Trophic Analysis and Modeling

Partnership of

VIMS, FWS, URS, CEBAM

Vantage

Nomothetic (deriving general rules/models)
Not ideographic (not explaining all particulars)

Goal

Create tool to understand and predict mercury movement to at-risk biota (including humans eating fish)

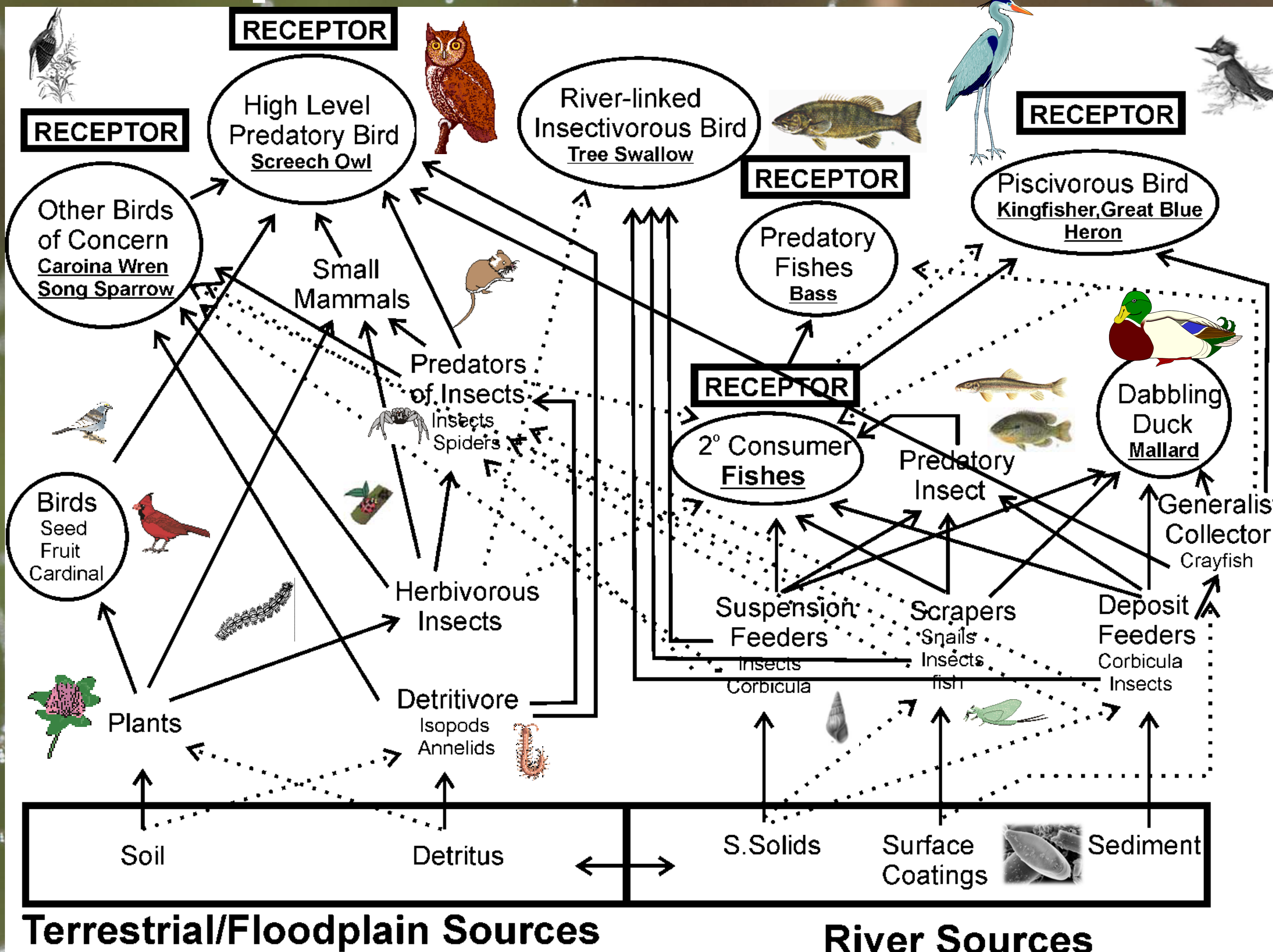
Premise

Once mercury enters the biota, its most important movements to understand involve trophic exchange.

Technique/Approach

N and C isotopes facilitate understanding of mercury movement in trophic webs

Trophic Web Framework



Quantification

Isotopic discrimination in biochemical processes reduces the amount of lighter isotopes (^{12}C, ^{14}N) in organisms relative to that of the heavier isotopes (^{13}C, ^{15}N)

1. **Models with N isotope trophic discrimination**
2. **Mixture models/polygons to understand resource use**

Nitrogen isotopes work best for trophic position
Carbon isotopes work best to identify sources

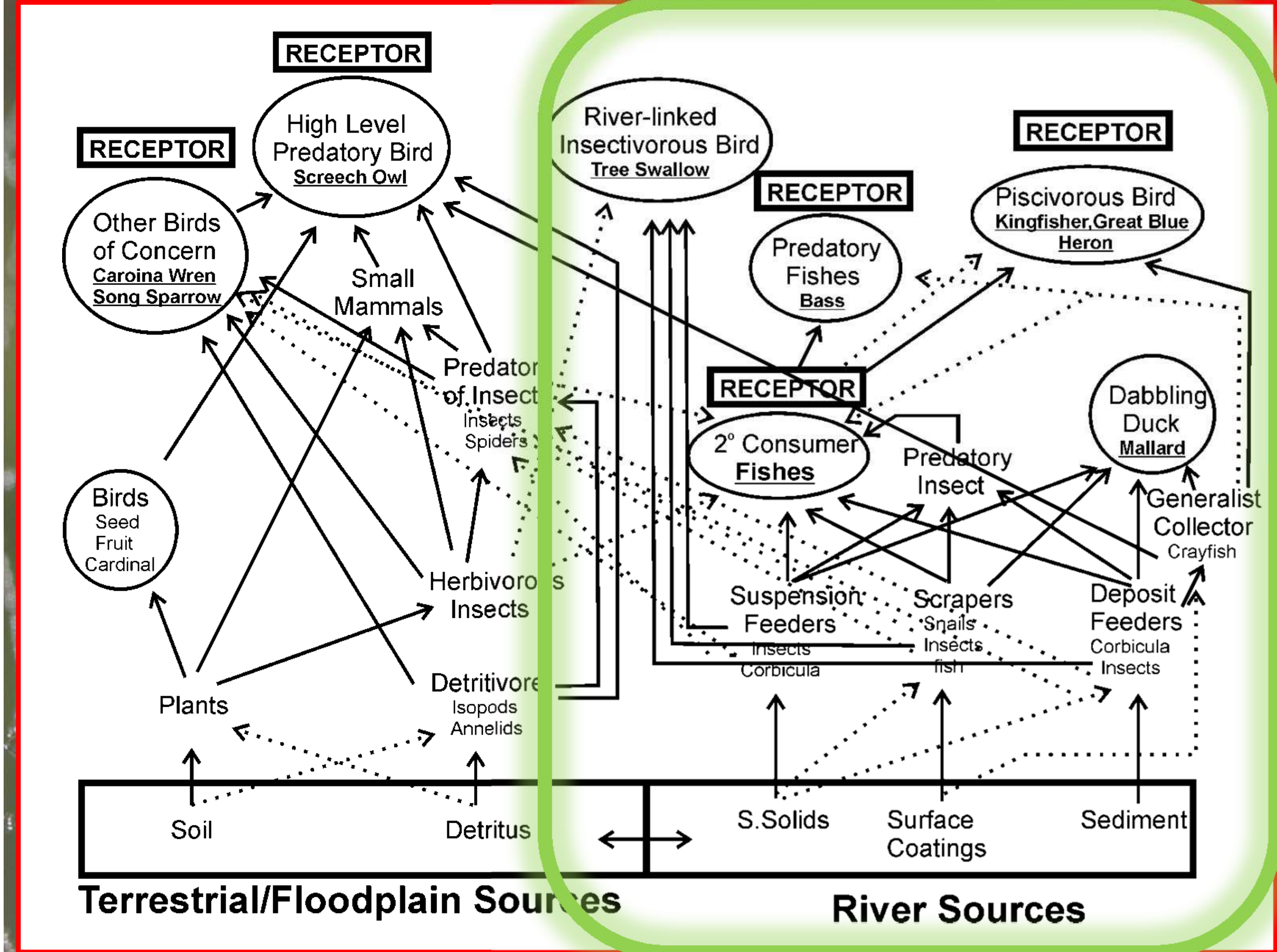
$$[Hg]_i = 10^{a+b\delta^{15}N_i} = 10^a 10^{b\delta\ ^{15}N_i}$$

