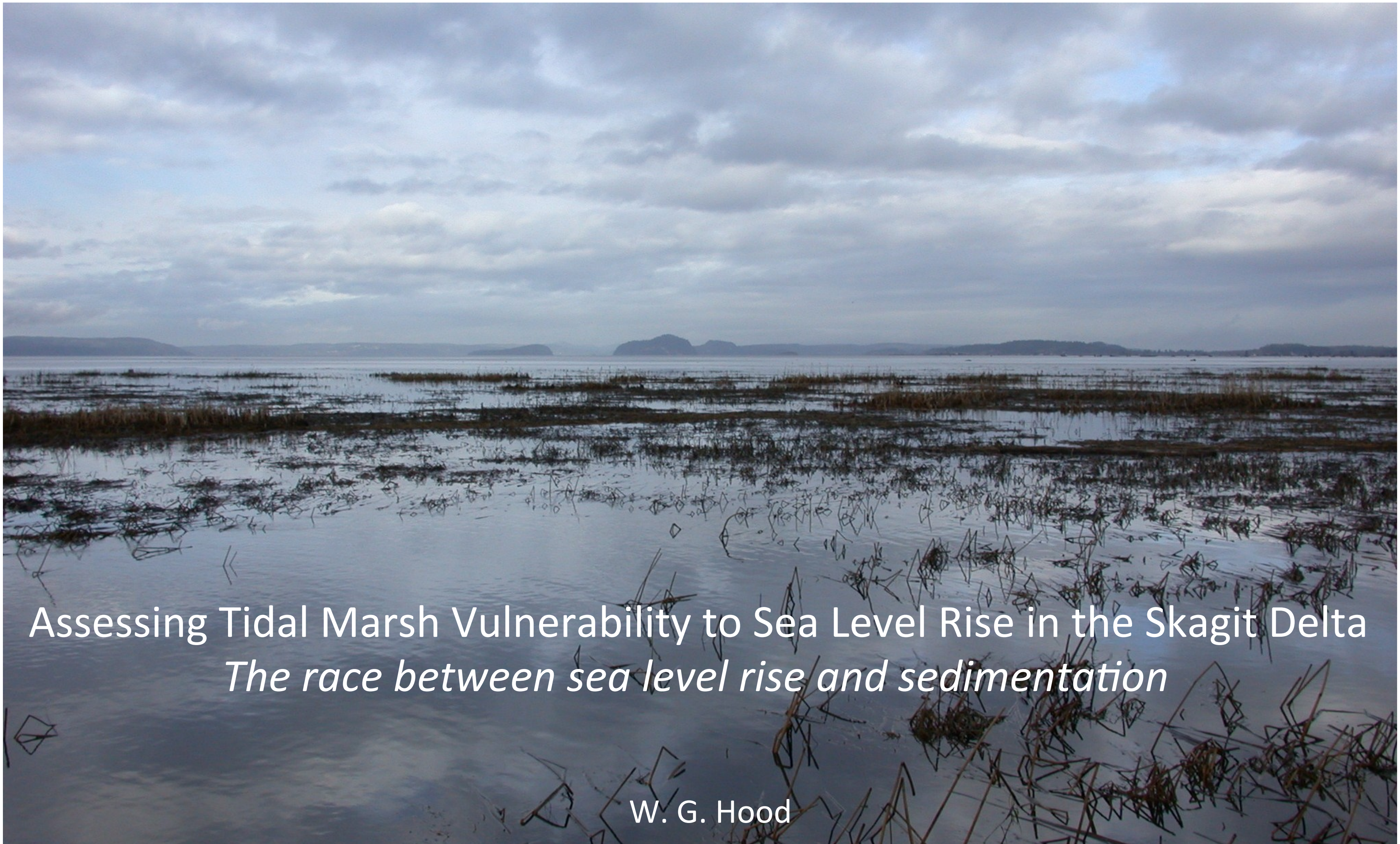


Assessing Tidal Marsh Vulnerability to Sea Level Rise in the Skagit Delta

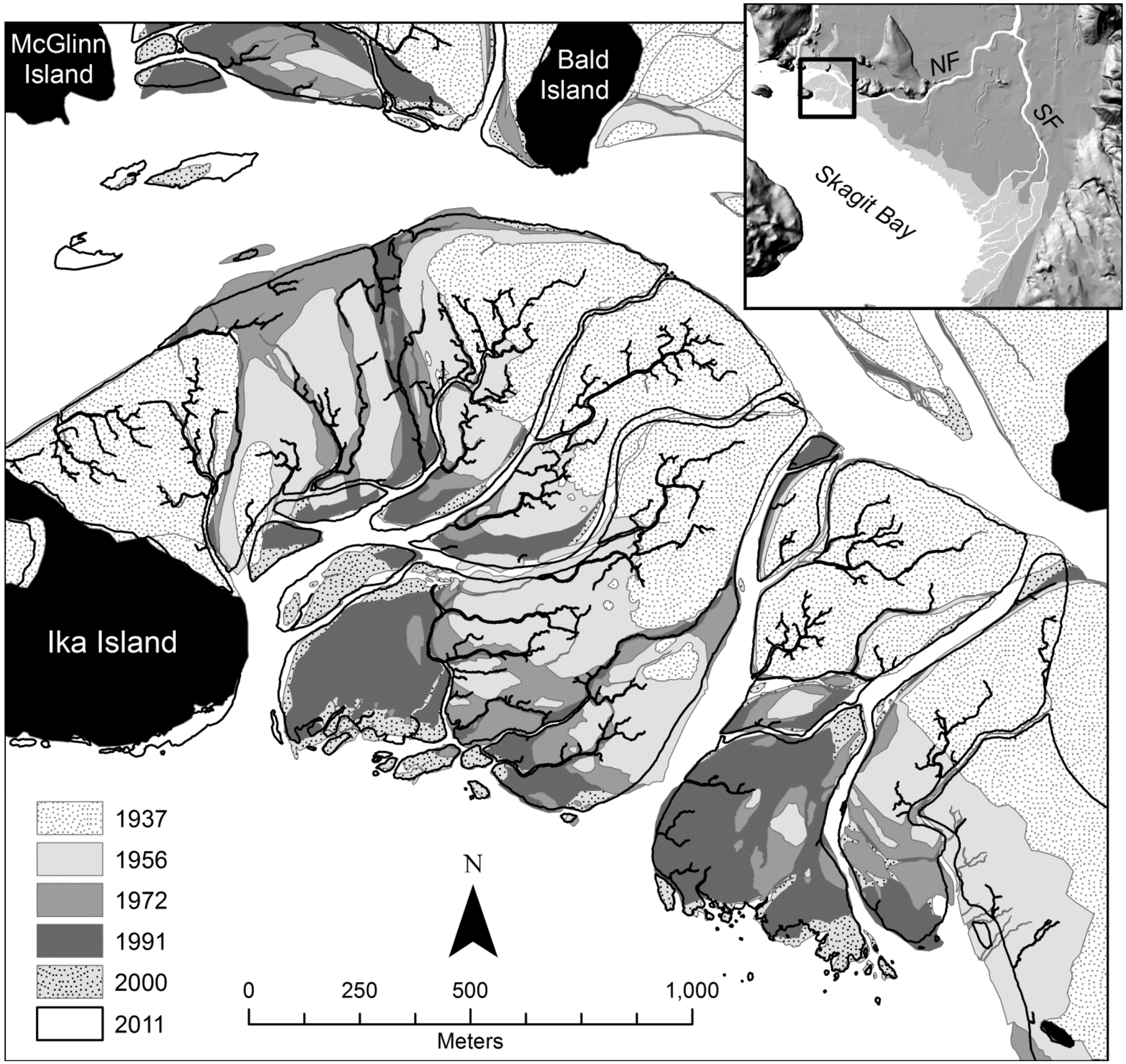
The race between sea level rise and sedimentation

