THE IMPORTANCE OF MATCHING THE SPATIAL SCALES OF PROBABILISTIC MONITORING DESIGNS WITH MANAGEMENT QUESTIONS

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Acknowledgments

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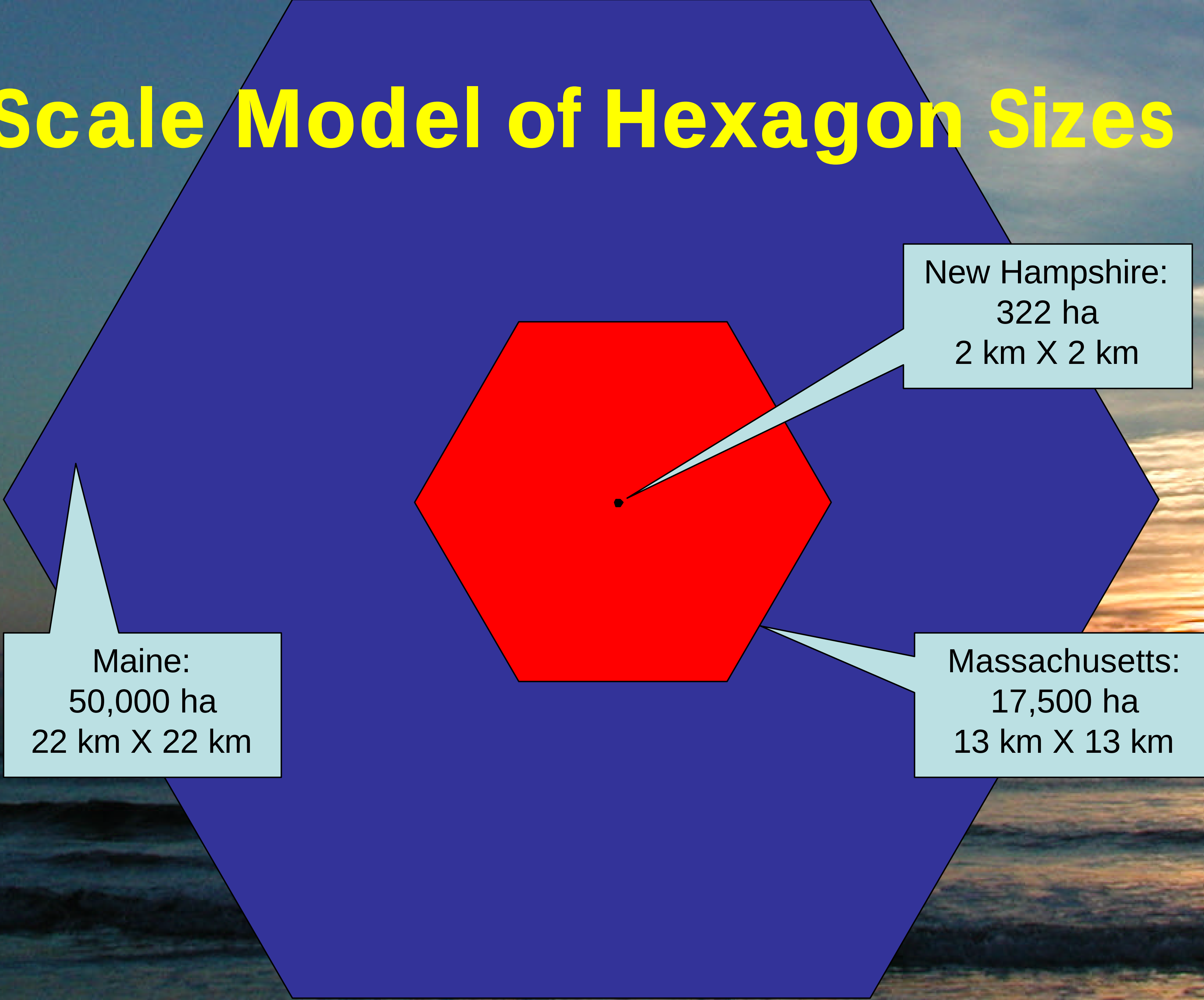
Objectives

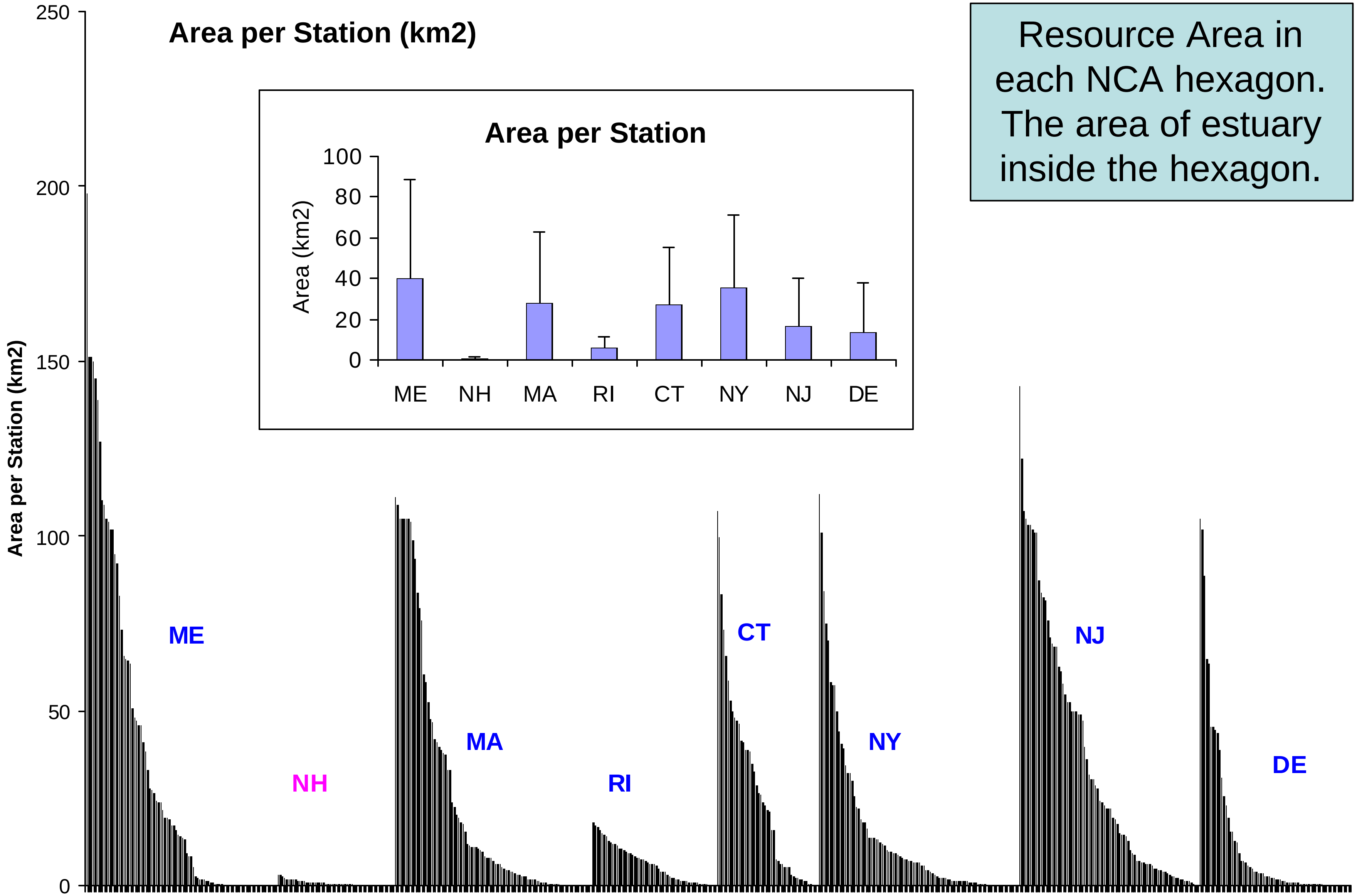
- To investigate the effects of spatial scales on the outcomes of Probability-Based Monitoring (PBM) programs
  - Representativeness
  - Spatial Autocorrelation
  - Confidence Intervals
- To provide practical advice to State managers for implementing PBMs.

Methods

- Use “natural experiment” of NH’s small scale for the National Coastal Assessment
- Conduct fine-scale studies at 4 NH sites
- Make comparisons between results for mercury in sediment at three scales:
  - Gulf of Maine
  - New Hampshire
  - Small study areas

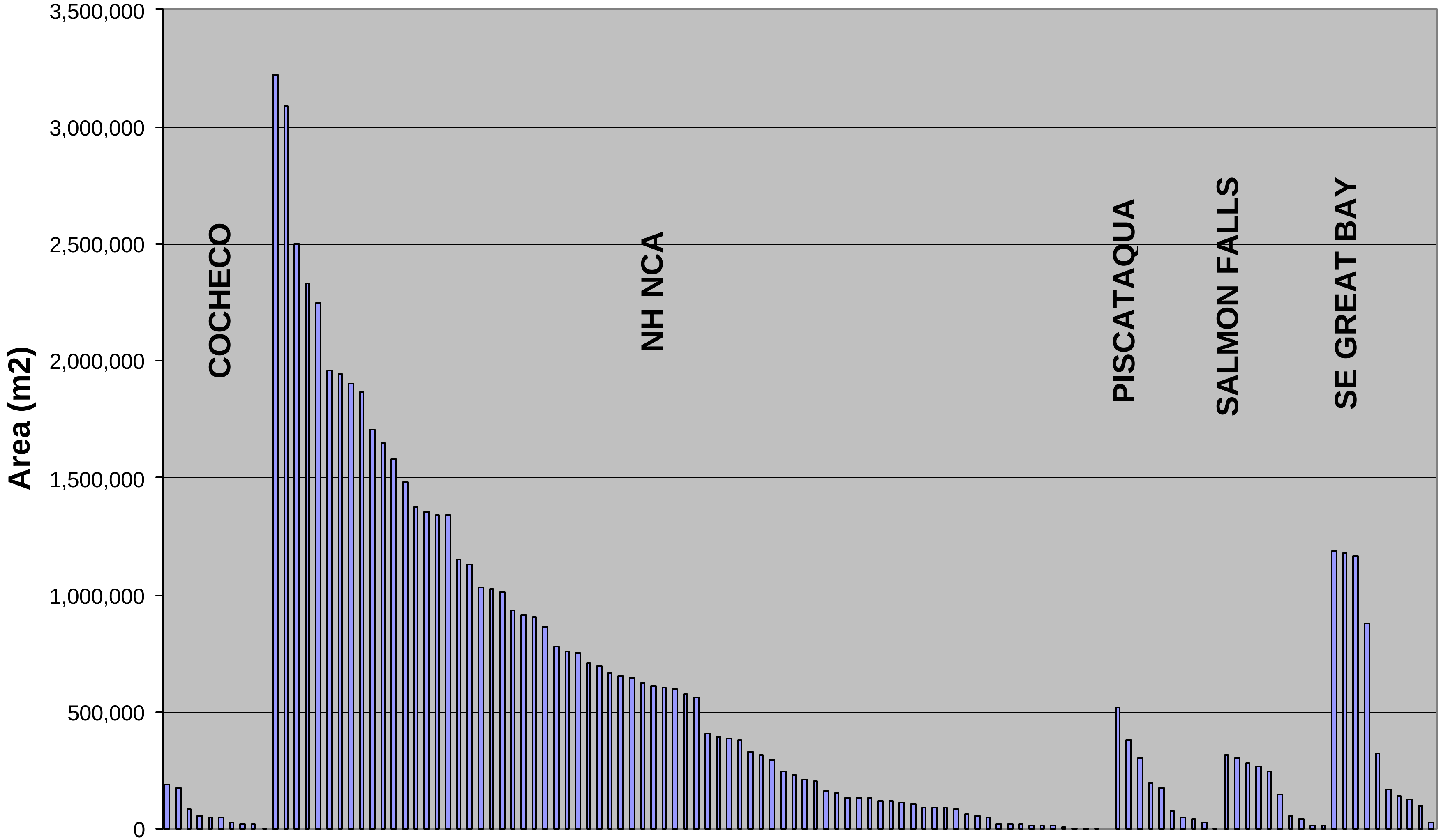
Scale Model of Hexagon Sizes





Resource Area in each NCA hexagon. The area of estuary inside the hexagon.