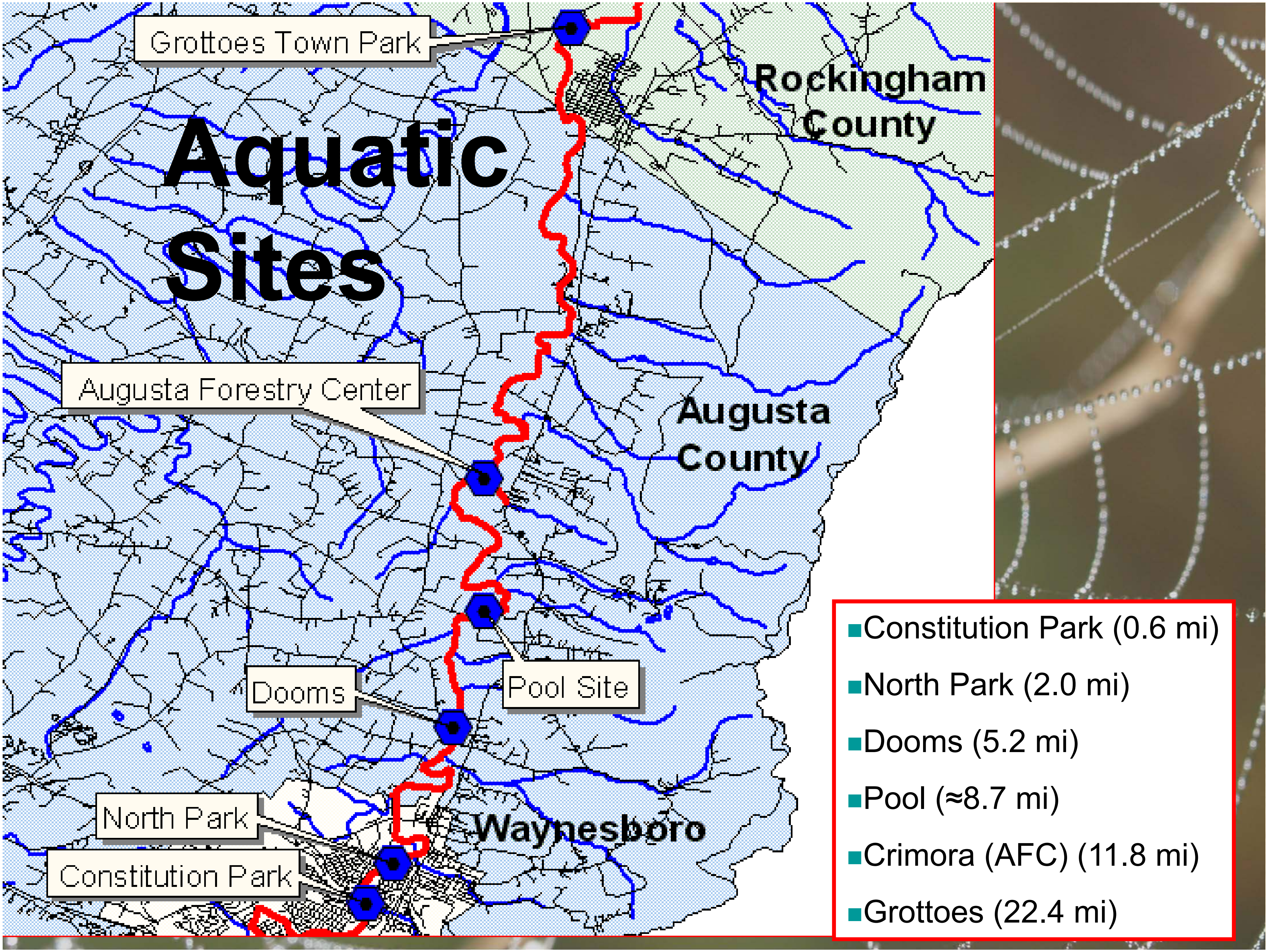
Baseline

Biomagnification

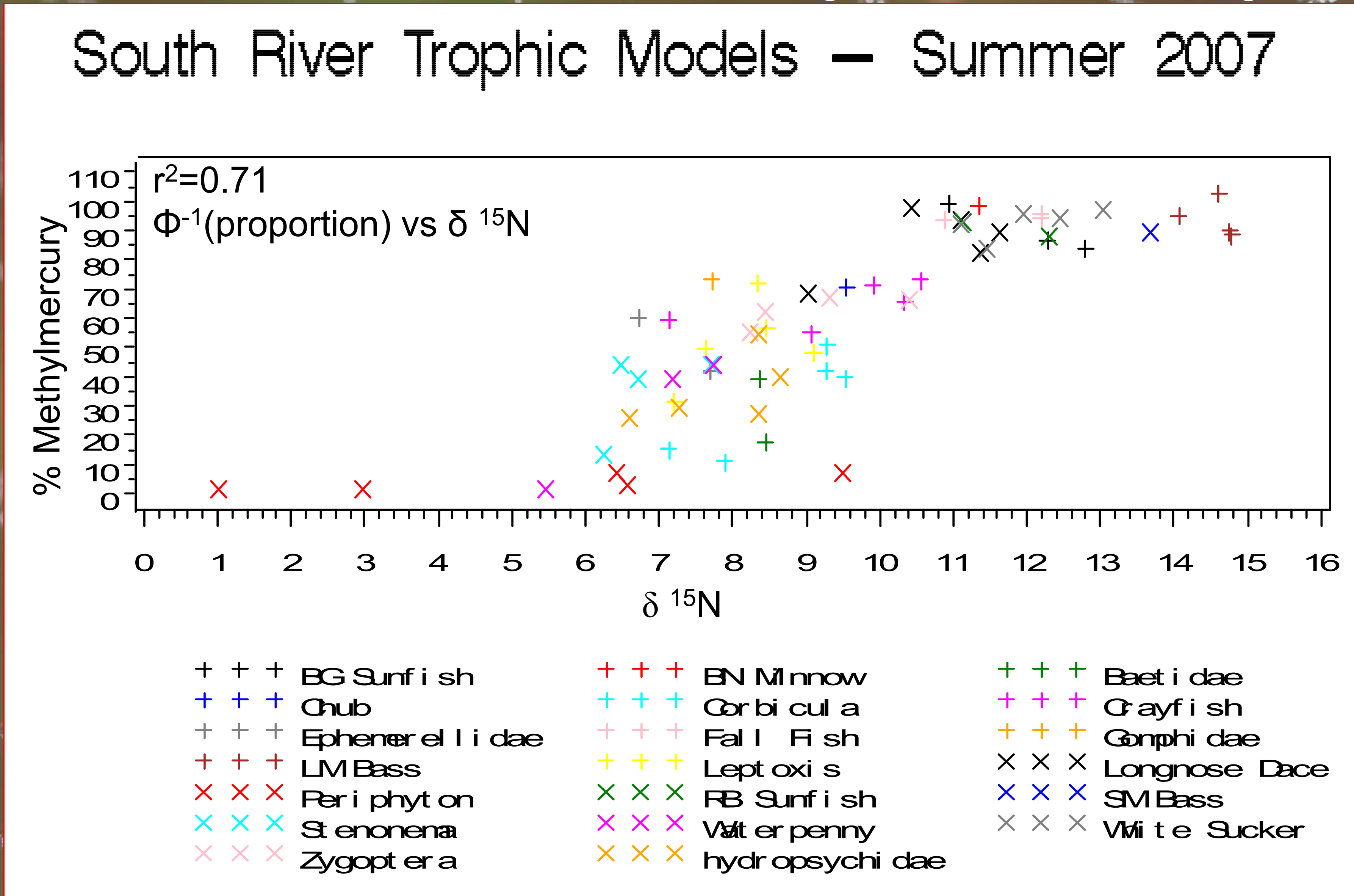
I. Aquatic Component

Trophic Transfer Models

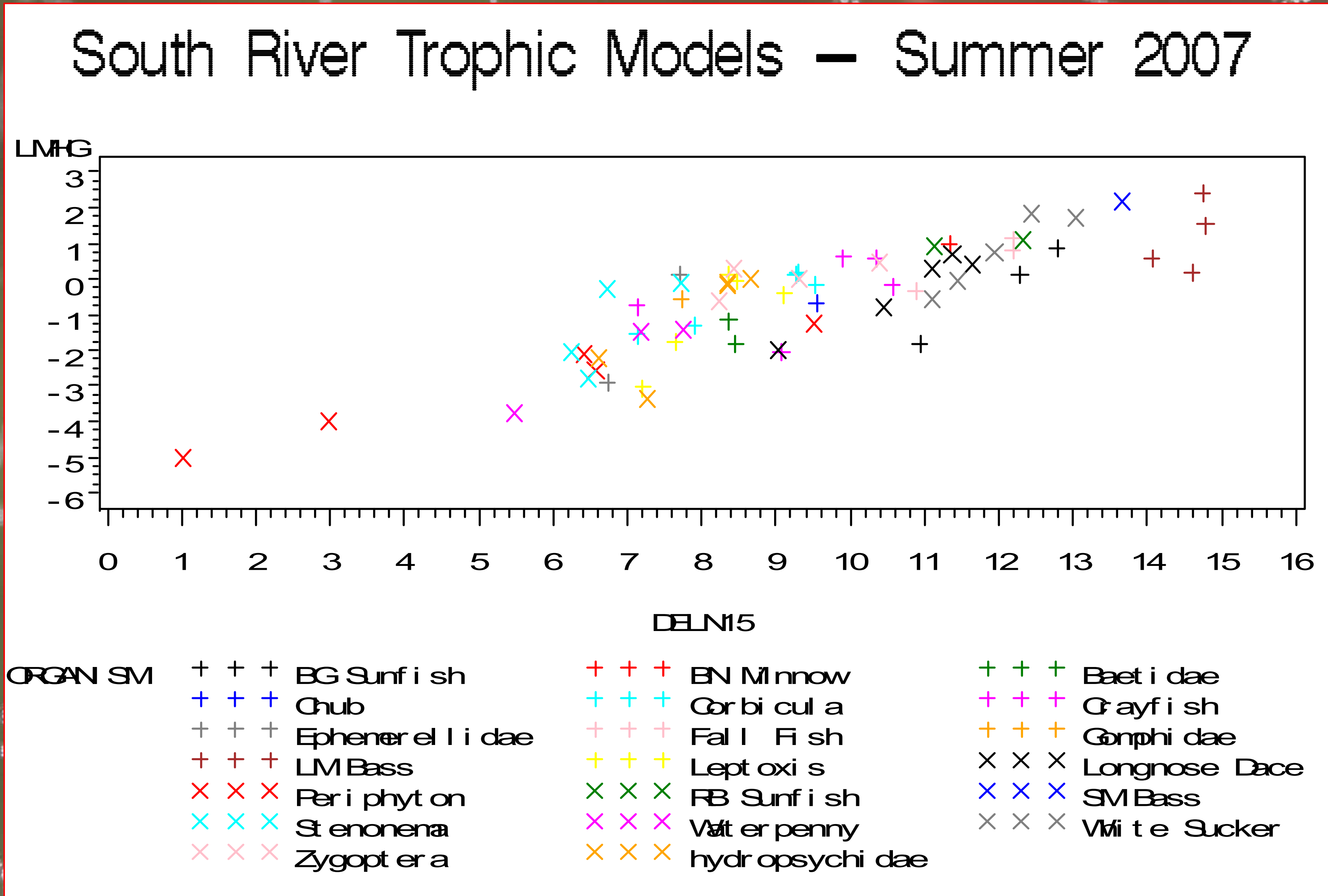



Aquatic Sites
Grottoes Town Park
Rockingham County
Augusta Forestry Center
Augusta County
Pool Site
Dooms
North Park
Constitution Park
Waynesboro
■Constitution Park (0.6 mi)
■North Park (2.0 mi)
■Dooms (5.2 mi)
■Pool (≈8.7 mi)
■Crimora (AFC) (11.8 mi)
■Grottoes (22.4 mi)

