# MEASUREMENTS OF LANDSCAPE CONNECTIVITY FOR BLIND TIDAL CHANNEL NETWORKS AND SELECTED POCKET ESTUARY OUTLETS WITHIN THE SKAGIT TIDAL DELTA AND BAY

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## Purpose of creating landscape connectivity estimates in a Geographic Information System (GIS)

Within the delta and nearshore ecosystems of the Skagit River, Beamer et al. (2005) used habitat connectivity as an attribute to help predict the use of specific habitats for Chinook salmon recovery planning. Landscape connectivity was defined as a function of both the length and the complexity of the pathway that juvenile Chinook salmon must follow to access certain types of habitat, like blind tidal channels in the Skagit delta or pocket estuaries in adjacent nearshore areas. Habitat connectivity decreases as the complexity of the route fish must swim increases and as the distance the fish must swim increases. Within the Skagit delta, the complexity of the route fish must take to find habitat was determined by the delta distributary channel bifurcation order. Beamer et al. (2005) show results from 2003, when the Skagit River had an outmigration population size of 5,500,000 juvenile Chinook salmon. In this year, landscape connectivity explained 68% of the variation in seasonal density of Chinook salmon at monitored sites within the Skagit estuary (see pages 20-21 of Beamer et al. 2005). As a result, the Skagit Chinook Recovery Plan (SRSC and WDFW 2005) states that Chinook salmon population recovery should include:

- Restoration of habitat connectivity within the delta because of the loss of historic connectivity due to human-caused blocking of distributary channels, and
- Application of concepts of habitat connectivity as a means to prioritize and predict outcomes of specific delta and pocket estuary restoration sites.

Landscape connectivity measurements for habitat throughout the Skagit estuary can be useful to salmon recovery managers interested in planning and tracking implementation progress of restoration, as well as to researchers conducting juvenile Chinook salmon monitoring (e.g., Greene and Beamer 2006). Thus, we created a GIS layer of point data representing all outlet mouth locations of blind tidal channel networks within the Skagit tidal delta as of year 2000, and selected pocket estuaries within adjacent nearshore areas (e.g., Skagit Bay or Padilla Bay). For each point, we calculated landscape connectivity.

**Brief description of methods and example calculation of landscape connectivity**

A GIS point data layer, *LandscapeConnectivity_Skagit2000*, shows the mouth location of 643 blind tidal channel networks within the Skagit tidal delta and selected pocket estuaries within adjacent nearshore areas (e.g., Skagit Bay or Padilla Bay) to which landscape connectivity values were calculated (Figure 1).

We used two intermediary GIS data layers, *fish_direction* (Figure 1) and *tidelta2000* (Figure 2), to calculate landscape connectivity for each point in *LandscapeConnectivity_Skagit2000*.

*Tidelta2000* contains habitat polygons, such as wetlands, channels, and dikes, mapped over year 2000 orthophotos. Per methods described in Appendix D.V, page 79 of Beamer et al. (2005), values for bifurcation order were assigned to each channel polygon. Measurements of channel width were made at each bifurcating (splitting) channel, and used to determine channel order per Table D.V.1. in Beamer et al. (2005). Rules followed for determining bifurcation order are shown in Appendix A.

*Fish_direction* reflects the pathways juvenile Chinook salmon are expected to move through the delta channel network and along the nearshore to find and colonize habitat. Pathway location and direction outside of the tidal delta is based on drift buoy results (Appendix D.VI, page 81 in Beamer et al. 2005) and low tide channel locations visible on orthophotos. *Fish_direction* arcs were assigned the 'BI' (index bifurcation order) value of associated polygons from the *tidelta2000* data layer. For arcs outside of the delta, rules for determining BI values are shown in Appendix B.

*Fish_direction* arcs were selected to represent likely pathways to each point in *LandscapeConnectivity_Skagit2000*. In some cases, multiple routes were created in order to compare connectivity values. Values for length multiplied by BI for route arcs were then summed for each point and divided into the number 1 to calculate the landscape connectivity value for each point. Table 1 shows attributes used for landscape connectivity calculations. An example of landscape connectivity calculation to a long term blind channel monitoring site, Cattail Saltmarsh, is shown in Figure 3.

