Conceptual Tidal Channel Design for the Leque Island Restoration Site

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Problem Statement

The Leque Island tidal marsh restoration site comprises 103 ha (254.5 ac) of currently diked fallow farmland at the mouth of the Old Stillaguamish River. The dikes surrounding the site are failing in several places and their complete, or nearly complete, removal is being proposed by the landowner (Washington Department of Fish and Wildlife) and Ducks Unlimited to restore tidal inundation to the site, which was historically a tidal marsh, to provide habitat for fish and wildlife, including threatened juvenile Chinook salmon and migratory waterfowl. The purpose of this report is to provide recommendations for the location, number and size (i.e., length) of tidal channels that will allow effective exchange of water, fish, and nutrients between the marsh and Port Susan Bay.

Several questions need to be addressed regarding the appropriate tidal channel design: [1] How many tidal channels should drain the project site? [2] How large (long) should the tidal channels be? [3] Where should the tidal channels be located on the site? These questions are answered below by using tidal channels of the Skagit and Stillaguamish Delta marshes as reference standards for the desired geometry of the restoration site channels, and by using available lidar data to situate the proposed tidal channel network.

Recent research has shown that tidal marsh restoration in Puget Sound and the Columbia River estuary typically severely underestimates the number of tidal channels that a restoration site should have compared to reference sites--by a factor of five (Hood 2015a). This deficit in tidal channel outlets likely impacts site accessibility to juvenile salmon and other estuarine nekton. It also likely impacts tidal exchange of sediments, nutrients, and organic material that typically affect marsh ecology and marsh persistence in the face of sea level rise. Thus, this conceptual design aims to avoid this design mistake that till now has been so common to tidal marsh restoration in the region.

Methods

Allometric analysis of tidal channel planform relative to marsh area (e.g., Hood 2007, 2014) was used to make predictions and recommendations for the Leque Island restoration project. Several reference marsh systems are located in the vicinity of the project site and experience similar tidal ranges; the North Fork Skagit Delta, the South Fork Skagit Delta, and the active Stillaguamish Delta at the Hatt Slough outlet (Fig. 1). The Leque Island restoration site has high exposure to southerly fetch, as do the North Fork Skagit and Stillaguamish/Hatt Slough deltas. However, the South Fork Skagit Delta is relatively sheltered from significant storm fetch, so it was removed from consideration as a reference site. Storm wave height and fetch, as well as riverine sediment supply, have been previously implicated in affecting tidal channel planform geometry (Hood 2015b). Given that sediment supply to Leque Island is most likely from the

Fig. 1. General location of reference sites.

Stillaguamish River, in particular the Hatt Slough outlet, the North Fork Skagit River reference may have limitations given the very high sediment load of the Skagit River and the dominance of the North Fork distributary over the South Fork. The Stillaguamish River is much smaller than the Skagit and thus has a smaller sediment load, making the Stillaguamish/Hatt Slough Delta the most appropriate reference site.

Tidal channel length can be predicted from marsh area for up to the 15 largest tidal channels draining a site by using allometric analysis (Fig. 2; Hood, in review). The degree to which predictions can be made depends on the sample size of marsh islands in the reference system. Such predictions are not available for the Stillaguamish Delta, because the sample size and size range of marsh islands with more than one tidal channel are too small in this delta. Consequently, the North Fork Skagit system predictions were initially used. This analysis predicts the total channel length, including all tributaries, for the largest, 2nd-largest, 3rd-largest, etc. channels draining a marsh island of a given area. However, it was assumed that engineers would find it impractical to excavate a complete channel network, that only excavation of the channel system mainstem and a few tributaries for the largest channels would be practical. Thus, an additional analysis was made for this report that used total channel length as a predictor for mainstem channel length for the North Fork Skagit blind tidal channels. As expected, an allometric scaling relationship was found between the two variables