Fraction Methylmercury



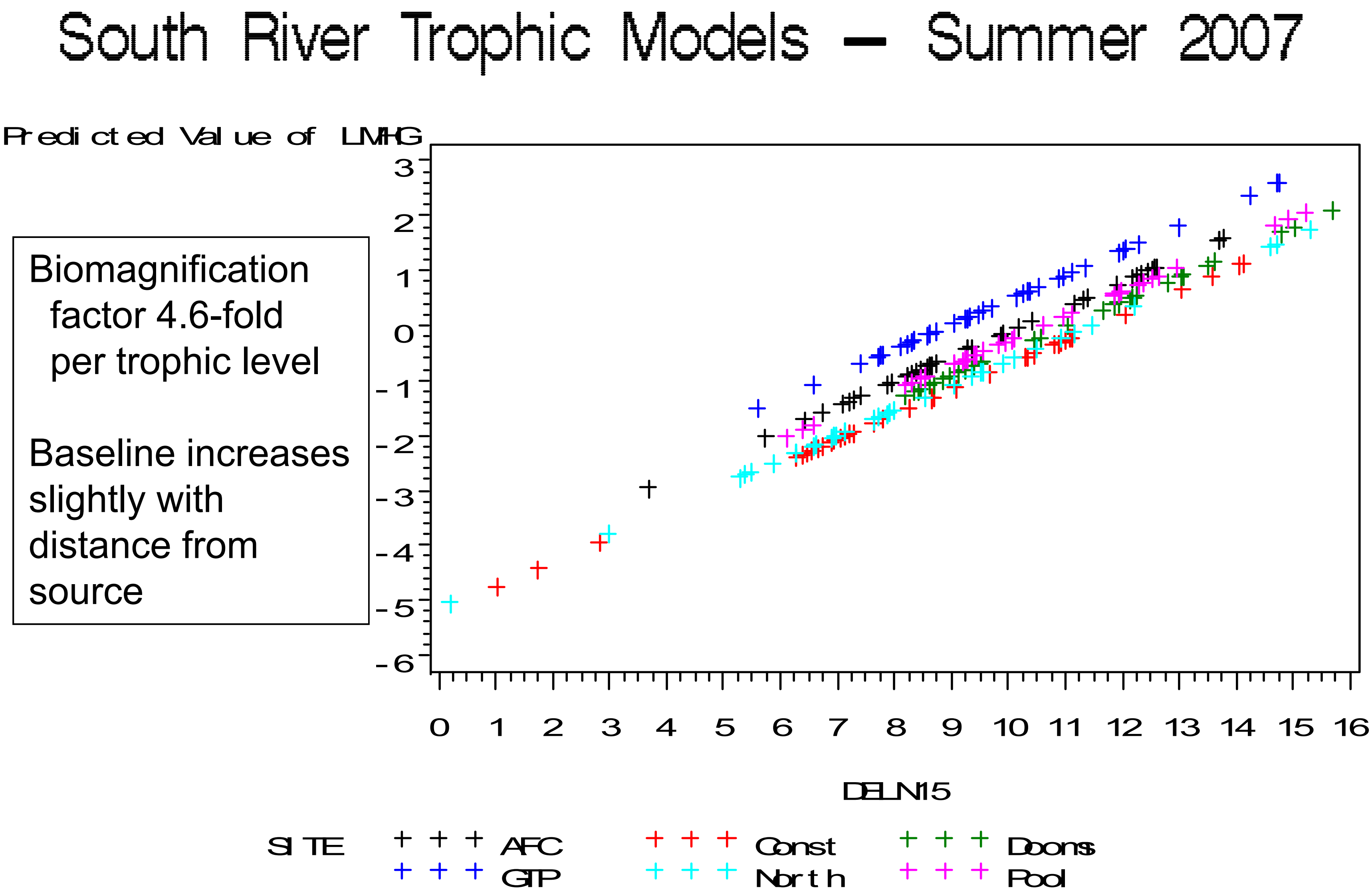
Methylmercury - Aquatic



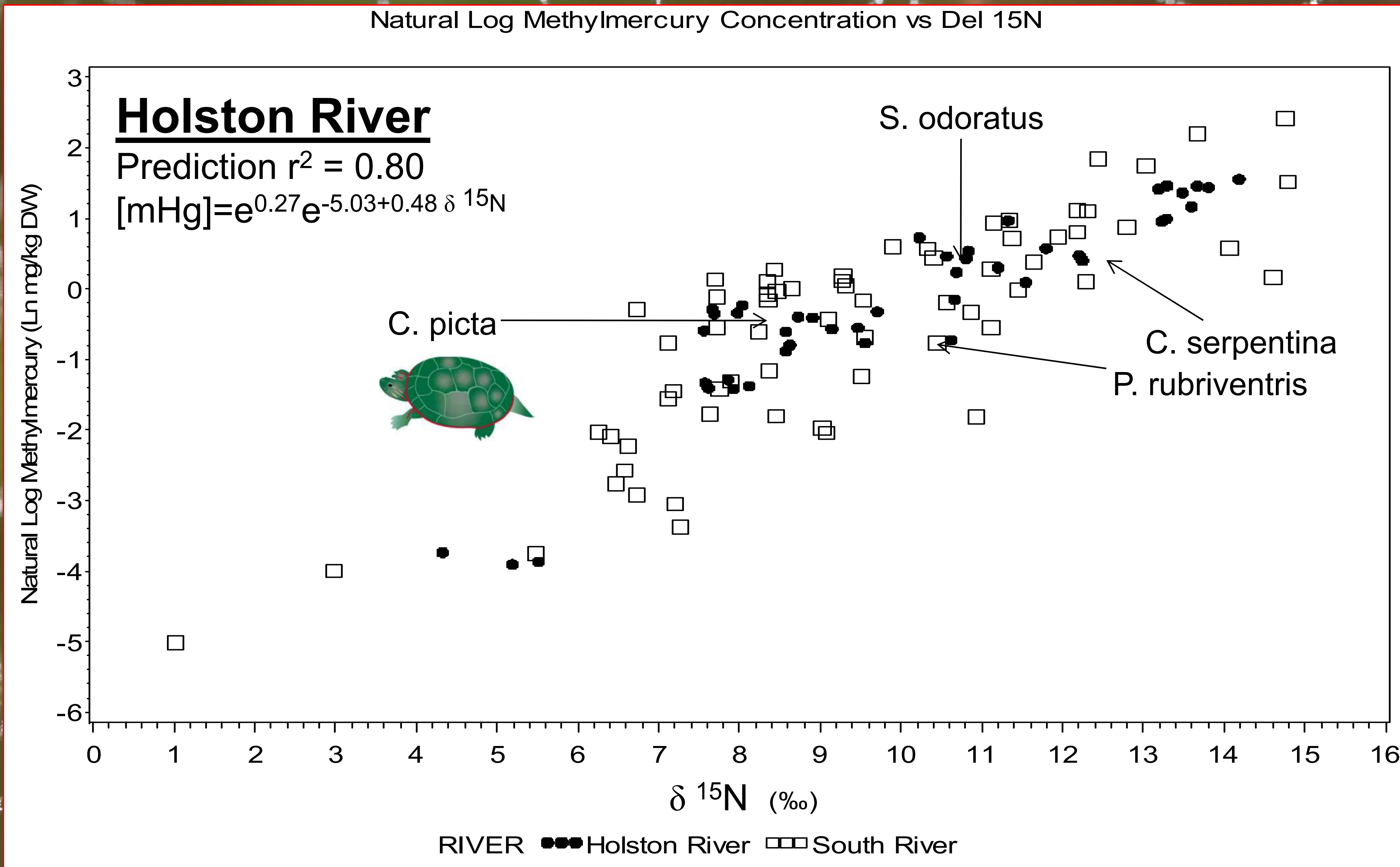
Methylmercury - Aquatic

Biomagnification factor 4.6-fold per trophic level

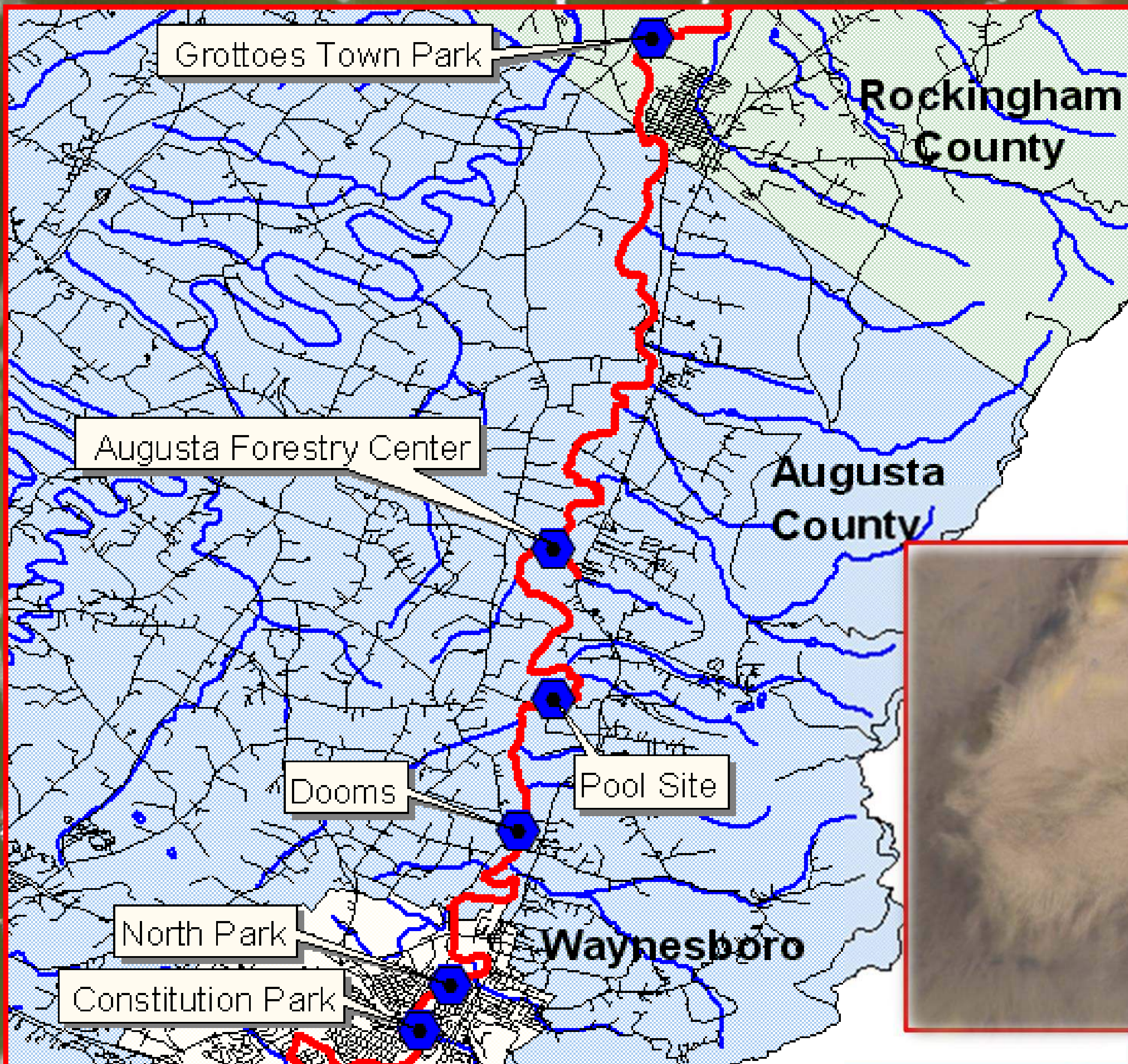
Baseline increases slightly with distance from source