Resource Area in NH NCA and Special Study Hexagons



First Experiment: Representativeness

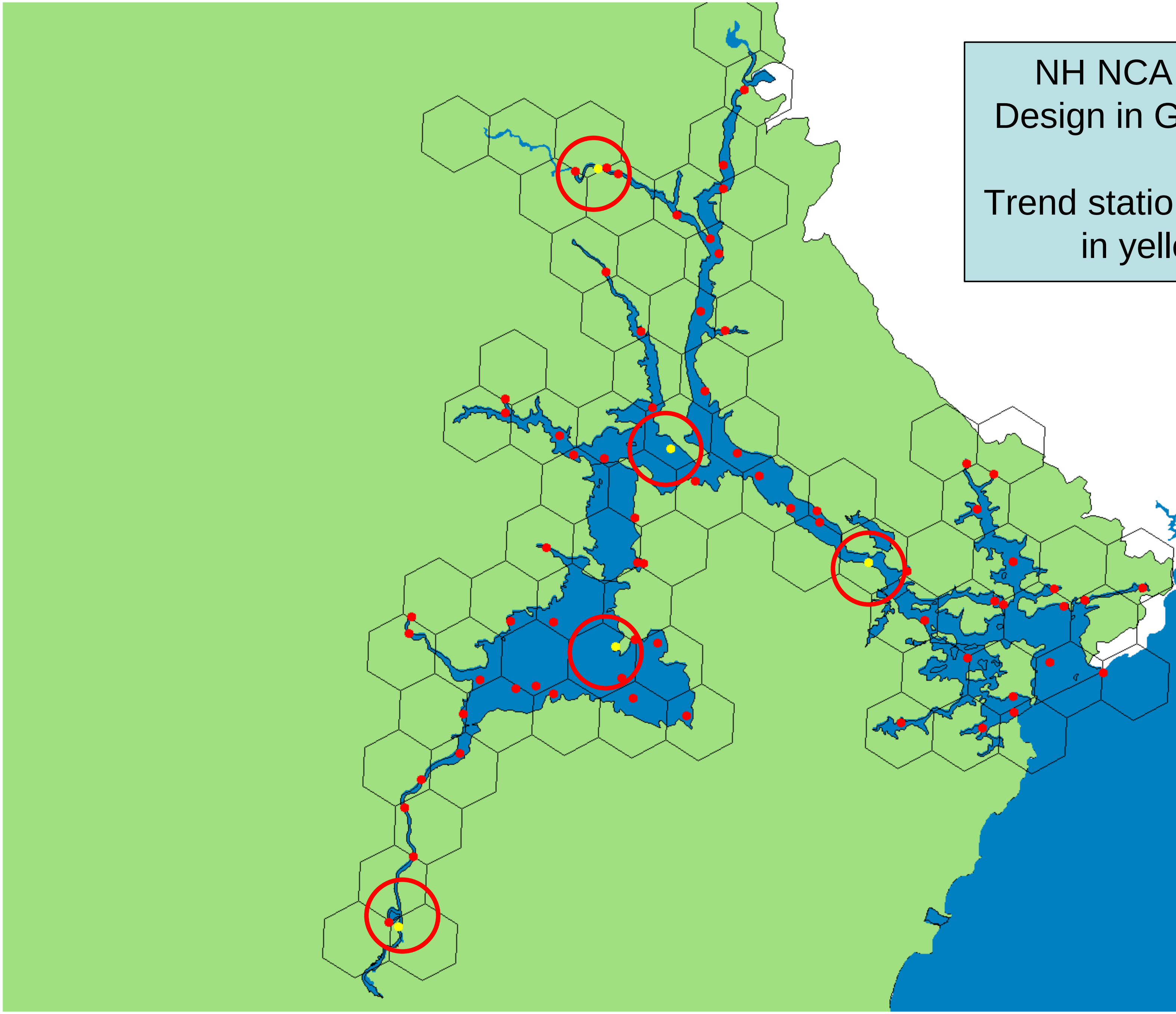
Outcome: The NCA study design reasonably estimates average values at multiple spatial scales.

Methods

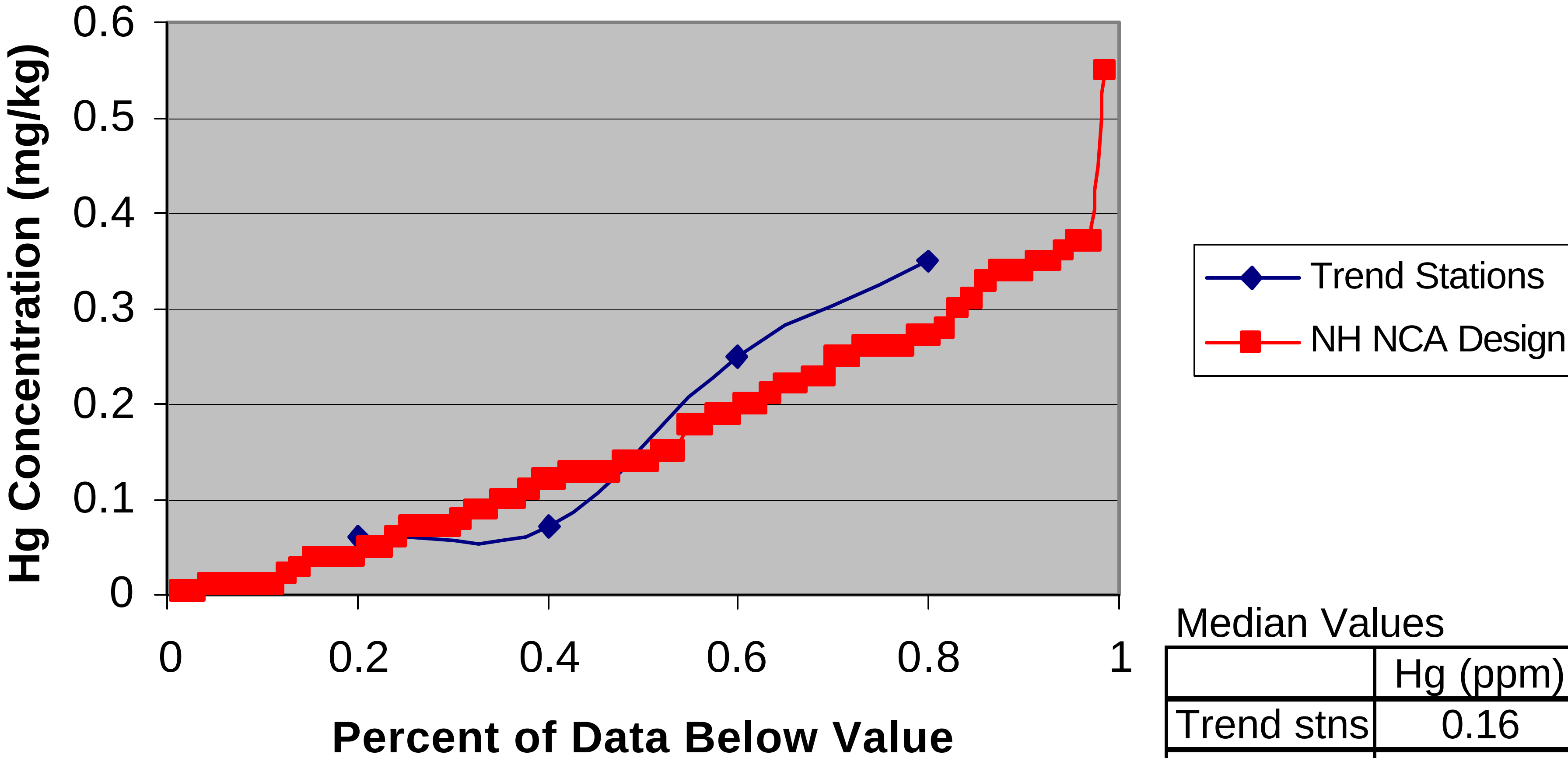
- Compare cumulative distribution function (CDF) from a random subsample of NH NCA data to whole NH NCA dataset
- Compare CDF for 4 intensive study areas to NH NCA samples from the same area
- Use mercury in sediment concentrations as a common parameter

NH NCA Study Design in Great Bay

Trend stations shown in yellow.

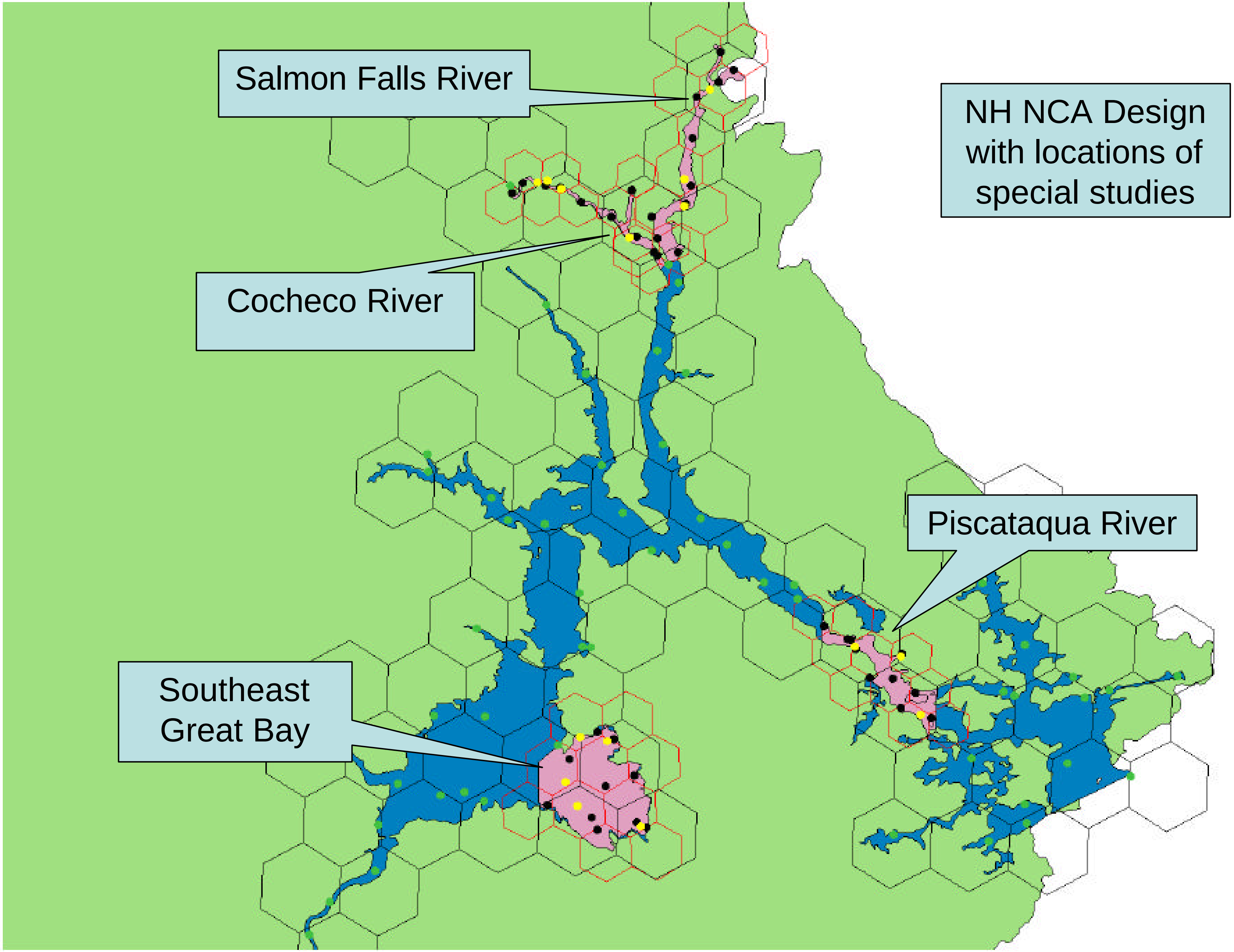


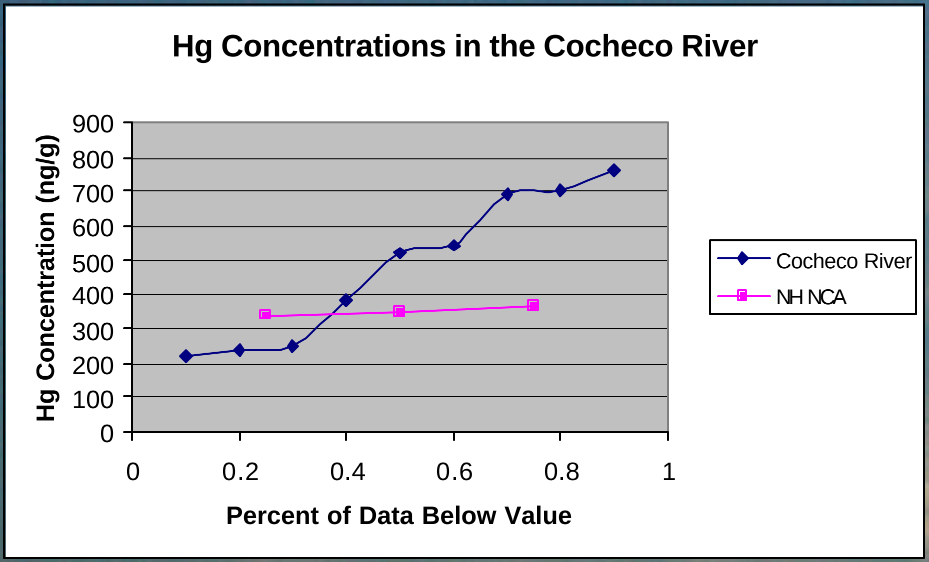
Comparison of Hg CDFs for different scales