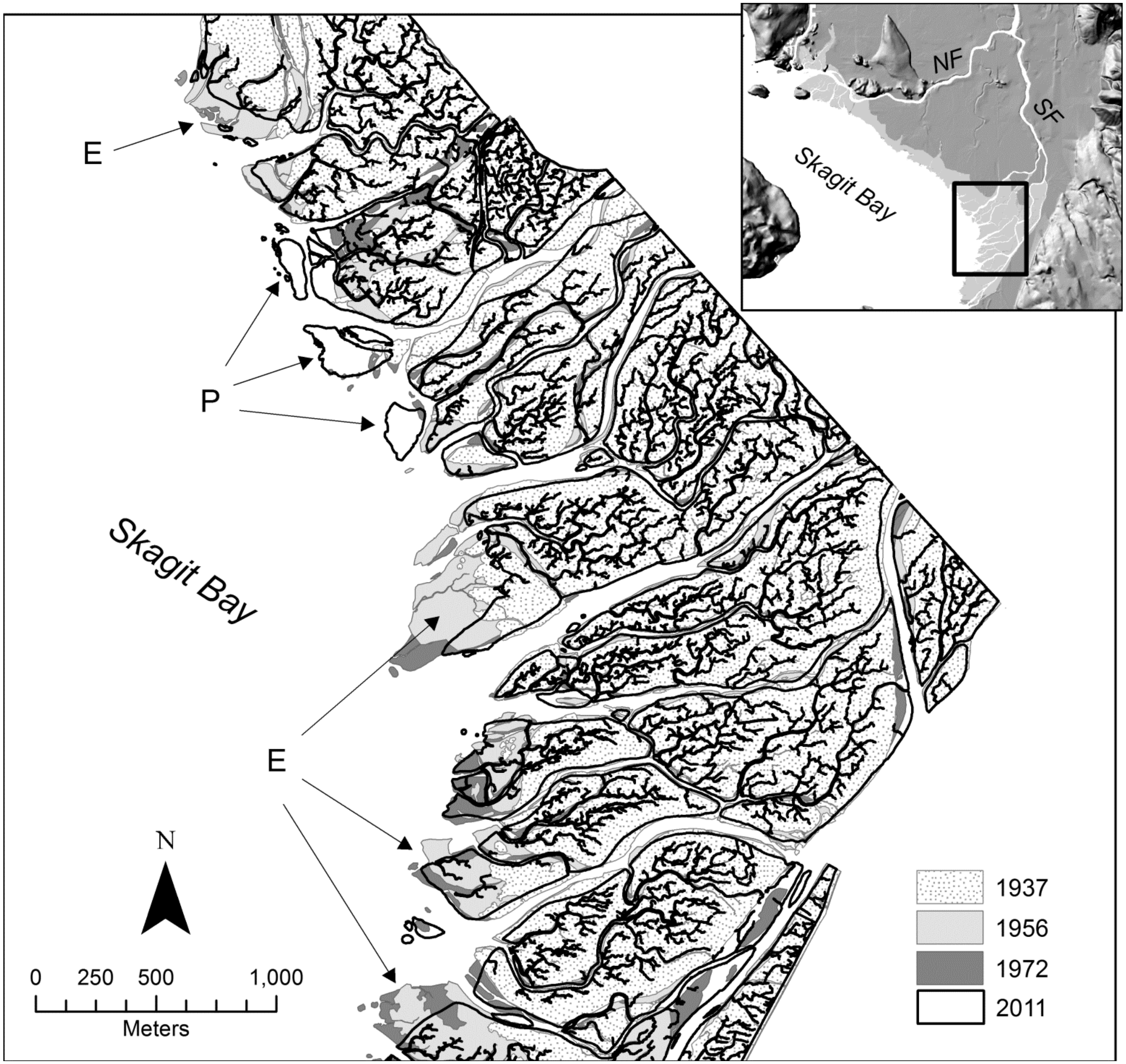
W. G. Hood

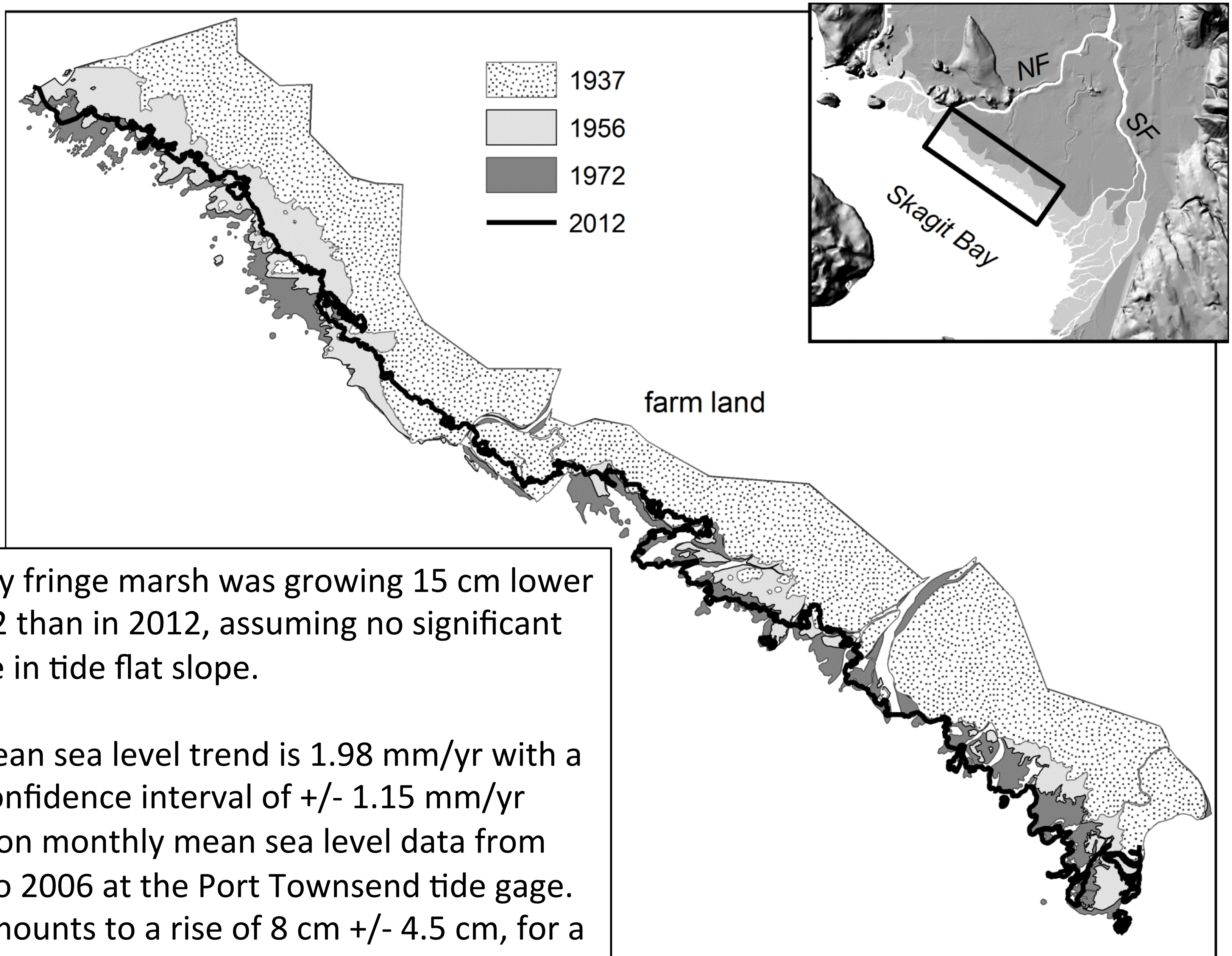
SKAGIT CLIMATE SCIENCE CONSORTIUM

17 October 2012 Workshop

Historical Observations in the active Skagit Delta

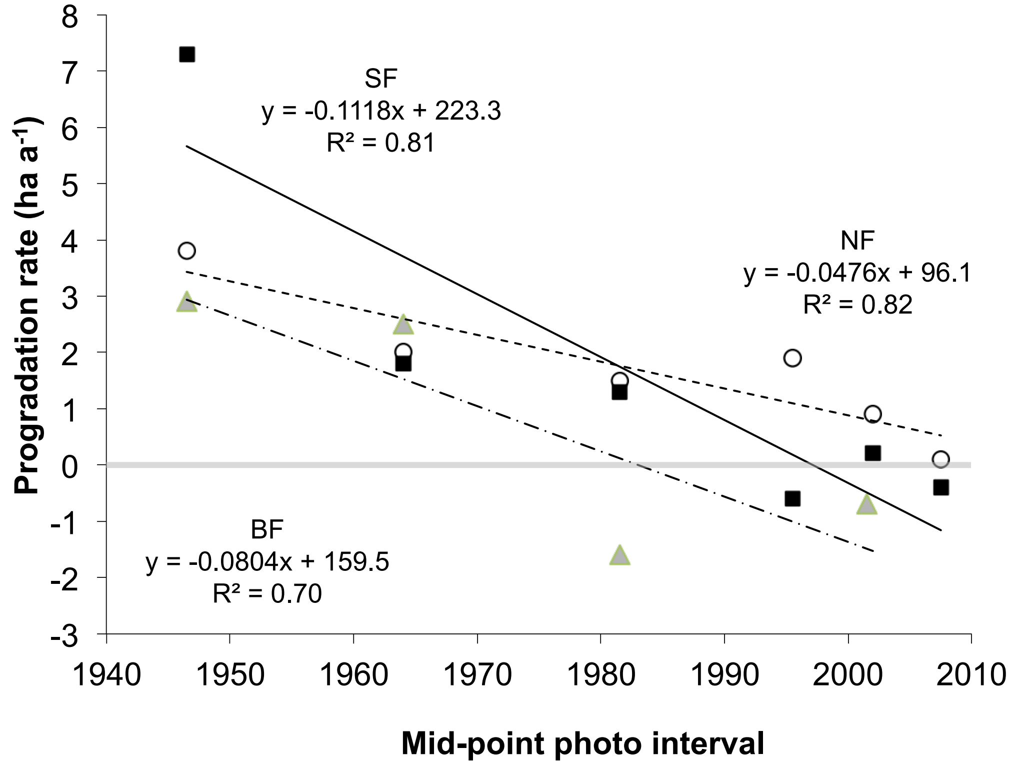

McGlinn Island
Bald Island
Ika Island
NF
SF
Skagit Bay
1937
1956
1972
1991
2000
2011
N
0
250
500
1,000
Meters


NF
SF
Skagit Bay
E
P
Skagit Bay
E
N
0 250 500 1,000
Meters
1937
1956
1972
2011



The bay fringe marsh was growing 15 cm lower in 1972 than in 2012, assuming no significant change in tide flat slope.

The mean sea level trend is 1.98 mm/yr with a 95% confidence interval of +/- 1.15 mm/yr based on monthly mean sea level data from 1972 to 2006 at the Port Townsend tide gage. This amounts to a rise of 8 cm +/- 4.5 cm, for a possible rise of up to 12.5 cm.



	Marsh area lost (ha) 2012 to 2100	Marsh area in 2012 (ha)	% loss (2012 to 2100)	Adjusted total loss (ha)
North Fork	238	420	56.7%	238
South Fork	559	1176	47.5%	559
Bay fringe	402	255	157.6%	255