Methylmercury – Two Rivers Combined

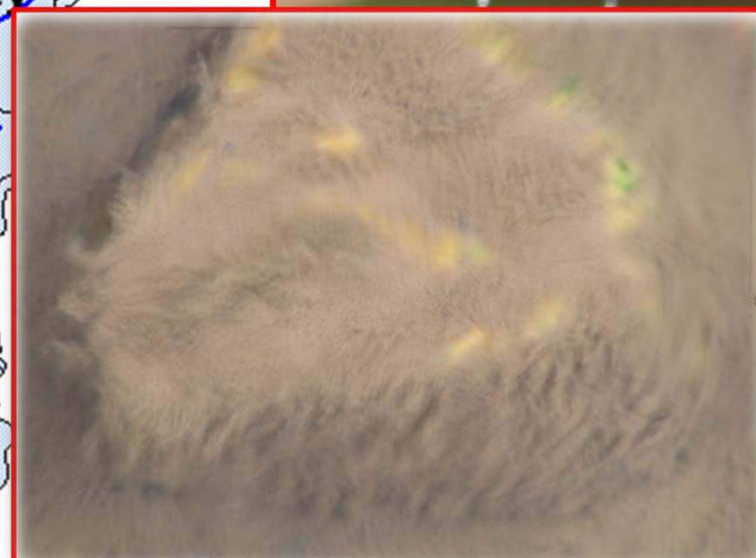


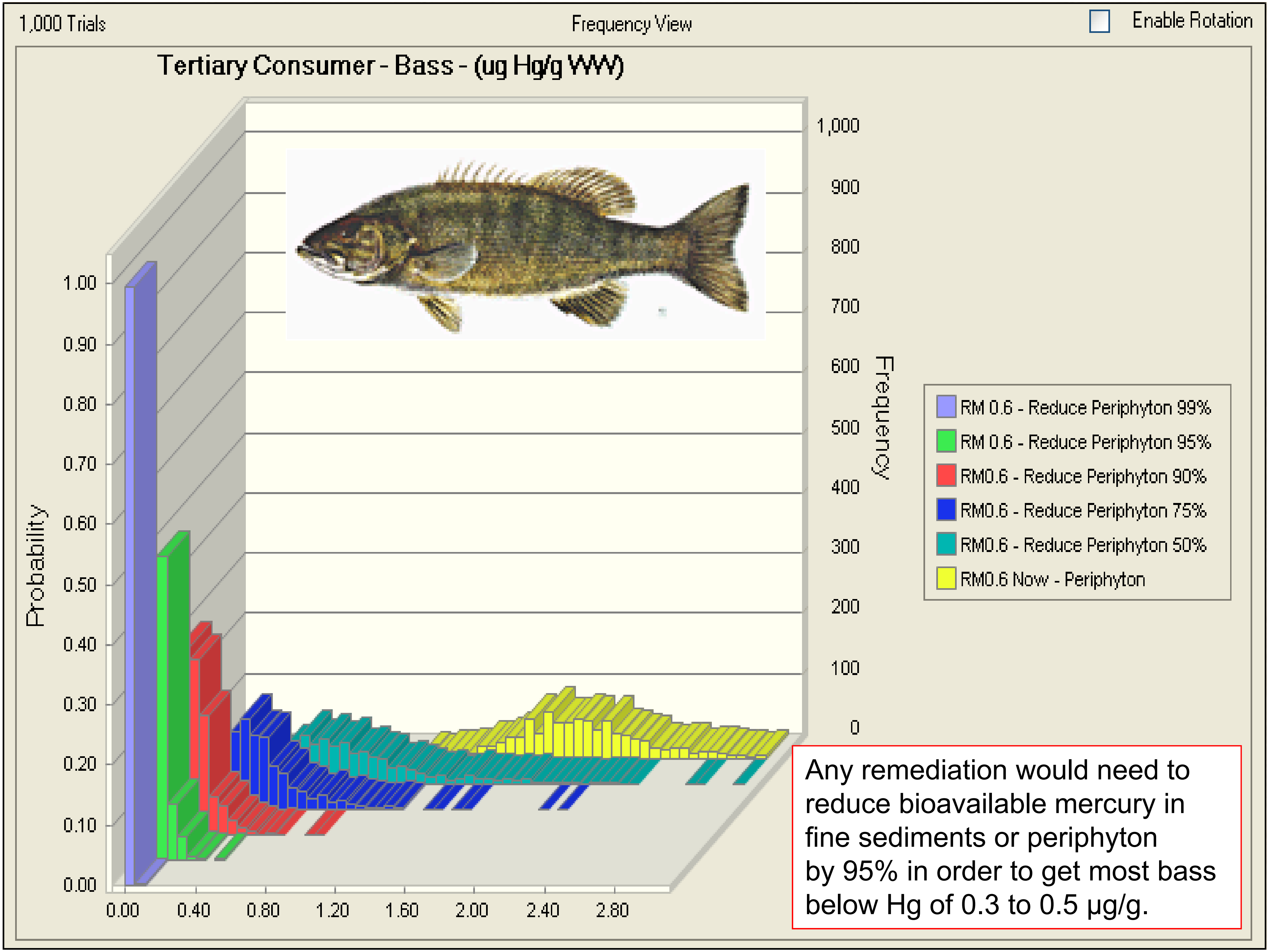
Biota Linked to Solids in 2008



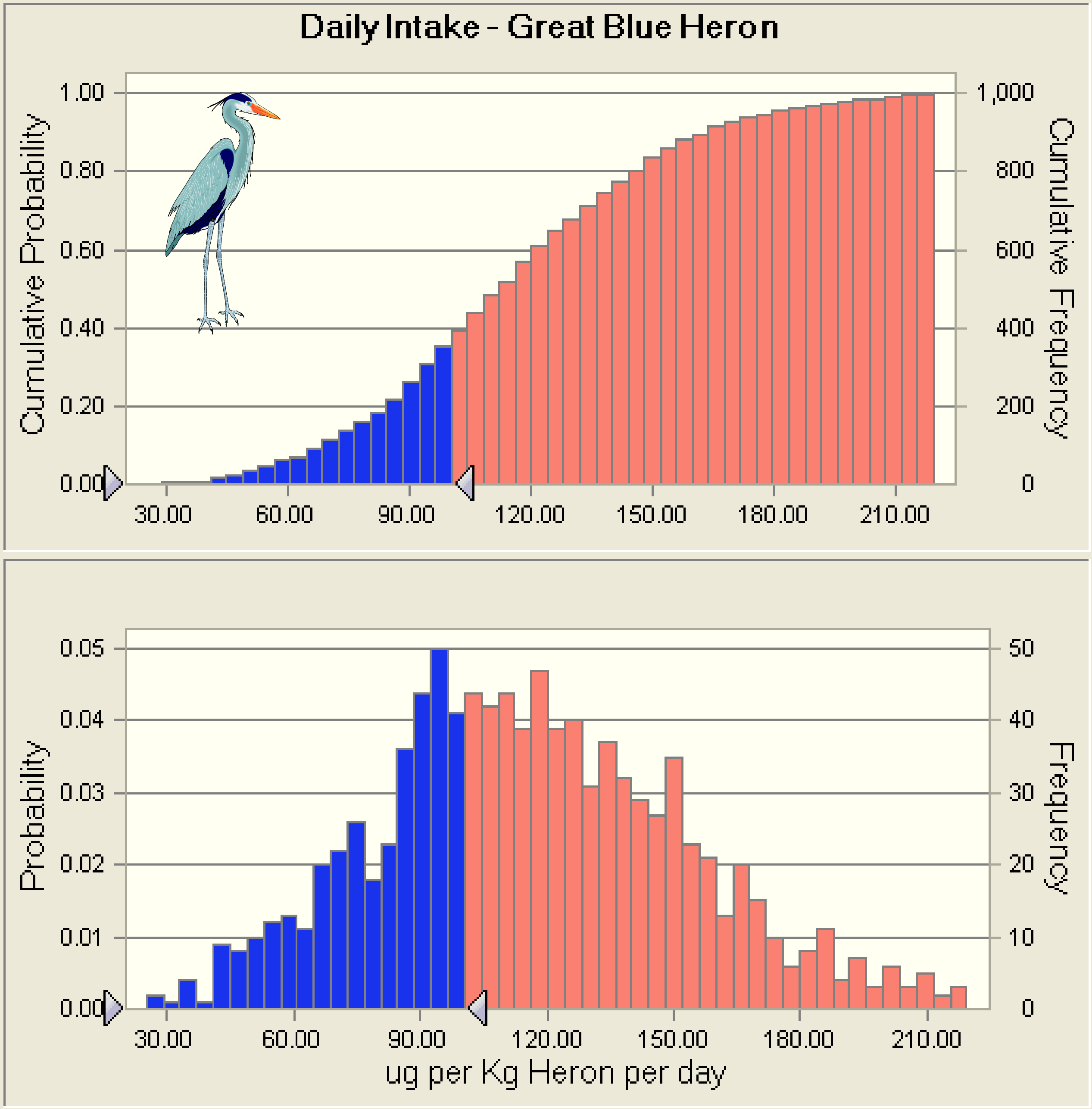
6 Locations
Samples
- Settled Sediments
- Nat. Sediments
- Nat. Periphyton
- Art. Periphyton

Link biota to
Suspended solids
& surficial sediments




1,000 Trials
Frequency View
Enable Rotation
Tertiary Consumer - Bass - (ug Hg/g WW)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
Frequency
1,000
900
800
700
600
500
400
300
200
100
0
RM 0.6 - Reduce Periphyton 99%
RM 0.6 - Reduce Periphyton 95%
RM0.6 - Reduce Periphyton 90%
RM0.6 - Reduce Periphyton 75%
RM0.6 - Reduce Periphyton 50%
RM0.6 Now - Periphyton
Any remediation would need to reduce bioavailable mercury in fine sediments or periphyton by 95% in order to get most bass below Hg of 0.3 to 0.5 µg/g.