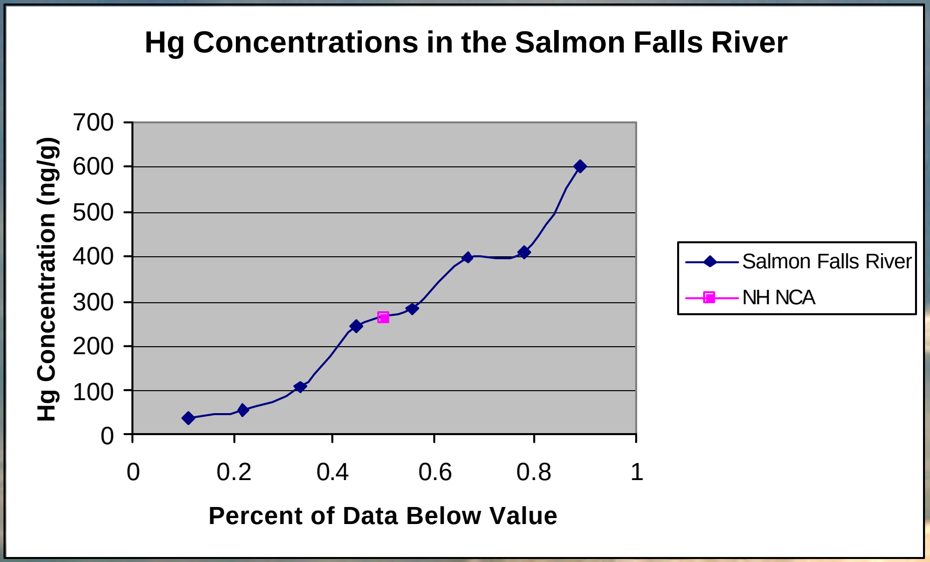
Median Values

	Hg (ppm)
Trend stns	0.16
All data	0.14

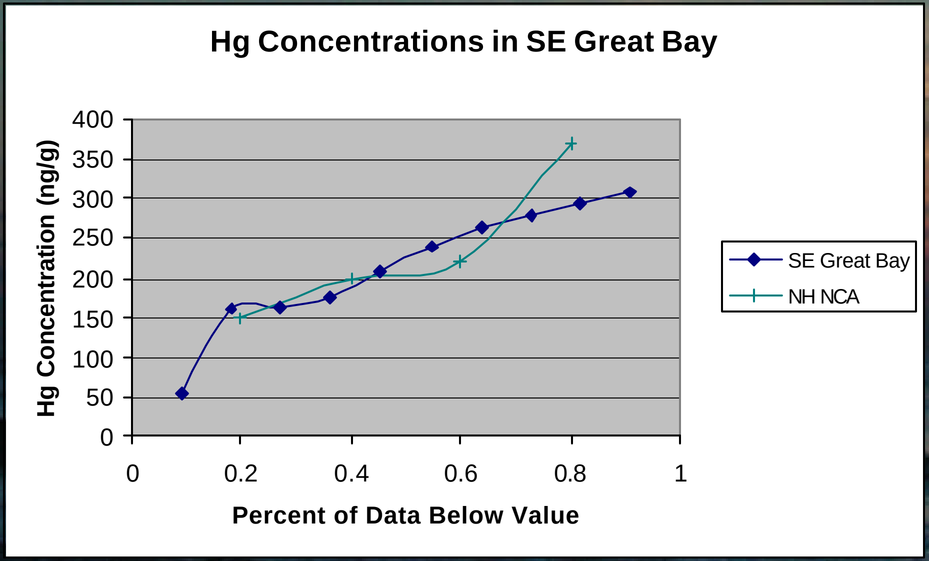

Salmon Falls River
NH NCA Design with locations of special studies
Cocheco River
Piscataqua River
Southeast Great Bay



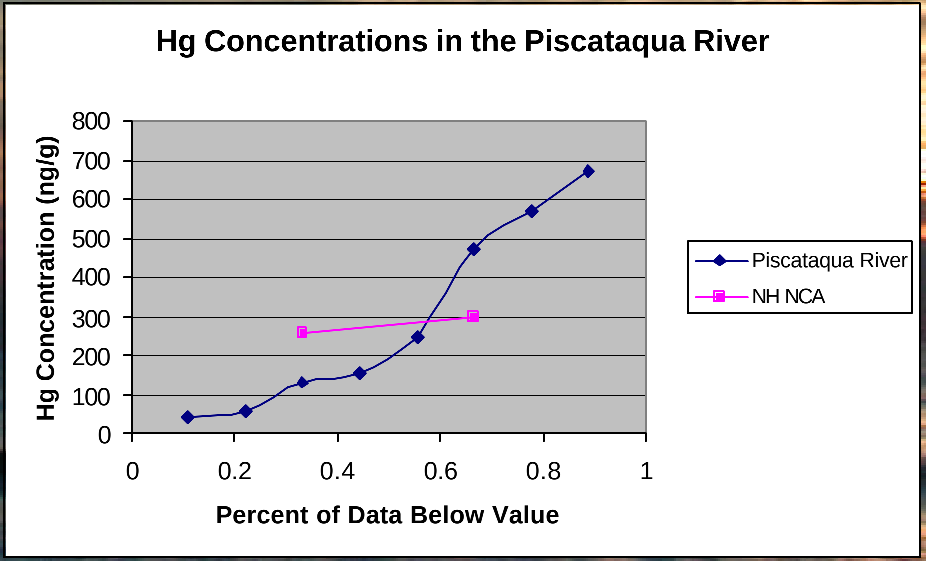
Hg Concentrations in the Cocheco River
Hg Concentration (ng/g)
900
800
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Percent of Data Below Value
Cocheco River
NH NCA



Hg Concentrations in the Salmon Falls River
Hg Concentration (ng/g)
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Percent of Data Below Value
Salmon Falls River
NH NCA



Hg Concentrations in SE Great Bay
Hg Concentration (ng/g)
400
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1
Percent of Data Below Value
SE Great Bay
NH NCA



Hg Concentrations in the Piscataqua River
Hg Concentration (ng/g)
800
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Percent of Data Below Value
Piscataqua River
NH NCA

Representativeness Conclusions

- NCA study design captures median values of CDFs but misses extremes.
- Representativeness was demonstrated at two different scales so is likely to be robust.

Second Experiment: Spatial Autocorrelation

Outcome: For stations <20 km apart, spatial correlation is likely.

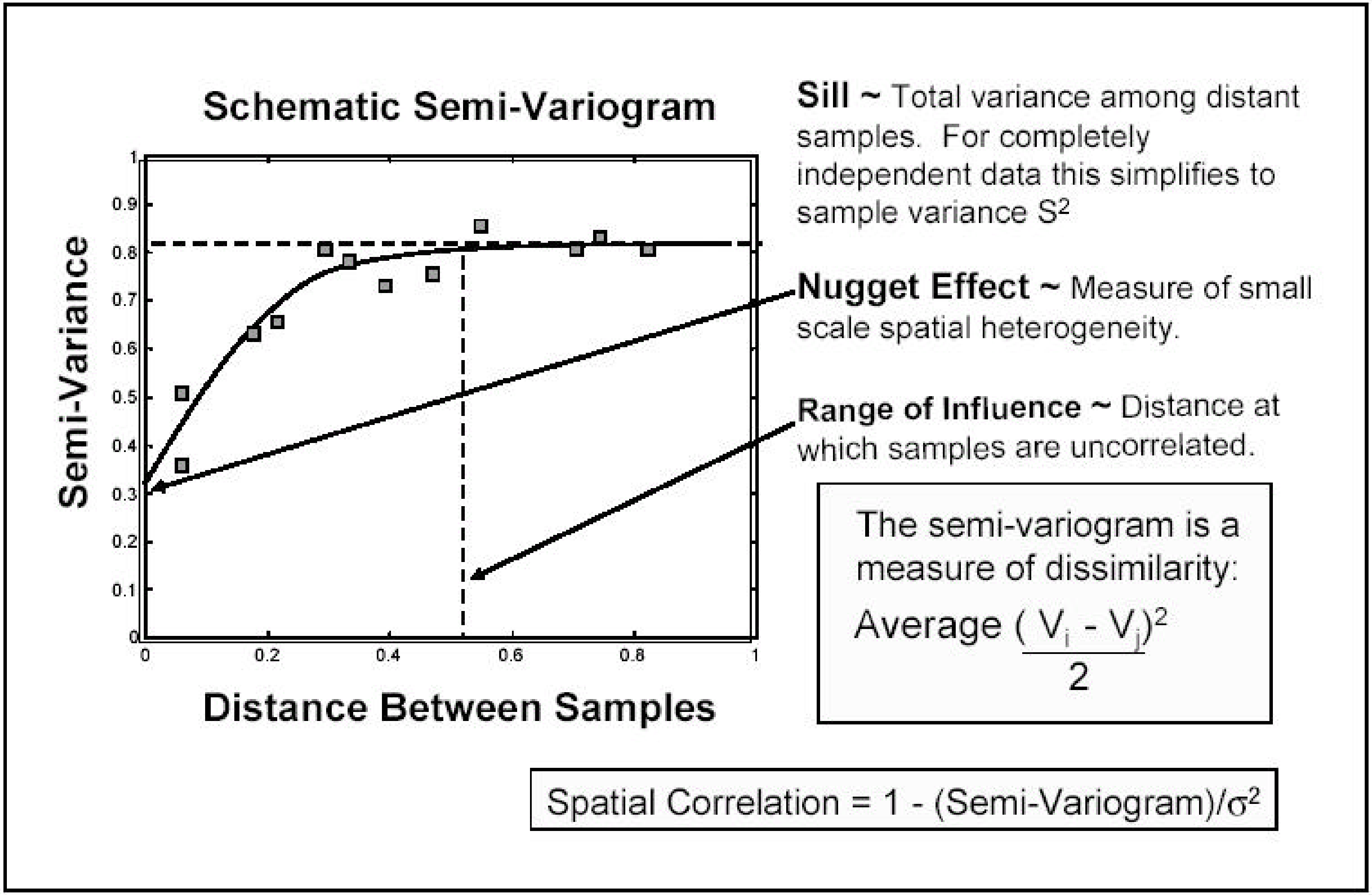
Spatial Correlation

- As hexagon sizes shrink, the stations converge.
- Adjacent stations provide similar information.
- Autocorrelated stations are not independent.