56.8%

Complication 1: Sediment Supply and Fate

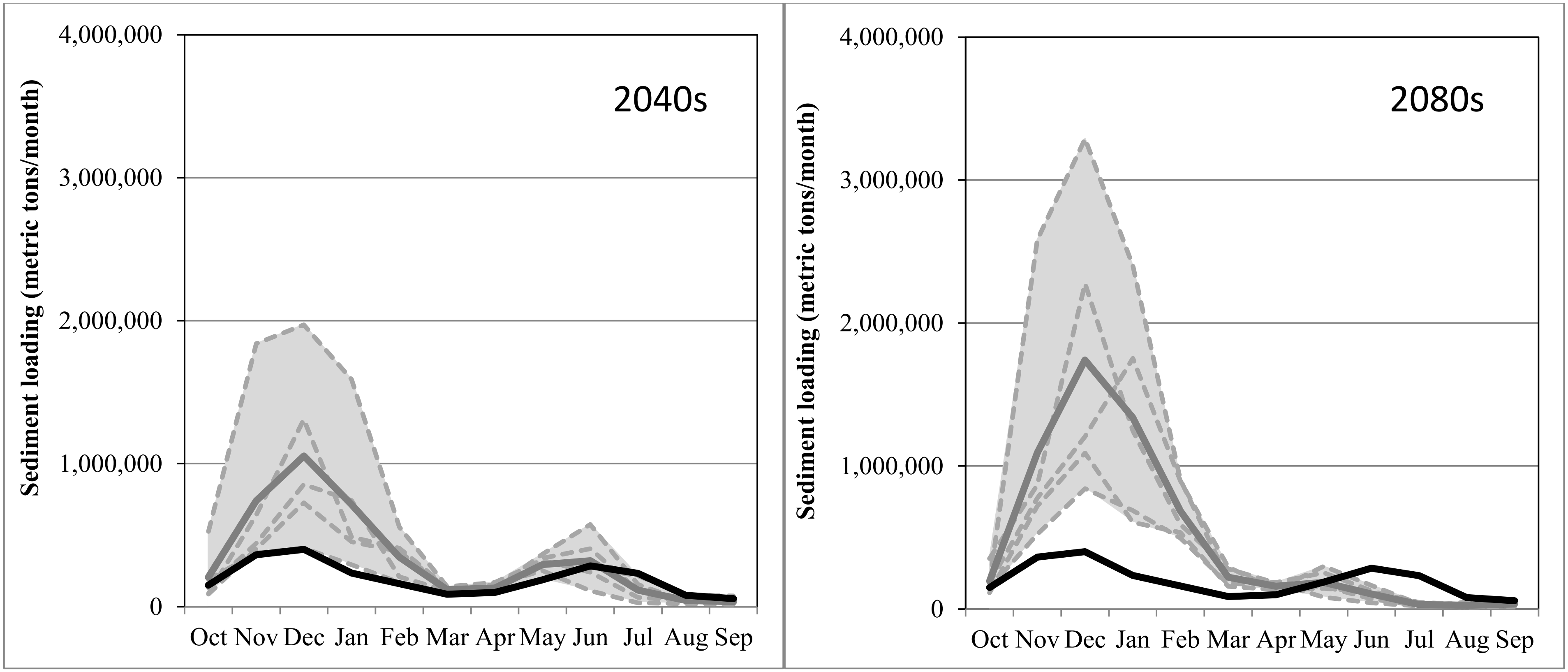
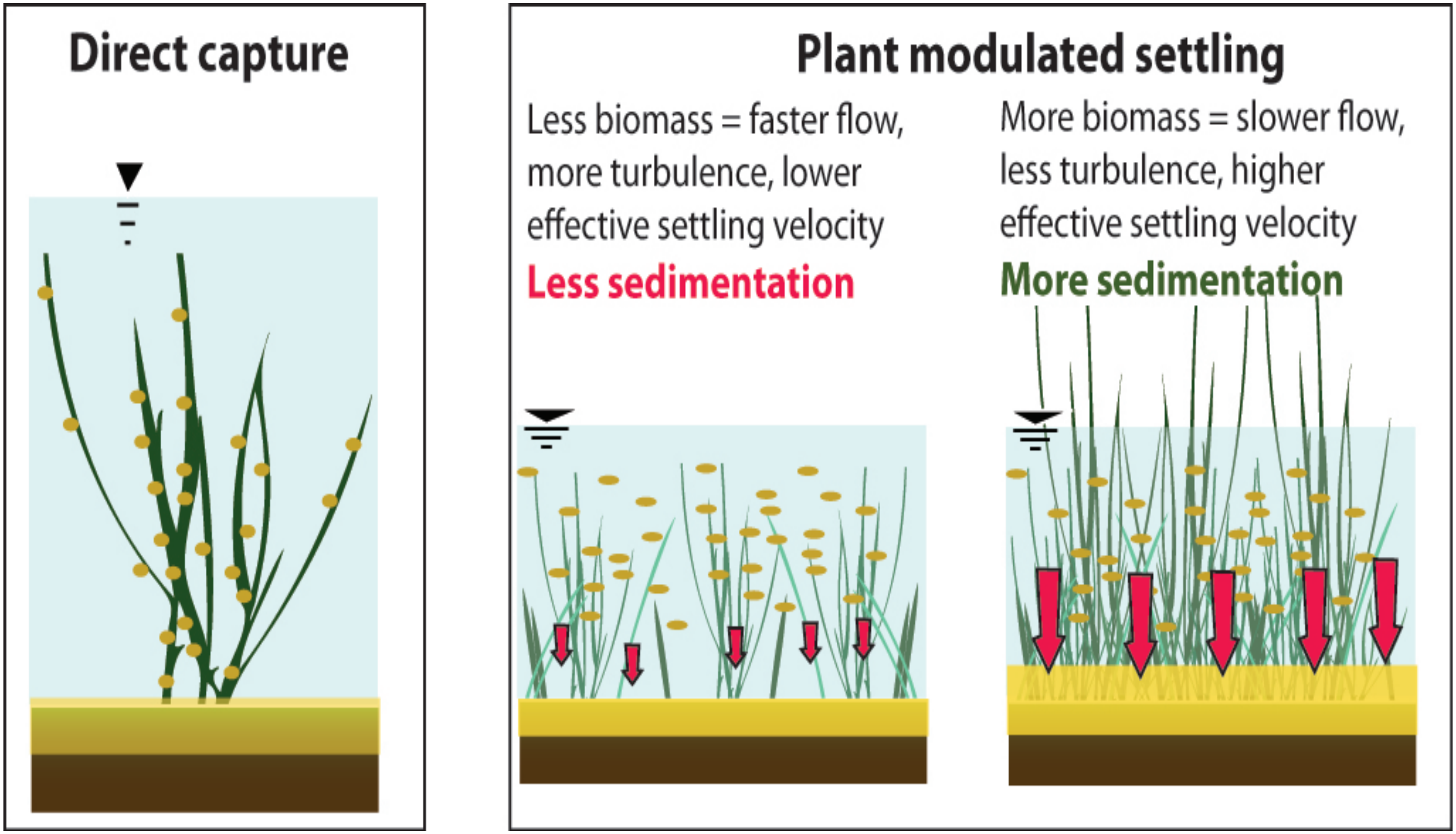


Figure 6. Simulated long-term mean, sediment loading for the Skagit River at Mount Vernon for two future time periods of the 2040s (left panel) and 2080s (right panel). Solid black traces show monthly averages for historical conditions, the gray bands show the range of values from five climate change scenarios, gray dotted lines represent monthly averages from each climate change scenario, and the solid gray lines show the average of the five future ensemble.

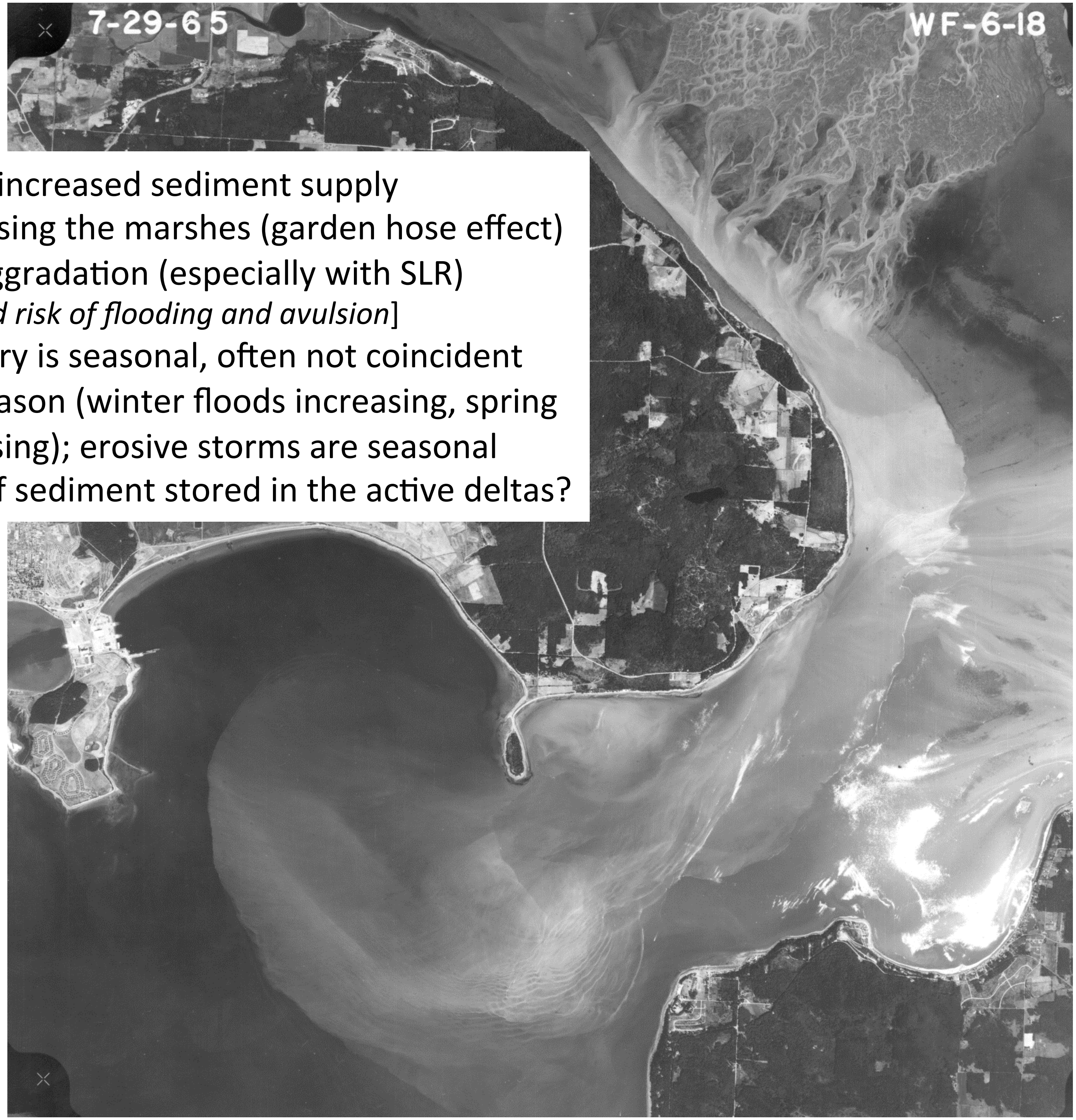
Hamlet et al. 2012



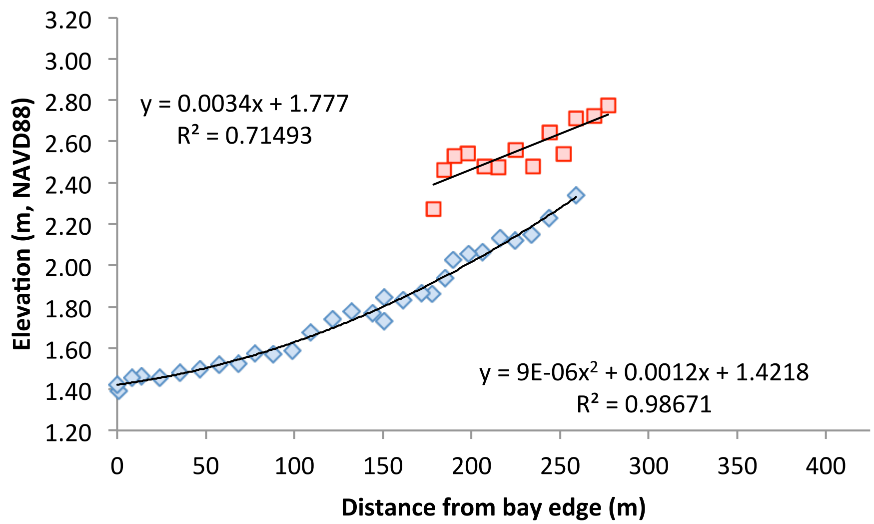
Seasonality: maximal accretion when sediment delivery coincides with the growing season.