1,000 Trials | Split View | 997 Displayed



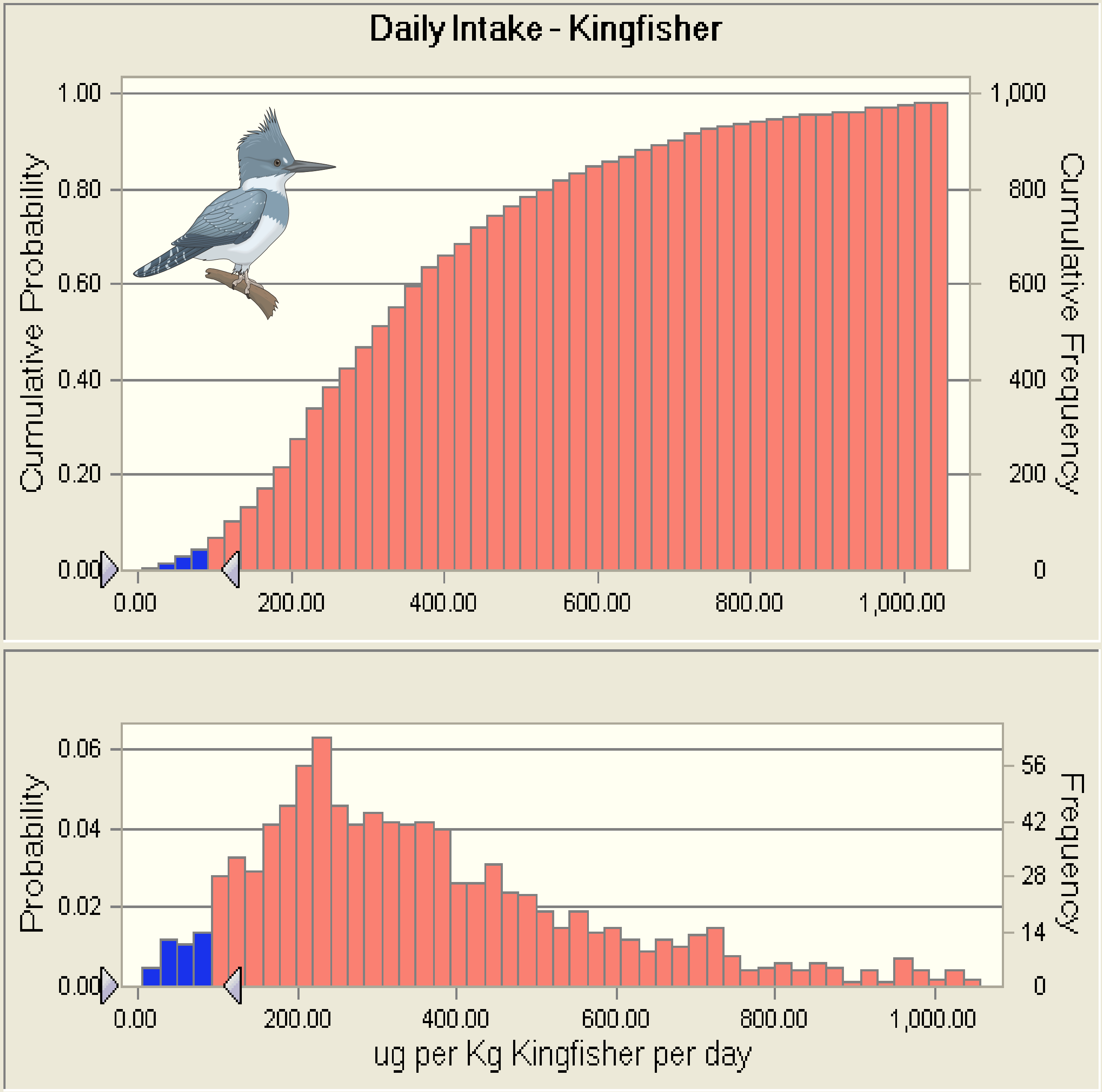
Statistic	Forecast values
Trials	1,000
Mean	116.50
Median	114.30
Mode	---
Standard Deviation	36.73
Variance	1,349.11
Skewness	0.3099
Kurtosis	3.00
Coeff. of Variability	0.3153
Minimum	25.10
Maximum	258.68
Mean Std. Error	1.16

Toxicity Ref. Value (TRV):
Circa 65 to 100 ug/kg bw-day

Great Heron, Bald Eagle, Wood Stork PRA
78 (LOAEL), 26 (NOAEL)
(Ecotox.17:632, 2008)

0.10 Certainty: 34.90 % 100.12

1,000 Trials | Split View | 980 Displayed



Statistic	Forecast values
Trials	1,000
Mean	377.98
Median	319.57
Mode	---
Standard Deviation	242.51
Variance	58,810.02
Skewness	1.38
Kurtosis	5.33
Coeff. of Variability	0.6416
Minimum	4.59
Maximum	1,466.90
Mean Std. Error	7.67

Toxicity Ref. Value (TRV):
Circa 65 to 100 ug/kg bw-day

Great Heron, Bald Eagle, Wood Stork PRA
78 (LOAEL), 26 (NOAEL)
(Ecotox.17:632, 2008)

0.10 | Certainty: 5.34 % | 100.75

Significance

- Trophic dynamics determine relative [mHg] in biota
- Trophic dynamics can be predicted quantitatively
- Effectiveness needed in any remedial activities is near 95%
- Likely, a mixture of activities needed
- Avian piscivores potentially impacted, esp. kingfisher
  - Nesting sites limiting for kingfisher in this reach
  - Compensate by building artificial nesting berms/sites

- TROPHIC MANIPULATIONS
  - Modify river to favor sport fish feeding lower in food web* (trout)
  - Shift sports fishing focus to lower trophic level species
  - Modify Hg (esp. MHg) input into food web base
  - Modify river to shift
    - possible trophic cascade dynamics
    - keystone/dominant species
    - Invertebrate/forage fish prey (Δ substrate/hydrology/SAV)

*Swanson et al. 2006. Env. Sci. Technol. 40(5):1439-1446
Lepak et al. 2009. Ecotoxicol. DOI 10,1007/s10646-009-0306-5

Phase II Study
Define Present Trophic Linkages

<u>Simple 1 Isotope and 2 Sources</u>

$$\delta^{13}C_{Consumer} = f_{Source\,A}\,\delta^{13}C_{Source\,A} + f_{Source\,B}\,\delta^{13}C_{Source\,B}$$

$$1 = f_{Source\,A} + f_{Source\,B}$$

-23 -24.5 -26.5

Periphyton Waterpenny Sediments

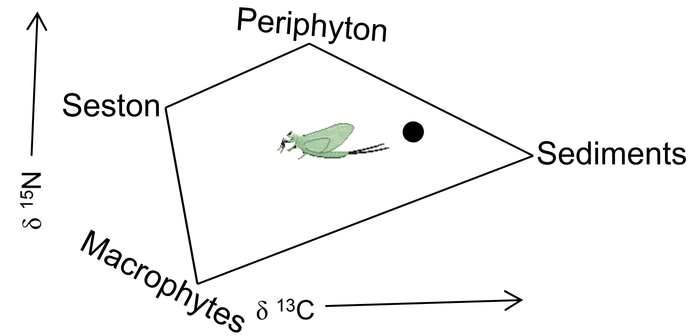
$$f_{Periphyton} = \frac{\delta^{13}C_{Waterpenny} - \delta^{13}C_{Sediments}}{\delta^{13}C_{Periphyton} - \delta^{13}C_{Sediments}} = 0.57$$

BUT $\delta^{13}C$ of consumer adjusted for trophic-related changes?

0.8 /TL (Rounick/Winterbourn 1986), 0.4/TL (Post 2002), 0.11/TL for Inverts (Caut et al. 2009)

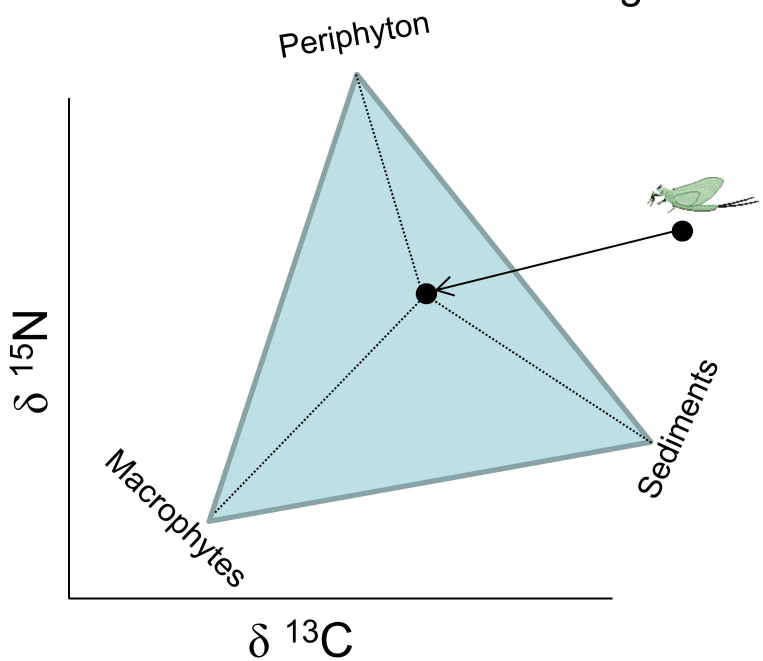
$$f_{Periphyton} = \frac{(\delta^{13}C_{Waterpenny} - 0.8) - \delta^{13}C_{Sediments}}{\delta^{13}C_{Periphyton} - \delta^{13}C_{Sediments}} = 0.34$$

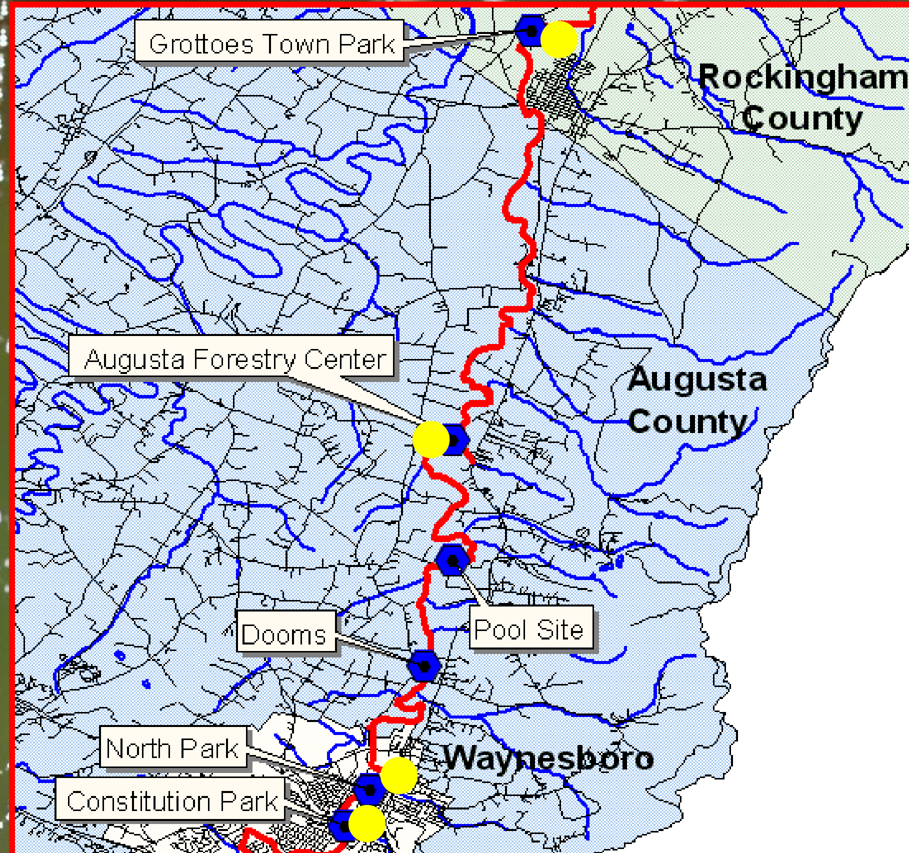
Minimally Define with Polygon



2 Isotopes and 3 Sources

Estimates three source fractions
Also include sources' [C] and [N]
EPA IsoConc Excel Add-in Program