Table 1. Attributes used to calculate connectivity, and their descriptions.

| **Attribute** | **Description** |
|---|---|
| Bi | Index bifurcation order of route arc |
| Length_km | Length of route arc in kilometers |
| Km_x_bi | "Length_km" multiplied by "Bi" |
| Sum | Sum of all "Km_x_bi" values for a specific fish migration pathway |
| Landscape Connectivity | 1/Sum |

## Results

Average landscape connectivity of all 643 GIS points representing blind tidal channel networks in the Skagit delta or Skagit Bay pocket estuaries is 0.02815. However, average landscape connectivity varies as much as four times by six spatial strata within the greater Skagit estuary (Figure 4). Spatial strata within the Skagit tidal delta (i.e., sub-delta polygons) were identified for planning restoration and monitoring juvenile Chinook salmon population response to restoration in Greene and Beamer (2006). Spatial strata are shown in Figure 5.

North Fork blind channels have the highest average landscape connectivity with South Fork blind channels ranking second for the six spatial strata (Figure 4). Blind channels in Central Fir Island (along the Skagit Bay front) average about one half the average value of the North Fork and are intermediate of all six spatial strata. The three remaining spatial strata (Stanwood-Camano, Swinomish Channel / S. Padilla Bay, and Skagit Bay pocket estuaries) are all similarly low in average landscape connectivity. Blind channels within the Swinomish Channel / S. Padilla Bay sub-delta polygon have the lowest average landscape connectivity due mainly to fish pathway modification caused by the North Fork Jetty and McGlinn Island Causeway fill at the junction between the North Fork and Swinomish Channel making fish migration into Swinomish Channel difficult. Similarly, average landscape connectivity for Central Fir Island blind channels is lower than North Fork and South Fork delta areas due to loss of historic fish migration pathways through Browns, Hall, and Dry Sloughs.

Both North Fork and South Fork blind channels have a large range of connectivity values due to the length of their respective main distributary channels as well as extensive channel branching in the downstream areas of these sub-delta polygons (Figures 4 and 6). However, blind channels are relatively rare in the upstream portions of each channel compared to downstream so very limited opportunity currently exists for fish to colonize blind channel habitat in the upper parts of these sub-delta polygons (Figure 6).