Methods

- Investigate spatial autocorrelation by charting semivariograms for mercury in sediments at three different scales
  - Gulf of Maine
  - New Hampshire
  - Special study sites

Definition of Semivariogram



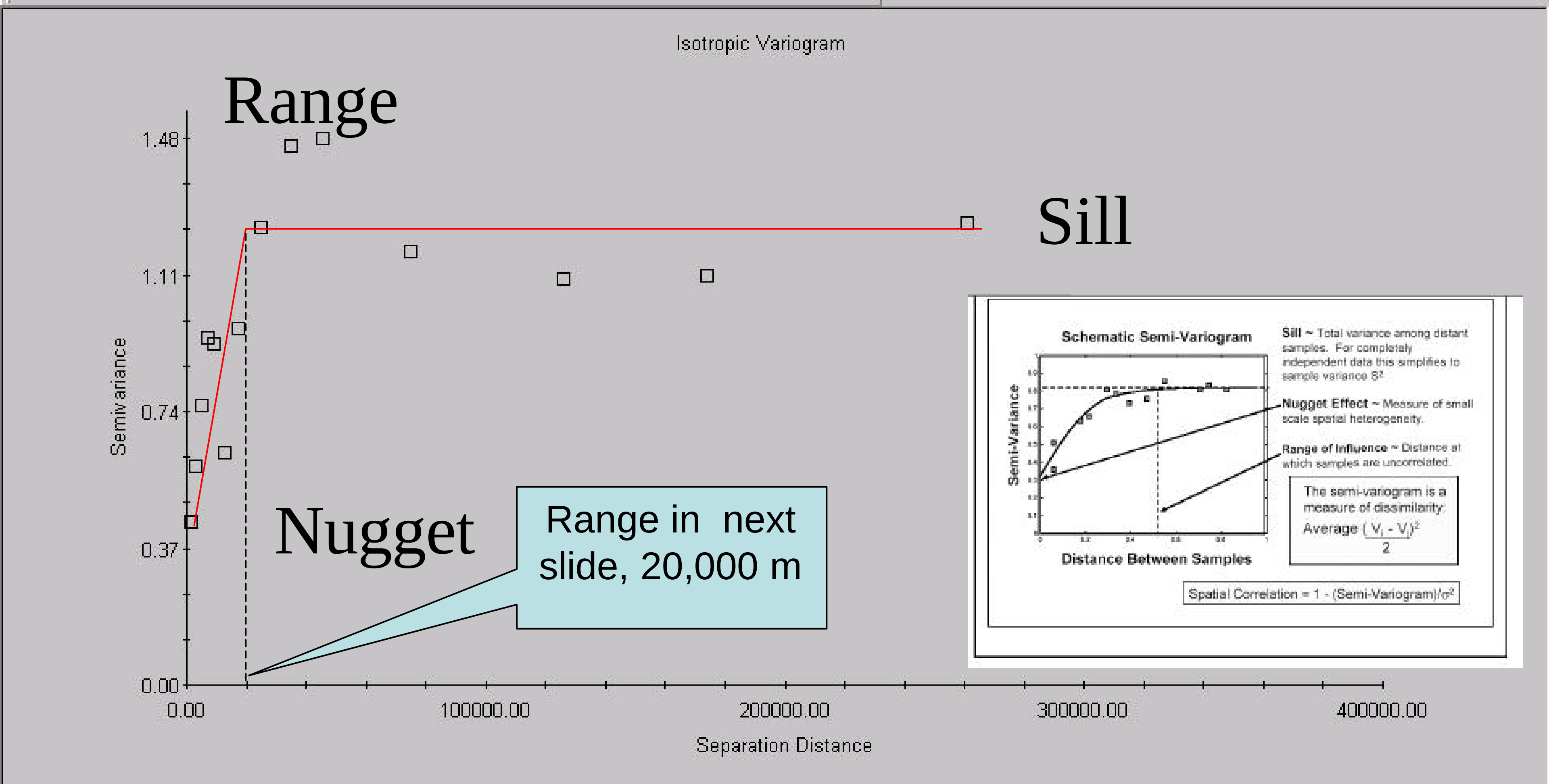
Source: John W Kern

Semivariogram for Ln [Hg]
Gulf of Maine

Range ~20 km

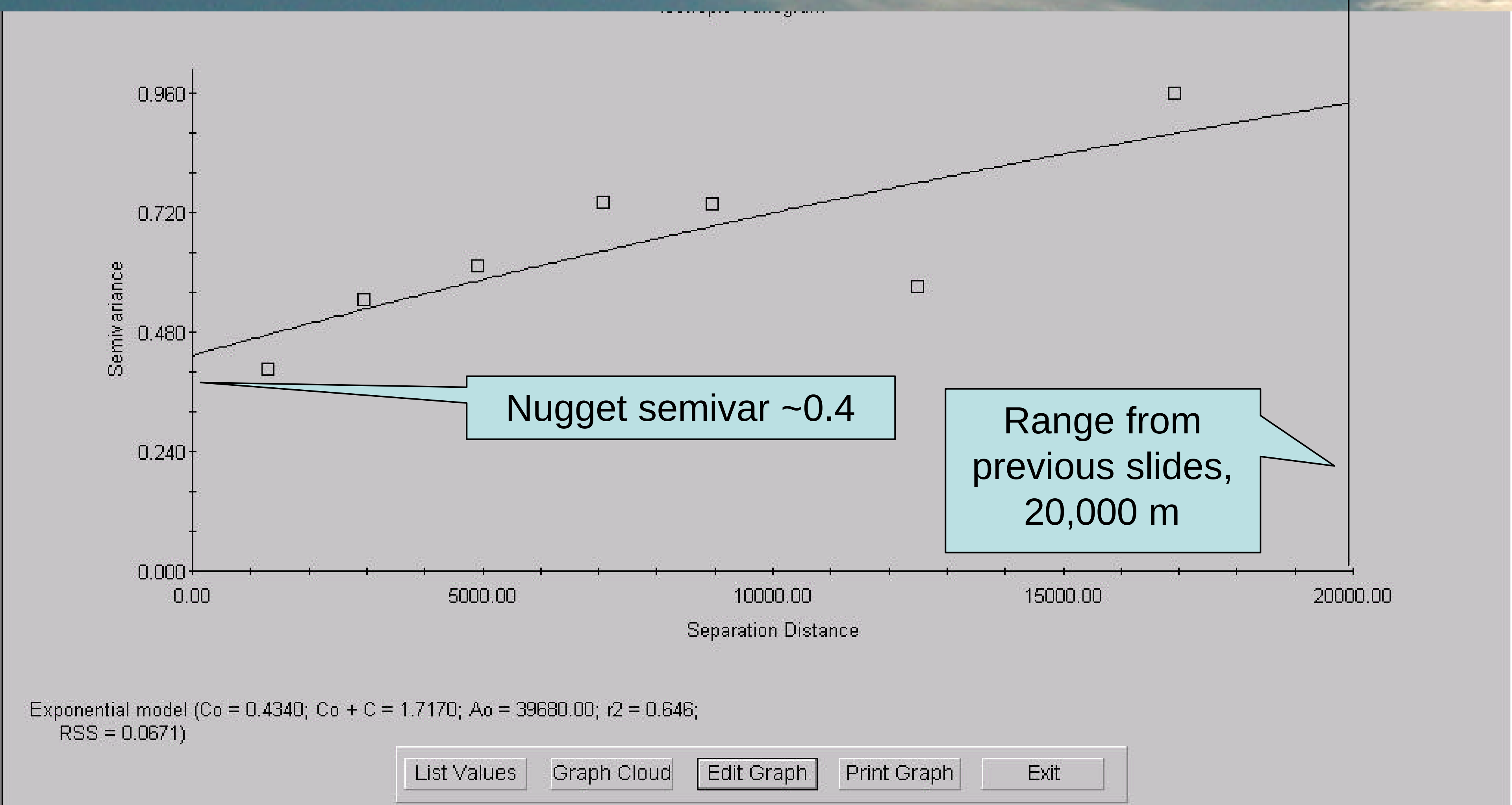
Nugget Semivariance ~0.35

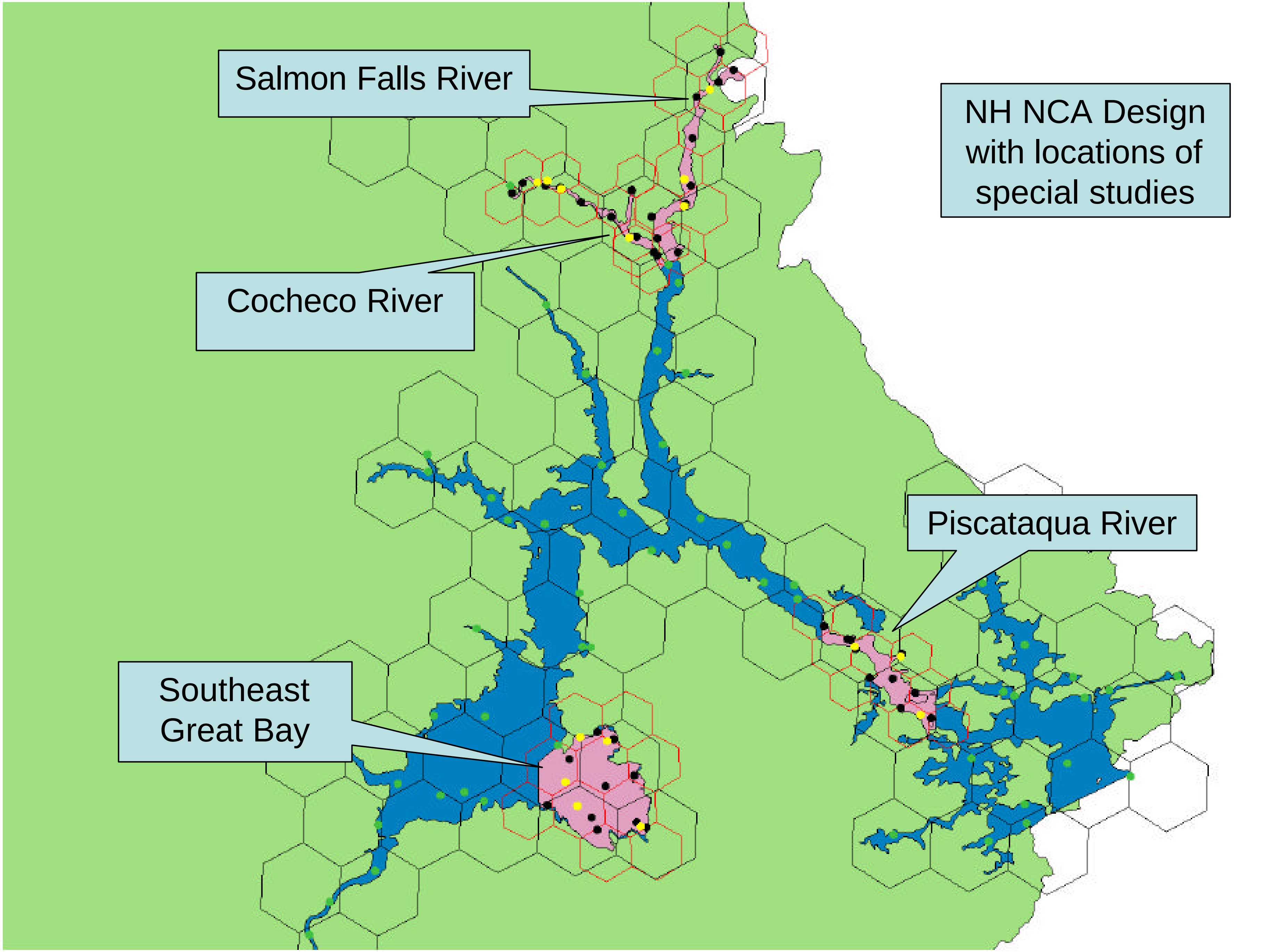
Sill Semivariance ~1.2



Semivariogram for Ln [Hg]
NH NCA (2000-2001)

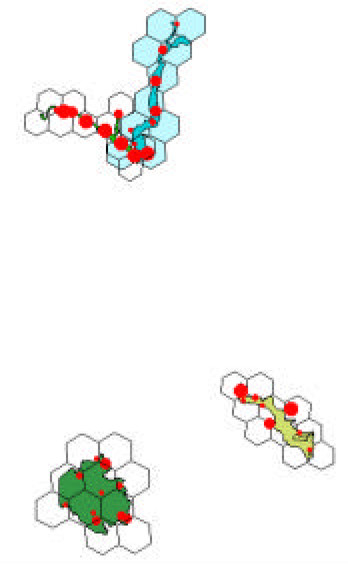
All NH NCA sites appear to be autocorrelated

