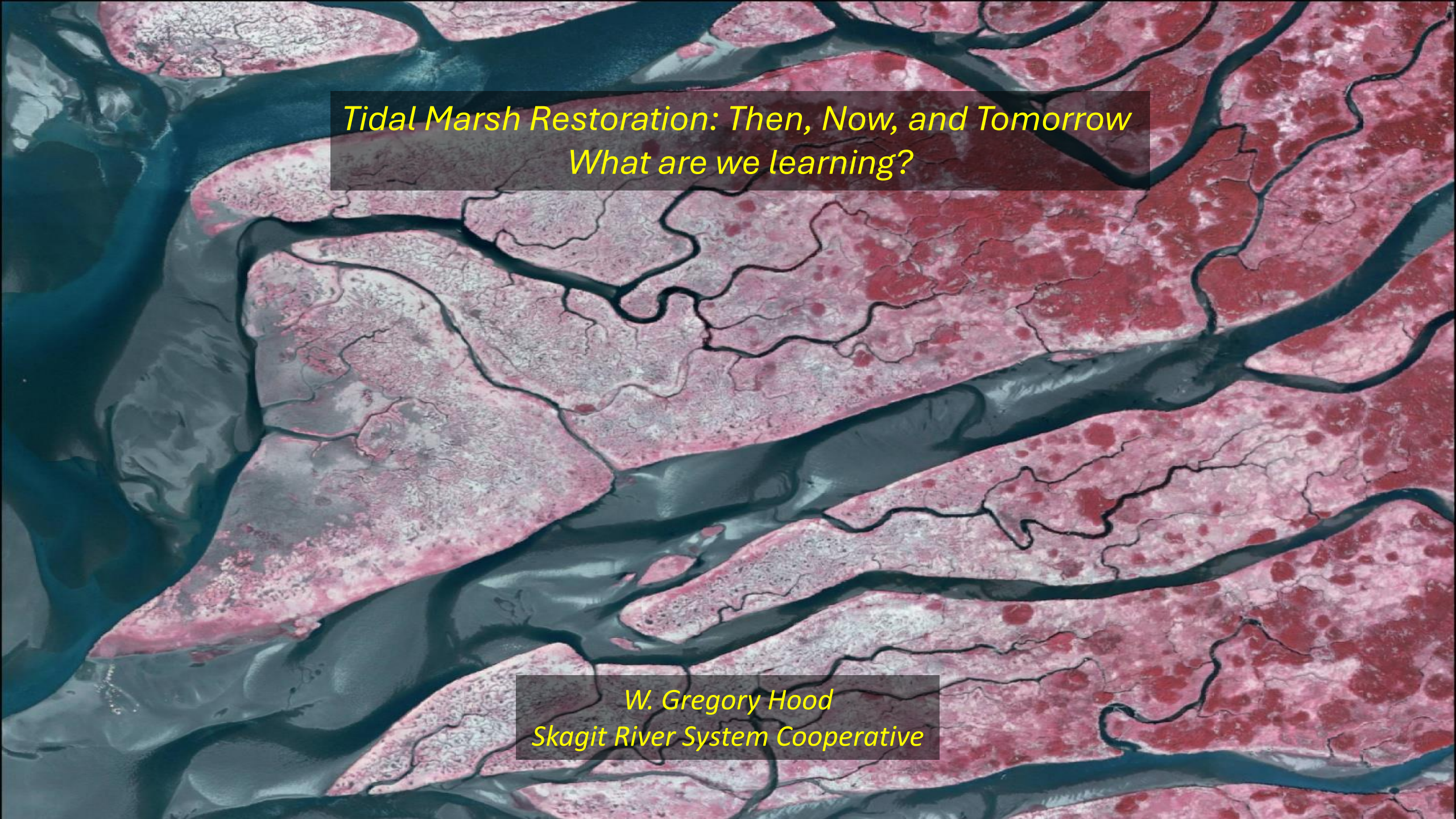


Tidal Marsh Restoration: Then, Now, and Tomorrow
What are we learning?

W. Gregory Hood
Skagit River System Cooperative

Gog-li-hi-ti 1985

6 acres
(2.4 ha)

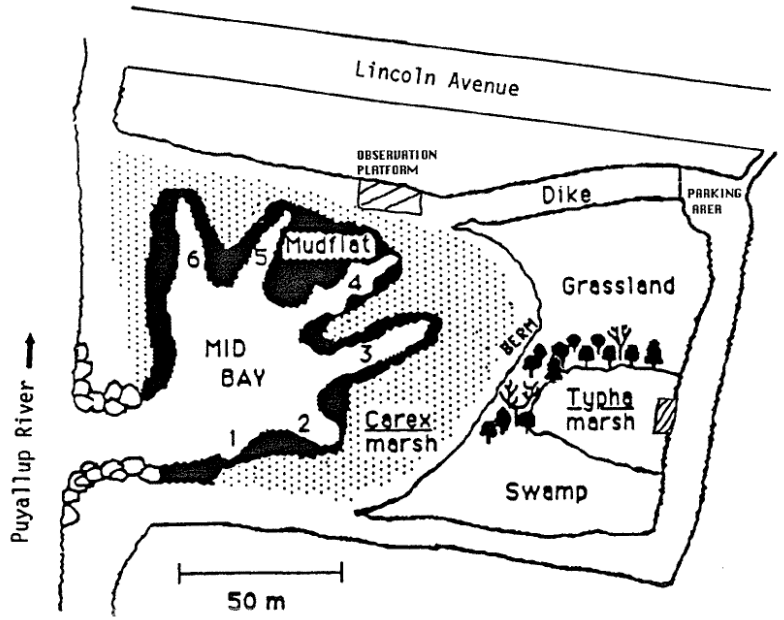
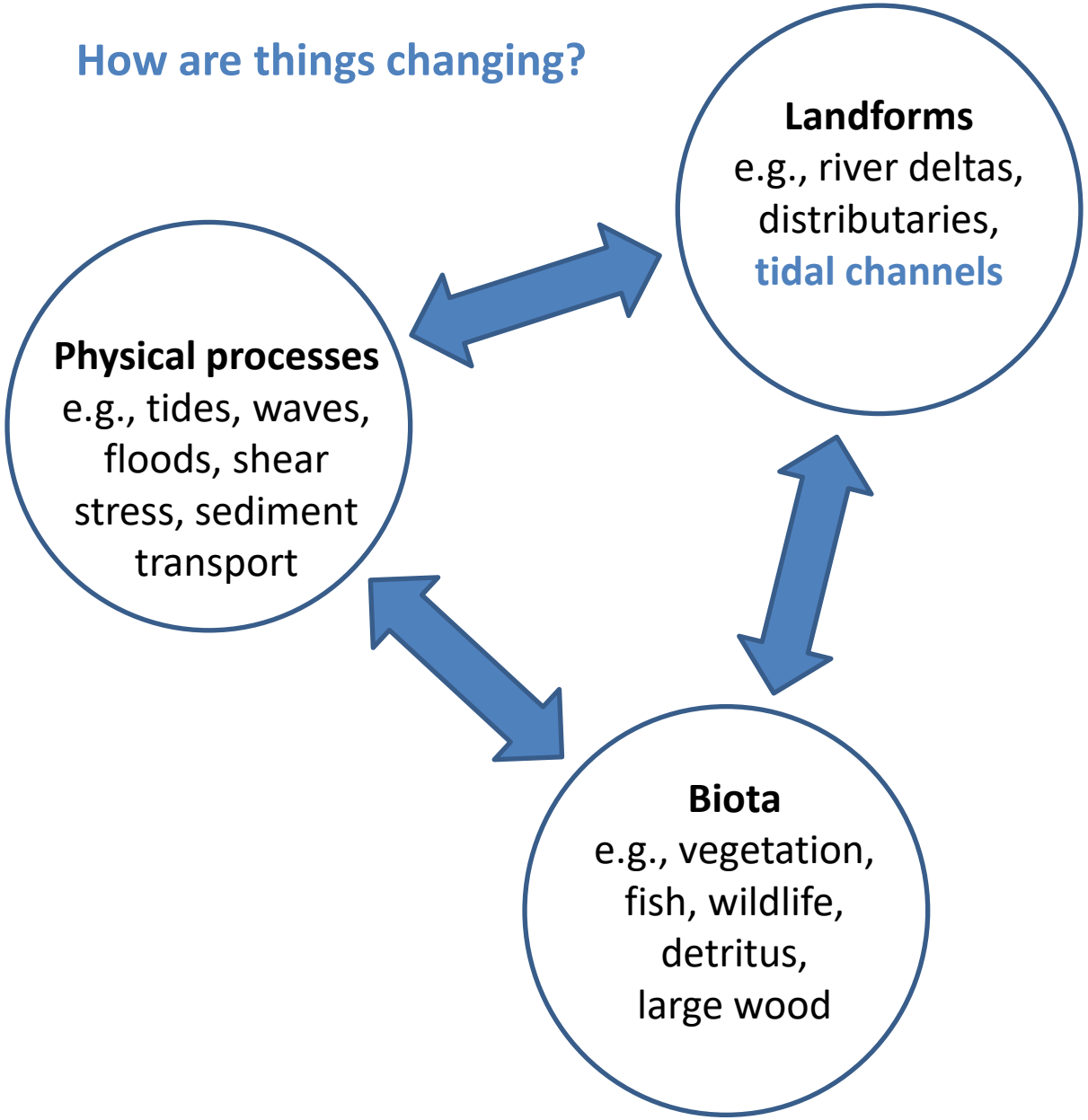


Figure 2. Present (July 1990) distribution of habitat types in Gog-Le-Hi-Te wetland system.

Chehalis (Cosmopolis) Mitigation Slough 1990

We knew next to nothing about tidal channel geomorphology
Monitoring was basic; typically, low replication of reference sites
Predictive models were qualitative, general
Restoration motivated and dominated by biologists and their perspective

How are things changing?



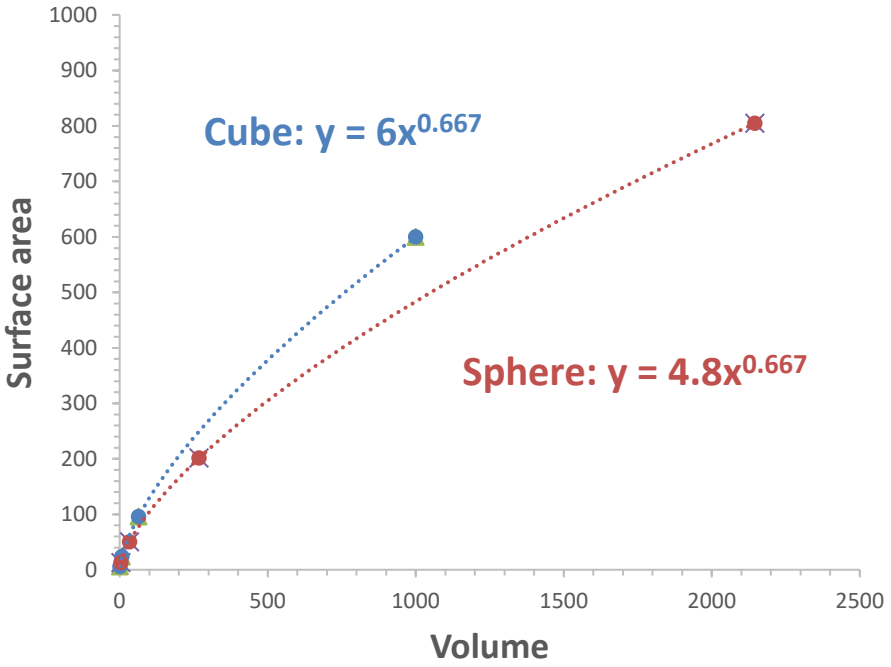
Developing quantitative predictive models

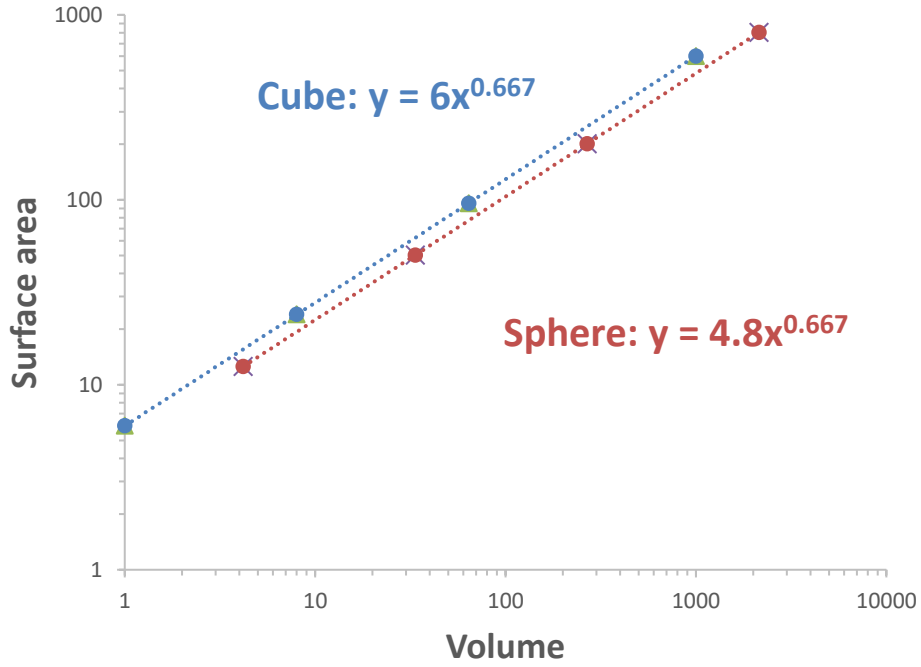
2D, 3D hydrodynamic models
wave models
channel geometry models
fish accessibility models (?)
vegetation models (?)