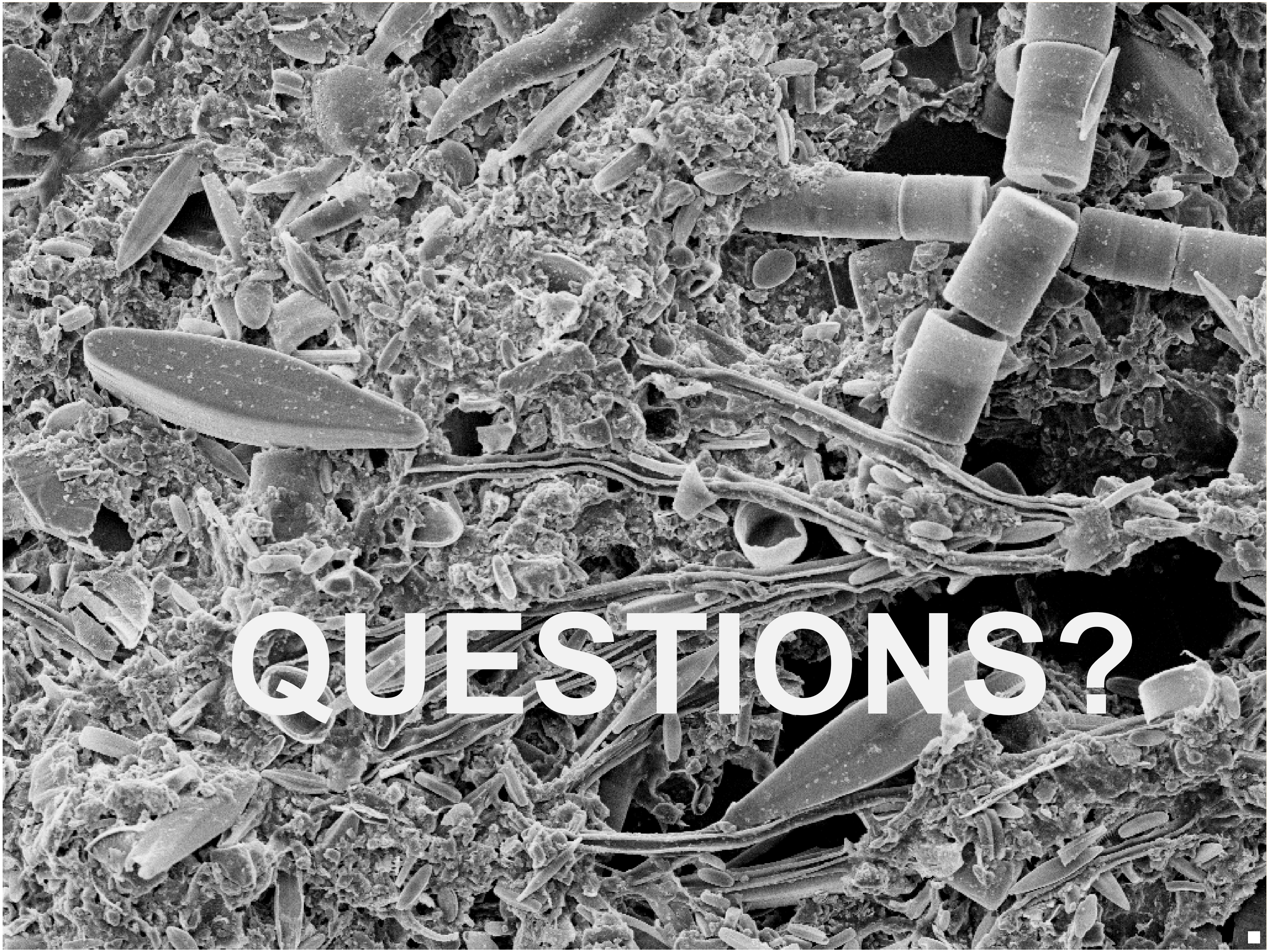




SAMPLINGS
May/June
August
Oct/Nov

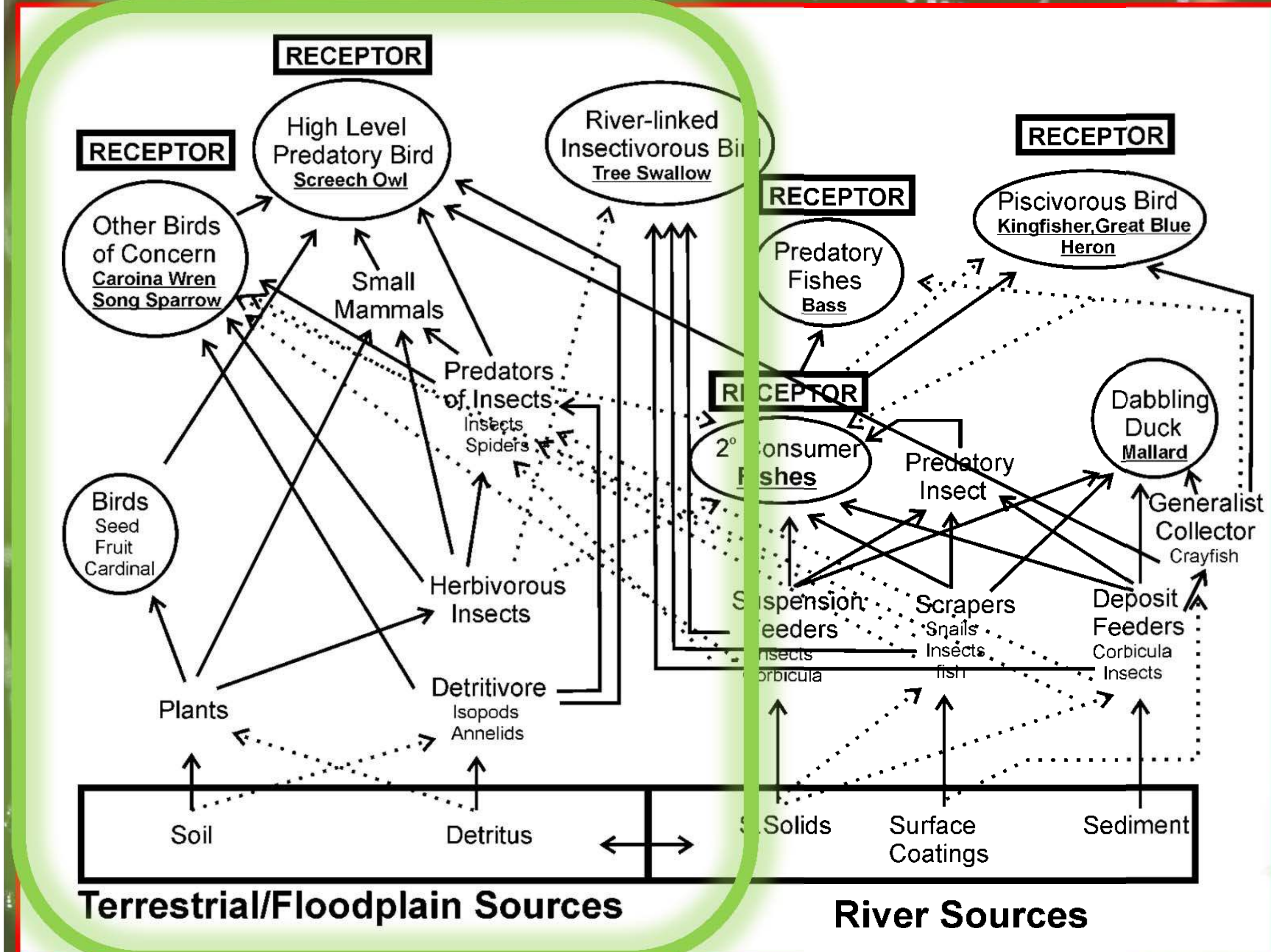
SOURCES
Periphyton
Sediment/Seston
Macrophytes

BIOTA
Baetidae
Ephmerellidae
Heptageniidae
Hydropsychidae
Crayfish
Forage fish species
Small/Largemouth Bass

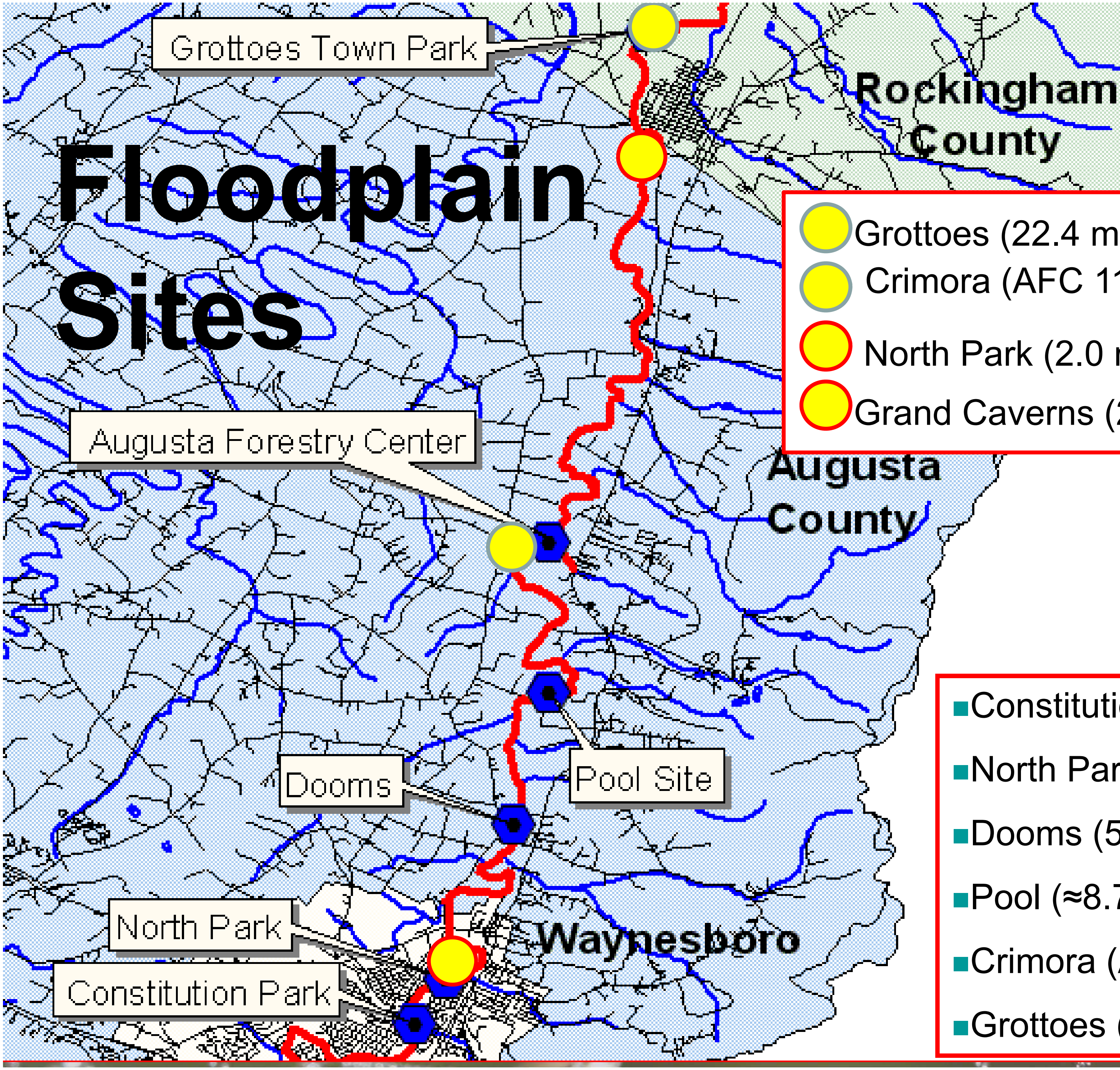

QUESTIONS?