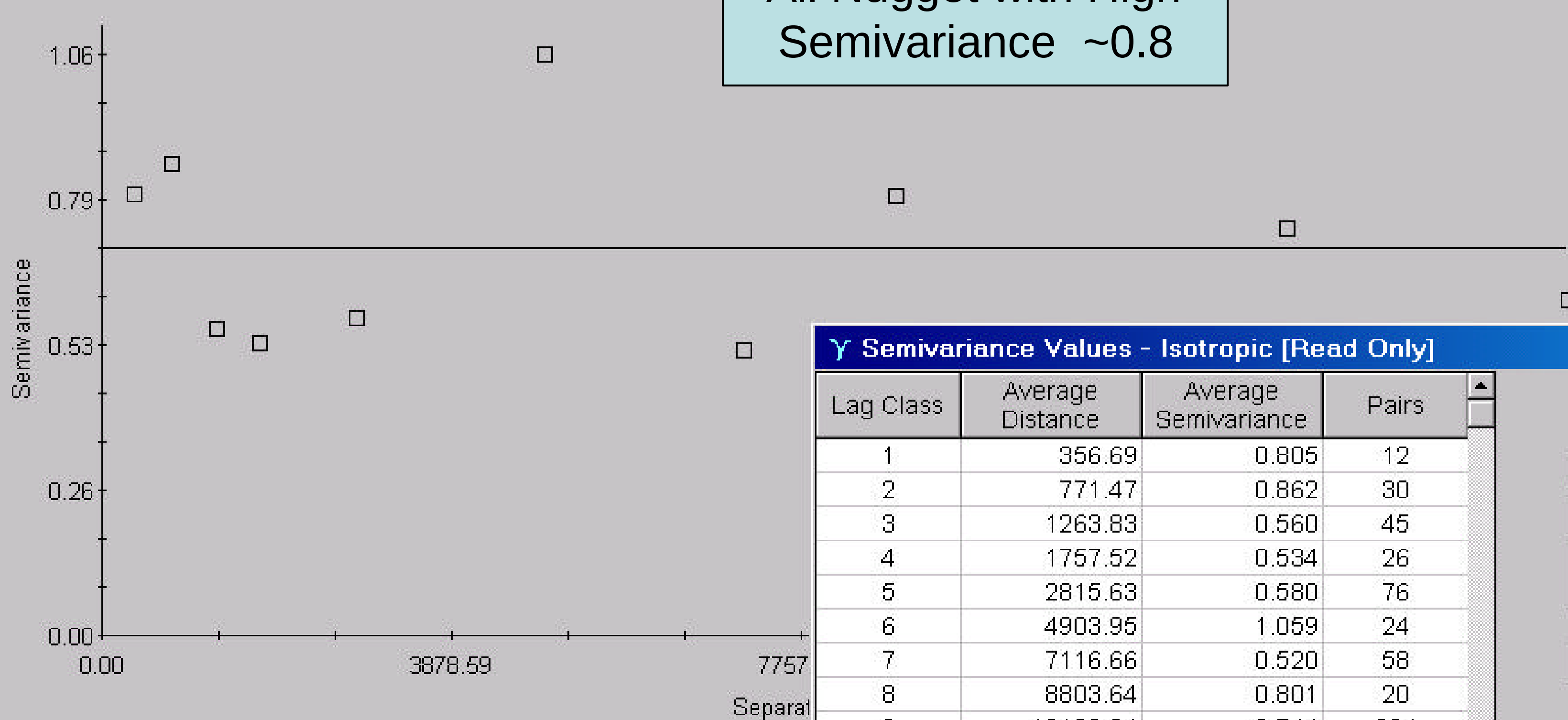




Salmon Falls River
NH NCA Design with locations of special studies
Cocheco River
Piscataqua River
Southeast Great Bay

Semivariogram for Ln [Hg]
4 Special Study Areas Combined





All Nugget with High Semivariance ~0.8

Semivariance Values - Isotropic [Read Only]

Lag Class	Average Distance	Average Semivariance	Pairs
1	356.69	0.805	12
2	771.47	0.862	30
3	1263.83	0.560	45
4	1757.52	0.534	26
5	2815.63	0.580	76
6	4903.95	1.059	24
7	7116.66	0.520	58
8	8803.64	0.801	20
9	13123.94	0.744	224
10	16253.53	0.611	80

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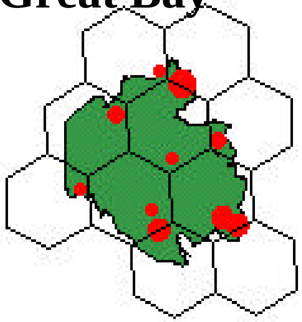
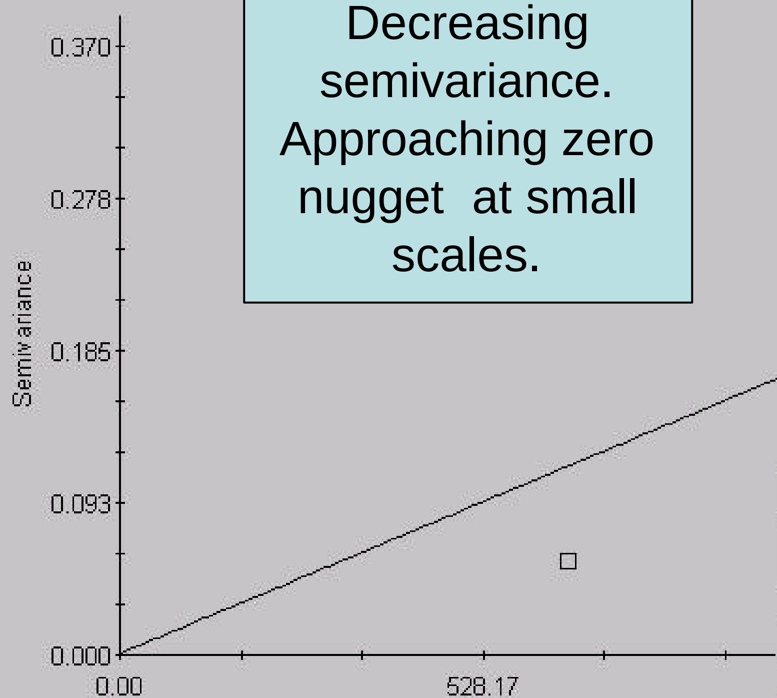
Semivariogram for Ln [Hg]
SE Great Bay

SE Great Bay



Isotropic Variogram



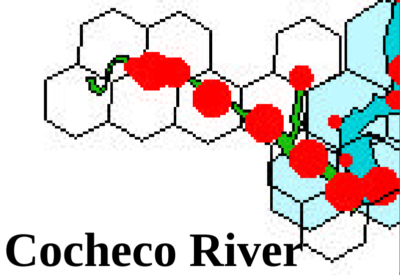
Decreasing semivariance. Approaching zero nugget at small scales.

Semivariance Values - Isotropic [Read Only]

Lag Class	Average Distance	Average Semivariance	Pairs
1	651.97	0.057	7
2	1249.11	0.253	19
3	2110.32	0.368	17

Linear model (Co = 0.0010; Co + C = 0.7420; Ao = 4240.00; r2 = 0.937;
RSS = 4.508E-03)

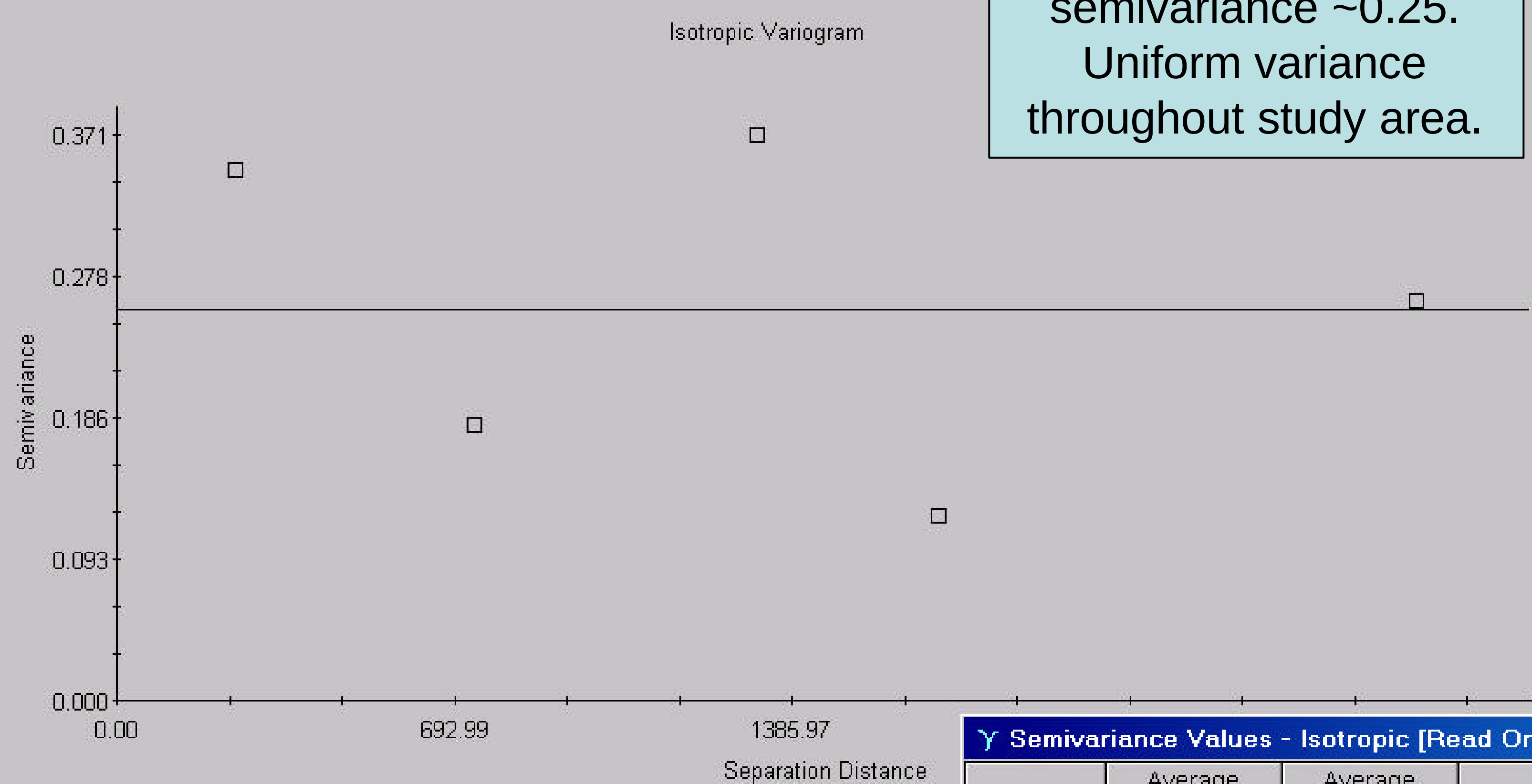
Semivariogram for Ln [Hg]
Cocheco River



GS+ Geostatistics for the Environmental Sciences (Cocheco.par)

File Edit Data Autocorrelation Interpolate Map Window Help

All nugget but low semivariance ~0.25. Uniform variance throughout study area.



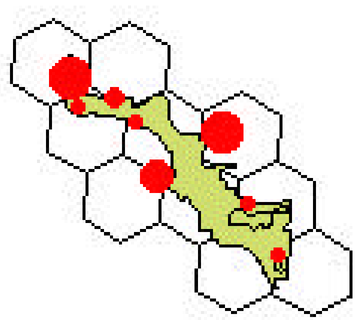
Linear model (Co = 0.2569; Co + C = 0.2569; Ao = 2665.81; r2 = 0.059; RSS = 0.0454)

List Values | Graph Cloud | Edit Graph | Print G

Semivariance Values - Isotropic [Read Only]

Lag Class	Average Distance	Average Semivariance	Pairs
1	243.76	0.348	3
2	734.12	0.181	8
3	1313.06	0.371	6
4	1685.82	0.122	5

Piscataqua River



Semivariogram for Ln [Hg]
Piscataqua R.

ronmental Sciences (Piscataqua.par)