Technology

Personal- & supercomputers
GIS and aerial photography
Lidar
RTK-GPS
Drones
ADVs, ADCPs, level loggers, etc.

The Geometry of Forms (body form, landform)



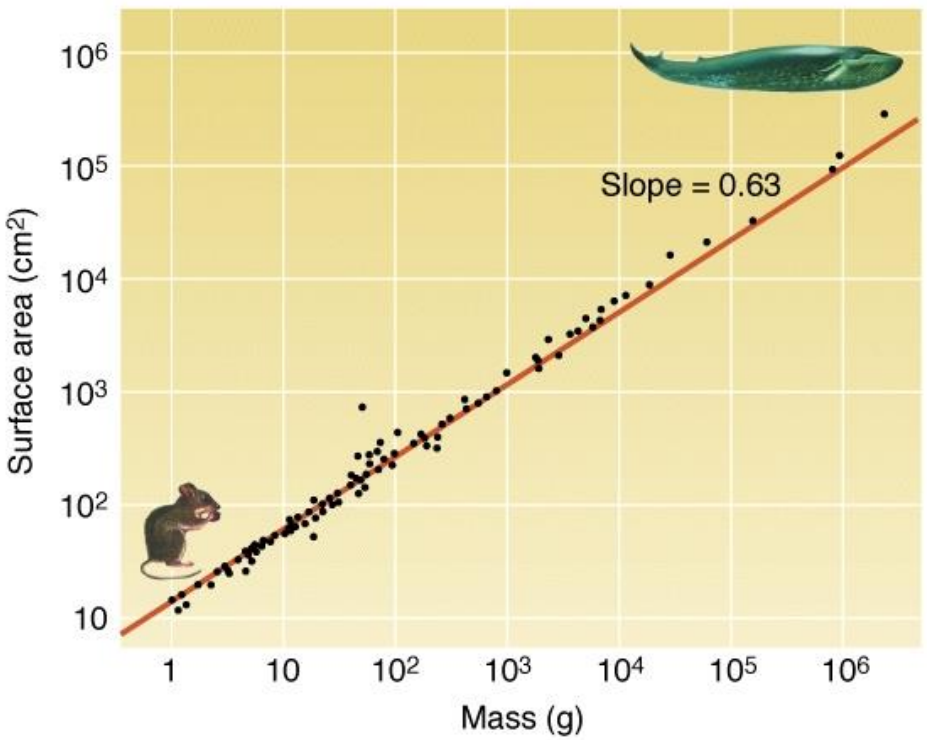


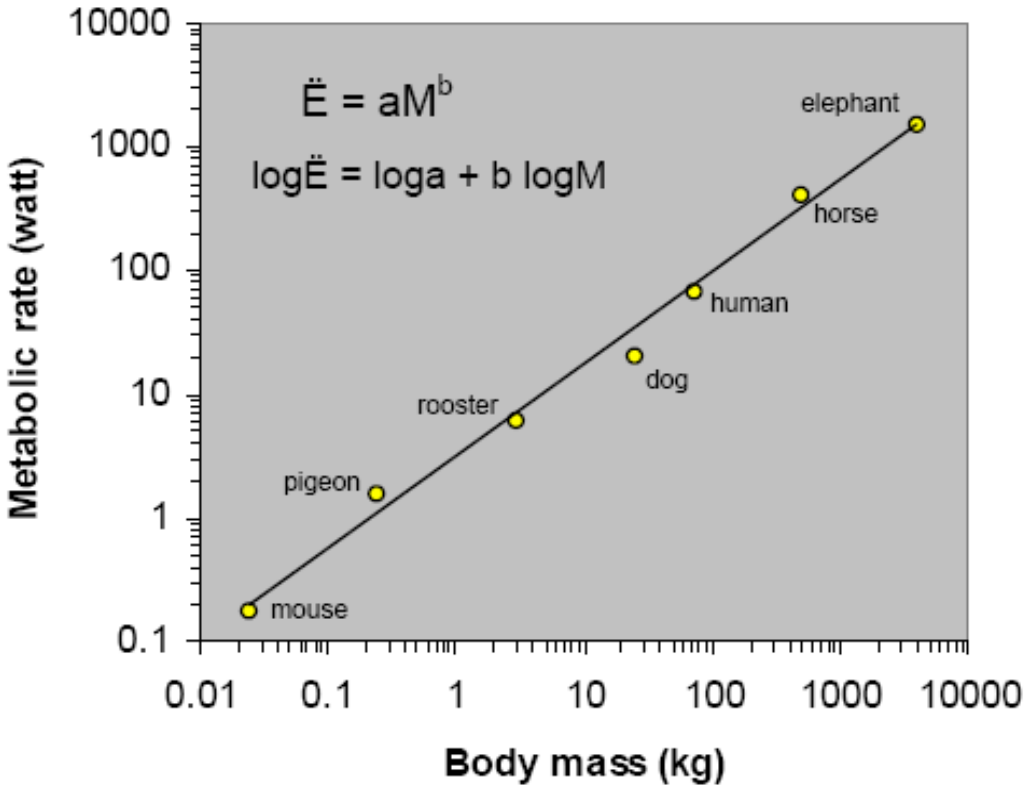
$A = cV^{2/3}$

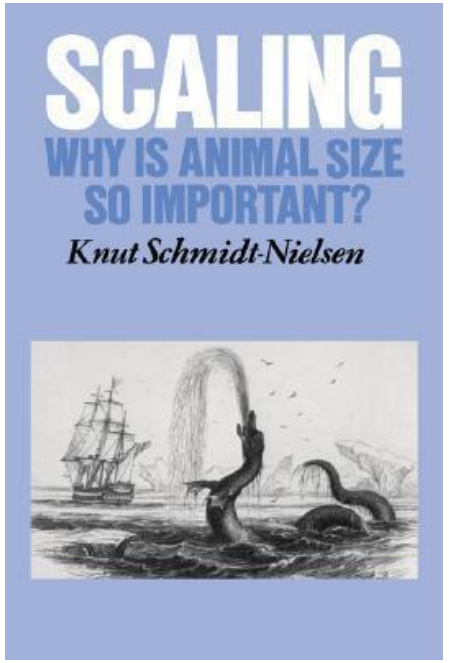
$\log A = \log c + 2/3 \log V$

Dimensional analysis

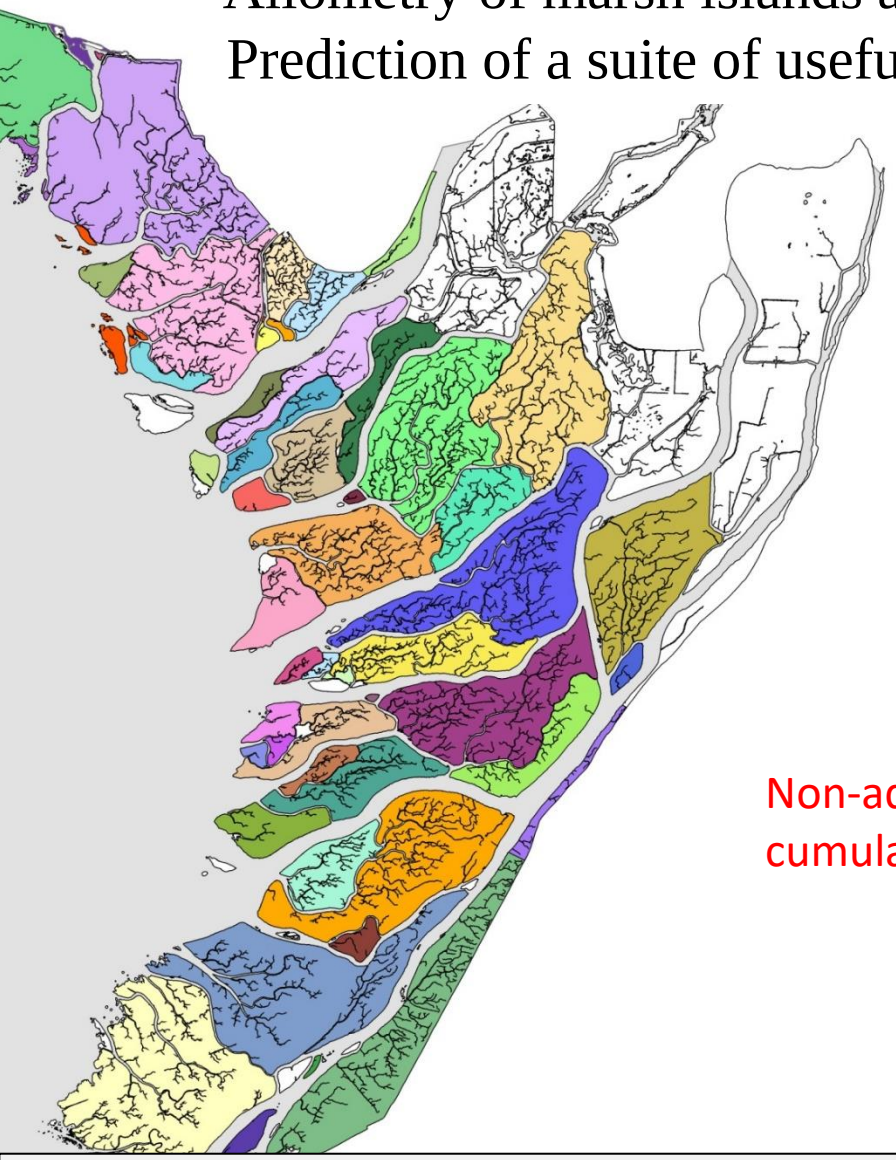
$L^2 = c(L^3)^{2/3}$


Surface area (cm²)
10⁶
10⁵
10⁴
10³
10²
10
Slope = 0.63
1
10
10²
10³
10⁴
10⁵
10⁶
Mass (g)