II. Floodplain Food Web

Floodplain Component



Floodplain Sites



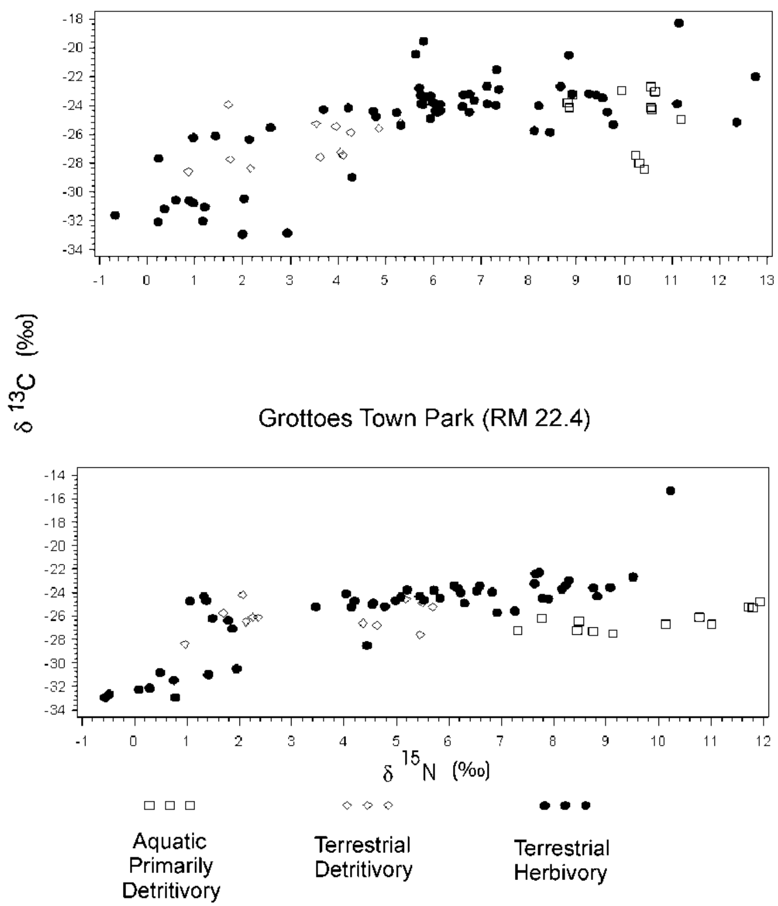
- Grottoes (22.4 mi) 2009
- Crimora (AFC 11.8) 2009
- North Park (2.0 mi) 2010
- Grand Caverns (20 mi) 2010

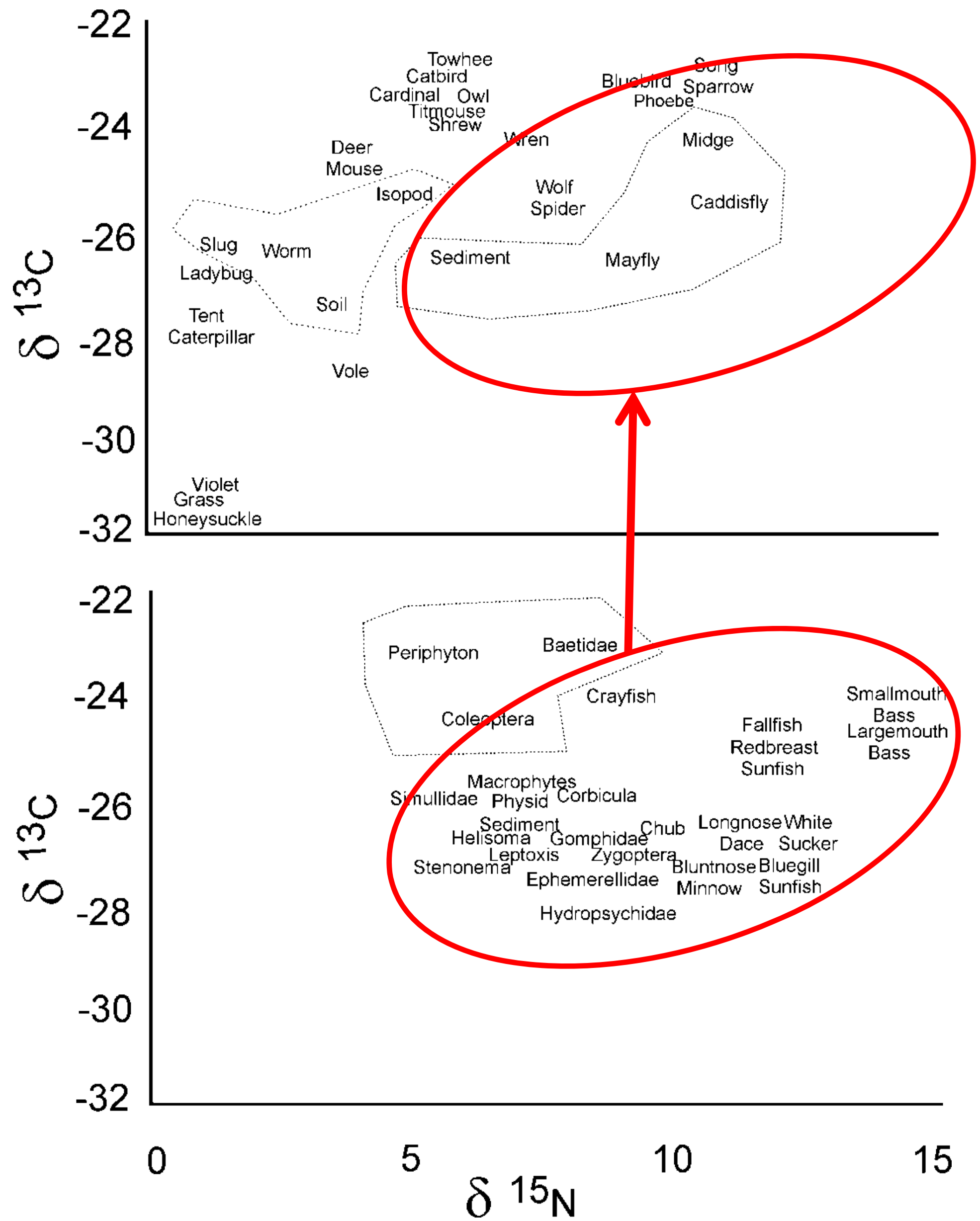
- Constitution Park (0.6 mi)
- North Park (2.0 mi)
- Dooms (5.2 mi)
- Pool (≈8.7 mi)
- Crimora (AFC) (11.8 mi)
- Grottoes (22.4 mi)

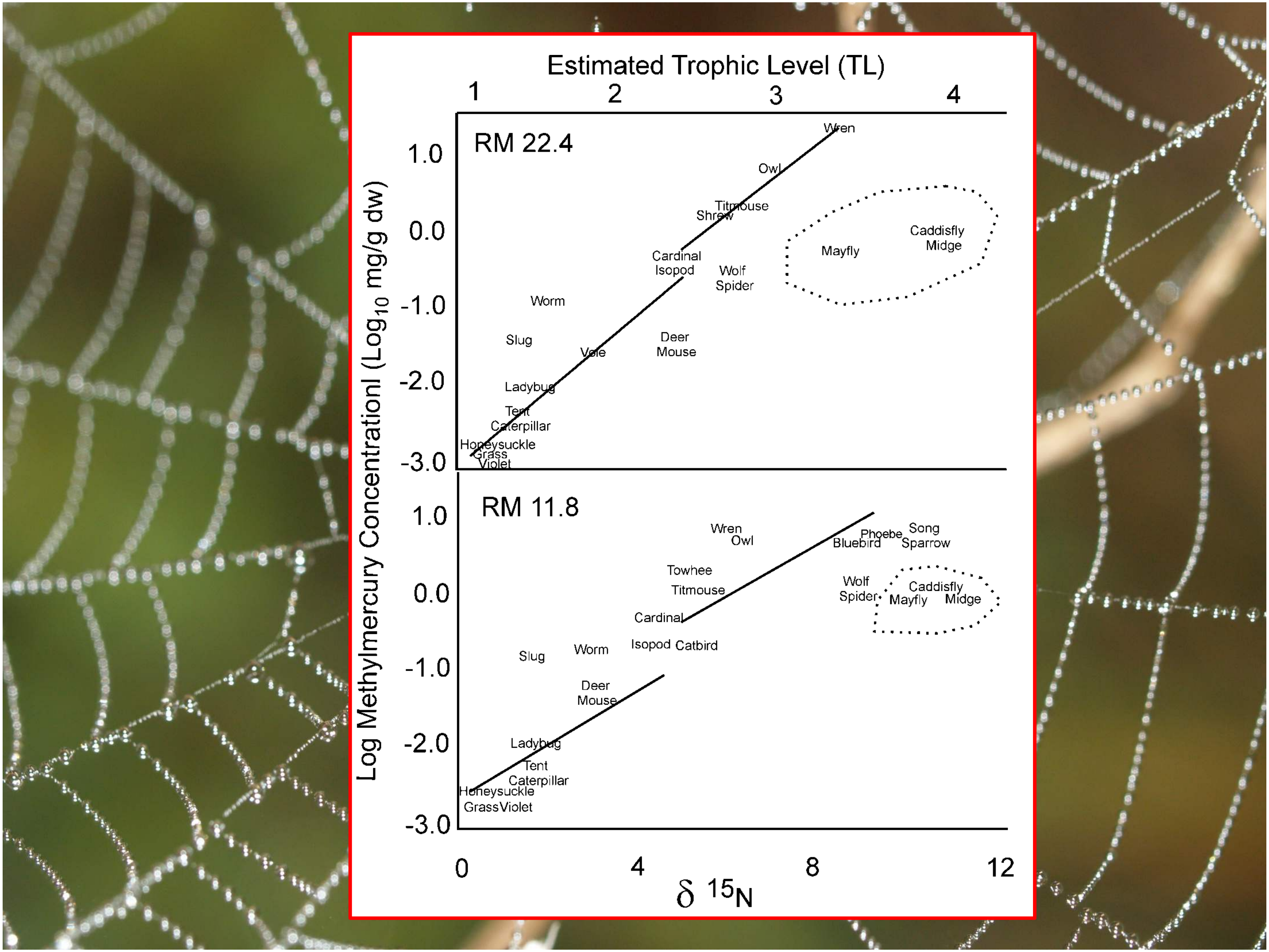
2009

Adjacent to Augusta Forestry Center (RM 11.8)