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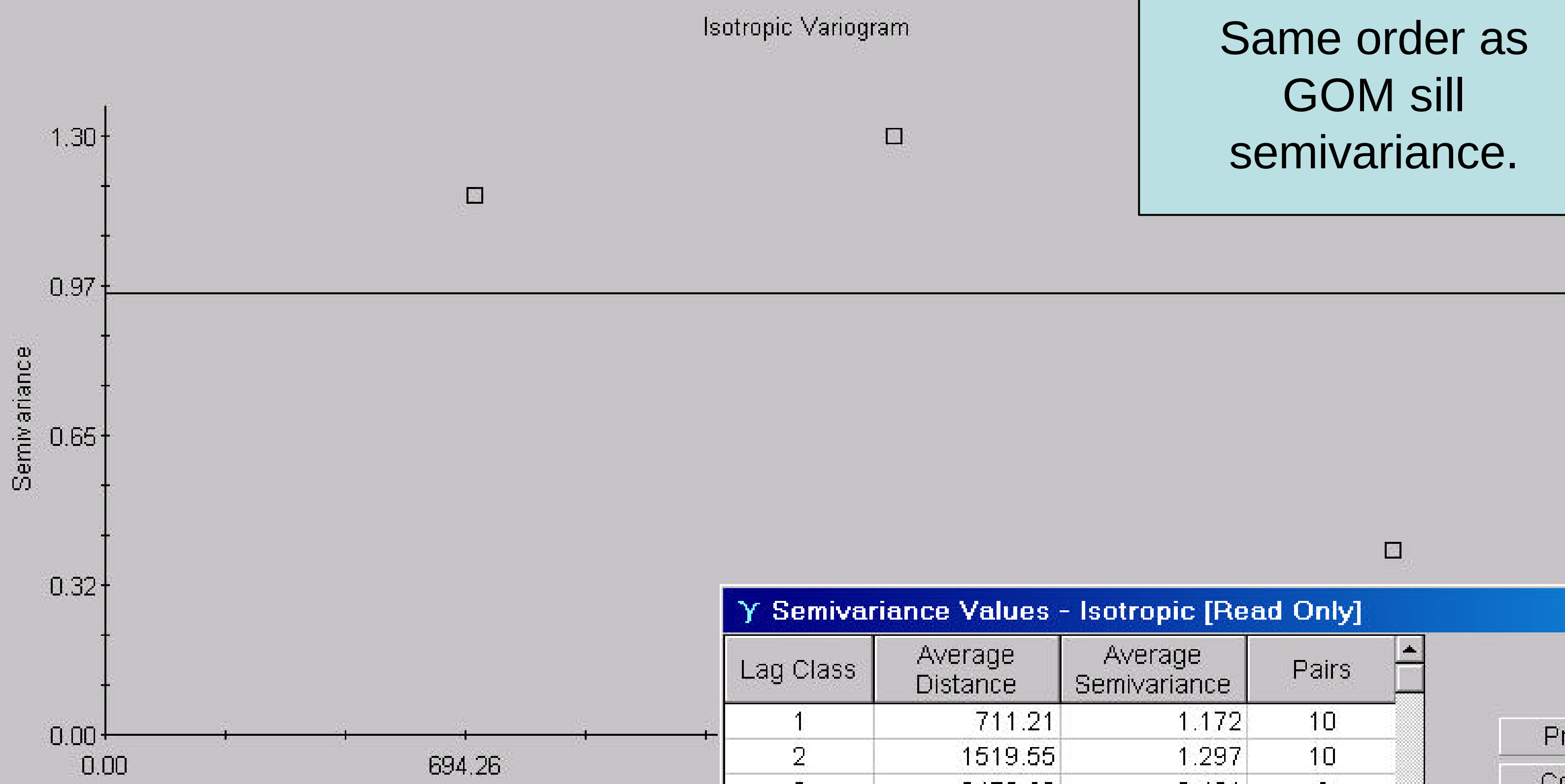
All nugget but high semivariance ~1.0. Same order as GOM sill semivariance.



Linear model (Co = 0.9567; Co + C = 0.9567; Ao = 2478.68; r2 = 0.677; RSS = 0.471)

Semivariance Values - Isotropic [Read Only]

Lag Class	Average Distance	Average Semivariance	Pairs
1	711.21	1.172	10
2	1519.55	1.297	10
3	2478.68	0.401	6

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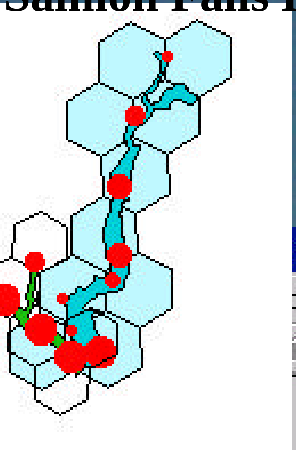
Salmon Falls River



Semivariogram for Ln [Hg]

Salmon Falls R

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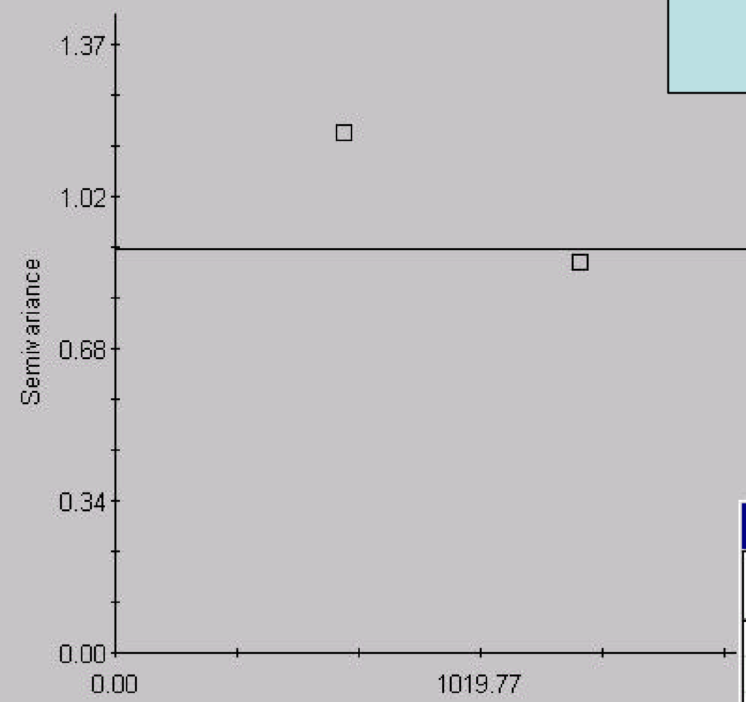
for the Environmental Sciences (SalmonFalls.par)

Same as for Piscataqua River



Linear model (Co = 0.9049; Co + C = 0.9049; Ao = 4459.30; r2 = 0.230; RSS = 0.803)

Semivariance Values - Isotropic [Read Only]

Lag Class	Average Distance	Average Semivariance	Pairs
1	634.71	1.167	4
2	1295.75	0.878	10
3	2506.89	0.931	6
4	3608.90	1.365	4
5	4459.30	0.183	3

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Decimals

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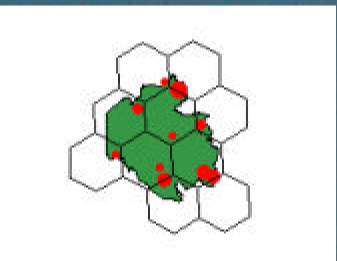
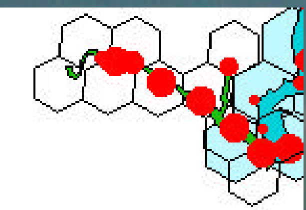
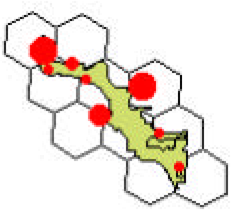
Summary – High Density Hg Data

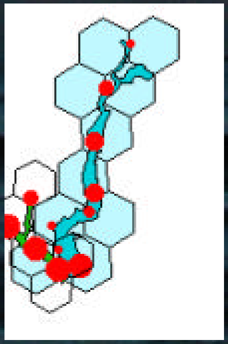


- **SE Great Bay.** Median [Hg] = 0.22 Max = 0.30
  - Semivariance suggestive of small nugget at fine scale.



- **Cocheco.** Median [Hg] = 0.52 Max=0.76
  - All nugget but low semivariance (0.26).
  - Consistently high Hg concentrations.





- **Piscataqua.** Median [Hg] = 0.20 Max = 0.67
- **Salmon Falls.** Median [Hg] = 0.27 Max = 0.60
  - All nugget with high semivariance (0.90-0.97)
  - Mixture of high and low Hg concentrations. Heterogeneous.

Spatial Correlation Conclusions

- On a broad scale, stations > 20 km apart are uncorrelated and independent
- NH NCA stations are ~ 2 km apart so autocorrelation appears to be present. However, the type and level of autocorrelation is not uniform.
- Drill down into four areas with high Hg in NH NCA survey revealed three different contamination structures.

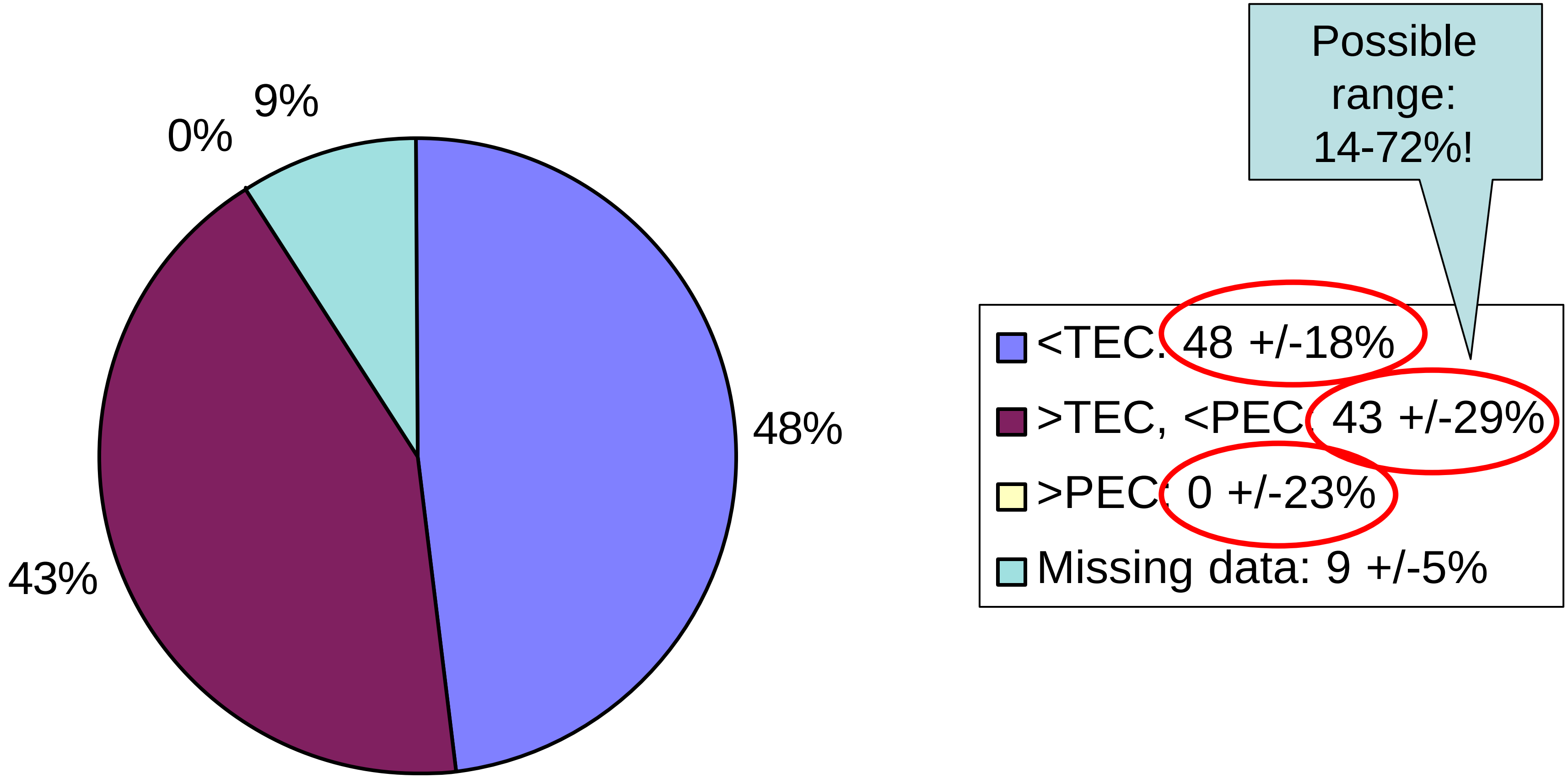
Third Experiment: Variance Calculations

Outcome: Variance was higher than expected. For small scales, variance algorithm and assumption of independence may be in error.