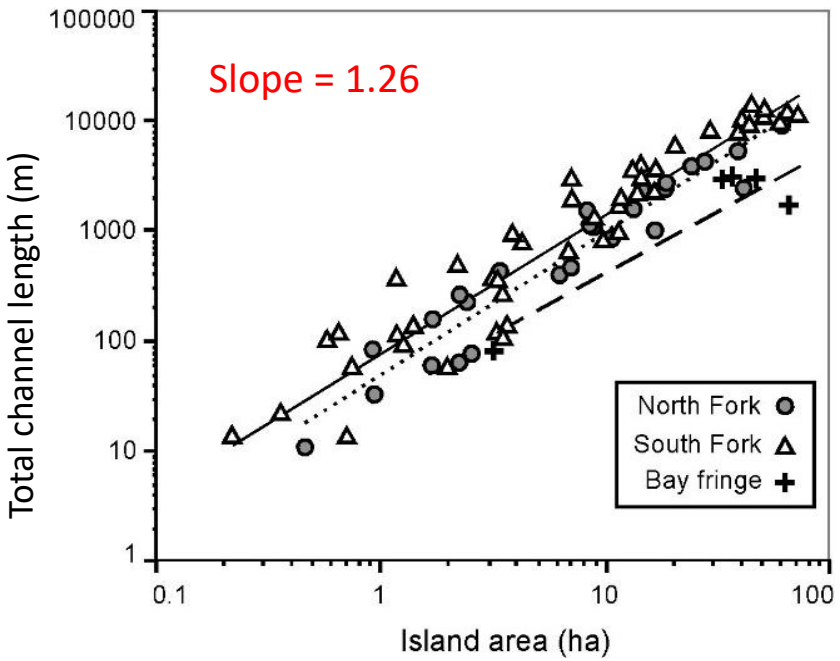

Ë = aM^b
logË = loga + b logM
Metabolic rate (watt)
10000
1000
100
10
1
0.1
elephant
horse
human
dog
rooster
pigeon
mouse
0.01
0.1
1
10
100
1000
10000
Body mass (kg)

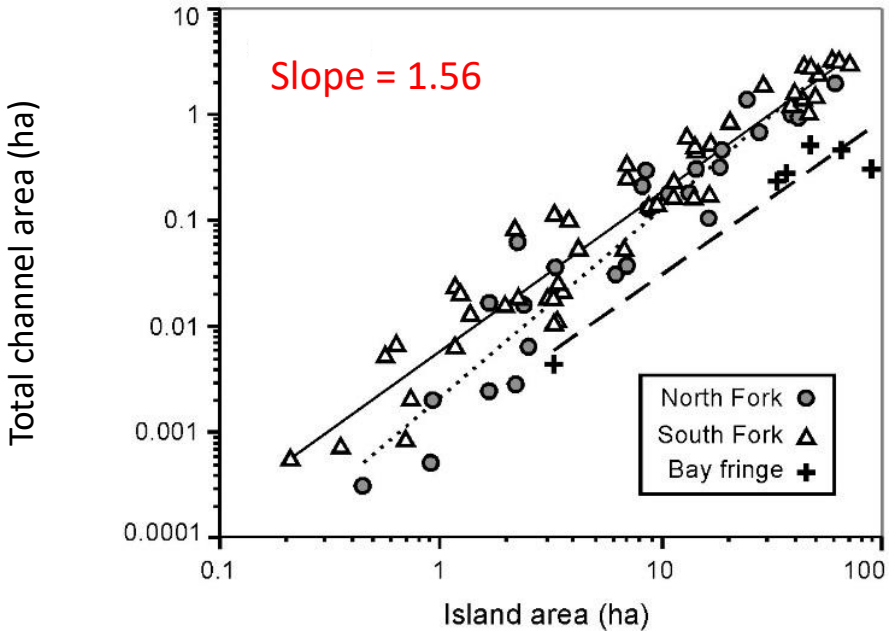

SCALING
WHY IS ANIMAL SIZE SO IMPORTANT?
Knut Schmidt-Nielsen

Allometry of marsh islands and channel geometry.
Prediction of a suite of useful channel geometries.

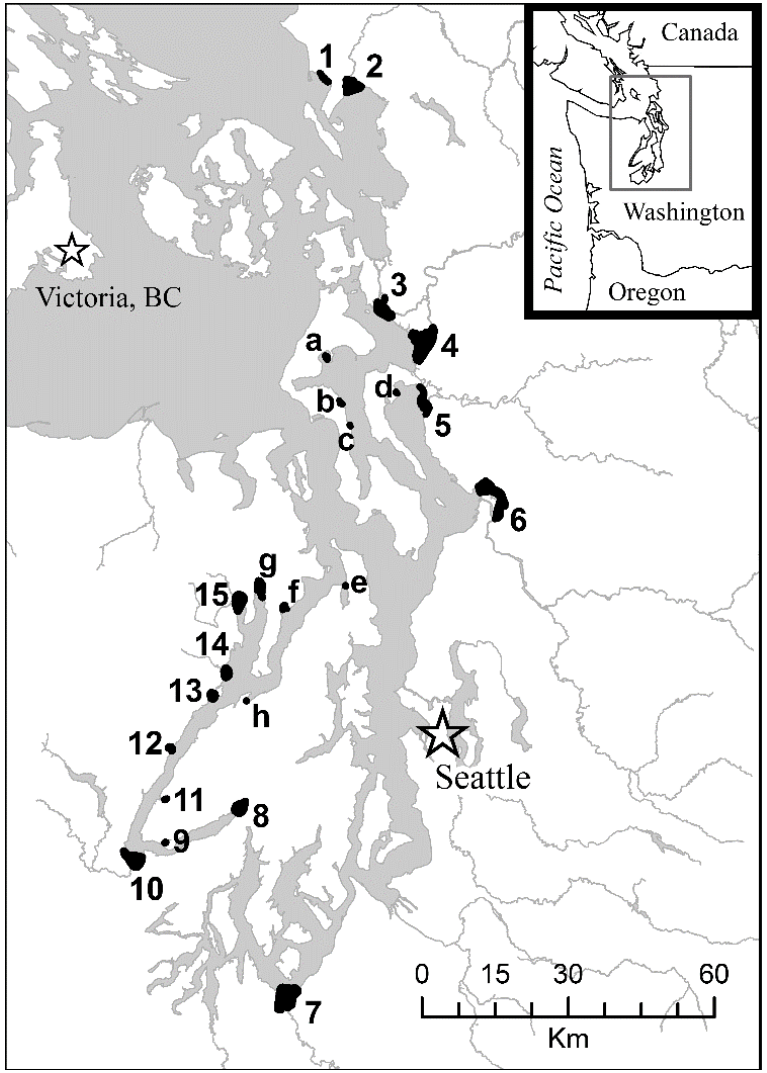


Non-additive
cumulative effects

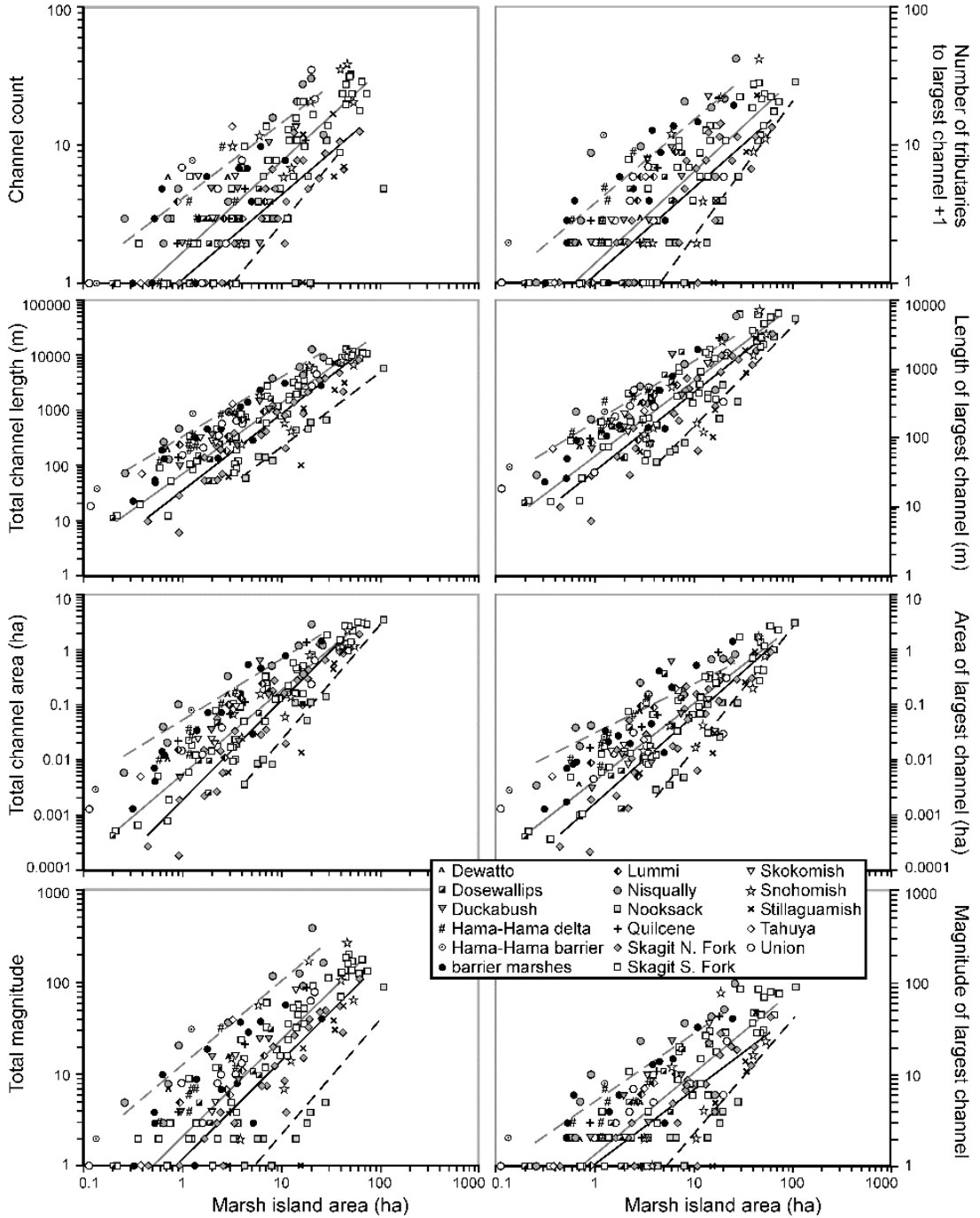




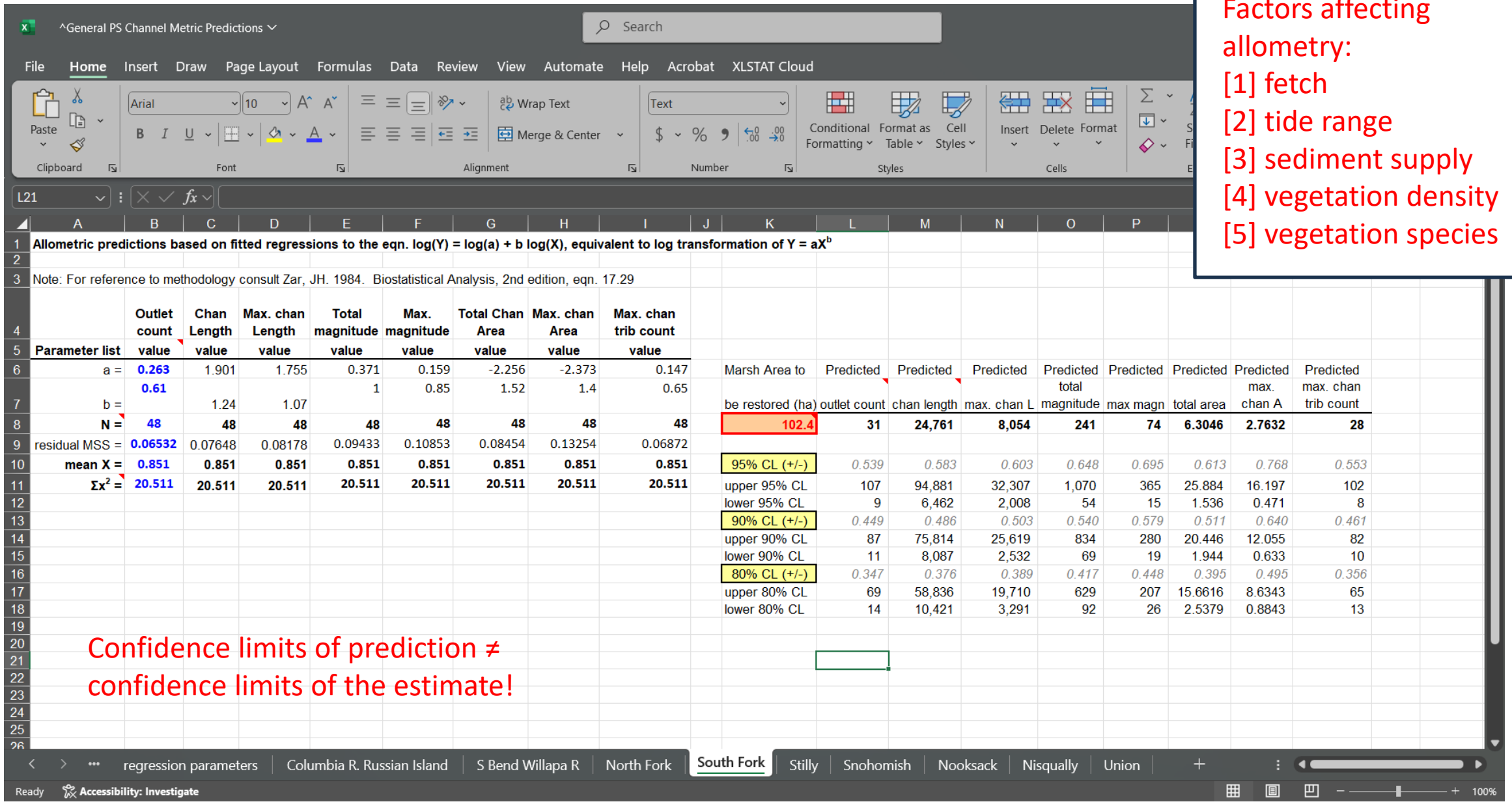
Hood WG. 2007. Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation process. *Water Resources Research* 43, W03409, doi:10.1029/2006WR005083



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



How to?