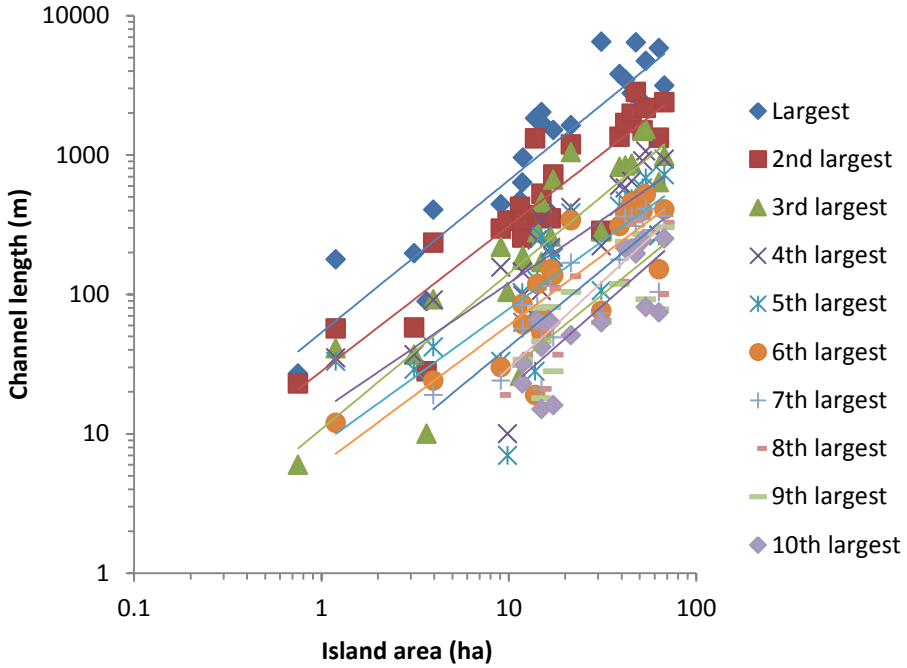

Fig 2. Allometric scaling of channel length with marsh area for the largest, 2nd-largest, 3rd-largest, etc., channel draining South Fork Skagit Delta marsh islands of a given area. Regression correlation coefficients (R^2) range from 0.61 to 0.84.

with high predictability (R^2 = 0.95; Fig. 3). A similar scaling relationship was found for the Stillaguamish Delta data set. Using this scaling relationship, the predicted whole channel lengths were converted to predicted mainstem channel lengths. The predicted mainstem length of the largest channel draining a 103-ha site (e.g., Leque Island) was 1,642 m. Fortunately, a large remnant of a historical blind tidal channel remains on the Leque Island restoration site, allowing comparison between prediction and observation. This remnant was assumed to be the mainstem of the largest channel that historically drained the site, but its length amounts to only 1, 042 m. This indicates that the North Fork system is not the appropriate reference system as it over-predicts the length of the mainstem. However, comparison of whole channel length predictions for the largest channels draining marsh islands of a given size between the North Fork and Stillaguamish deltas shows that Stillaguamish channels are typically 54% as long as North Fork channels (Hood 2015b). When this adjustment is made and then the mainstem length is calculated from the adjusted whole-channel length, the predicted mainstem length becomes 1,039 m, which is almost exactly the length of the historical remnant on the restoration site. Thus, channel mainstem lengths were predicted for the 103-ha site Leque Island restoration site using the following 3-step procedure: [1] allometric prediction of whole channel lengths using the North Fork allometric relationship; [2] adjusting the North Fork whole channel length predictions by a scalar of 54% to obtain predictions for Stillaguamish whole channel lengths; [3] prediction of the Stillaguamish mainstem lengths from the adjusted whole channel lengths using the scaling relationship in Figure 3.

The size of the largest through 5th-largest tributaries to the largest and 2nd-largest tidal channels draining a marsh island of a given size can be similarly predicted by allometric analysis