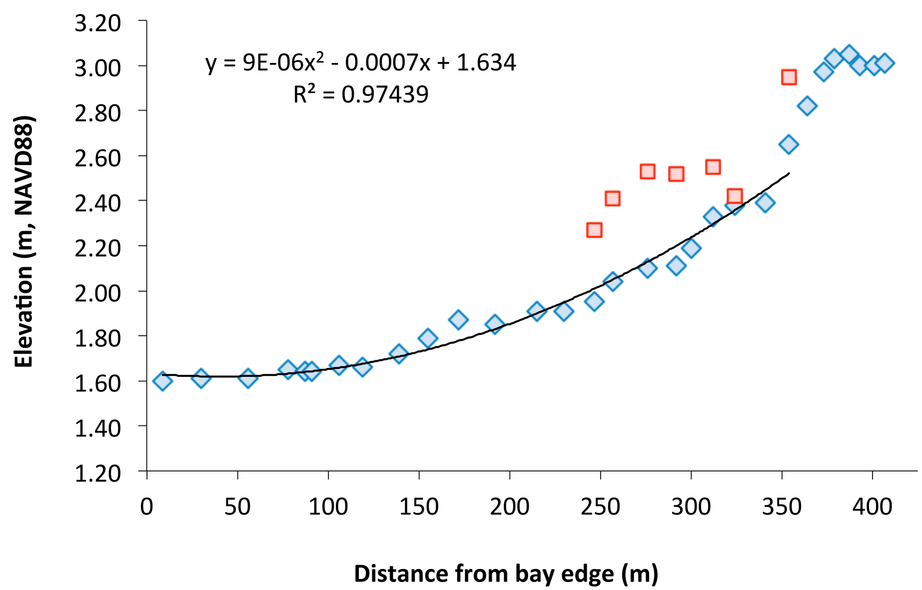
Uncertainty over fate of increased sediment supply

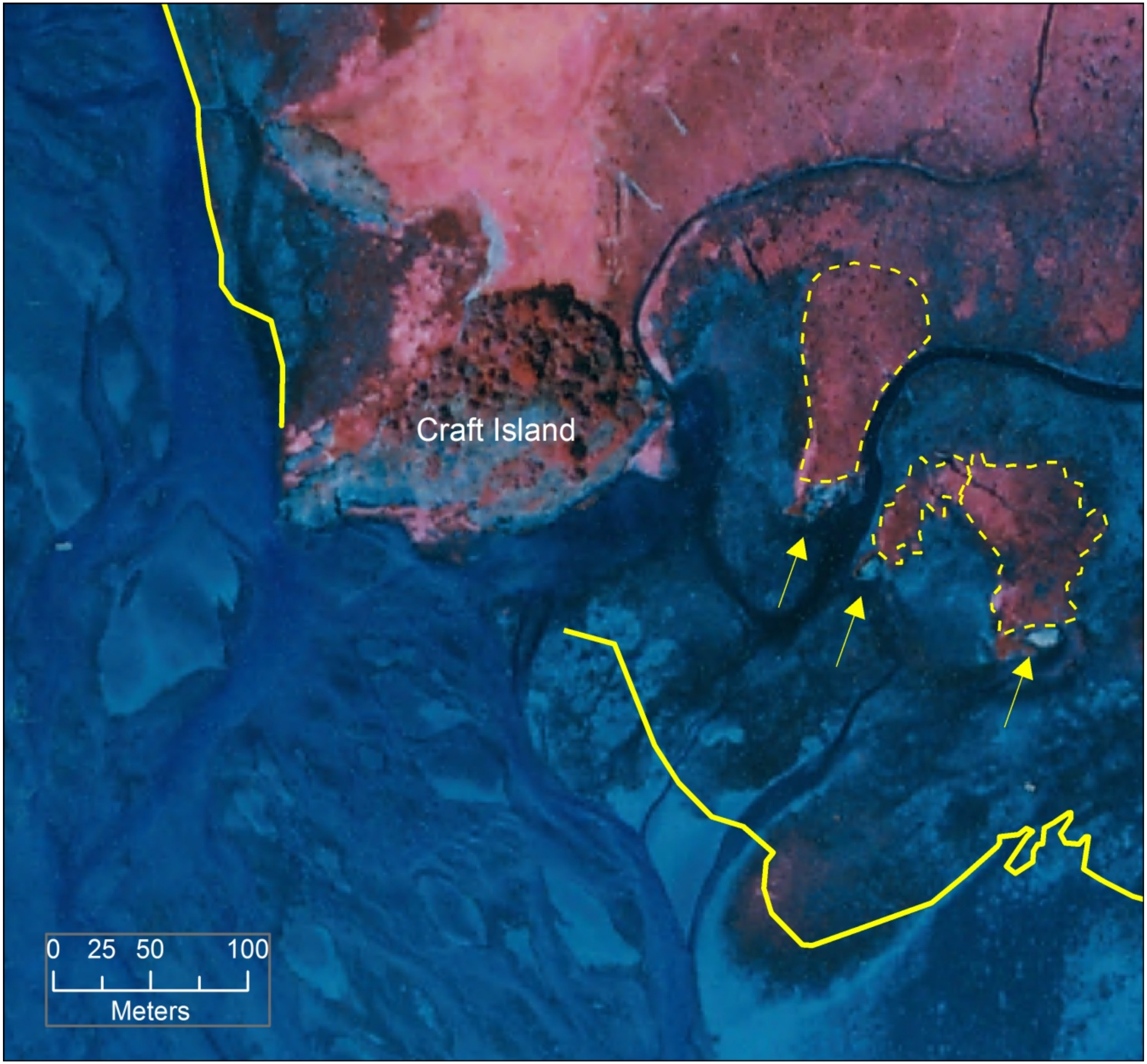
1. Sediment bypassing the marshes (garden hose effect)
2. River channel aggradation (especially with SLR)
   [*leads to increased risk of flooding and avulsion*]
3. Sediment delivery is seasonal, often not coincident with growing season (winter floods increasing, spring freshets decreasing); erosive storms are seasonal
4. Some fraction of sediment stored in the active deltas?

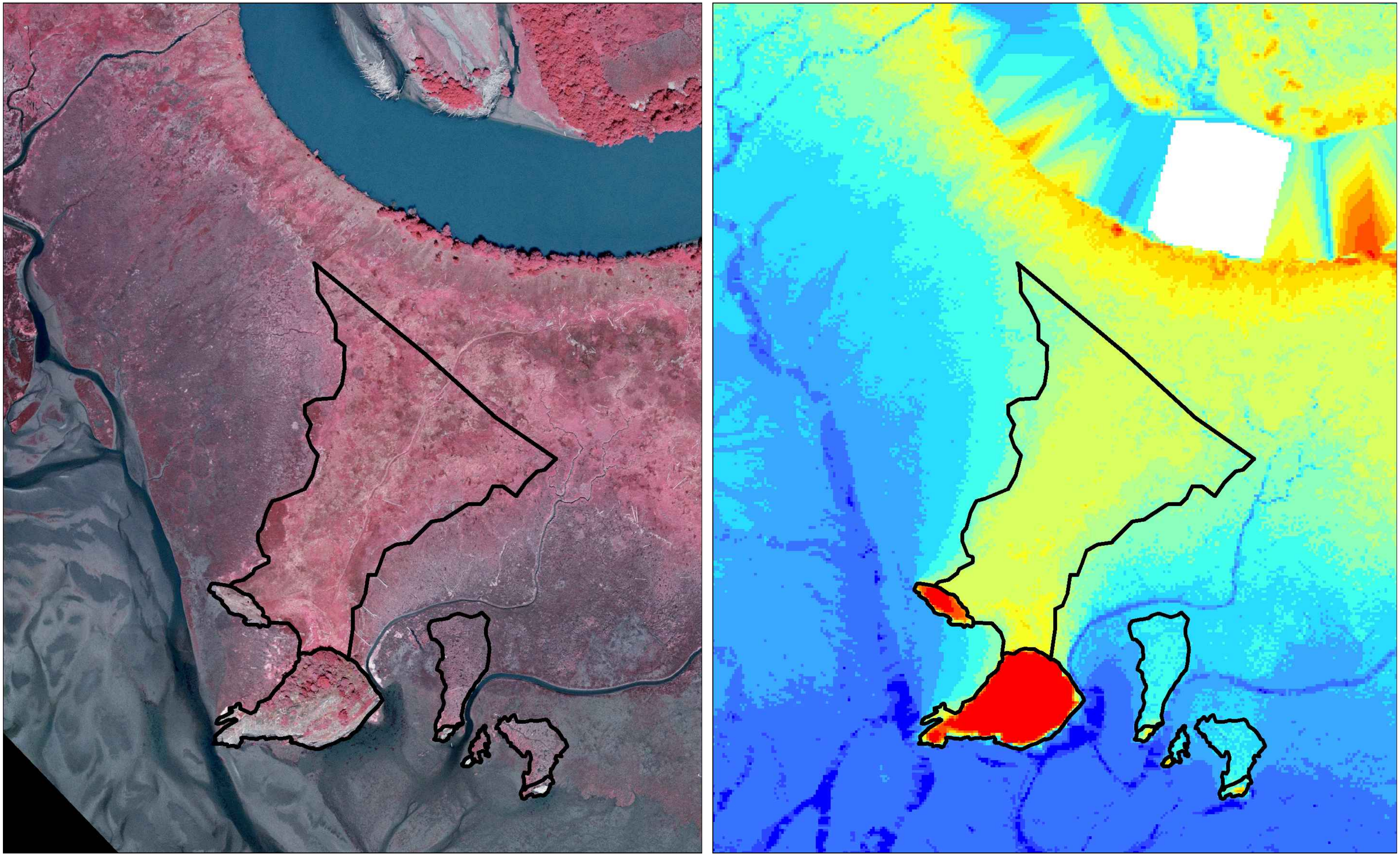


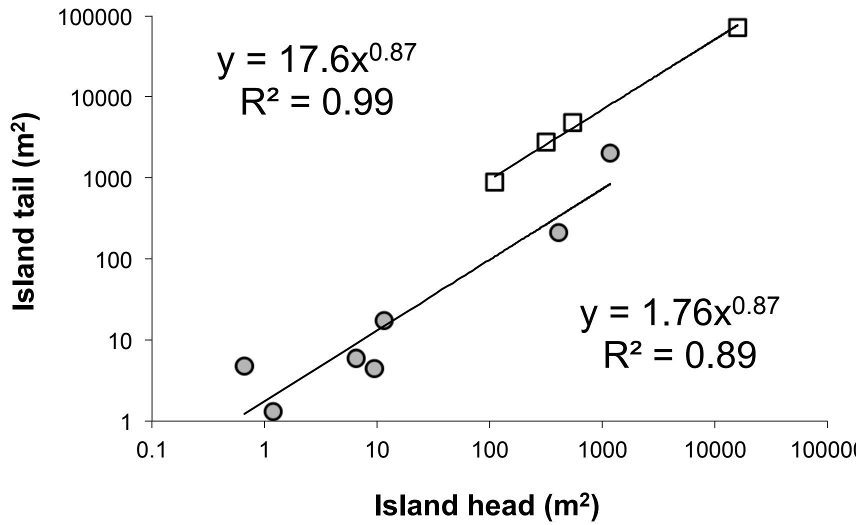
Complication 2: Wave Attack and Erosion


y = 0.0034x + 1.777
R² = 0.71493
y = 9E-06x² + 0.0012x + 1.4218
R² = 0.98671
Elevation (m, NAVD88)
Distance from bay edge (m)
3.20
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
0
50
100
150
200
250
300
350
400


y = 9E-06x² - 0.0007x + 1.634
R² = 0.97439
Elevation (m, NAVD88)
Distance from bay edge (m)
3.20
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
0
50
100
150
200
250
300
350
400


