_t	total number of patches for time t				
f_n class 5 channel edge length not adjacent to patches (m) E proportion of total classes 0-4 channel edge length in patches a_a edge length of channel classes 0-4 (m) e_n edge length of channel classes 0-4 (m) e_n edge length of channel classes 0-4 (m) w_n edge length of channel edge length of channel edge length of mainten w_n w_n w_n total number of wetlands in the i th patch (ha) w_n total area of historical floodplain not including developed areas w_n habitat connectivity index w_n <td>F</td> <td>within patches; these are off channels and may be outside the</td> <td>$F = \frac{f_a}{f_a + f_n}$</td>	F	within patches; these are off channels and may be outside the	$F = \frac{f_a}{f_a + f_n}$			
Eproportion of total classes 0-4 channel edge length in patches e_a edge length of channel classes 0-4 (m) e_n edge length of channel classes 0-4 (m) e_n edge length of channel classes 0-4 (m) w_n edge length of channel classes 0-4 (m) w_n edge length of channel classes 0-4 (m) w_n edge length of channel classes 0-9 (altered) (m) X proportion of wetland area connected to the mainstem x_{ik} area of the kth wetland in the i th patch (ha) K_i total number of wetlands in the i th patch P total number of patches Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat ConnectivityHabitat connectivity index Y_v value of the vth variable (A, D, O, K, S, F, E, X) w_v HabConI = $\frac{\sum_{v=1}^{V} (Y_v * 100 * w_v)}{V}$	fa	class 5 channel edge length adjacent to patches (m)				
a_a edge length of channel classes 0-4 (m) $E = \frac{C_a}{e_a + e_n}$ a_n edge length of channels class 99 (altered) (m) $E = \frac{C_a}{e_a + e_n}$ X proportion of wetland area connected to the mainstem X_i x_{ik} area of the kth wetland in the i th patch (ha) $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_i} x_{ik}}{Z}$ P total number of wetlands in the i th patch $X = \frac{\sum_{i=1}^{p} \sum_{k=1}^{K_i} x_{ik}}{Z}$ P total number of patches Z X_i total area of historical floodplain not including developed areas (ha) (Z=L+R+M) Z Habitat connectivity index Y_v value of the vth variable (A, D, O, K, S, F, E, X) W_v $HabConI = \frac{\sum_{v=1}^{V} (Y_v * 100 * W_v)}{V}$	f_n	class 5 channel edge length not adjacent to patches (m)				
e_n edge length of channels class 99 (altered) (m) $u = u$ X proportion of wetland area connected to the mainstem x_{ik} area of the kth wetland in the i th patch (ha) K_i total number of wetlands in the i th patch P total number of patches Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat Connectivity index Y_v value of the vth variable (A, D, O, K, S, F, E, X) W_v weighting factor for the v th variable (= 1 for all variables)	Ε	proportion of total classes 0-4 channel edge length in patches	- e.			
e_n edge length of channels class 99 (altered) (m) $u = u$ X proportion of wetland area connected to the mainstem x_{ik} area of the kth wetland in the i th patch (ha) K_i total number of wetlands in the i th patch P total number of patches Z total area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat Connectivity index Y_v value of the vth variable (A, D, O, K, S, F, E, X) W_v weighting factor for the v th variable (= 1 for all variables)	ea	edge length of channel classes 0-4 (m)	$E = \frac{a}{e + e}$			
X _{ik} area of the kth wetland in the i th patch (ha) X_{ik} $X = \sum_{i=1}^{r} \sum_{k=1}^{r} X_{ik}$ K_itotal number of wetlands in the i th patch $X = \frac{\sum_{i=1}^{r} \sum_{k=1}^{r} X_{ik}}{Z}$ Ptotal number of patches Z Ztotal area of historical floodplain not including developed areas (ha) (Z=L+R+M) Z Habitat Connectivity Z Z HConIhabitat connectivity index Z Y_{v} value of the vth variable (A, D, O, K, S, F, E, X) W_{v} W Wweighting factor for the v th variable (= 1 for all variables) $HabConI = \frac{\sum_{v=1}^{v} (Y_v * 100 * W_v)}{V}$	en	edge length of channels class 99 (altered) (m)	- a · - n			
Ptotal number of patchesZPtotal number of patchesImage: Comparison of the patchesZtotal area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat ConnectivityImage: Comparison of the patchesHConIhabitat connectivity indexYvvalue of the vth variable (A, D, O, K, S, F, E, X)Wvweighting factor for the v th variable (= 1 for all variables)	Х	proportion of wetland area connected to the mainstem	P K _i			
Ptotal number of patchesZPtotal number of patchesImage: Comparison of the patchesZtotal area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat ConnectivityImage: Comparison of the patchesHConIhabitat connectivity indexYvvalue of the vth variable (A, D, O, K, S, F, E, X)Wvweighting factor for the v th variable (= 1 for all variables)	Xik	area of the kth wetland in the i th patch (ha)	$\sum_{i=1}^{n}\sum_{k=1}^{n}x_{ik}$			
Initial data completionInitial data completionZtotal area of historical floodplain not including developed areas (ha) (Z=L+R+M)Habitat ConnectivityInitial connectivity indexHConIhabitat connectivity indexYvvalue of the vth variable (A, D, O, K, S, F, E, X)wvweighting factor for the v th variable (= 1 for all variables)VV	Ki	total number of wetlands in the i th patch	$X = \frac{1-1}{Z}$			
Image: matrix processing of the pr	Р	total number of patches				
HConIhabitat connectivity index V_{ν} Y_{ν} value of the vth variable (A, D, O, K, S, F, E, X) V_{ν} W_{ν} weighting factor for the v th variable (= 1 for all variables) $HabConI = \frac{\sum_{\nu=1}^{\nu} (Y_{\nu} * 100 * W_{\nu})}{V}$	Z					
$\frac{Y_{v}}{W_{v}} \text{ value of the } vth \text{ variable } (A, D, O, K, S, F, E, X)$ $\frac{Y_{v}}{W_{v}} \text{ weighting factor for the } v^{\text{th}} \text{ variable } (= 1 \text{ for all variables})$ $HabConI = \frac{\sum_{v=1}^{v} (Y_{v} * 100 * w_{v})}{V}$	Habitat Connectivity					
	HConI	habitat connectivity index	$\sum_{i=1}^{V} (X_{i+1}) (X$			
	Y_{ν}	value of the vth variable (A, D, O, K, S, F, E, X)	$\sum_{\nu=1} (Y_{\nu} * 100 * W_{\nu})$			
V total number of variables	wν	weighting factor for the v th variable (= 1 for all variables)	$HabConI = \frac{V}{V}$			
	V	total number of variables				