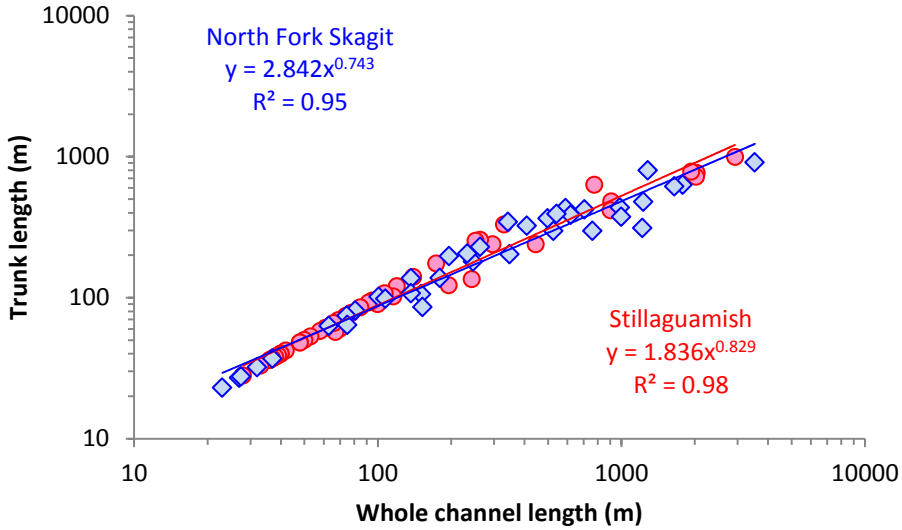

Fig. 3. Scaling of whole channel vs. mainstem length for tidal channels in the North Fork Skagit (blue) and Stillaguamish (red) deltas. There is no significant difference between the two areas.

(Hood, in review). The largest and second-largest channels draining all but the smallest islands in the Stillaguamish/Hatt Slough Delta typically have more than 5 tributary channels (Hood 2015). For example, in a 103-ha marsh the largest channel is predicted to have 28 tributaries; similarly, the second-largest would also have far more than five tributaries. However, the available sample size of marsh islands in most Puget Sound deltas is insufficient to predict the lengths of more than the five largest tributaries. Thus, the same 3-step procedure was followed to predict tributary channel lengths as for the (mainstem) tidal channel predictions. For the 3rd-largest (mainstem) tidal channel, a single tributary was predicted as a similar fraction of the mainstem length as was the case for the largest tributary to the largest and 2nd-largest mainstem channels, i.e., 32% of the mainstem length.

Results

Using the Stillaguamish/Hatt Slough Delta reference, the restoration site was predicted to have 13 tidal channels draining the area, with a lower 80% confidence limit of the prediction (CLP) of 2 channel outlets and an upper 80% CLP of 72. In comparison, using the North Fork Skagit Delta as a reference, the restoration site was predicted to have 18 tidal channels draining the area, with a lower 80% confidence limit of the prediction (CLP) of 11 channel outlets and an upper 80% CLP of 31. The much wider confidence limits of the Stillaguamish system are a statistical consequence of the much smaller population of marsh islands in this delta compared to that of the North Fork Skagit River. Thus, according to the Stillaguamish/Hatt Slough Delta reference data the appropriate target for tidal channel count for the Leque Island restoration site is approximately 13 tidal channels.

Predicted mainstem channel lengths are shown in Table 1. For the very smallest channels, the 12th- and 13th-largest channels, a minimum length of 40 m was assumed, because smaller channels than that are almost never seen in the reference data set for either the North Fork Skagit or Stillaguamish deltas. Note that the lower 80% confidence limits of the

predictions in Table 1 (not shown) are about 50% of the prediction, while the upper 80% confidence limits are about 2.5 times the prediction. The confidence limits are asymmetrical, because the prediction is derived from a power function.

Table 1. Predicted mainstem lengths for the 103-ha Leque Island restoration site.

Channel size rank	Mainstem length (m)	Mainstem length (ft)
1	1,039	3,409
2	792	2,599
3	446	1,465
4	378	1,240
5	250	820
6	206	677
7	157	516
8	114	373
9	83	274
10	61	201
11	45	147
12	40	131
13	40	131

Predicted tributary lengths are shown in Tables 2 and 3.

Table 2. Predicted tributary lengths to the largest (mainstem) tidal channel for the 103-ha Leque Island restoration site.

Channel size rank	Mainstem length (m)	Mainstem length (ft)
1	329	1,080
2	191	625
3	152	498
4	120	394
5	93	304

Table 3. Predicted tributary lengths to the 2nd-largest mainstem tidal channel for the 103-ha Leque Island restoration site.

Channel size rank	Mainstem length (m)	Mainstem length (ft)
1	255	572
2	121	328
3	116	319
4	84	251
5	50	170

Where should tidal channels and their tributaries be located?