^General PS Channel Metric Predictions

Search

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L21

Allometric predictions based on fitted regressions to the eqn. log(Y) = log(a) + b log(X), equivalent to log transformation of $Y = aX^b$

Note: For reference to methodology consult Zar, JH. 1984. Biostatistical Analysis, 2nd edition, eqn. 17.29

Parameter list	Outlet count value	Chan Length value	Max. chan Length value	Total magnitude value	Max. magnitude value	Total Chan Area value	Max. chan Area value	Max. chan trib count value
a =	0.263	1.901	1.755	0.371	0.159	-2.256	-2.373	0.147
b =	0.61	1.24	1.07	1	0.85	1.52	1.4	0.65
N =	48	48	48	48	48	48	48	48
residual MSS =	0.06532	0.07648	0.08178	0.09433	0.10853	0.08454	0.13254	0.06872
mean X =	0.851	0.851	0.851	0.851	0.851	0.851	0.851	0.851
Σx^2 =	20.511	20.511	20.511	20.511	20.511	20.511	20.511	20.511

Marsh Area to be restored (ha)	Predicted outlet count	Predicted chan length	Predicted max. chan L	Predicted total magnitude	Predicted max magn	Predicted total area	Predicted max. chan A	Predicted max. chan trib count
102.4	31	24,761	8,054	241	74	6.3046	2.7632	28
95% CL (+/-)	0.539	0.583	0.603	0.648	0.695	0.613	0.768	0.553
upper 95% CL	107	94,881	32,307	1,070	365	25.884	16.197	102
lower 95% CL	9	6,462	2,008	54	15	1.536	0.471	8
90% CL (+/-)	0.449	0.486	0.503	0.540	0.579	0.511	0.640	0.461
upper 90% CL	87	75,814	25,619	834	280	20.446	12.055	82
lower 90% CL	11	8,087	2,532	69	19	1.944	0.633	10
80% CL (+/-)	0.347	0.376	0.389	0.417	0.448	0.395	0.495	0.356
upper 80% CL	69	58,836	19,710	629	207	15.6616	8.6343	65
lower 80% CL	14	10,421	3,291	92	26	2.5379	0.8843	13

Confidence limits of prediction ≠ confidence limits of the estimate!

regression parameters | Columbia R. Russian Island | S Bend Willapa R | North Fork | South Fork | Stilly | Snohomish | Nooksack | Nisqually | Union

Ready Accessibility: Investigate 100%

Factors affecting allometry:

[1] fetch

[2] tide range

[3] sediment supply

[4] vegetation density

[5] vegetation species

https://salishsearestoration.org/wiki/Tidal_Channel_Reference_Model

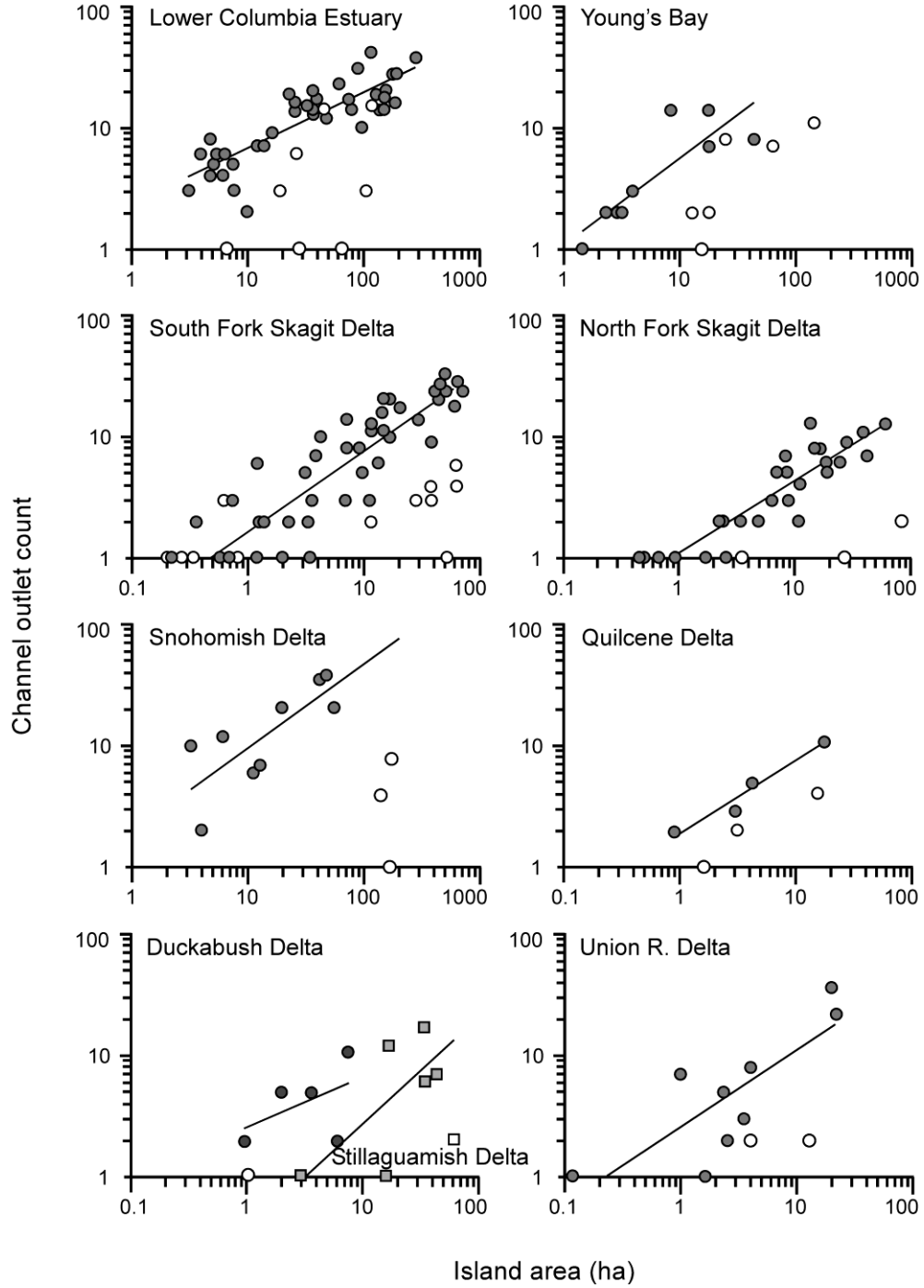
What can happen if you ignore allometry? An example.

How many tidal channels, how many dike breaches?

We are underestimating the number of dike breaches necessary to mimic reference marsh systems by 5-fold.

This likely affects fish access to tidal channel networks.

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



What can happen if you ignore allometry? Another example.

Both sites deviate strongly from allometry
1 outlet vs. dozens predicted
1/3 the total channel length predicted

Both are mostly unvegetated after 8 yrs (FIF) and 9 yrs (Qw)
Both have a lot of *Cotula coronopifolia* [mucilaginous seed coats]

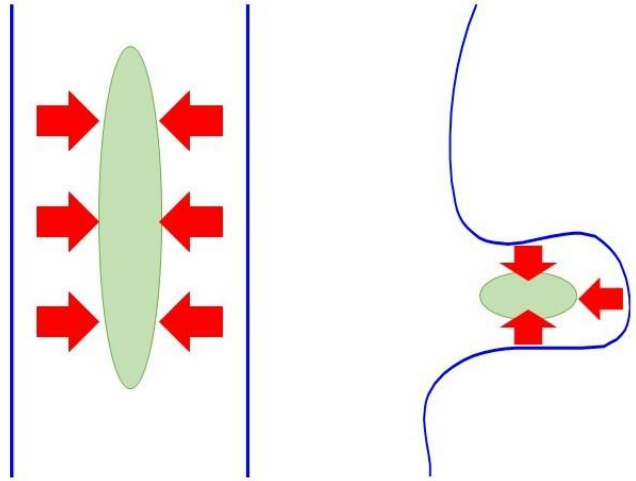

Qwuloolt
30 June 2023

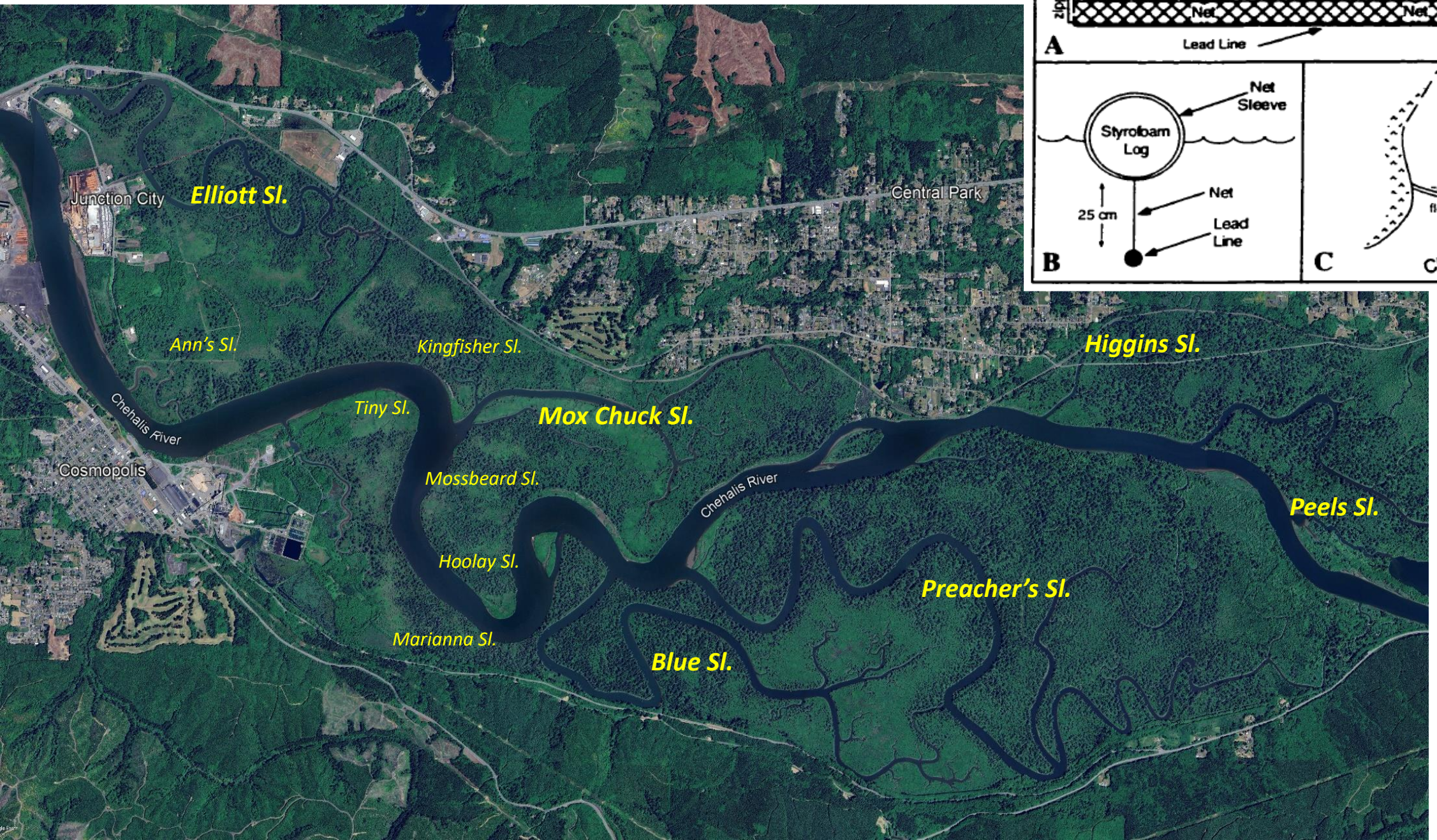
Fir Island Farms

Zis a ba – designed to allometric standards, 2nd summer post restoration

Tidal Channels (↓), Sheet Flow (↑), and Seed Retention (↓)

100 Bolboschoenus maritimus seeds/plot




Junction City
Elliott Sl.
Central Park
Ann's Sl.
Kingfisher Sl.
Higgins Sl.
Tiny Sl.
Mox Chuck Sl.
Chehalis River
Cosmopolis
Mossbeard Sl.
Chehalis River
Peels Sl.
Hoolay Sl.
Preacher's Sl.
Marianna Sl.
Blue Sl.