Craft Island
0 25 50 100
Meters

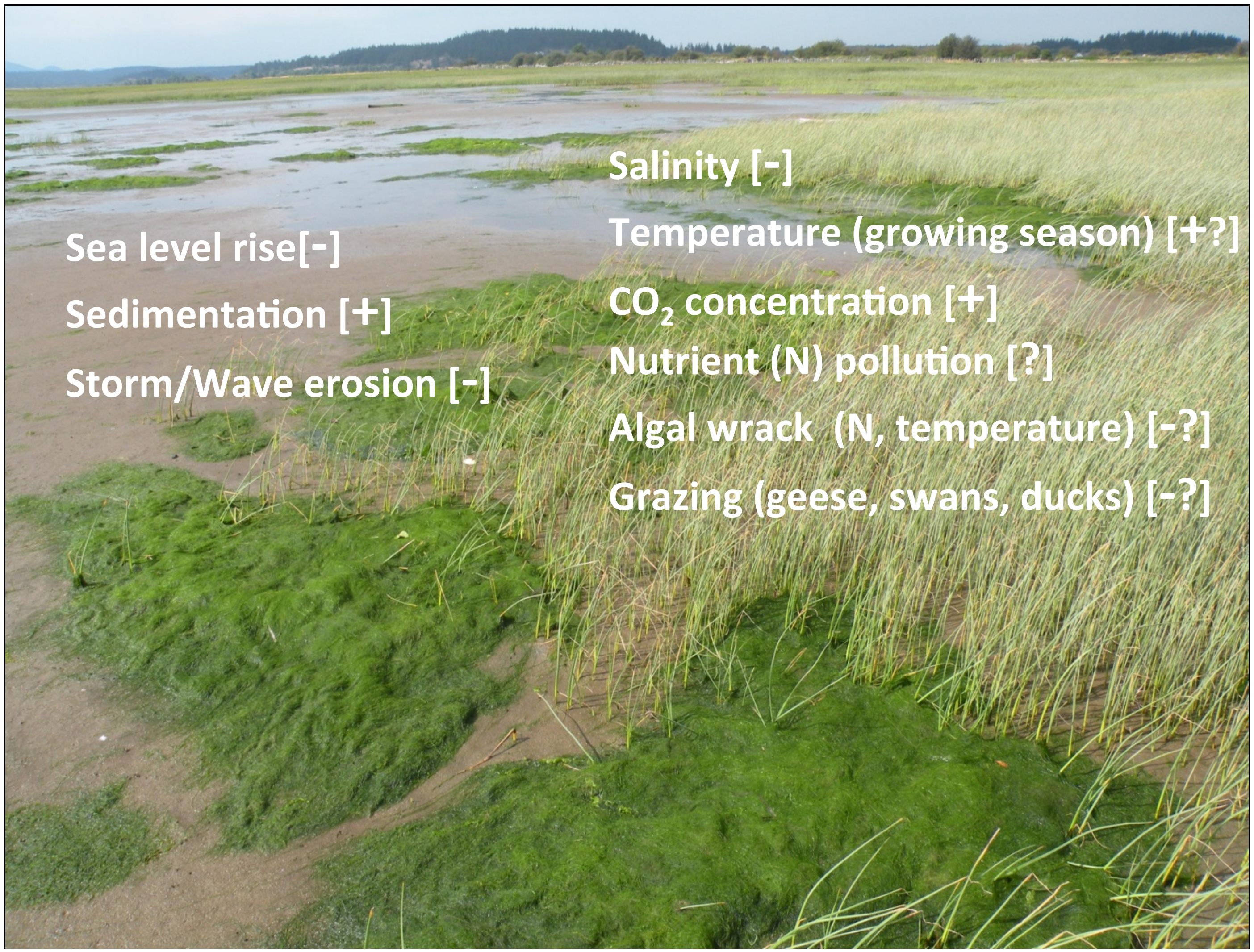




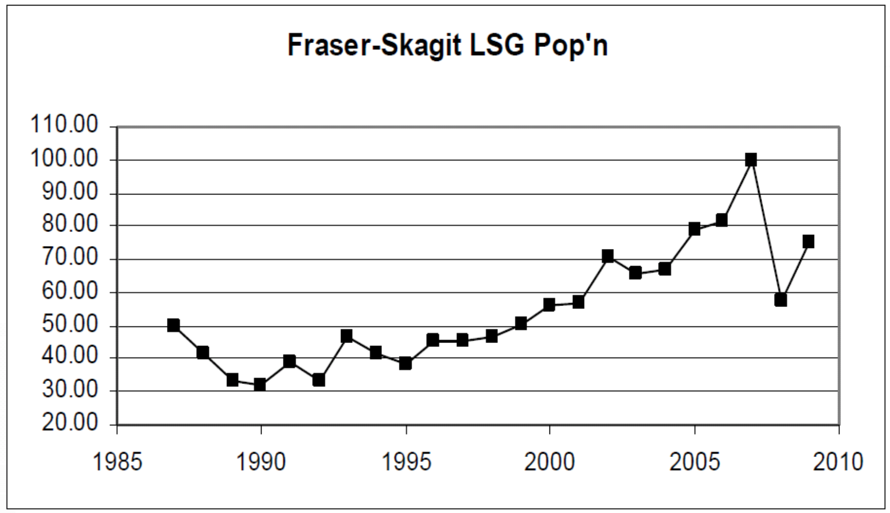
Conclusion: erosion from wave attack plays a role in bay fringe marsh erosion.
Implication: SLR will increase wave height and energy, leading to greater erosion.

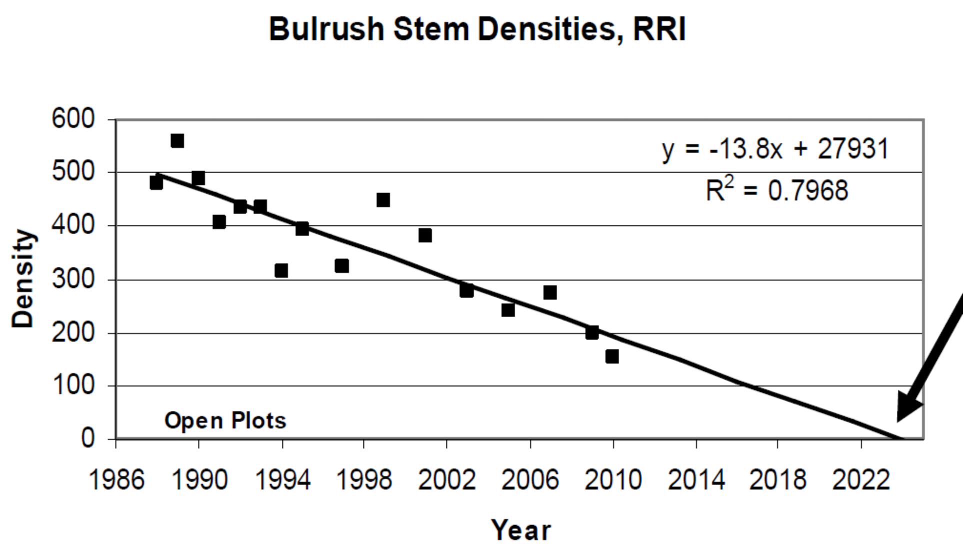
Sea Level Rise and Marsh Vegetation Vulnerability

Additional Complications



Snow geese disturbance (Boyd 2011)