Methods

The next step in the design process was to look for opportunities for tidal channel placement. This was done by consulting the lidar data and selecting low linear topography that would likely develop into channels following tidal restoration, either through passive erosion or active excavation. Observation of unplanned historical dike failures in the Snohomish Delta through a succession of historical air photos shows that such low-lying areas evolve into tidal channels over many decades (Hood, unpublished observations). Active excavation would accelerate channel development. Additionally, maps of high water velocity and high bed shear stress (Fig. 4) derived from the hydrodynamic model developed by Khangaonkar et al. (2014), were consulted as an additional guide for the location of the largest tidal channels. Potential channel locations were drawn by eye in a GIS to form linear features that connected low topography (Fig. 5). Finally, existing partially repaired dike breaches were used to identify the outlet locations of some of the largest tidal channels.

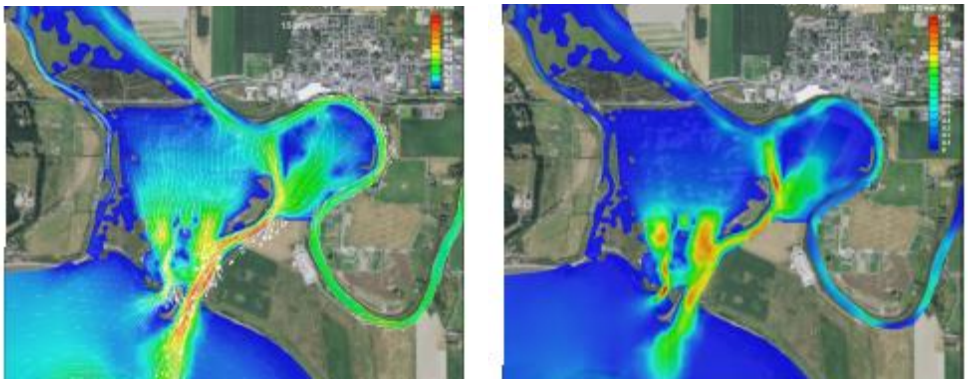

Fig. 4. Maps of surface water velocity (left frame) and bed shear stress (right frame) for the full restoration design concept with no training dike; warm colors are higher values (from Khangaonkar et al., 2014).

There were two topographic constraints on tidal channel outlet location. First, proposed tidal channels were routed away from an existing fringing marsh on the east side of the property, between the outlet for channel 2 and the spur dike. This fringing marsh is at higher elevation than the area proposed for tidal restoration, which has subsided during more than a century of agricultural use, so drainage through the higher fringing marsh would have required profound excavation of tidal channels through this area. Given the presence of functional tidal channels in the fringing marsh, such excavation would add marginal if any value to the project at considerable expense. Second, channel outlets were mostly avoided on the west side of the project site. Again, the existing marsh to the west of the project site is at higher elevation than the project site, making drainage from lower to higher ground problematic. An additional consideration is that drainage to the west would be through a large pre-existing tidal channel system in the western marsh that drains through only one outlet into Skagit Bay. Thus, any outlets to the west would have to be connected to this system and would

not significantly increase site accessibility to juvenile salmon. Salmon access would be constrained by the single Skagit Bay outlet and by the distance they would have to travel through the existing channel network to reach the Leque Island restoration site.

Results

The preferred restoration alternative is one where a spur dike remains along the northeastern border of the site. Retaining the spur dike adds an additional constraint to the possible location of channel outlets. It removes almost 2,000 feet of shoreline and opportunity for tidal channel outlet siting. Consequently, the number of tidal channel outlets from the restoration site would be reduced from the predicted 13 to 9 (Fig. 5). To maximize the number of channel outlets, two outlets were located on the higher-elevation west side, where aerial photographs suggest existing site drainage may easily connect to the external tidal channel network with comparatively modest effort and expense. The on-site portions of these channels are part of the current site drainage network, and thus would require modest modification rather than complete excavation.