10 m
zipper
Styrofoam Log
Styrofoam Log
Styrofoam Log
zipper
Net
Net
Lead Line
A
Net Sleeve
Styrofoam Log
25 cm
Net
Lead Line
B
Slough
Ebbing tide
flotsam boom
Chehalis River
C

Smaller tidal channels have higher insect flotsam density (P/A scaling)

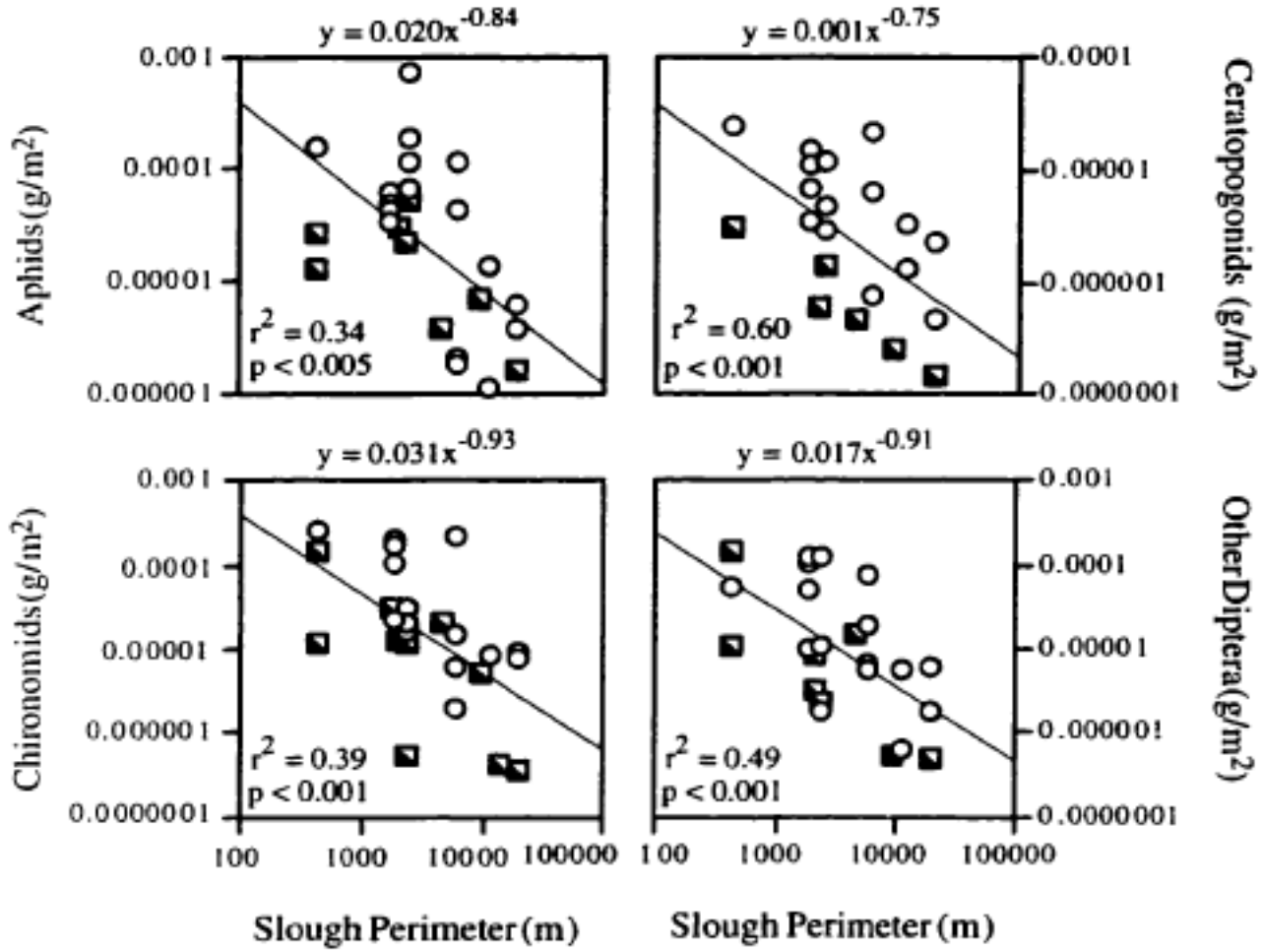
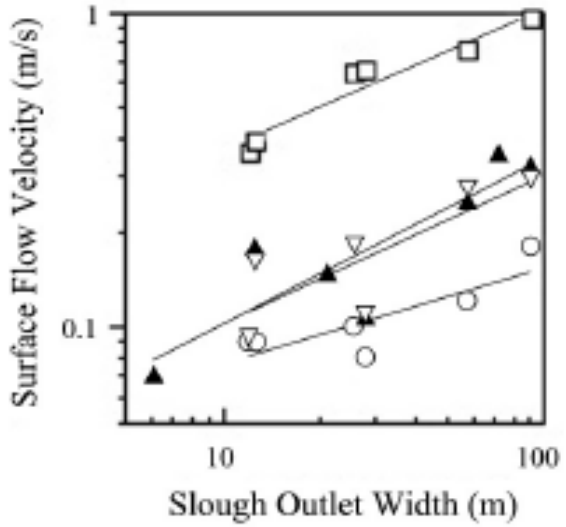
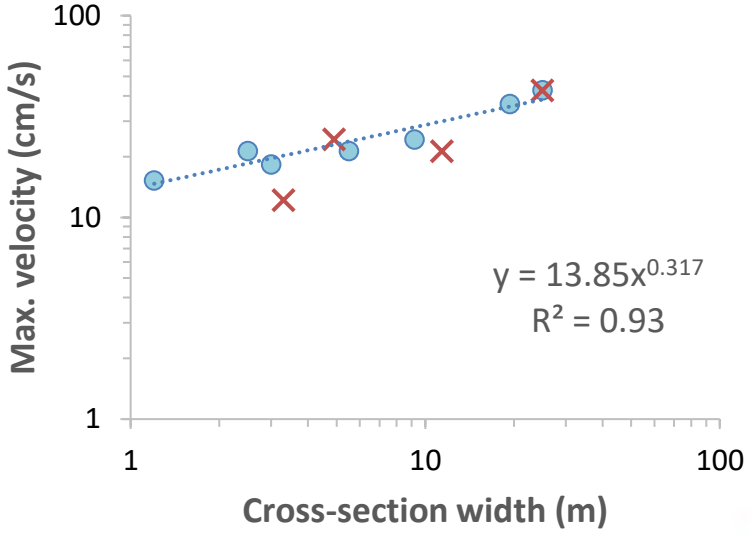


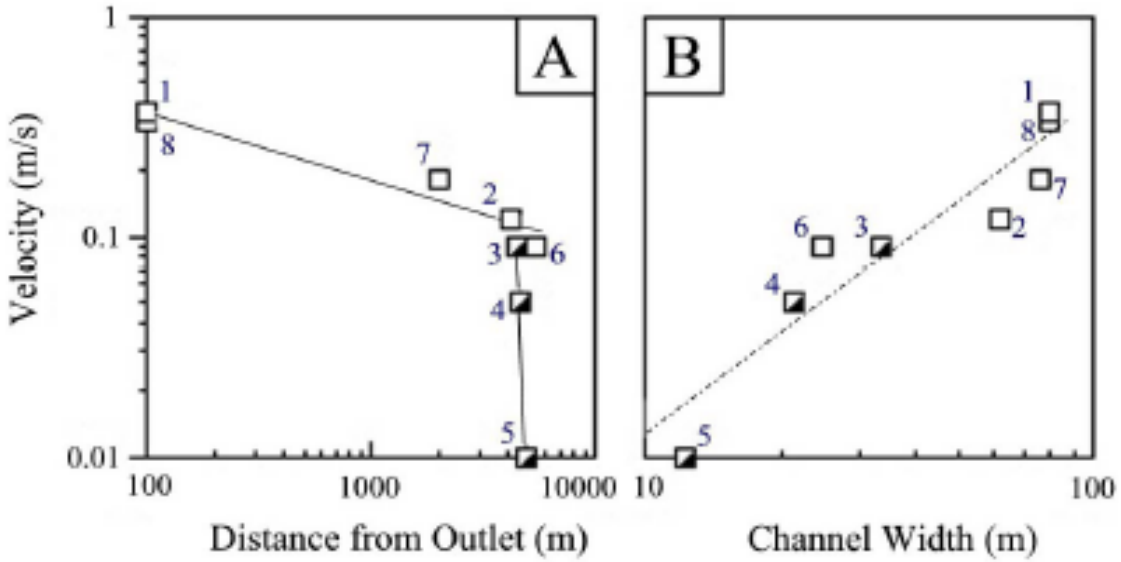
FIGURE 10. Scaling of detrital insect flotsam density (g wet wt/m^2 slough surface area) with slough size (perimeter) for 1993 (○) and 1995 (■) sampling periods.

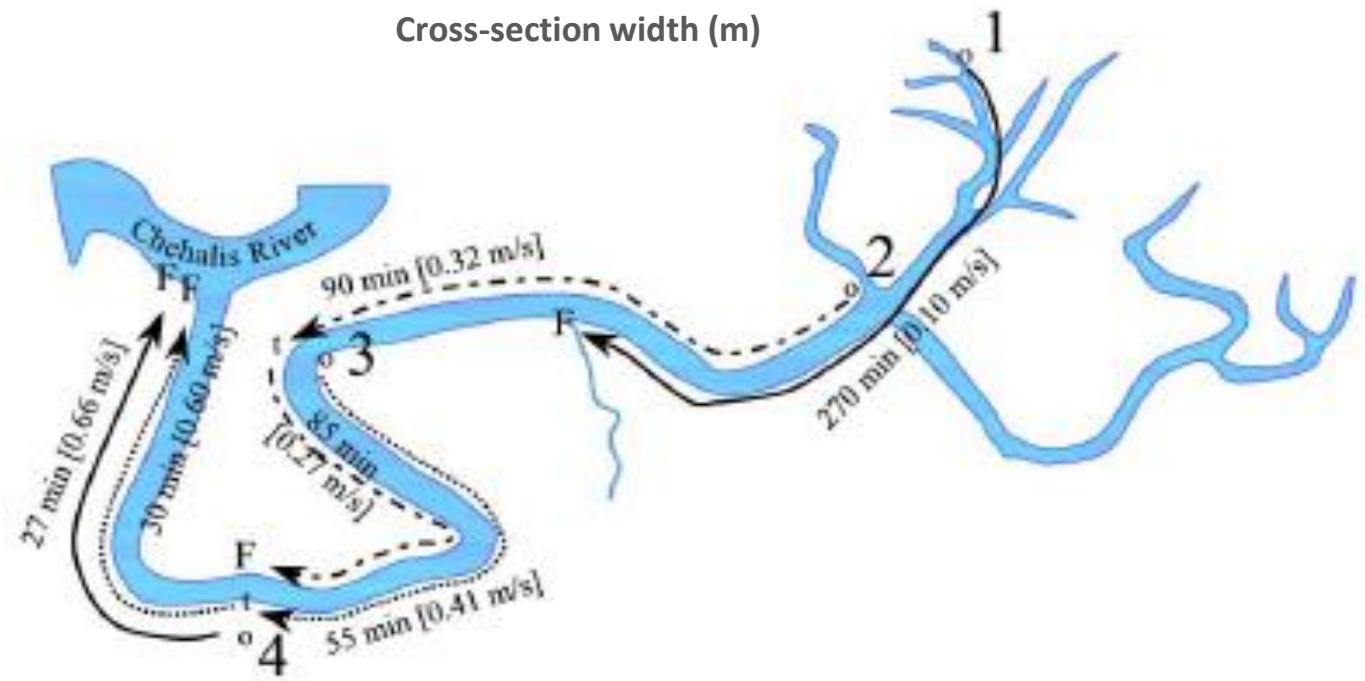
Chehalis Estuary



Skagit Delta







Allochthonous detritus moves more slowly in small tidal channels

Allochthonous detritus is more likely to be trapped in smaller channels and in the landward (smaller) reaches of channels