Proudly Operated by Battelle Since 1965

Equation

Restoration

2004-2009 7 sites

Lord - Walker Islands Crims Island Deep River, Svensen's Landing Lewis & Clark River Dike Breaches Fort Clatsop/South Slough Walluski River North, Elliot #1 Vancouver Water **Resources** Center

2010-2016 31 sites

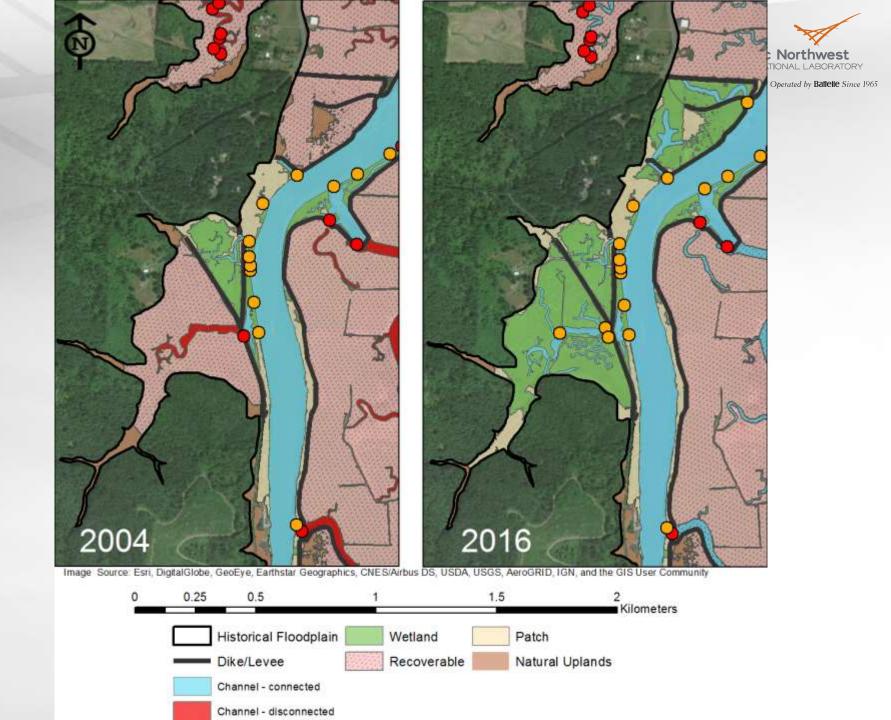
Haven Island

Fort Columbia

Fort Columbia Patch 8 (outside) Mill Road Colewort Creek (Nutel Landing) Gnat Creek #1 Gnat Creek #2 **Otter Point** South Tongue Point (Liberty Lane) **Dibblee Point** Honeyman Creek Kandoll Farm #2 LA (Louisiana) Swamp North Unit (Ruby Lake) Phase 1 Sandy River Dam Removal



Fee-Simon Karlson Island Multnomah Channel Metro North Unit (Widgeon/Deep/Millionaire) Phase 2 Steamboat Slough Thousand Acres **Batwater Station** Buckmire Slough **Elochoman Slough Thomas** LaCenter Wetlands North Unit (Three Fingered Jack) Phase 3 Crane Slough-Domeyer Kerry Island Trestle Bay Wallacut River Westport Slough USFWS #1