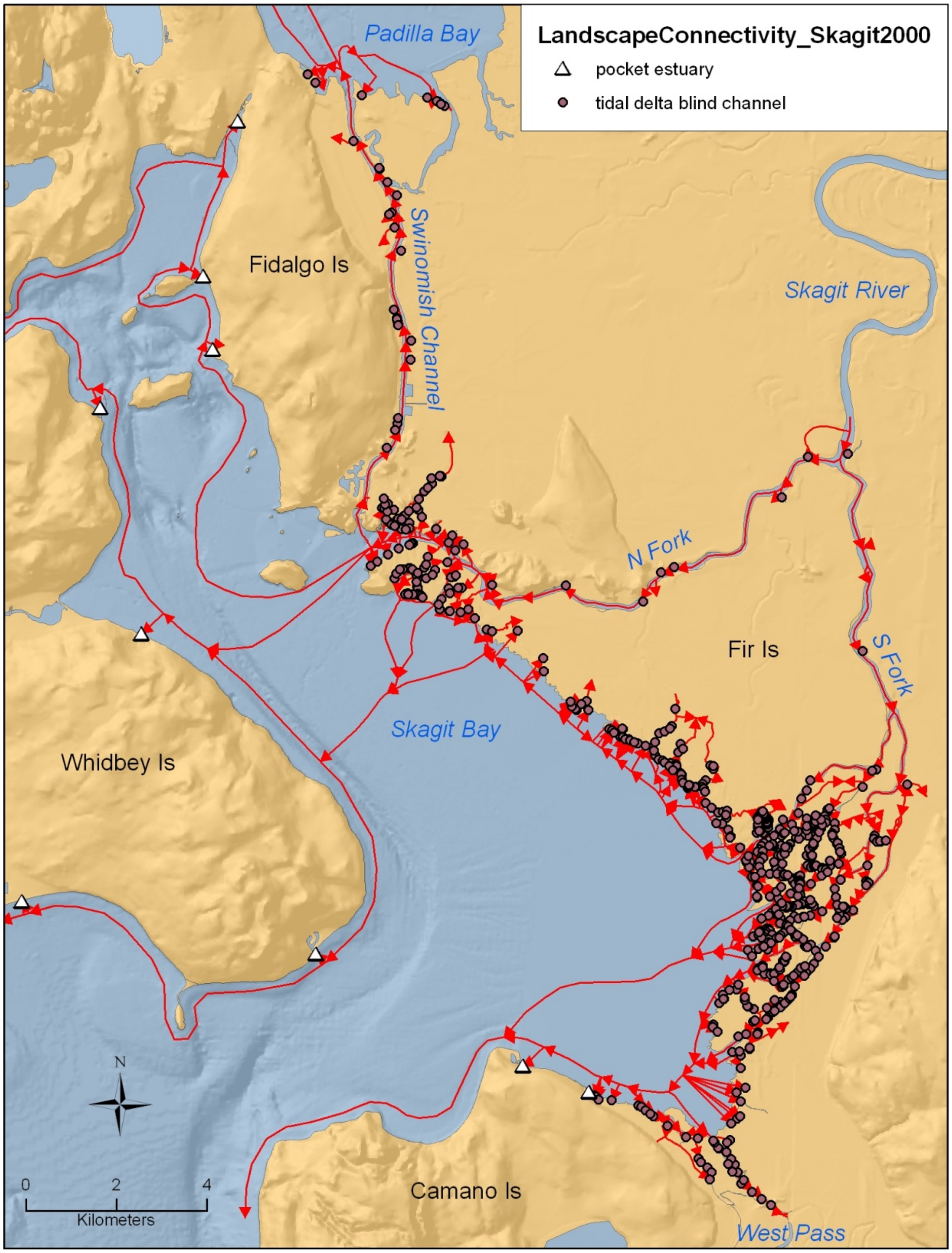



Figure 1. Tidal delta blind channel (brown dot) and pocket estuary (white triangle) points for which landscape connectivity was calculated, along with *fish_direction* arcs (red) showing pathways juvenile Chinook salmon are expected to move through to find and colonize habitat.