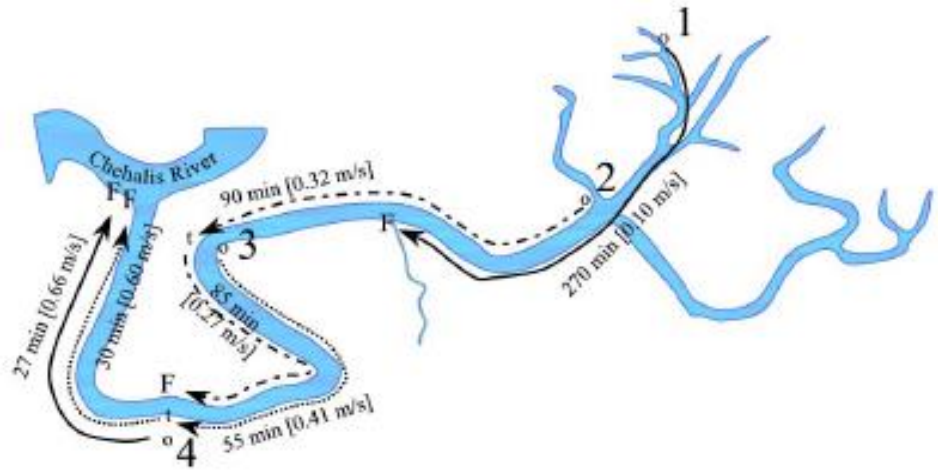
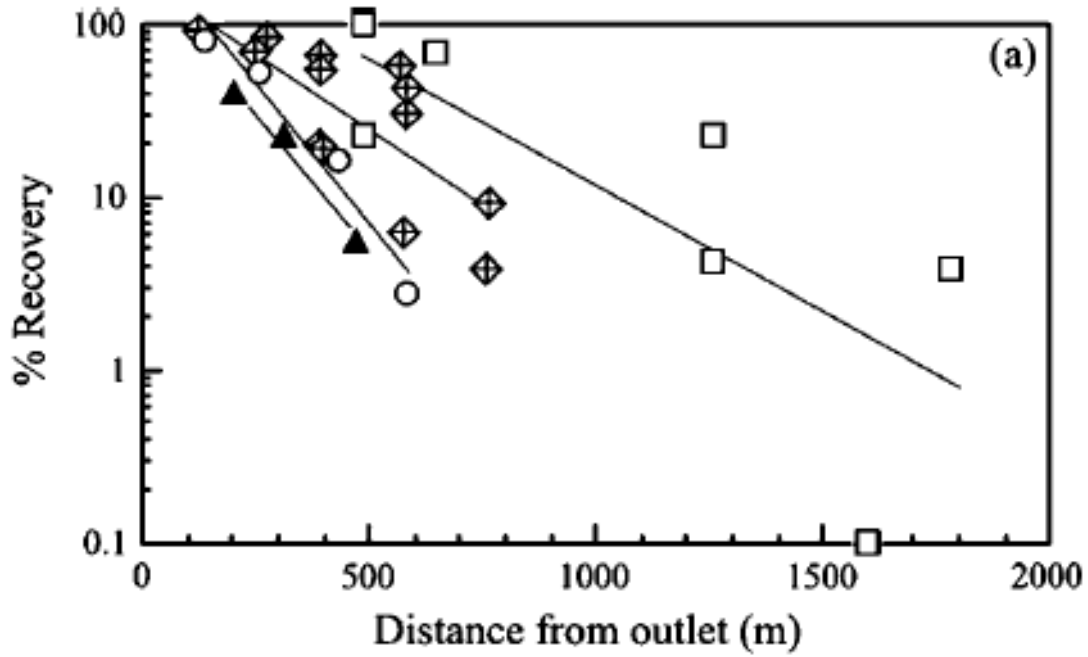
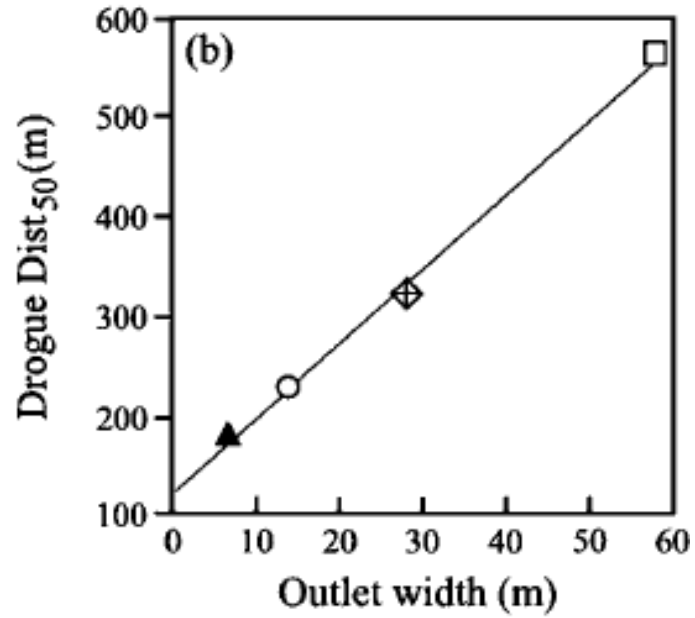
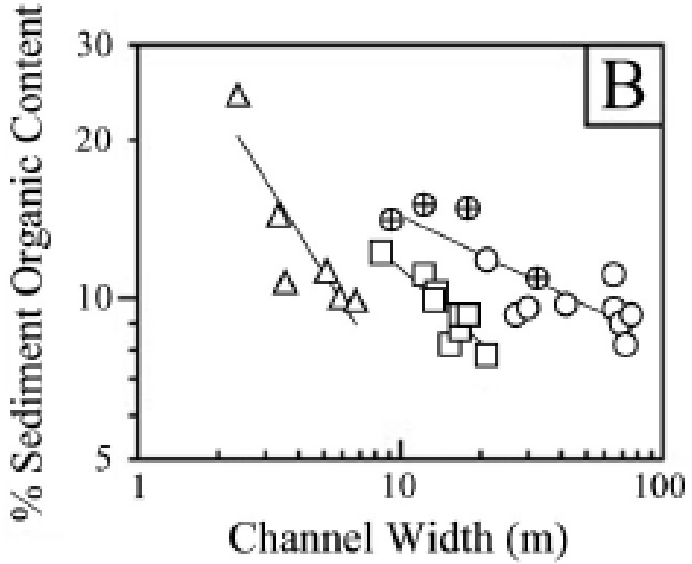


Fig. 5. (*a*) Drogue recovery vs. deployment distance from outlet for Mox Chuck (□, $y = 332e^{-0.003x}$, $r^2 = 0.59$, $F_{1,5} = 7.1$, $p < 0.05$), Ann's Sl. (⊕, $y = 186e^{-0.004x}$, $r^2 = 0.57$, $F_{1,11} = 14.7$, $p < 0.005$), Fairweather Sl. (○, $y = 284e^{-0.008x}$, $r^2 = 0.96$, $F_{1,2} = 42.8$, $p < 0.05$), and Tiny Sl. (▲, $y = 188e^{-0.007x}$, $r^2 = 0.99$, $F_{1,1} = 88.8$, $p < 0.07$). (*b*) Distance from outlet where drogues had 50% probability of export ($Dist_{50}$) vs. slough size ($y = 7.4x + 129$, $r^2 = 0.99$, $F_{1,2} = 731$, $p < 0.005$).

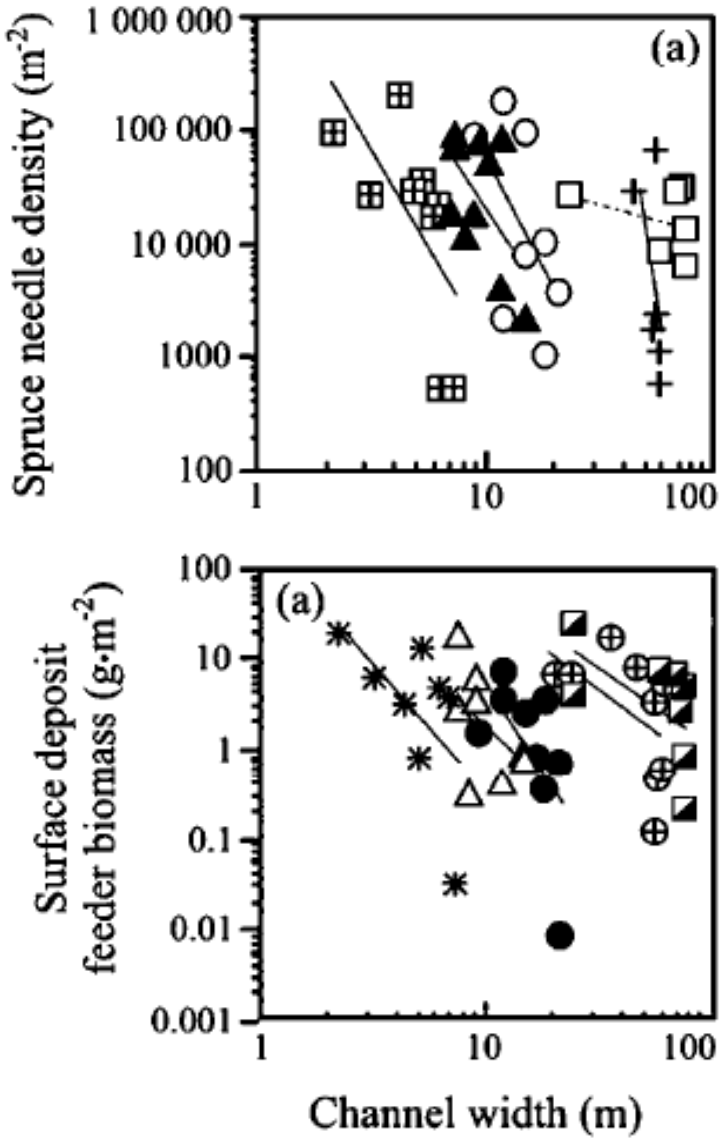




Sediments of smaller channels and in the landward (smaller) reaches of channels have higher content of trapped allochthonous detritus (organic Carbon) and more benthic surface deposit feeders.



Small channels are important too.
Don't take them for granted.