Variance/Confidence Intervals

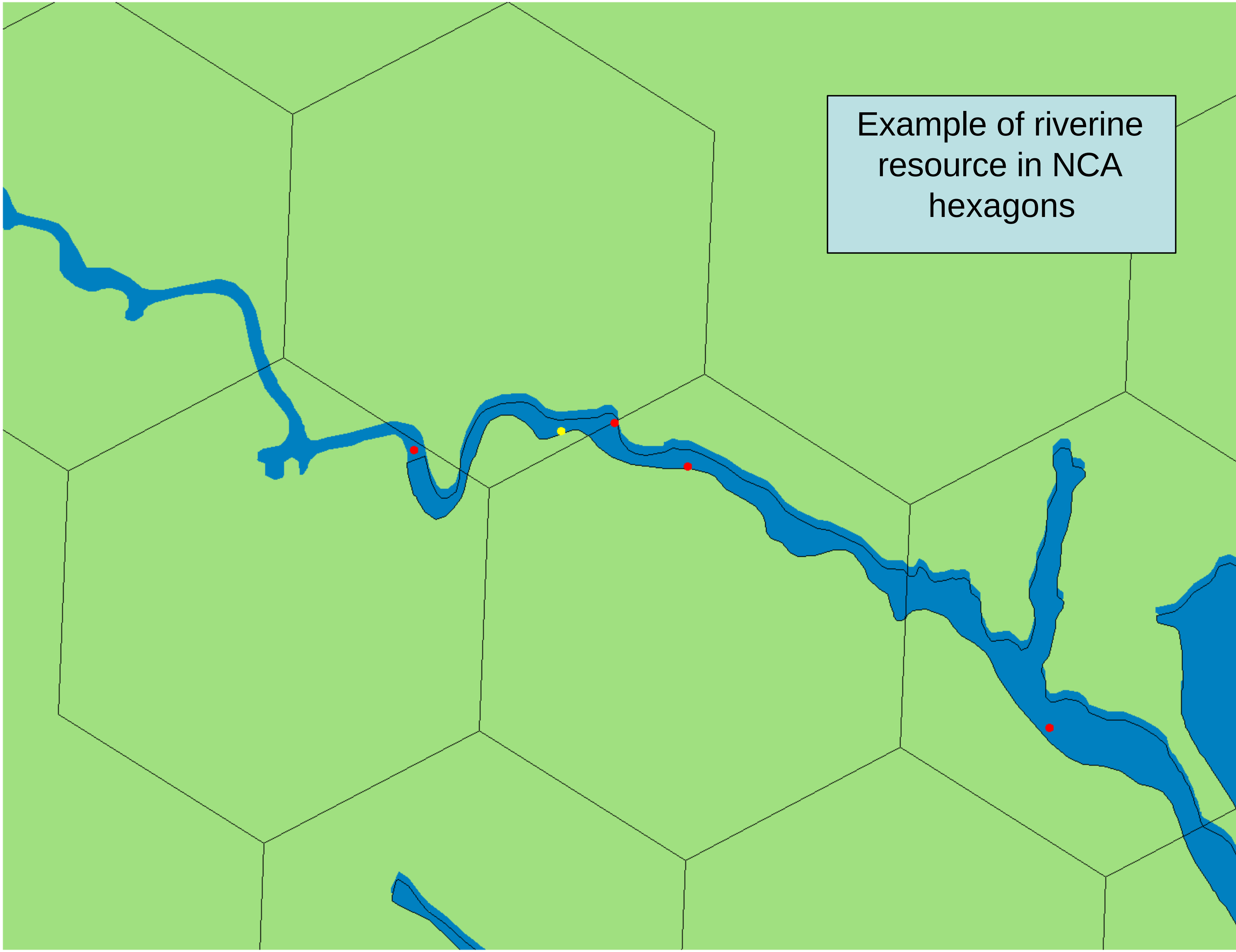
- With 82 NCA stations for the 18 miles of NH coastline, we would expect tight confidence intervals on the results.
- However, the Horvitz-Thompson Estimator algorithm produced very large error bars on our estimates.

Mercury in Sediment in NH's Estuaries



Variance estimates for percent of NH's estuaries <ERL for Hg

Scenario	LCL	UCL	CI	Error Bar
Original	35.55%	74.34%	38.80%	19.40%
Orginial with Area X1000	35.55%	74.34%	38.80%	19.40%
Original with Area X0.001	35.55%	74.34%	38.80%	19.40%
Smallest 10 Removed	38.90%	71.92%	33.03%	16.51%
Largest 10 Removed	36.71%	65.38%	28.67%	14.33%
Smallest and Largest 10 Removed	41.25%	63.14%	21.89%	10.94%
Medians	43.23%	53.27%	10.04%	5.02%


Example of riverine resource in NCA hexagons

Possible Causes for High Variance

- Is the recommended algorithm for variance calculations correct for the situation in NH? The jury is still out. Something is not quite right here.

<u>Other issues</u>

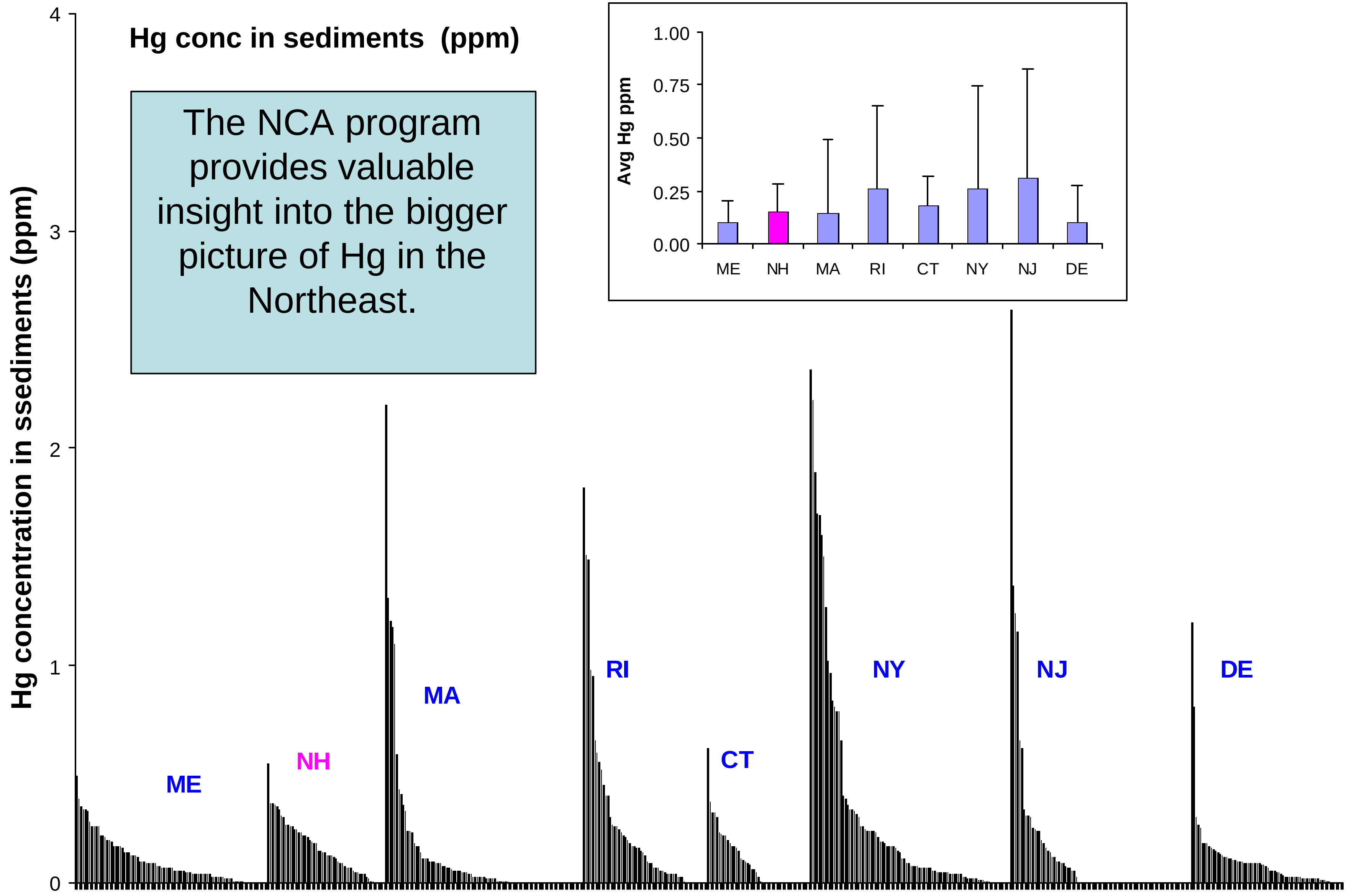
- Samples in NH are not independent because of scale
  - New analysis methods might be needed to address spatial autocorrelation.
- Are hexagons the appropriate sampling design for the resource in NH?
  - Most NH hexagons are <50% resource
  - Median %resource in a hex is 18%

What does this all mean?

Practical advice for managers

Value of the NCA Approach

- Provides unbiased comparisons of conditions between states.
- Provides accurate representation of median values of a parameter at the state and regional level.
- Cost-effective monitoring strategy for assessing 100% of surface waters for §305(b) reporting.


Hg conc in sediments (ppm)
The NCA program provides valuable insight into the bigger picture of Hg in the Northeast.
Hg concentration in ssediments (ppm)
4
3
2
1
0
ME
NH
MA
RI
CT
NY
NJ
DE
Avg Hg ppm
1.00
0.75
0.50
0.25
0.00
ME NH MA RI CT NY NJ DE

Potential Problems with the NCA Approach at Small Scales

- For stations <20 km apart, autocorrelation is likely. May violate assumption of independence.
- Inflated variance/confidence intervals can develop at small spatial scales. Possible errors in variance estimator algorithm at this scale.
- **State managers need to consider these factors when using NCA data or data from small scale PBMs for CWA reporting requirements.**

Questions/Comments

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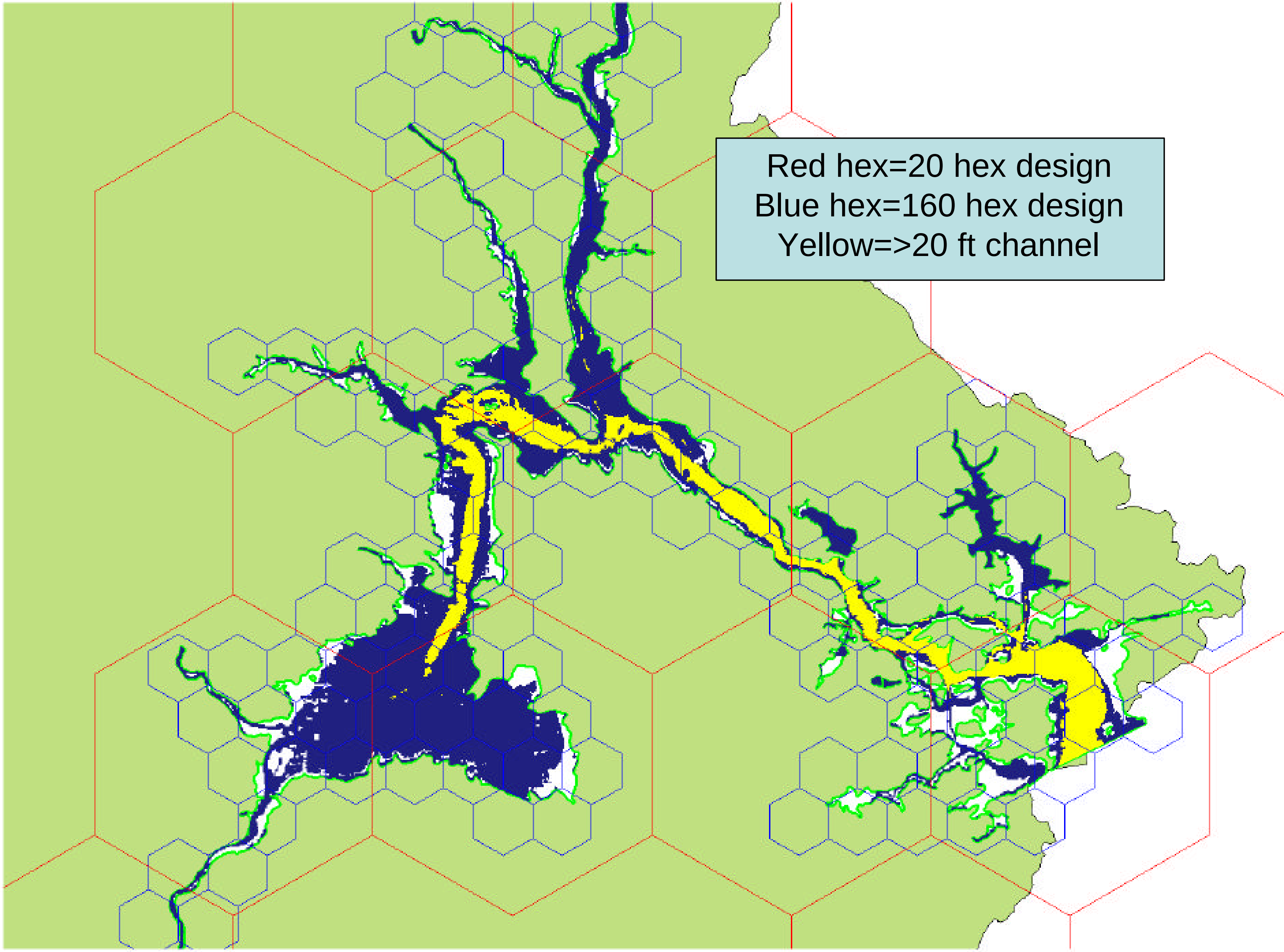
Extra slides in case questions come up…