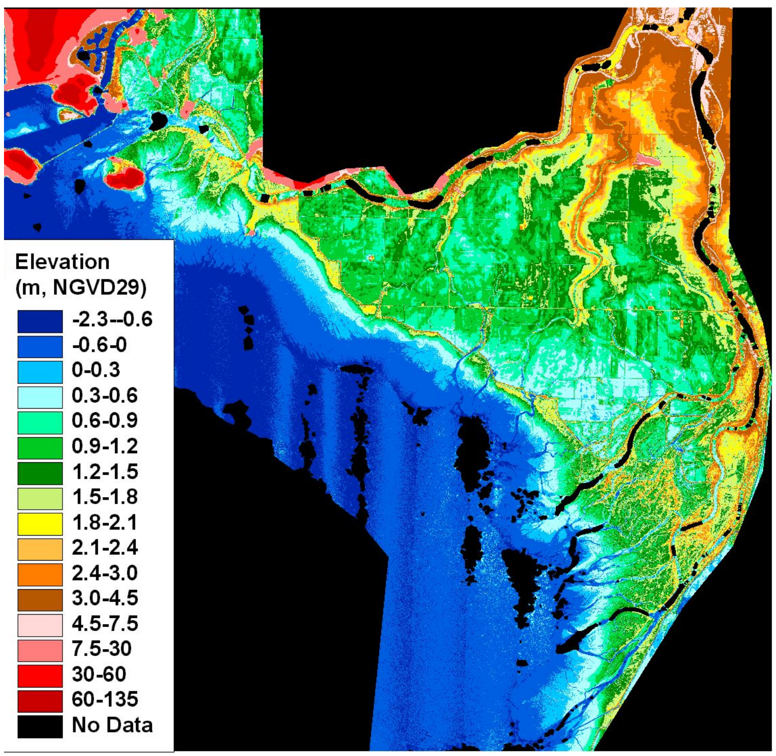


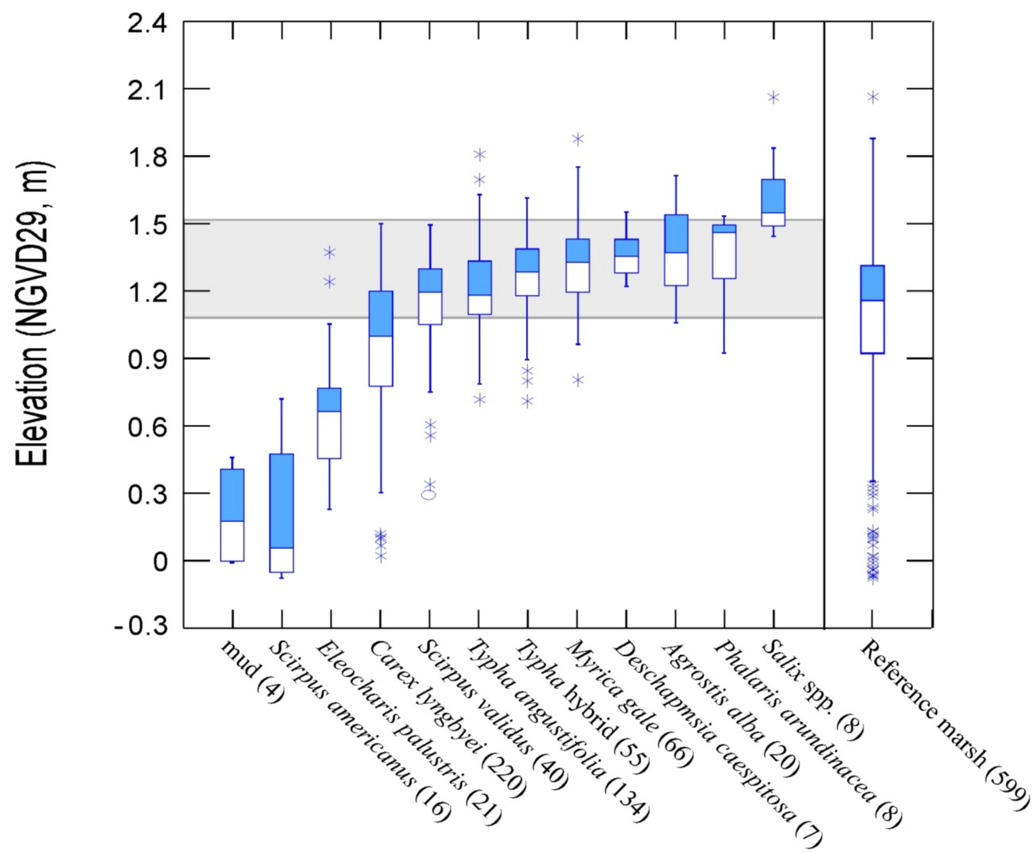


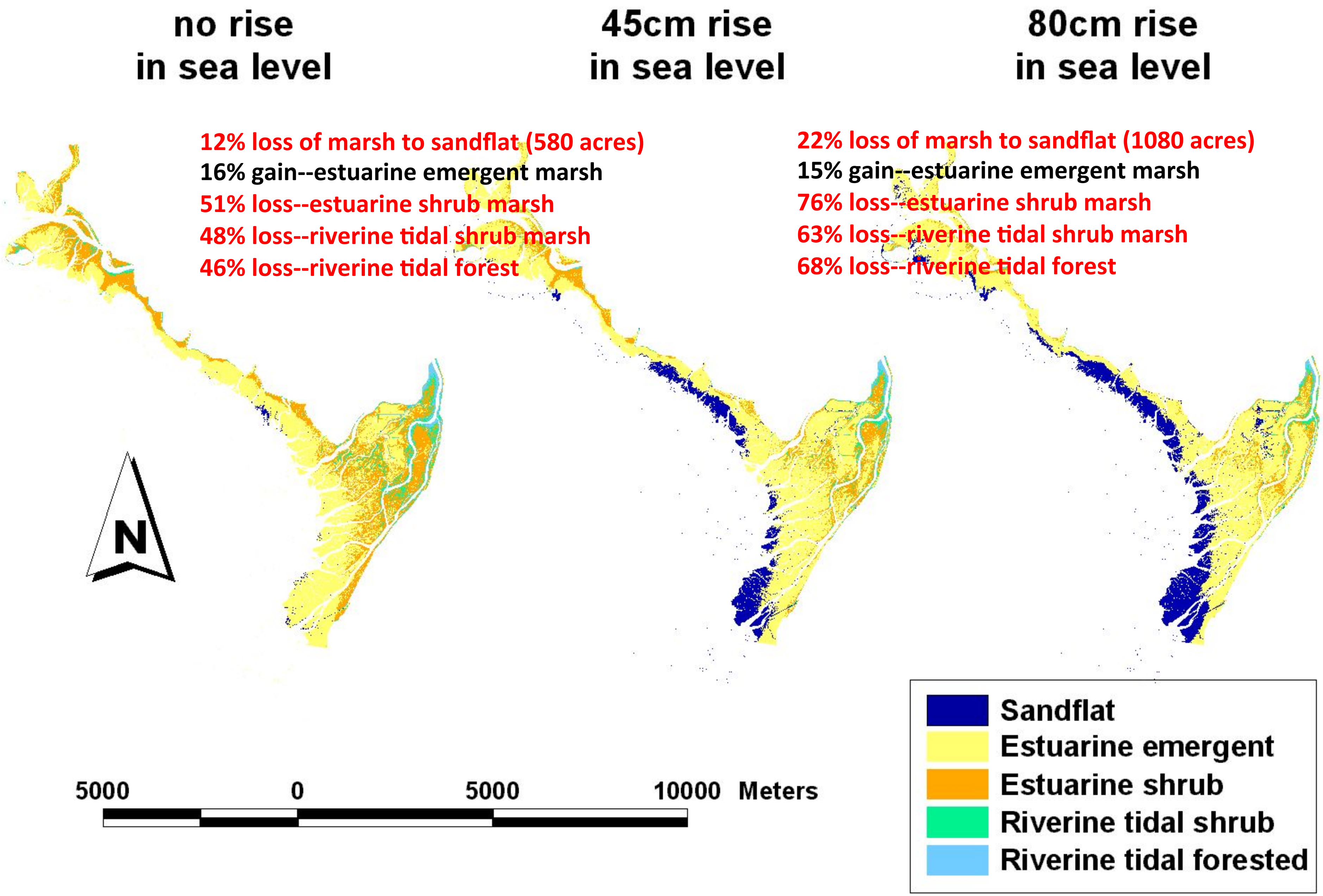
Approach: Ignore complications, *explore* vegetation vulnerability only to SLR. (bathtub model) Save complications for later model elaboration.

Link sea level rise predictions to LIDAR data and to known elevation distributions of vegetation in the tidal marshes of the Skagit delta.

Explore management options to minimize risk to tidal wetlands.