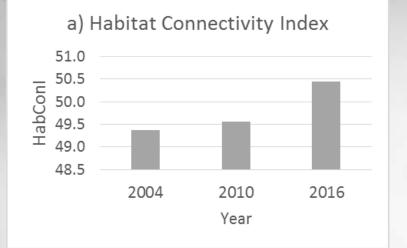
Summary Results

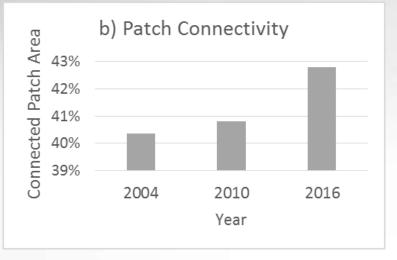


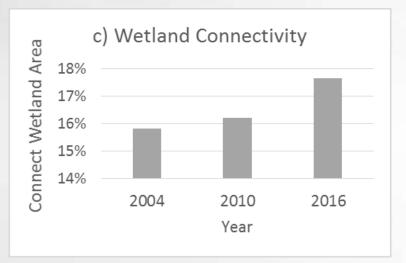
		2004	2010	2016
Р	number of patches	326	323	327
L	total area of patches (ha)	22723	23002	24126
R	total area of recoverable area (ha)	21942	21725	21014
Μ	total area of remaining natural (ha)	11647	11617	11236
Sum x	Connected tidal wetlands in patches (ha)	8909	9120	9943
Х	proportion of connected wetland area	0.29	0.30	0.32
0	Proportion of open outlets	0.84	0.85	0.86
0	total number of open channel outlets	4425	4437	4569
С	total number of closed channel outlets	818	810	739
F	Proportion class 6 edge connected to patch	0.73	0.73	0.74
Е	Proportion class 1-5 edge connected to patch	0.63	0.63	0.65

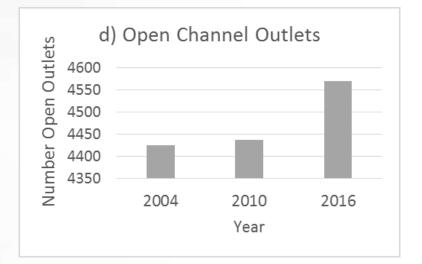
Calculated for 3 time periods





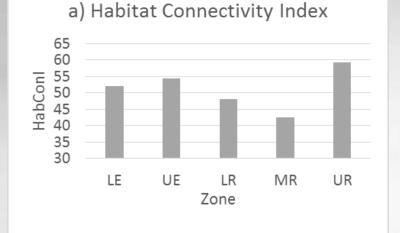


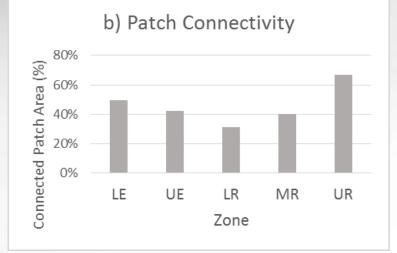


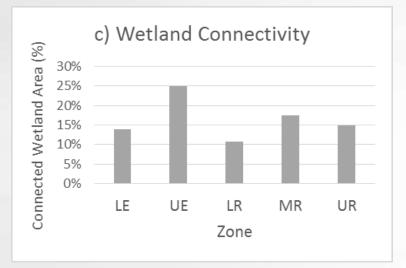


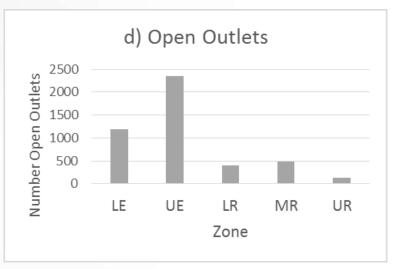
Calculated for 5 Zones











Summary and Implications



- ~ 1/3 of the potential tidally connected wetland area is currently connected
- ~ 1000 ha of wetland habitat were restored as of 2016 as part of CEERP; an 11.4% increase
- ~ 2500 ha of habitat patches were reconnected
- ~ 2/3 3/4 of tidal channels are within patches
- A high proportion (~ 85%) of channel outlets were delineated as "open" however outlets of "closed" channels were not necessarily delineated similarly
- While much has been accomplished in the CEERP program, there is more to do
- This method is viable for quantifying habitat connectivity
- The framework is established so that updating the Index in future years will be straight-forward

Future Actions

Results are presented in CEERP 2018 Synthesis Memo

Comments welcome

Update every 5 years

Columbia Estuary Ecosystem Restoration Program

2018 SYNTHESIS MEMORANDUM

90% DRAFT

Edited by: Gary E. Johnson, Pacific Northwest National Laboratory Kurt L. Fresh, National Marine Fisheries Service (retired)

February 1, 2018