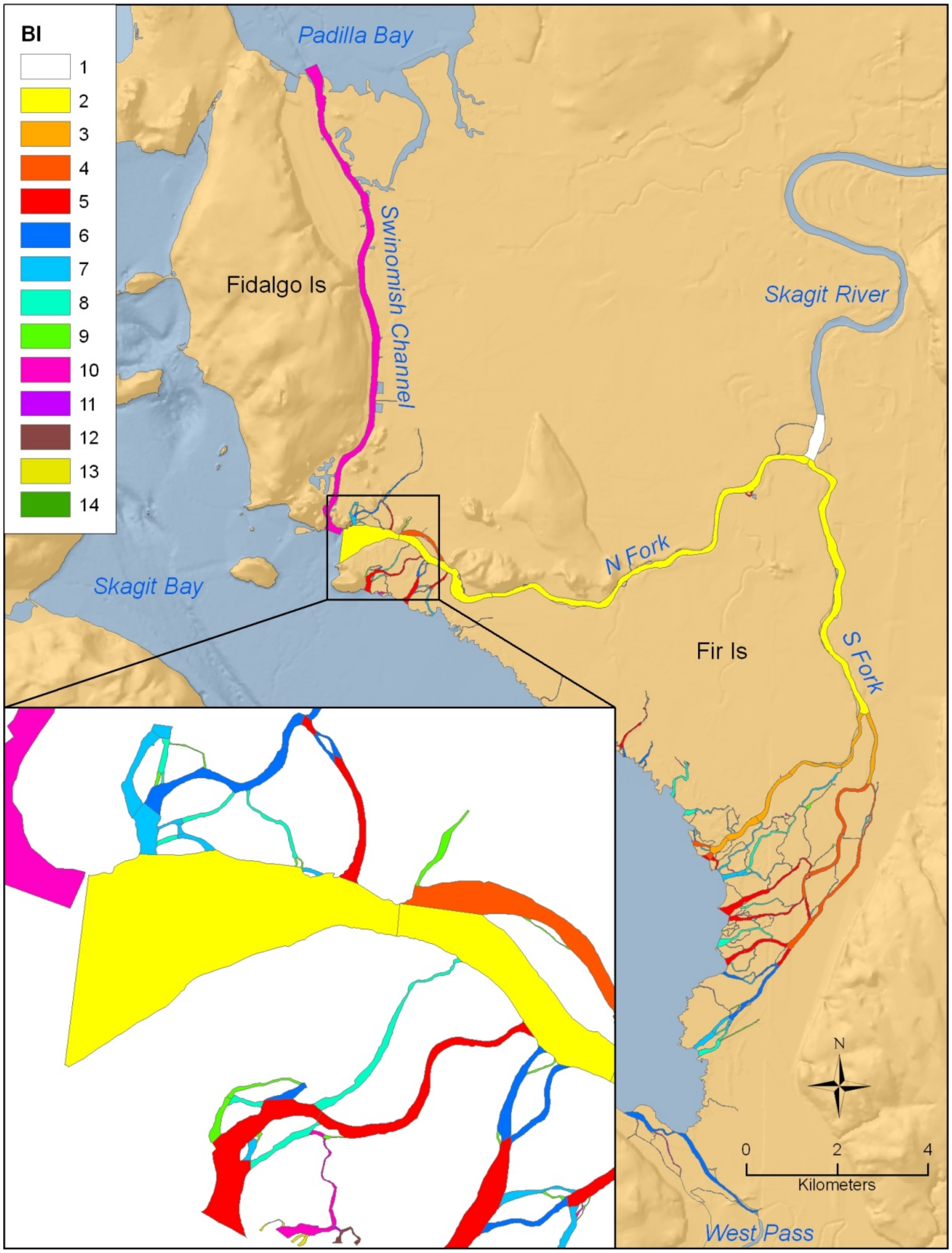