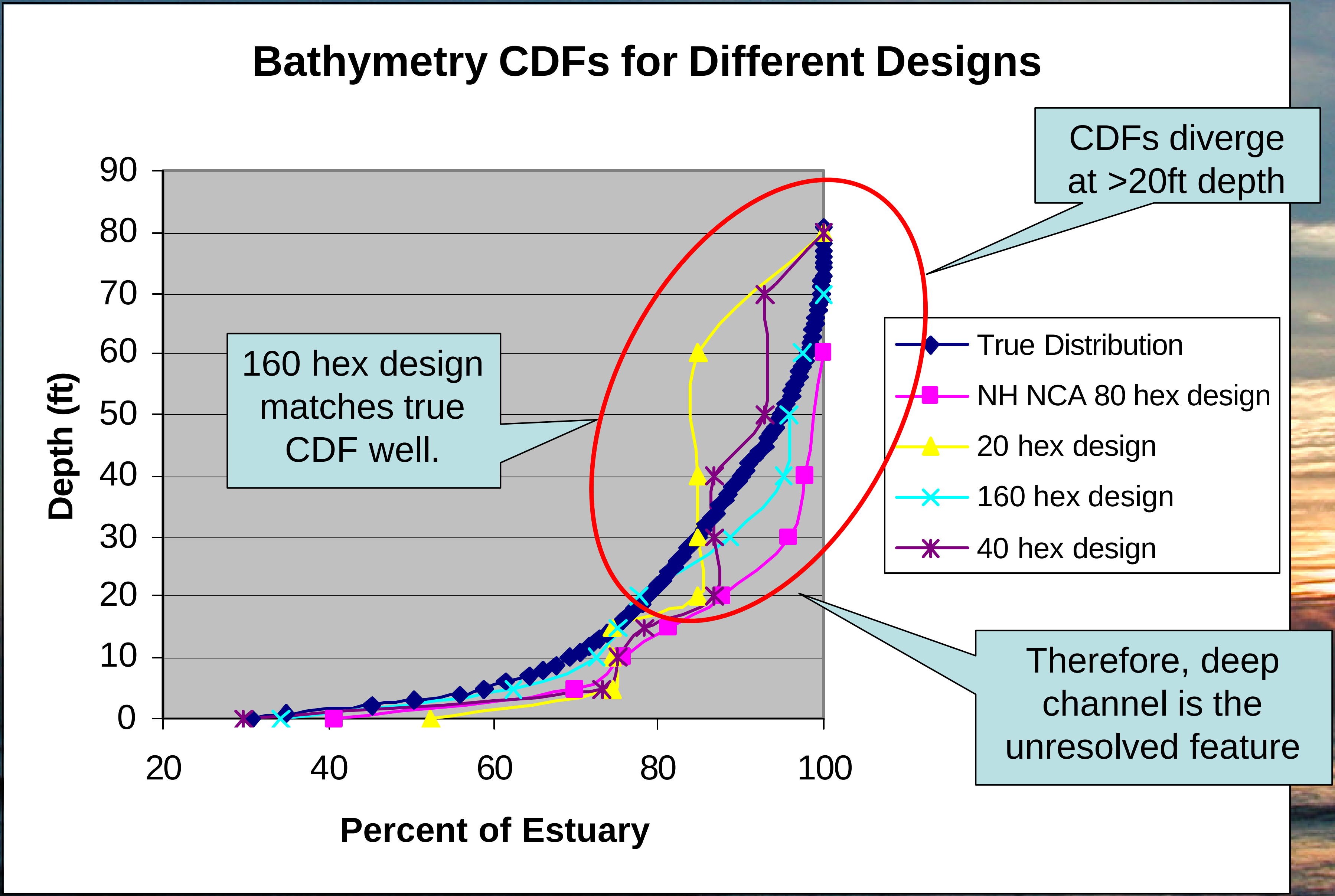
Resolution of Spatial Features

What hex size is needed?

Methods

- “Sampled” bathymetry coverage to determine estimated CDFs for different hex sizes.
- Compared estimated CDFs to “true” CDF.
- Identified unresolved features and relationship to hex size


Red hex=20 hex design
Blue hex=160 hex design
Yellow=>20 ft channel


Bathymetry CDFs for Different Designs
CDFs diverge at >20ft depth
160 hex design matches true CDF well.
Therefore, deep channel is the unresolved feature
Depth (ft)
0
10
20
30
40
50
60
70
80
90
20
40
60
80
100
Percent of Estuary
True Distribution
NH NCA 80 hex design
20 hex design
160 hex design
40 hex design

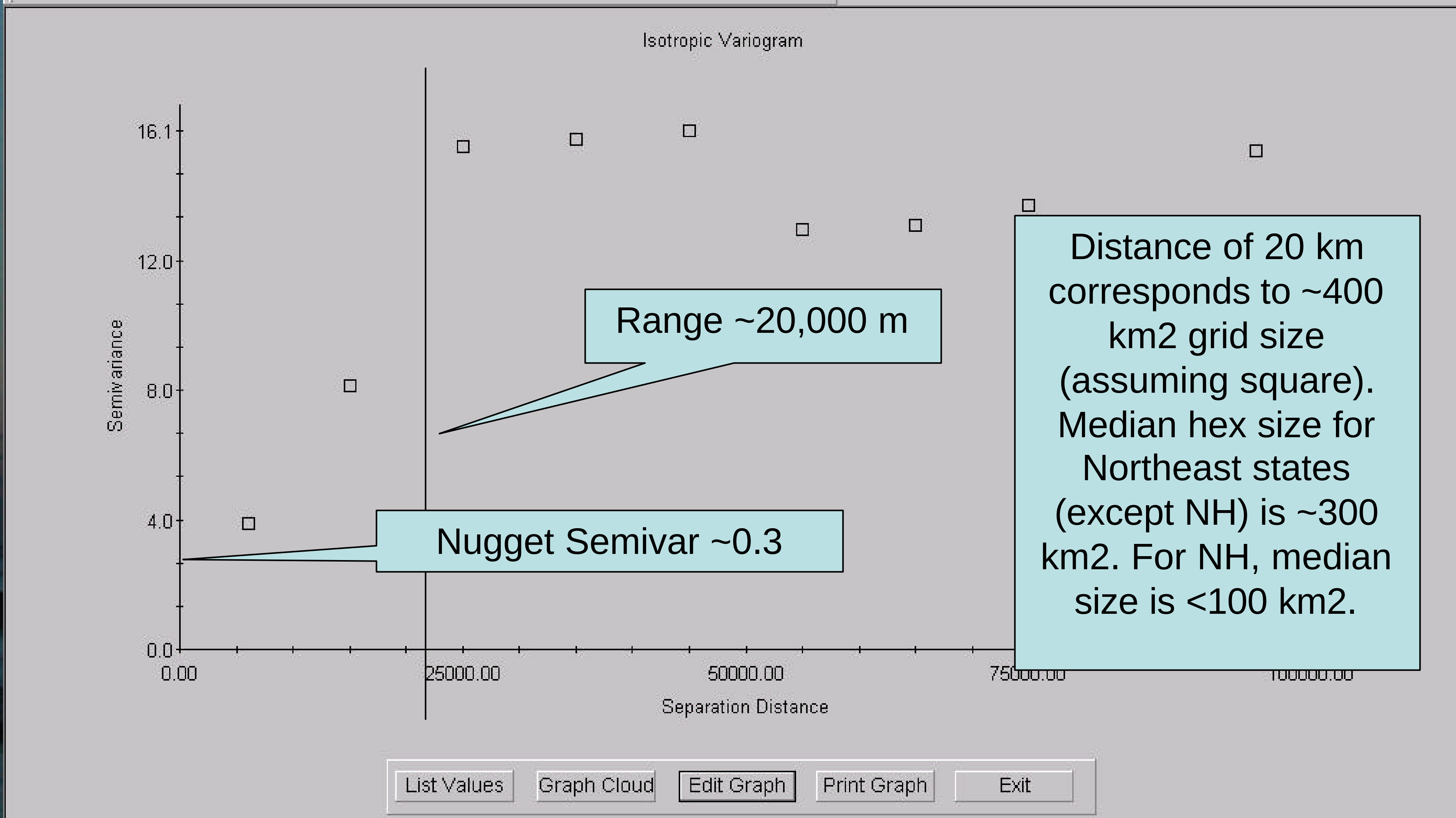
Percent of hex covered by unresolved feature

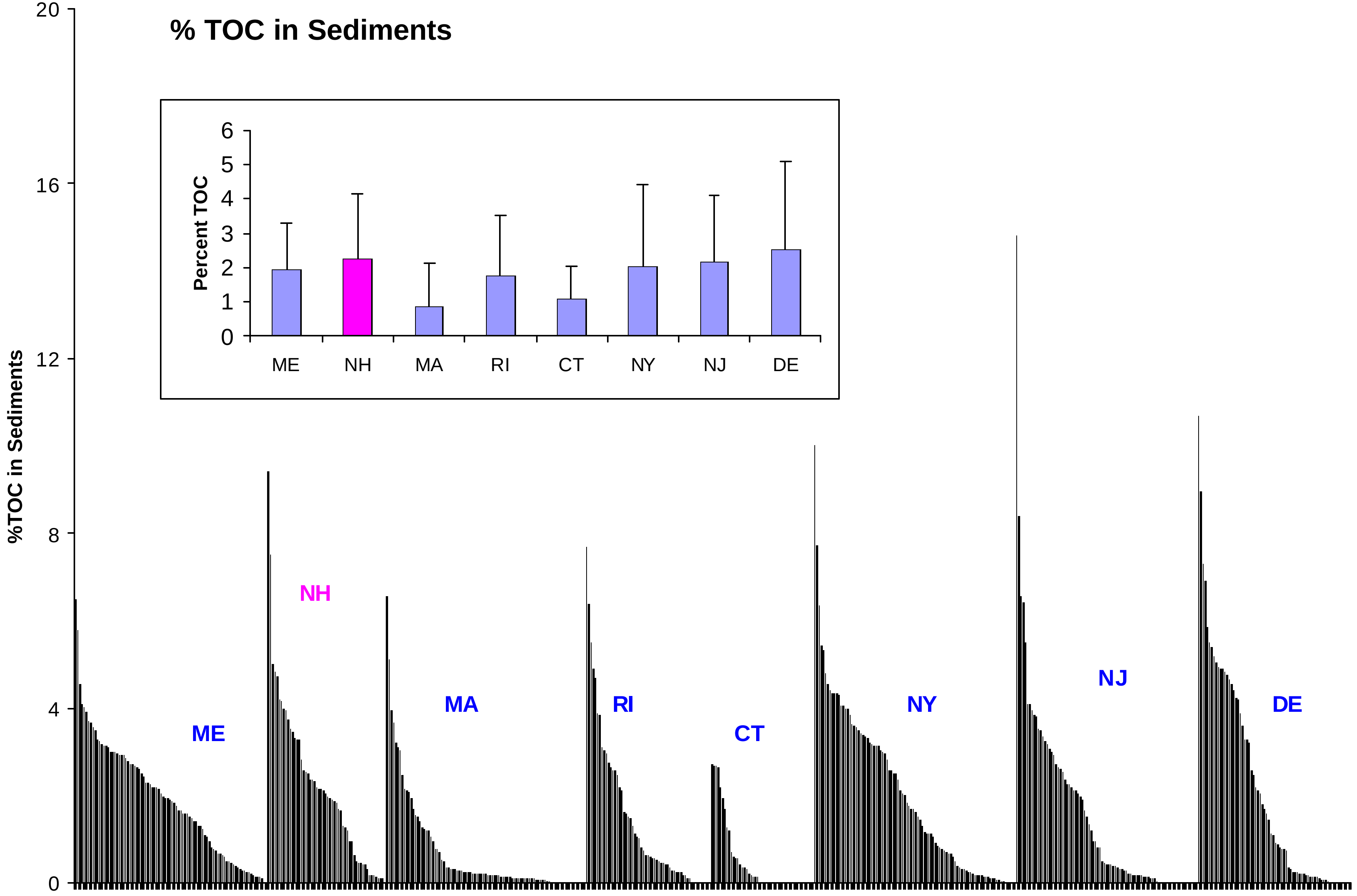
Study Design	% of Resource Area with >20 ft depth
20 hexs	17%
40 hexs	23%
80 hexs (NH NCA)	25%
160 hexs	32% (able to resolve feature)

Spatial Resolution Conclusions

- In this case, to resolve a given bathymetric feature, need hexagons that are ~1/3 filled by the feature.
- This result may not be translatable to other cases/situations.
- Could generate a rule of thumb if this result were repeated with different parameters in different locations.

Semivariogram for Ln [Hg] for the Northeast (DE through ME)





% TOC in Sediments
%TOC in Sediments
20
16
12
8
4
0
Percent TOC
6
5
4
3
2
1
0
ME
NH
MA
RI
CT
NY
NJ
DE
ME
NH
MA
RI
CT
NY
NJ
DE