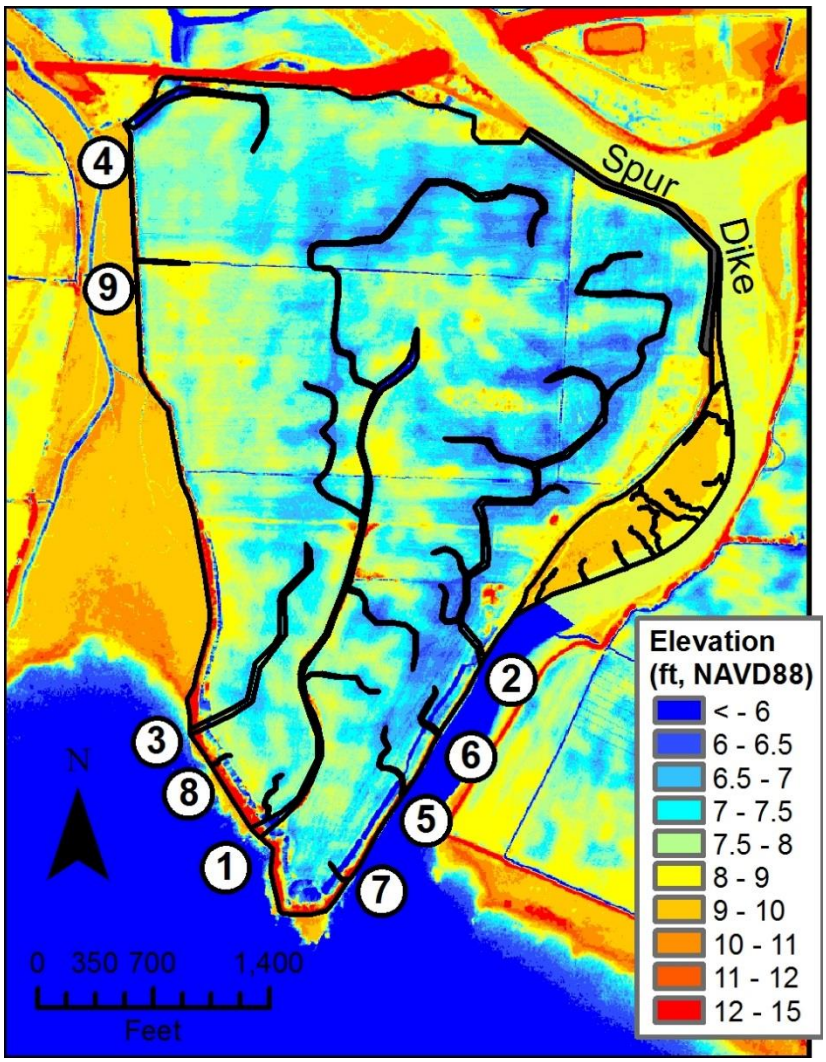

Fig. 5. Conceptual planform design of locations of potential tidal channels for the Leque Island spur dike restoration scenario. Tidal channels are labeled at their outlets by their size rank.

Retaining a spur dike removes the possibility of over-marsh, sheet flow, tidal exchange along this portion of the site perimeter. Sheet flow exchange is also precluded across the higher tidal marsh adjacent on the west and a portion of the east, such that 72% of the site perimeter has impeded drainage with only 28% allowing free over-marsh sheet flow exchange. This constrained tidal exchange is similar to that of historical dike failure sites, which have fewer tidal channel outlets than reference sites, but have longer tidal channel networks, because tidal prism exchange is forced through the channel network, without any overmarsh exchange across the site perimeter where dikes remain (Hood 2014). Thus, another consequence of retaining the spur dike and constraining channel outlet count is that the remaining tidal channels become longer than predicted to accommodate the site's tidal prism. This is reflected in the preferred scenario, where the largest remaining tidal channels are extended to drain areas that might otherwise have drained through the retained spur dike.

A full restoration scenario provides context for the preferred alternative (Fig. 6). Removal of the spur dike allows five channel outlets to be located in this area, increasing fish accessibility to the site, especially to salmon encountering the site from the northeast. The total channel length is unchanged compared to the preferred alternative, but the channel lengths are distributed amongst the channels more closely according to the allometric predictions. This occurs because the total tidal prism does not differ between alternative restoration scenarios (so total channel length is unchanged), but the flow routing does (new channels flow to the northeast).

Conclusion

Allometric analysis coupled with lidar data provide guidance for the number, size (i.e., length), and location of tidal channels that should drain a tidal marsh restoration site. The planforms provided in this report will provide initial habitat for juvenile salmon as soon as the channels are excavated and the dikes removed. Further development of additional small tributaries to these channels is likely through natural tidal erosion, though the rate of their development is likely to require one or more decades. Thus, channel excavation will rapidly accelerate site development and maximize its use by juvenile salmon and other estuarine organisms. The tidal channel recommendations presented in this report for the spur dike and full restoration scenarios are anticipated to benefit salmon by providing access to the new habitat that will develop on the site. In the event that further studies show that the spur dike feature is not necessary and warrants elimination from the design, then additional tidal channel connections could be incorporated on the northeast section of the site under the full restoration scenario. These additional connections would benefit salmon accessibility to the site beyond the spur dike scenario.