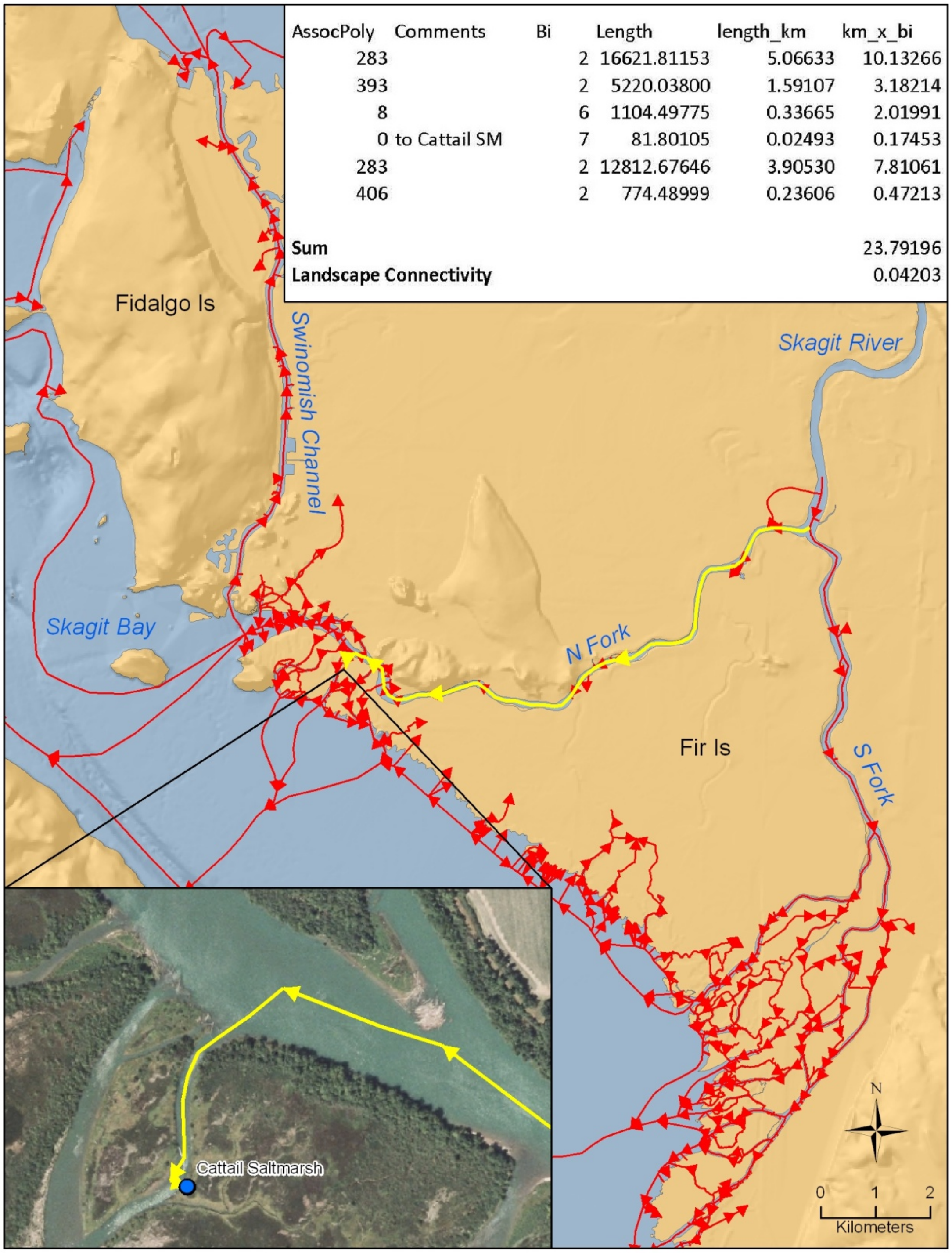