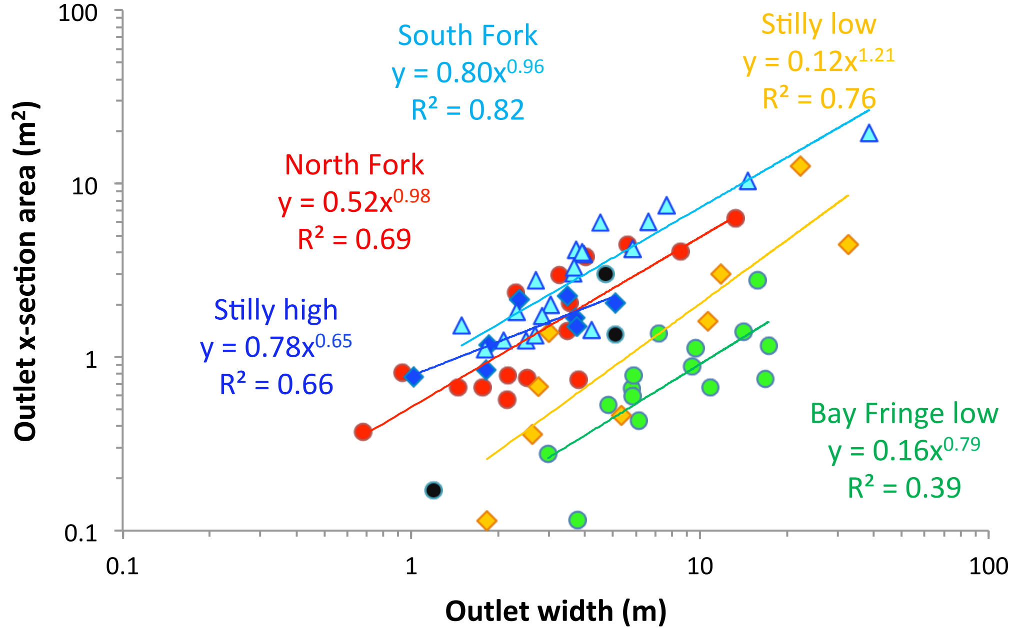


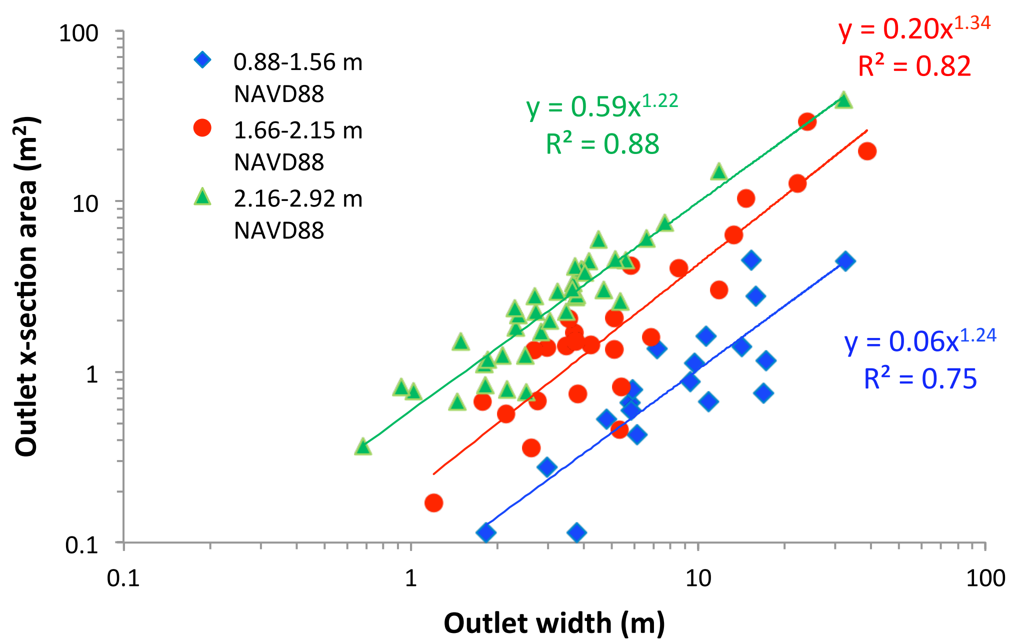


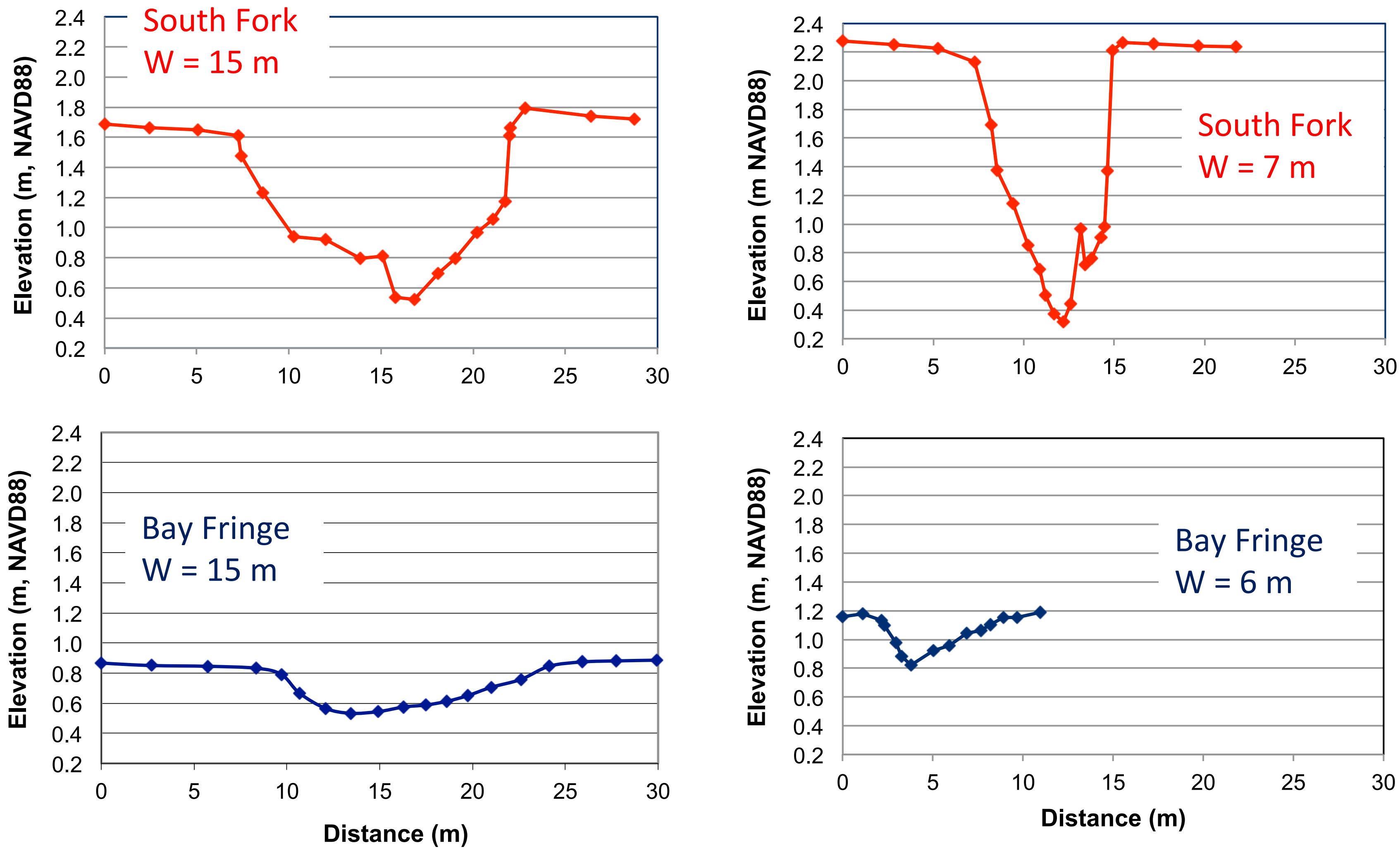


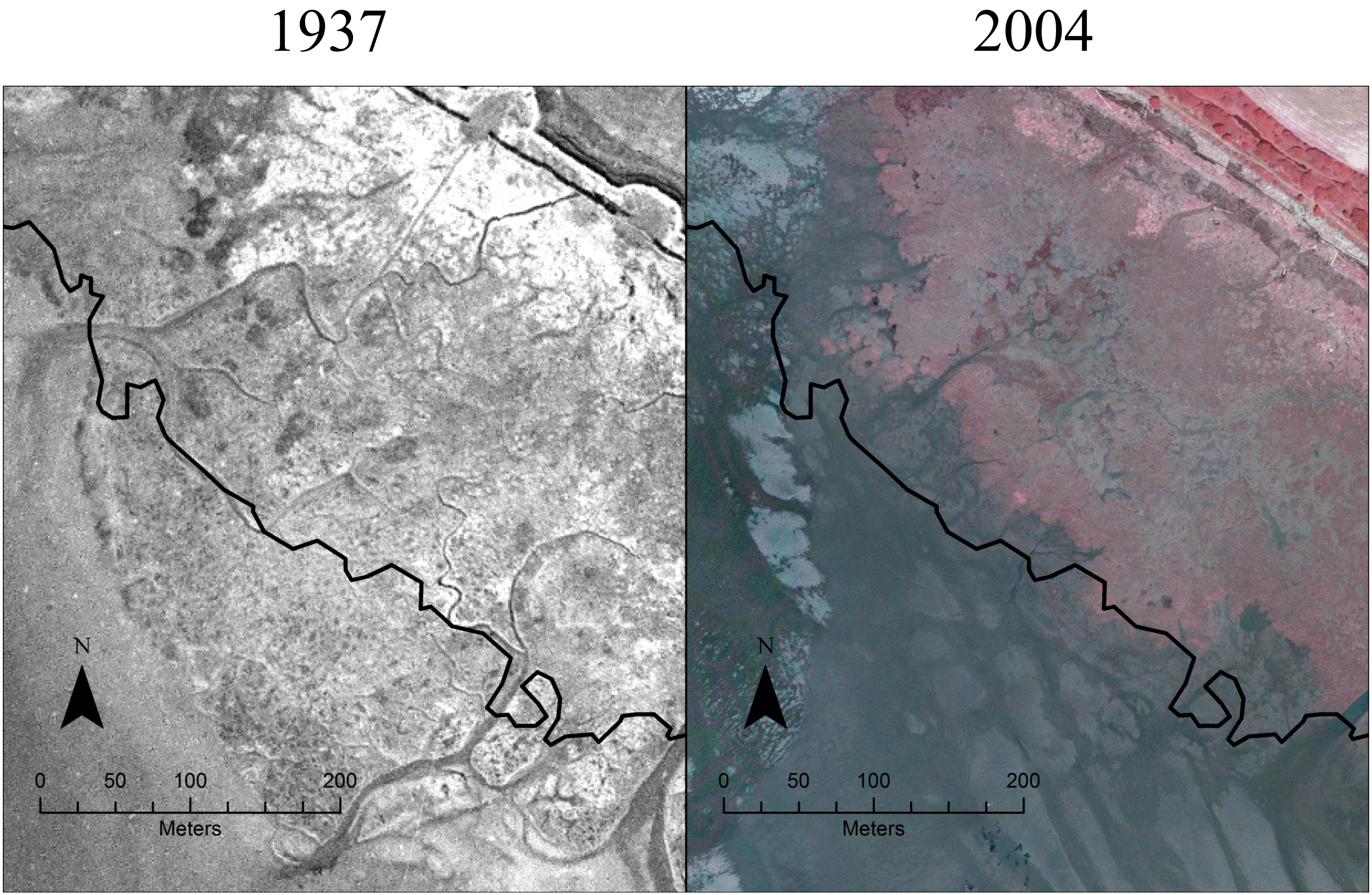
no rise
in sea level
45cm rise
in sea level
80cm rise
in sea level
12% loss of marsh to sandflat (580 acres)
16% gain--estuarine emergent marsh
51% loss--estuarine shrub marsh
48% loss--riverine tidal shrub marsh
46% loss--riverine tidal forest
22% loss of marsh to sandflat (1080 acres)
15% gain--estuarine emergent marsh
76% loss--estuarine shrub marsh
63% loss--riverine tidal shrub marsh
68% loss--riverine tidal forest
N
5000 0 5000 10000 Meters
Sandflat
Estuarine emergent
Estuarine shrub
Riverine tidal shrub
Riverine tidal forested

Tidal Channel Response to Sea Level Rise


South Fork
y = 0.80x^0.96
R² = 0.82
Stilly low
y = 0.12x^1.21
R² = 0.76
North Fork
y = 0.52x^0.98
R² = 0.69
Stilly high
y = 0.78x^0.65
R² = 0.66
Bay Fringe low
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 = 0.20x^1.34
R² = 0.82
y = 0.59x^1.22
R² = 0.88
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 = 15 m
Elevation (m, NAVD88)
South Fork
W = 7 m
Elevation (m NAVD88)
Bay Fringe
W = 15 m
Elevation (m, NAVD88)
Distance (m)
Bay Fringe
W = 6 m
Elevation (m, NAVD88)
Distance (m)


1937
2004
N
0
50
100
200
Meters
N
0
50
100
200
Meters

Summary

Certain

1. Marsh progradation rates are declining and becoming negative. Marsh loss has already occurred.
2. Marsh loss will continue to occur.
3. Storm waves contribute to marsh erosion, especially in the bay fringe. Sea Level Rise (SLR) will exacerbate wave erosion.
4. Salinity will increase during increasingly low summer flows.

Uncertain

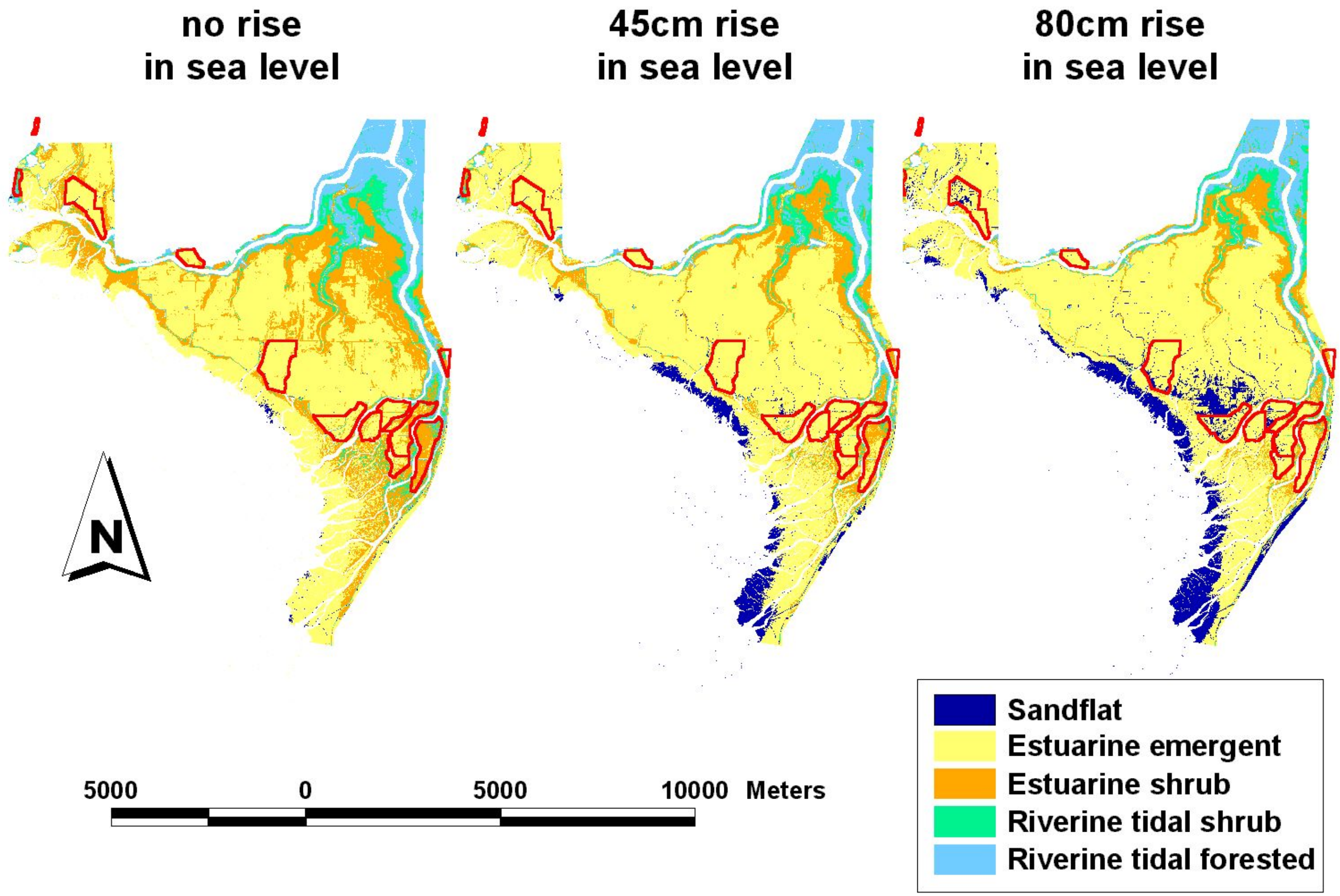
1. Fate of sediments delivered to the delta is unclear. Rate of future marsh accretion is unclear.
2. Waterfowl grazing may contribute to marsh loss.
3. Algal wrack may contribute to marsh loss.
4. Nutrient pollution may contribute to marsh loss.
5. Increasing CO_2 may ameliorate plant stress from inundation and salinity.
6. Increasing temperature may lengthen the growing season and thereby increase sedimentation.
7. The amount of future marsh loss is unclear.
8. Tidal shrub vegetation is at risk to SLR, increasing salinity, or both.