Current and future challenges

Sea level rise, warming, flood hydrograph changes

Research

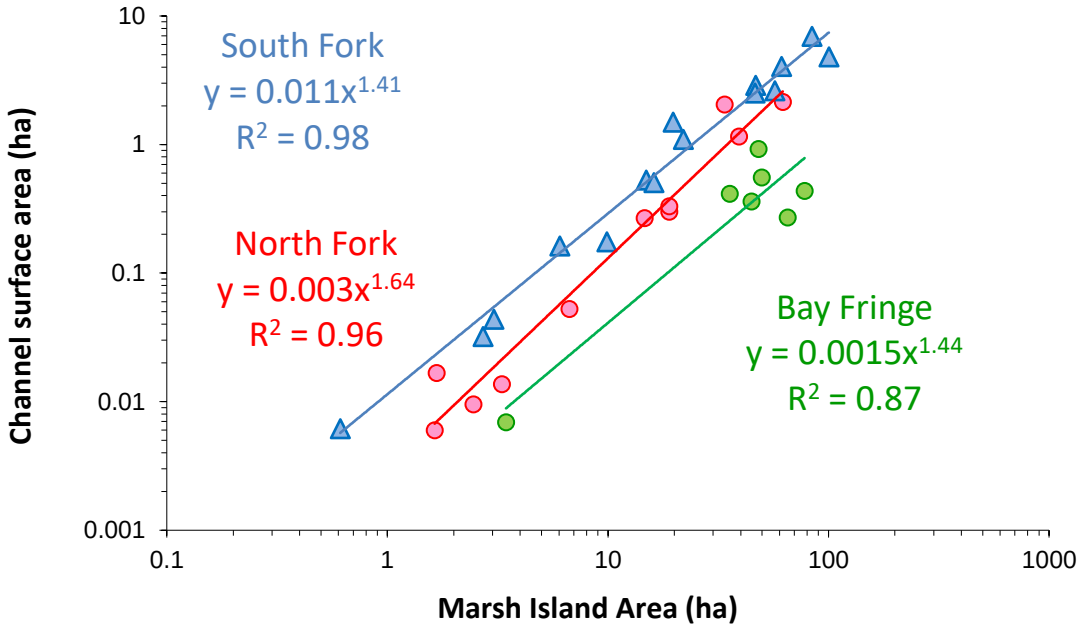
Linkage of fish to channel geometry for better design
Tidal beaver natural history
Large wood eco-geomorphological role
Improved predictive models

Monitoring

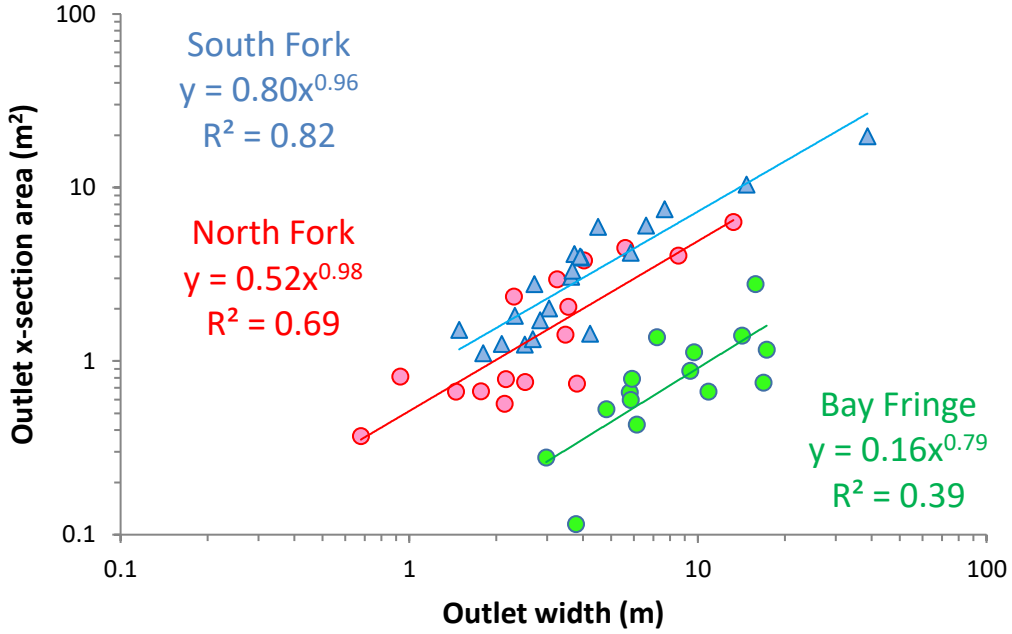
Better quantifying restoration trajectories
Time lags from restoration to salmon response
Learning to speed up recovery rates
Test hypotheses/models (not just compliance)

Engineering innovations?

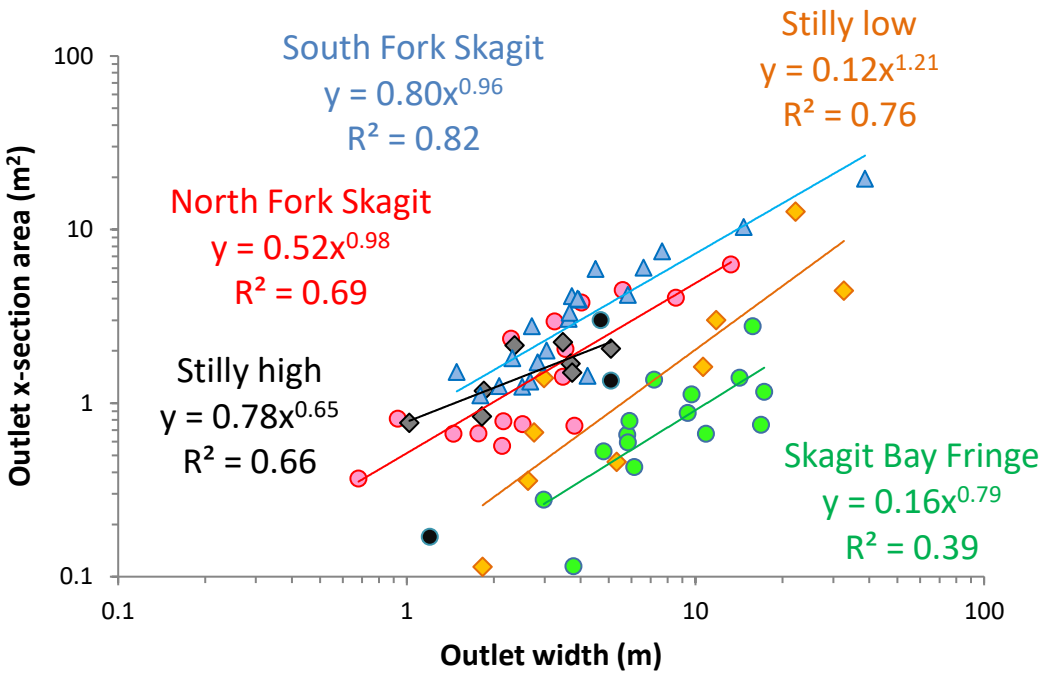
Vegetation mounds to dispose of sediments on site?
Large wood engineering without understanding its role?
Sediment supplementation for subsidence, SLR?
BDAs to engineer tidal water depths without understanding impacts?