Figure 2. Channels from the *tidelta2000* data layer, displayed by bifurcation order (BI) values.




| AssocPoly | Comments | Bi | Length | length_km | km_x_bi |
|---|---|---|---|---|---|
| 283 | | 2 | 16621.81153 | 5.06633 | 10.13266 |
| 393 | | 2 | 5220.03800 | 1.59107 | 3.18214 |
| 8 | | 6 | 1104.49775 | 0.33665 | 2.01991 |
| 0 | to Cattail SM | 7 | 81.80105 | 0.02493 | 0.17453 |
| 283 | | 2 | 12812.67646 | 3.90530 | 7.81061 |
| 406 | | 2 | 774.48999 | 0.23606 | 0.47213 |
| **Sum** | | | | | 23.79196 |
| **Landscape Connectivity** | | | | | 0.04203 |

Figure 3. Landscape connectivity for Cattail Saltmarsh, a long term blind channel fish monitoring site. Red and yellow arcs are from the GIS data layer *fish_direction*. Yellow arcs show the pathway chosen for calculating landscape connectivity to this site. The inset table shows the summed total of distance multiplied by bifurcation order for each arc in that pathway, and the calculated landscape connectivity.

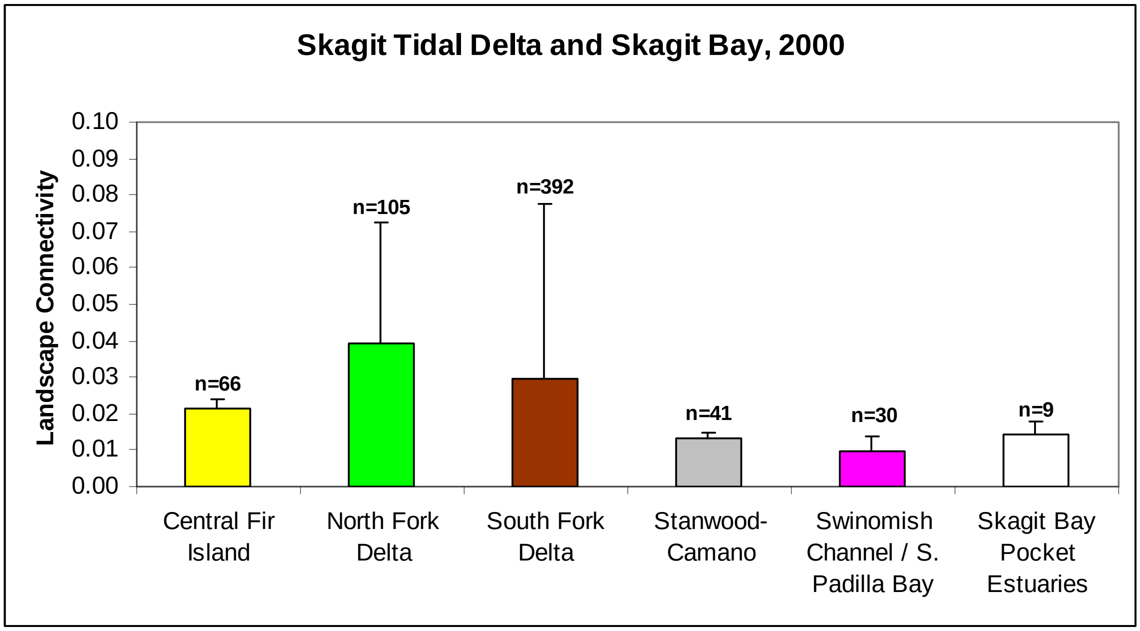



Figure 4. Average, standard deviation, and sample size of landscape connectivity measurement by spatial strata identified for planning restoration and monitoring juvenile Chinook salmon population response to estuary recovery actions (Greene and Beamer, 2006). Colors of bars coincide with colors of dots shown in Figure 5 for spatial strata.