Potential Management Responses to SLR (Adaptation)

Reduce risk of uncertainty by diversifying our delta restoration portfolio.

[1] Spatial diversity in restoration sites maximizes current habitat diversity, including habitats receiving little attention, e.g., tidal sweetgale communities, other tidal shrub and forest communities, and deltaic beaver marshes.

[2] Spatial site diversity also maximizes future habitat diversity, and diversifies possible habitat responses to climate change.



Reconsider our habitat restoration goals for salmon recovery.

We need to run faster just to stay in place. We have likely underestimated the amount of tidal habitat restoration necessary to recover Chinook salmon, because we have not accounted for the need to compensate for sea level rise impacts.

Increase landscape resiliency.

Restore natural processes, e.g., sediment delivery, tidal inundation, marsh accretion, landward marsh migration [1] Restore historical river distributaries,
[2] Pull-back dikes/levees.

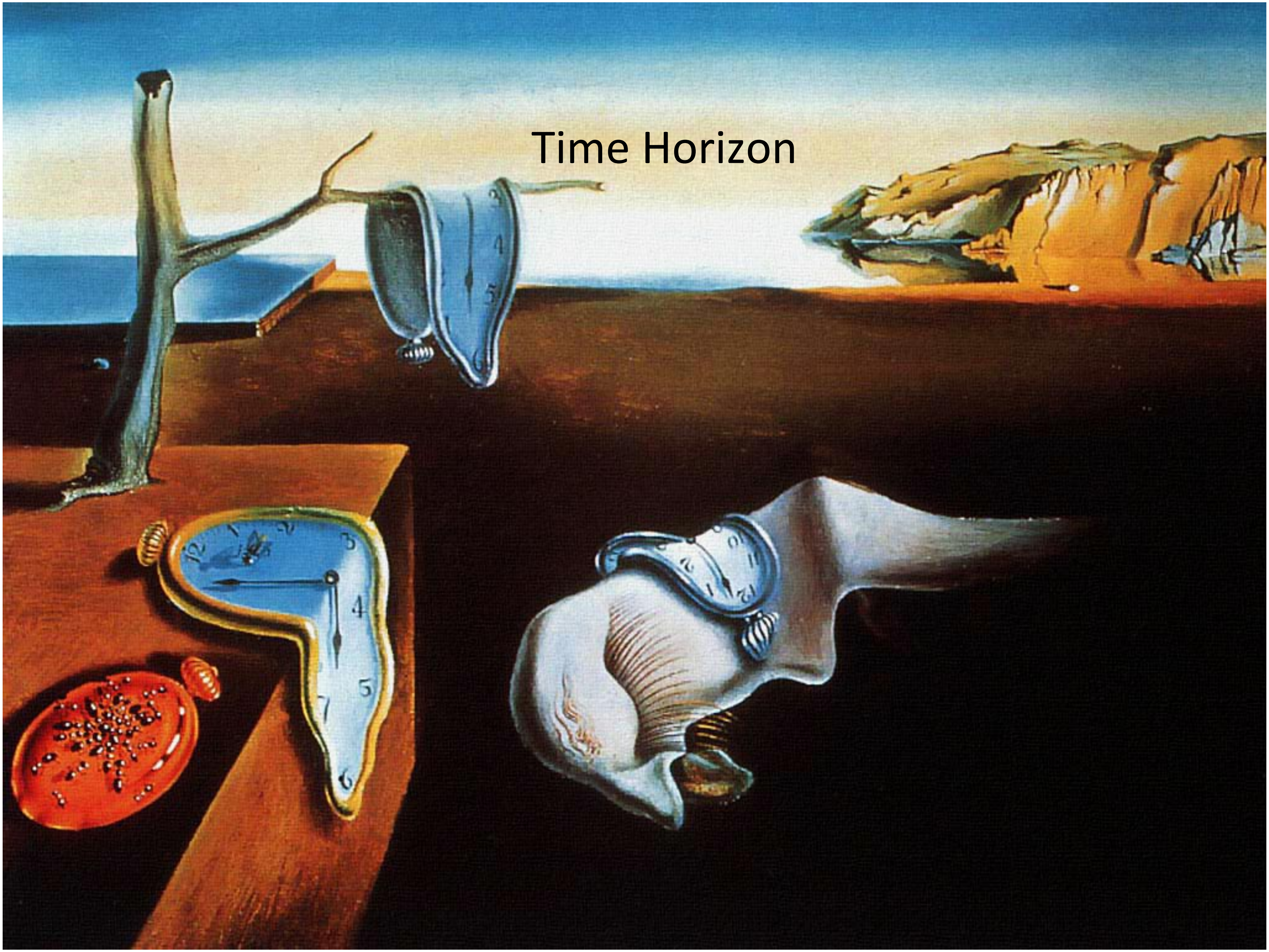
Monitor landscape change.

Develop early warning system—monitor change in vulnerable areas, e.g., bay fringe erosion, change in woody vegetation distribution, effects of waterfowl grazing.

Support research on data gaps and predictive models.

Priorities: sediment supply and fate, marsh accretion rates (change over time), storm-wave erosion, vegetation distribution (salinity + elevation), impact of algal wrack, waterfowl grazing, seasonality of the preceding, predictive model development.

Time Horizon



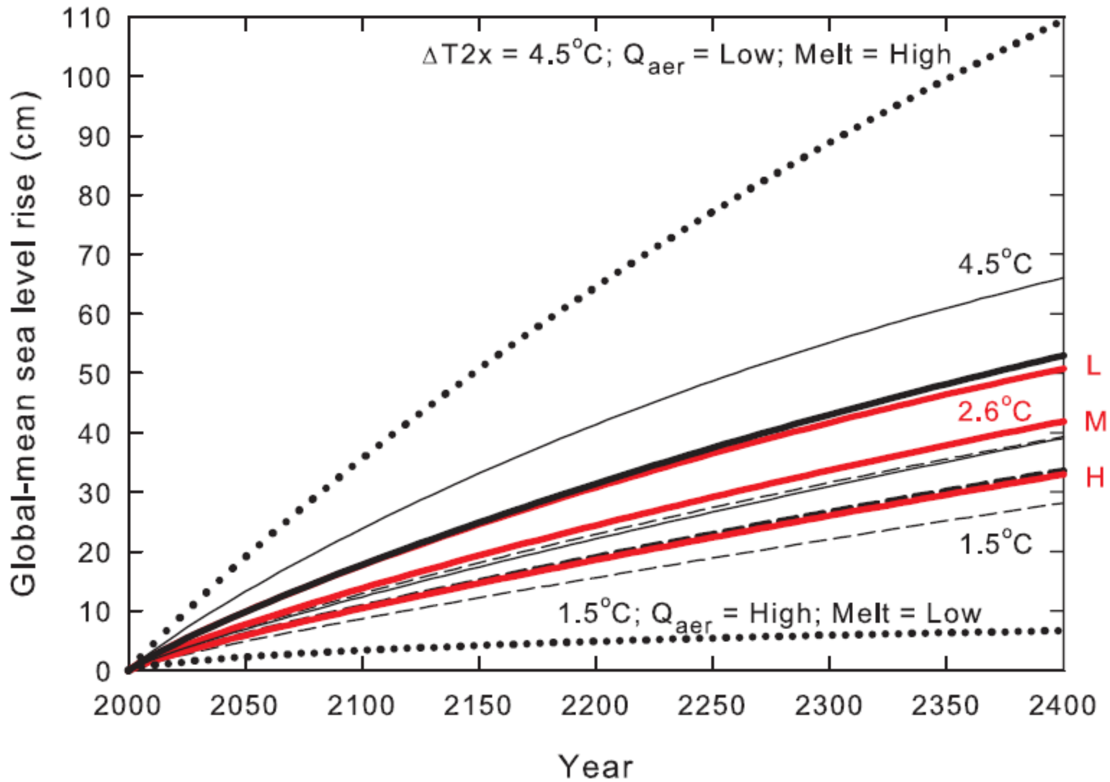


Fig. 3. CC sea level rise commitment (constant concentrations after 2000) for different climate sensitivities and aerosol forcing levels (L, M, and H on the right of figure indicate low, mid-, and high magnitudes for aerosol forcing, respectively). The central curves assume best-estimate values for all ice melt parameters. For these curves, aerosol forcing and climate sensitivity uncertainty ranges overlap. For example, the mid-aerosol-mid sensitivity ($\Delta T2\times = 2.6°C$; central red curve) results are very similar to the high-aerosol-high sensitivity ($\Delta T2\times = 4.5°C$; lowest full black curve) results and the low-aerosol-low sensitivity results ($\Delta T2\times = 1.5°C$; top dashed black curve). Extremes spanning sensitivity, aerosol, and melt uncertainties are shown by the bottom and top dotted curves.

Wigley TML. 2005. The climate change commitment. *Science* 307:1766-1769

Sea level rise is a long-term issue, requiring a mix of short-term and long-term planning horizons and adaptation.

Critical factor is rate of change, especially in SLR, accretion, and vegetation response.