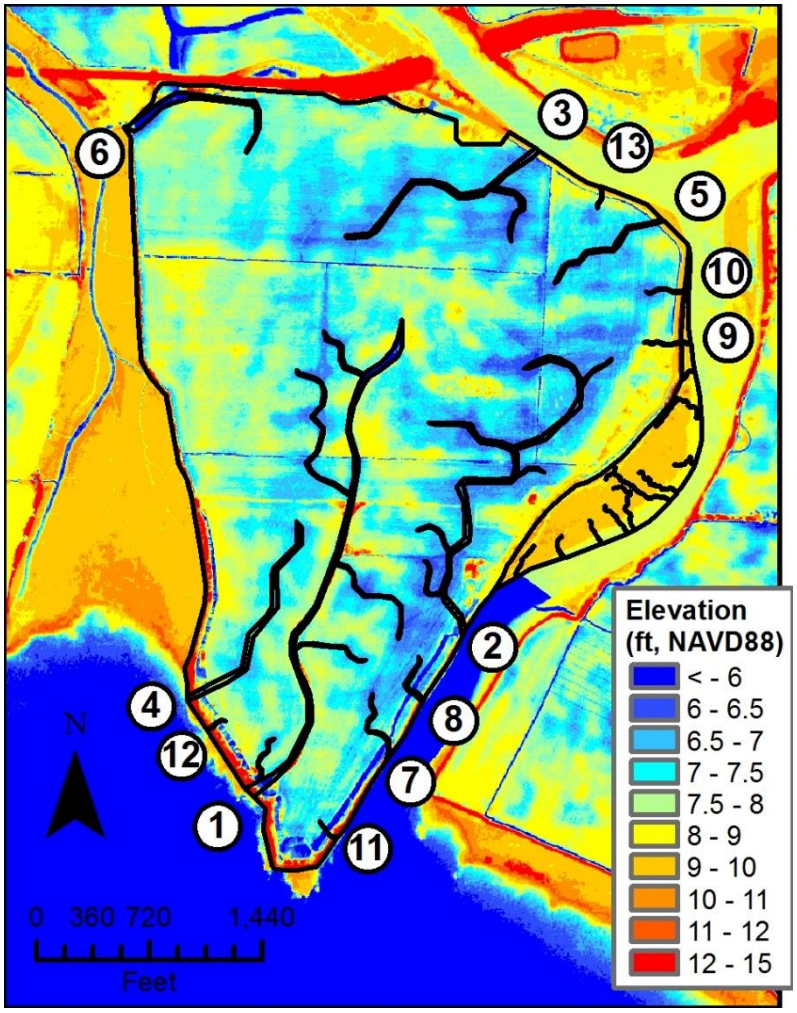

Fig. 6. Conceptual planform design of locations of potential tidal channels for the Leque Island full restoration scenario. Tidal channels are labeled at their outlets by their size rank.

References

Hood WG. 2015a. Predicting the number, orientation, and spacing of dike breaches for tidal marsh restoration. *Ecological Engineering* 83:319-327.

Hood WG. 2015b. Geographic variation in Puget Sound tidal channel planform geometry. *Geomorphology* 230:98-108.

Hood WG. 2014. Differences in tidal channel network geometry between reference marshes and marshes restored by historical dike breaching. *Ecological Engineering* 71:563-573.

Hood WG. 2007. Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation process. *Water Resources Research.* 43, W03409, doi:10.1029/2006WR005083

Hood WG. (in review) Parallel scaling of tidal channel length and surface area with marsh area for 1st through Kth-ranked channels and their tributaries: Application for tidal marsh restoration. *Estuaries & Coasts.*

Khangaonkar T, J Whiting, S Liske. 2014. Hydrodynamic Assessment of Proposed Restoration Alternatives - Phase II: Leque Island and zis a ba - Stillaguamish Estuary. Progress Report Meeting - Part 2, Presentation to Ducks Unlimited and Partners at Stillaguamish Tribe of Indians, 6 Nov. 2014.

Sokal RR and FJ Rohlf. 1995. Biometry, W. H. Freeman, NY.

Zar JH. 1984. Biostatistical Analysis. Prentice-Hall, Upper Saddle River, NJ.