Grottoes Town Park (RM 22.4)







Estimated Trophic Level (TL)
1
2
3
4
Log Methylmercury Concentrationl (Log10 mg/g dw)
RM 22.4
1.0
0.0
-1.0
-2.0
-3.0
Wren
Owl
Titmouse
Shrew
Cardinal
Isopod
Wolf
Spider
Caddisfly
Midge
Mayfly
Worm
Slug
Vole
Deer
Mouse
Ladybug
Tent
Caterpillar
Honeysuckle
Grass
Violet
RM 11.8
1.0
0.0
-1.0
-2.0
-3.0
Wren
Owl
Phoebe
Bluebird
Song
Sparrow
Towhee
Titmouse
Wolf
Spider
Caddisfly
Mayfly
Midge
Cardinal
Isopod
Catbird
Slug
Worm
Deer
Mouse
Ladybug
Tent
Caterpillar
Honeysuckle
Grass
Violet
0
4
8
12
δ 15N

$$\log_{10}[Hg \text{ or } MHg] = a + b\,\delta^{15}N + c(RM \text{ or } MS) + \epsilon$$

Mercury and Methylmercury Models (terrestrial herbivory-related samples after excluding feathers).

	r^2	a (95% CI)	b (95% CI)	c (95% CI)	MSE	$r^2_{Prediction}$
			TOTAL MERCURY			
$\delta^{15}N$						
RM 11.8	0.70	-1.47 (-1.76 to -1.18)	0.20 (0.14 to 0.27)	0.37 (-0.04 to 0.78)	0.274	0.53
RM 22.4	0.75	-1.82 (-2.11 to -1.54)	0.29 (0.21 to 0.37)	0.14 (-0.31 to 0.58)	0.241	0.62
TL						
RM 11.8	0.70	-2.03 (-2.44 to -1.62)	0.69 (0.48 to 0.91)	0.37 (-0.04 to 0.78)	0.274	0.53
RM 22.4	0.75	-2.63 (-3.08 to -2.17)	0.98 (0.70 to 1.26)	0.14 (-0.30 to 0.58)	0.241	0.62
			METHYLMERCURY			
$\delta^{15}N$						
RM 11.8	0.83	-2.66 (-2.99 to -2.34)	0.29 (0.21 to 0.36)	0.89 (0.43 to 1.34)	0.343	0.79
RM 22.4	0.87	-3.11 (-3.42 to -2.82)	0.41 (0.32 to 0.50)	0.55 (0.08 to 1.03)	0.273	0.85
River	0.78	-2.26 (-2.55 to -1.98)	0.19 (0.16 to 0.22)	0.02 (0.01 to 0.03)	0.100	0.76
TL						
RM 11.8	0.83	-3.45 (-3.91 to -3.00)	0.97 (0.73 to 1.21)	0.89 (0.43 to 1.35)	0.343	0.79
RM 22.4	0.87	-4.26 (-4.74 to -3.77)	1.40 (1.10 to 1.70)	0.55 (0.08 to 1.03)	0.273	0.85
River	0.78	-1.09 (-1.23 to -0.94)	0.66 (0.56 to 0.76)	0.02 (0.01 to 0.03)	0.100	0.76

Terrestrial models:c = 0 for poikilotherms or the shown parameter estimate for homeotherms. River model: c = the effect of downriver distance from the historic source (RM 0). The number of observations in the river, AFC09, and GTP models was 66, 43, and 40, respectively, for total and methylmercury models. The river model was generated for 6 locations from RM 0.6-22.4.

Methylmercury Food Web Magnification Factors (FWMF in fold increase per TL)

River 4.6

(Similar to Holston & general literature)

Floodplain RM 11.8 .... 9.3 (14.8?)

Floodplain RM 22.84 .... 25.1

"FASTER ON LAND"

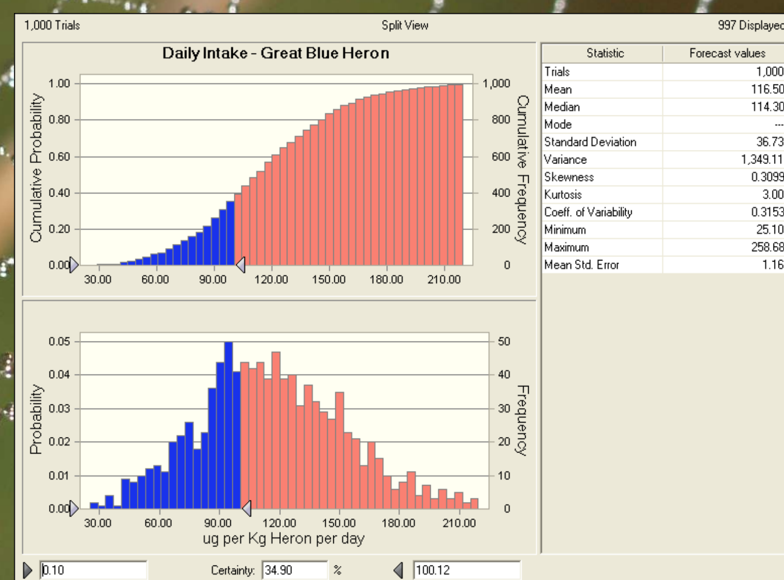
Birds – Exposure Assessment

Carolina Wren, Song Sparrow and Screech Owl

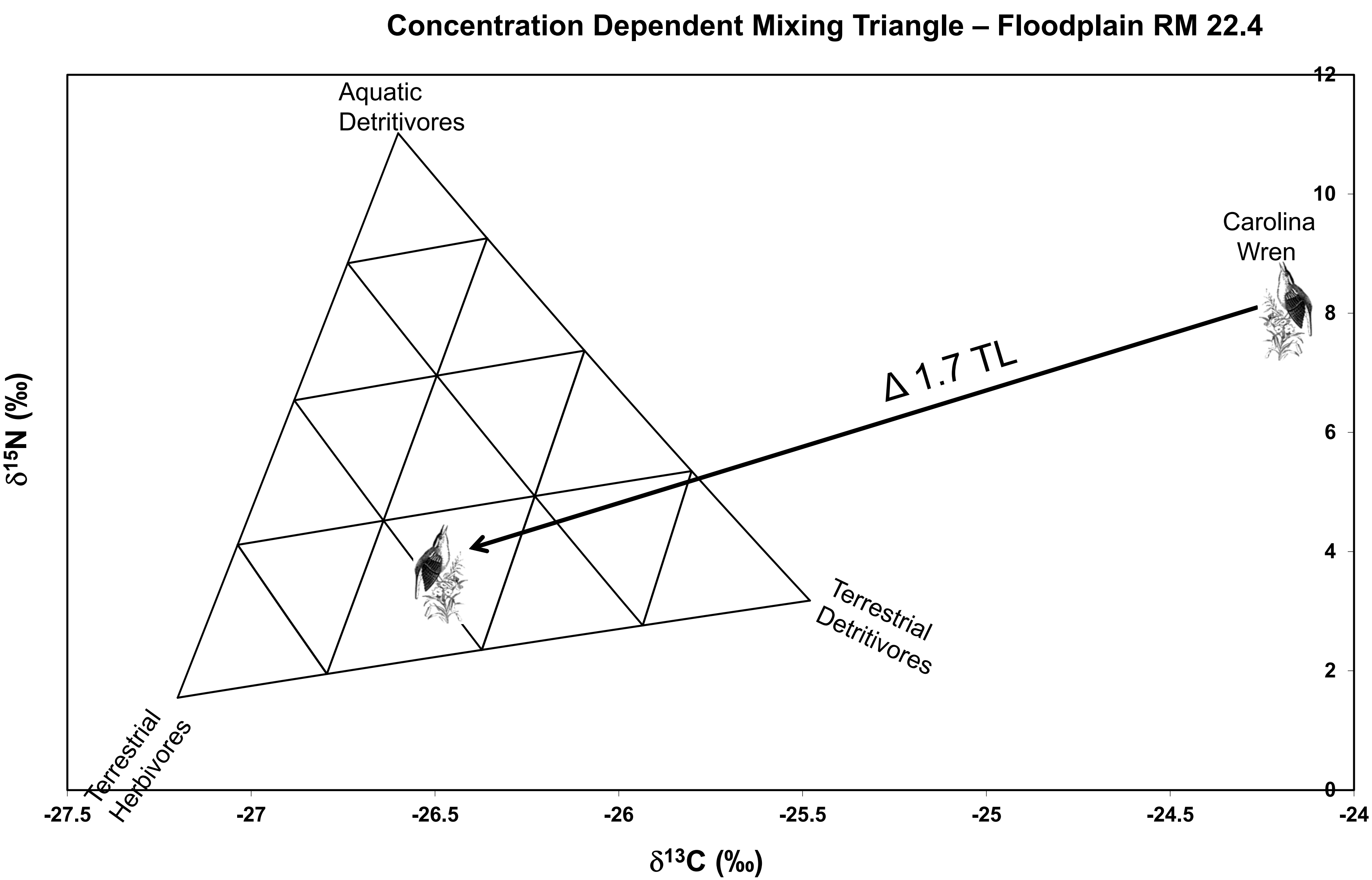
Dietary Information

- Mercury in Dietary Items
  - Data from past and 2010 Survey
- Expert Elicitation (Modified Delphi Method)
  - Frequency of Consumption of food Items
  - Amounts eaten of food items

Monte Carlo Simulation for Exposure Assessment



Refine Trophic Linkages Insights



Significance - Floodplain

- Trophic dynamics determine relative [Hg] in floodplain biota
- MHg is dominant Hg form in apex species of interest
- Trophic dynamics can be predicted quantitatively
- Predictive tool for judging effectiveness of any remediation action
- Floodplain remediation more difficult (impractical?)
- Compensate by replacing habitat?
- Create attractive feeding or nesting habitat away from river edge?


QUESTIONS?