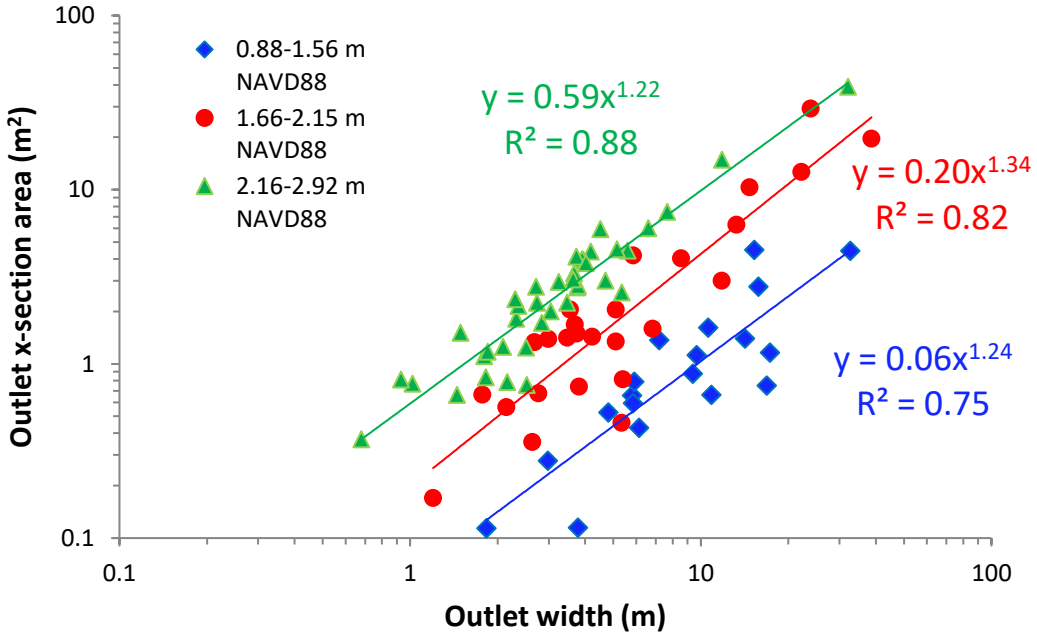


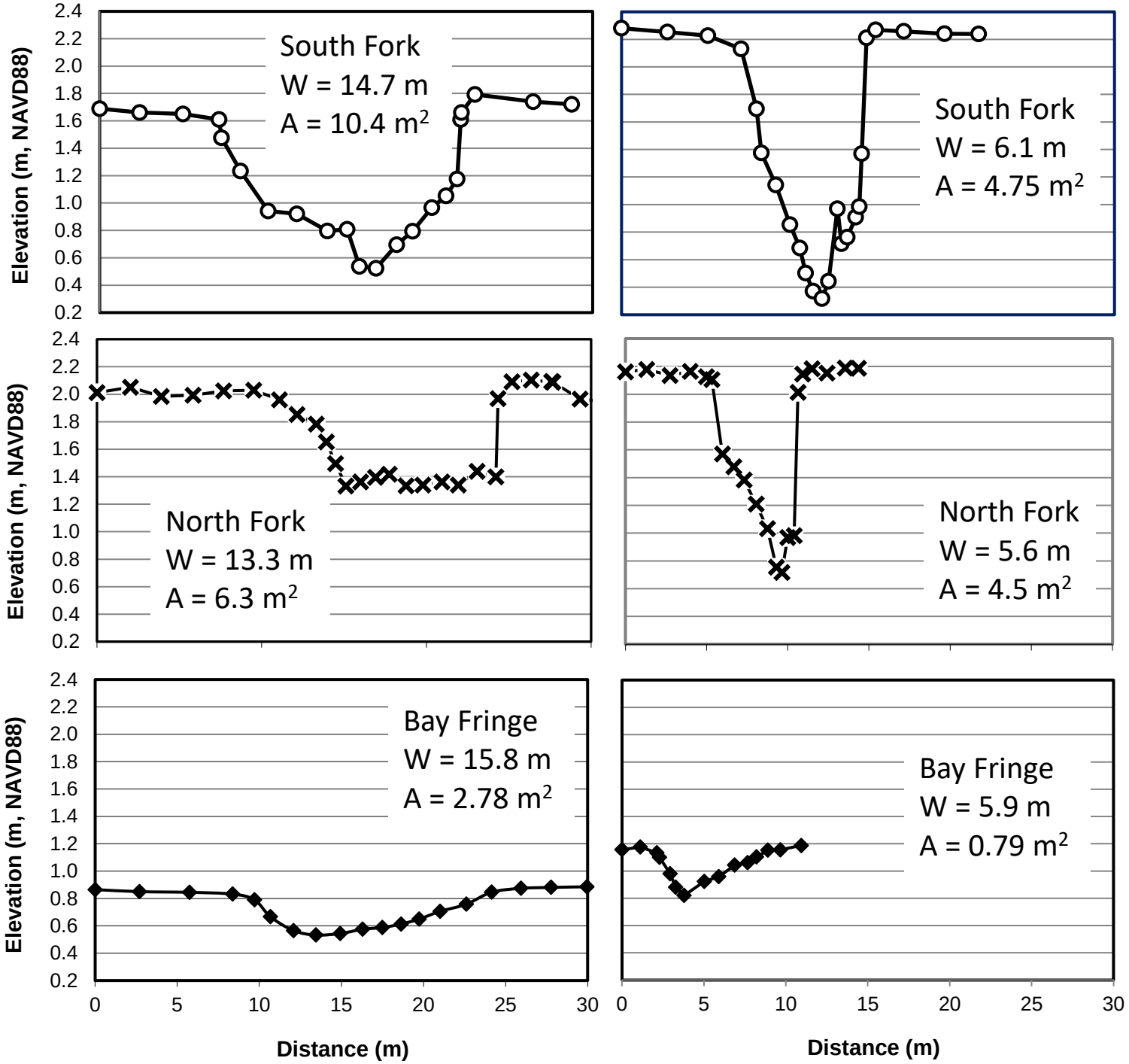
Planform geometry

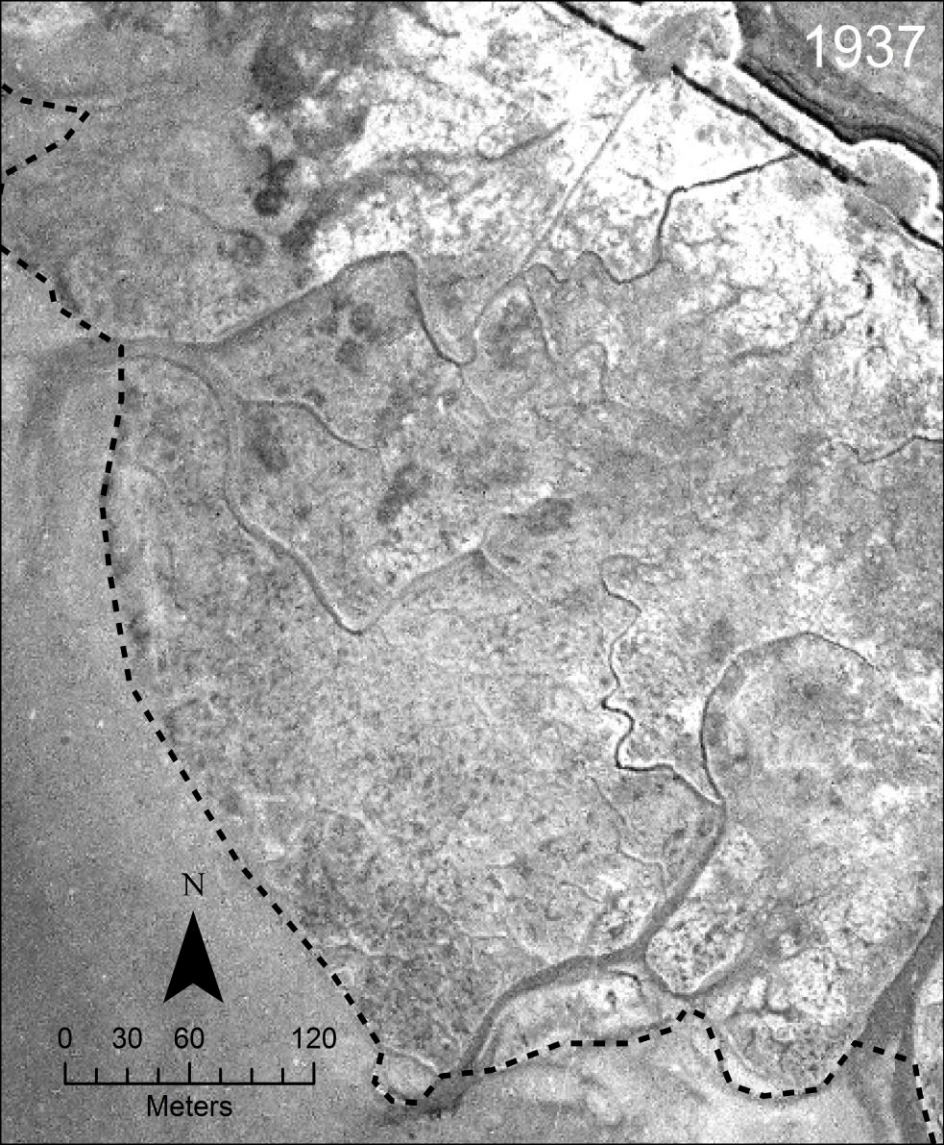


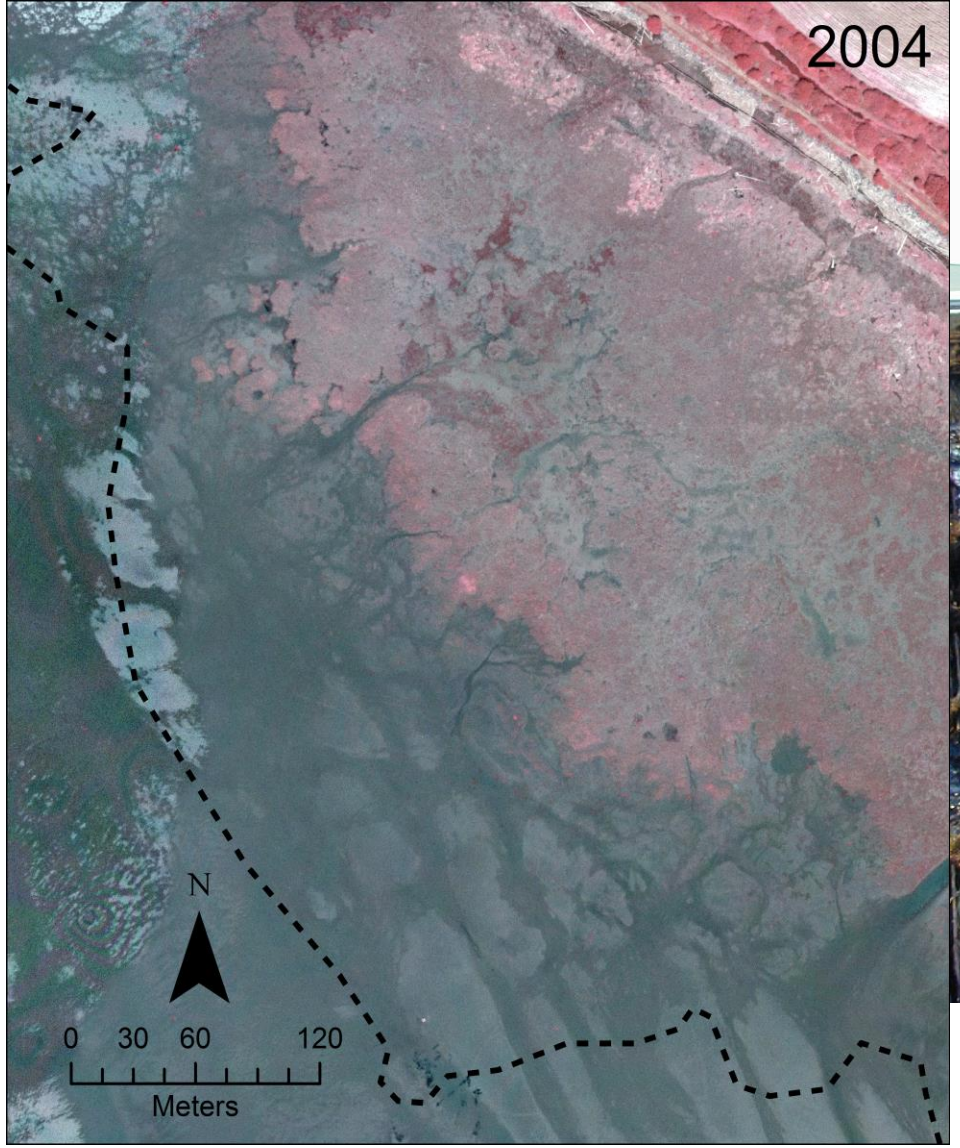
Cross-section geometry


South Fork Skagit
y = 0.80x^0.96
R² = 0.82
Stilly low
y = 0.12x^1.21
R² = 0.76
North Fork Skagit
y = 0.52x^0.98
R² = 0.69
Stilly high
y = 0.78x^0.65
R² = 0.66
Skagit Bay Fringe
y = 0.16x^0.79
R² = 0.39
Outlet x-section area (m²)
Outlet width (m)
100
10
1
0.1
0.1
1
10
100


0.88-1.56 m NAVD88
1.66-2.15 m NAVD88
2.16-2.92 m NAVD88
y = 0.59x^1.22
R² = 0.88
y = 0.20x^1.34
R² = 0.82
y = 0.06x^1.24
R² = 0.75
Outlet x-section area (m²)
Outlet width (m)
100
10
1
0.1
0.1
1
10
100

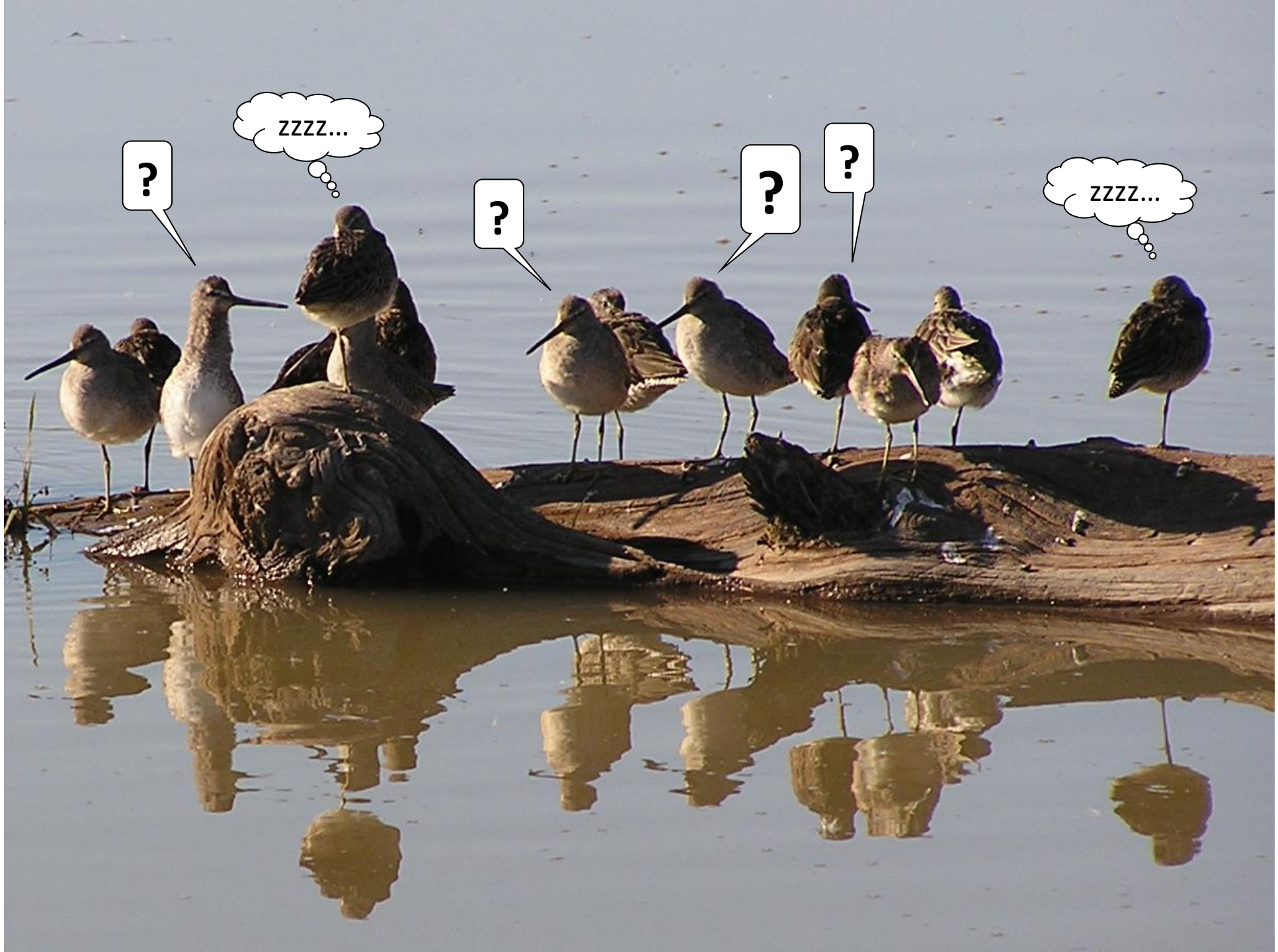

South Fork
W = 14.7 m
A = 10.4 m²
South Fork
W = 6.1 m
A = 4.75 m²
North Fork
W = 13.3 m
A = 6.3 m²
North Fork
W = 5.6 m
A = 4.5 m²
Bay Fringe
W = 15.8 m
A = 2.78 m²
Bay Fringe
W = 5.9 m
A = 0.79 m²
Elevation (m, NAVD88)
Distance (m)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
0
5
10
15
20
25
30





Erosion of high marsh in bay fringe of Skagit Delta → lower SCPU marsh → loss of tidal channels

Analogous to SLR, uncompensated by accretion → loss of tidal channels (repartitioned prism)


?
zzzz...
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?
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zzzz...