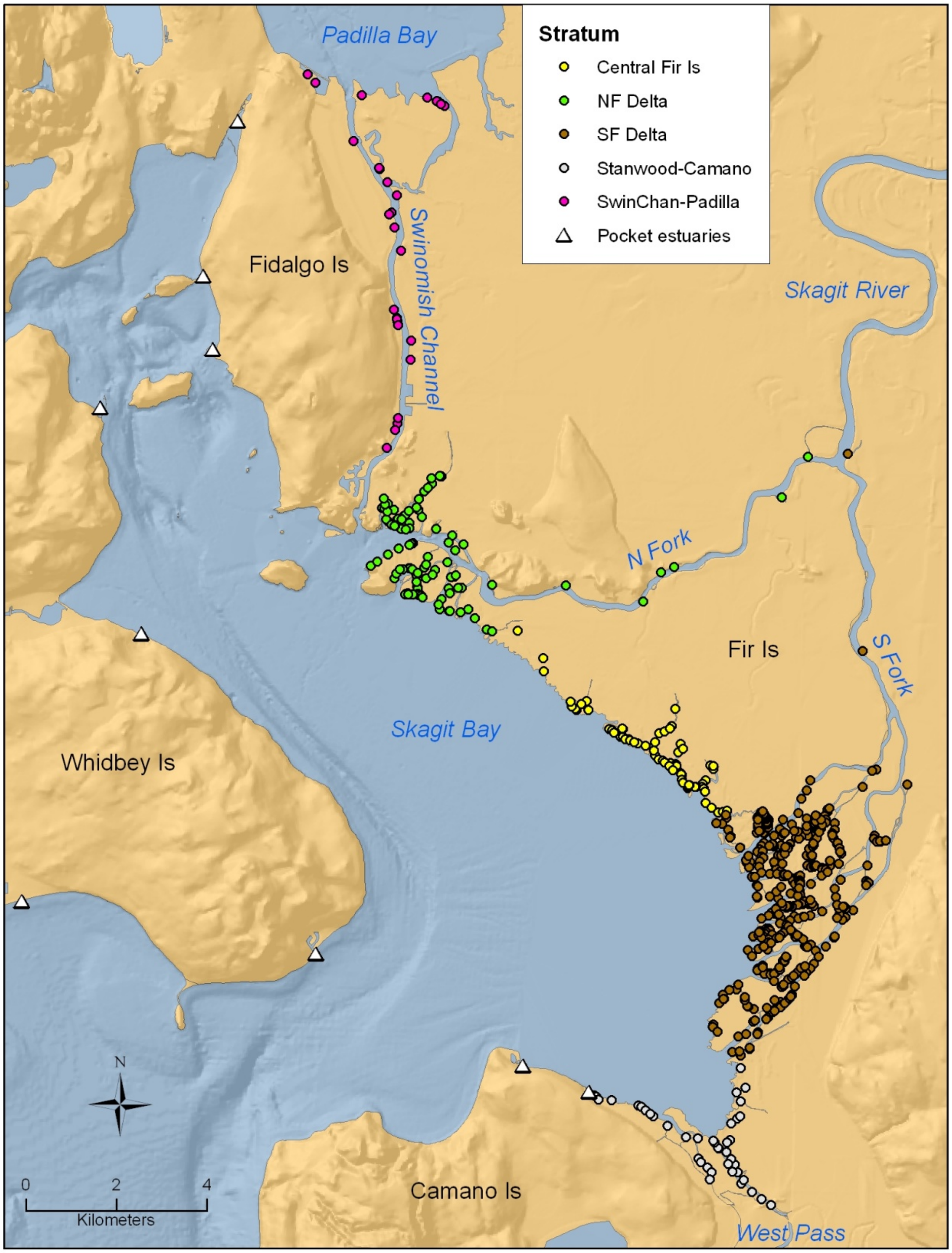



Figure 5. Blind channel and pocket estuary points by monitoring spatial strata described in Greene and Beamer (2006).

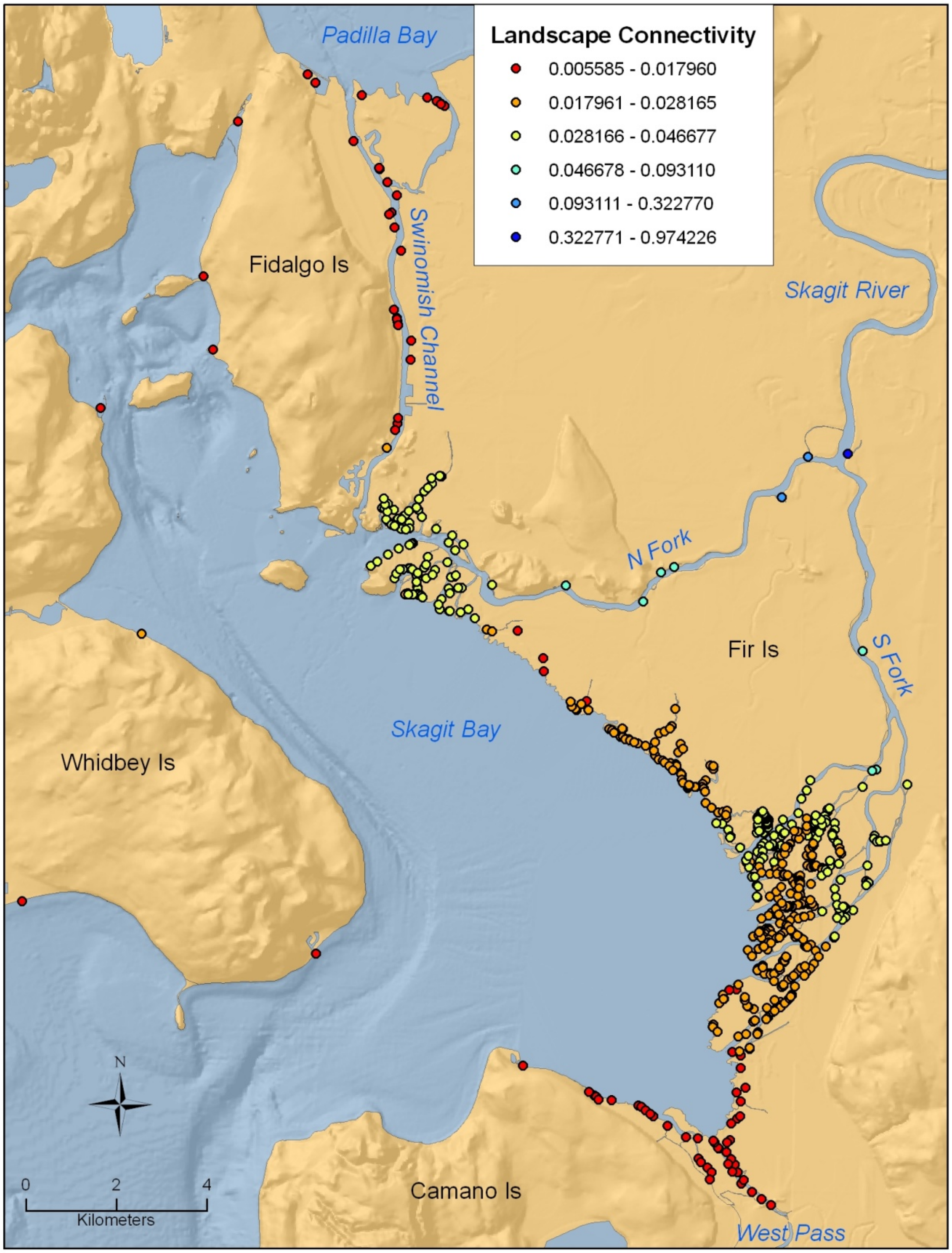



Figure 6. Landscape Connectivity value ranges for *LandscapeConnectivity_Skagit2000* data file, blue being the highest and red the lowest.

**References**

Beamer, E, A McBride, C Greene, R Henderson, G Hood, K Wolf, K Larsen, C Rice, and K Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: linking estuary restoration to wild Chinook salmon populations. Appendix to the Skagit Chinook Recovery Plan. Available at www.skagitcoop.org/.

Greene, CM, and EM Beamer. 2006. Monitoring of population responses by Skagit River Chinook salmon to estuary restoration. Northwest Fisheries Science Center, Seattle. Available at www.skagitcoop.org/.

Skagit River System Cooperative & Washington Department of Fish and Wildlife. 2005. Skagit Chinook Recovery Plan. Available at www.skagitcoop.org/.

**Appendix A**: Bifurcation order determination rules for *tidelta2000* polygons

Method for determining Bi value is:

1) Measure each bifurcating (splitting) channel poly at head, as well as at mouth of upstream poly. Enter values into 'hdwideft' and 'uplkwidft'.
2) Divide 'hdwideft' by 'uplkwidft' and multiply by 100 to get the percentage of head width to upper width (PCT_value).
3) Use 'PCT_value' to ascertain 'PlusBi' value from Table D.V.1. from the Chinook Plan ("Assignment of distributary channel order for channels that split into unequal widths").
4) Assign 'uplkbi' value for each poly that already has a Bi value for its upstream poly (this process will need to be repeated many times as you work your way downstream assigning Bi values).
5) Compute 'Bi' for each poly by adding 'uplkbi' and 'PlusBi' (this is the other part of the cycle that repeats with step 4).
6) Polys that are separate from their upstream poly (for some reason other than bifurcating) are assigned the same Bi as the upstream poly.
7) If two (or more) streams flow into a poly at its head, the Bi assigned to that poly should be equal to the lower Bi number of the incoming streams (5,8=5). If all incoming streams have the same Bi number, assign the poly a Bi of 1 number less (5,5=4).
8) Polys that have a stream flowing in one side will keep the same Bi as its upstream Bi, unless the stream flowing in is of a higher order (lower Bi number).

**Appendix B:** Bifurcation order determination rules for *fish_direction* arcs extending beyond the edges of the *tidelta2000* data layer

For arcs outside of the Skagit tidal delta (i.e. extending into Skagit Bay, beyond the *tidelta2000* polygon layer), the Bi was determined following these rules:

1) Arcs take the same Bi as the polygon it's flowing out of, unless there is more than one arc flowing out, in which case it's considered a split and each outflowing arc gets a (plus) +1.
2) When two or more arcs with the same Bi value come together, the Bi value of the resulting (joined) arc is the value of the upstream arcs (minus) -1 (7,7=6).
3) When two or more arcs of differing Bi values come together, the Bi value of the resulting (joined) arc is the same as the smallest value of the incoming arcs (6,4=4).
4) When an arc splits into two or more arcs, the Bi value of the downstream arcs is the Bi value of the upstream arc (plus) +1 (2=3,3).
5) Any arcs running along the front of the Skagit delta, out in the bay, are assigned the same Bi value all the way along, regardless of how many times it split off into truncated channels in the delta.
6) Short arcs were added from each nearby arc to snap to each sampling site. These arcs were given a Bi value of the nearby arc (plus) +1.