Steelhead natal source inferences using otolith microchemistry

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Background

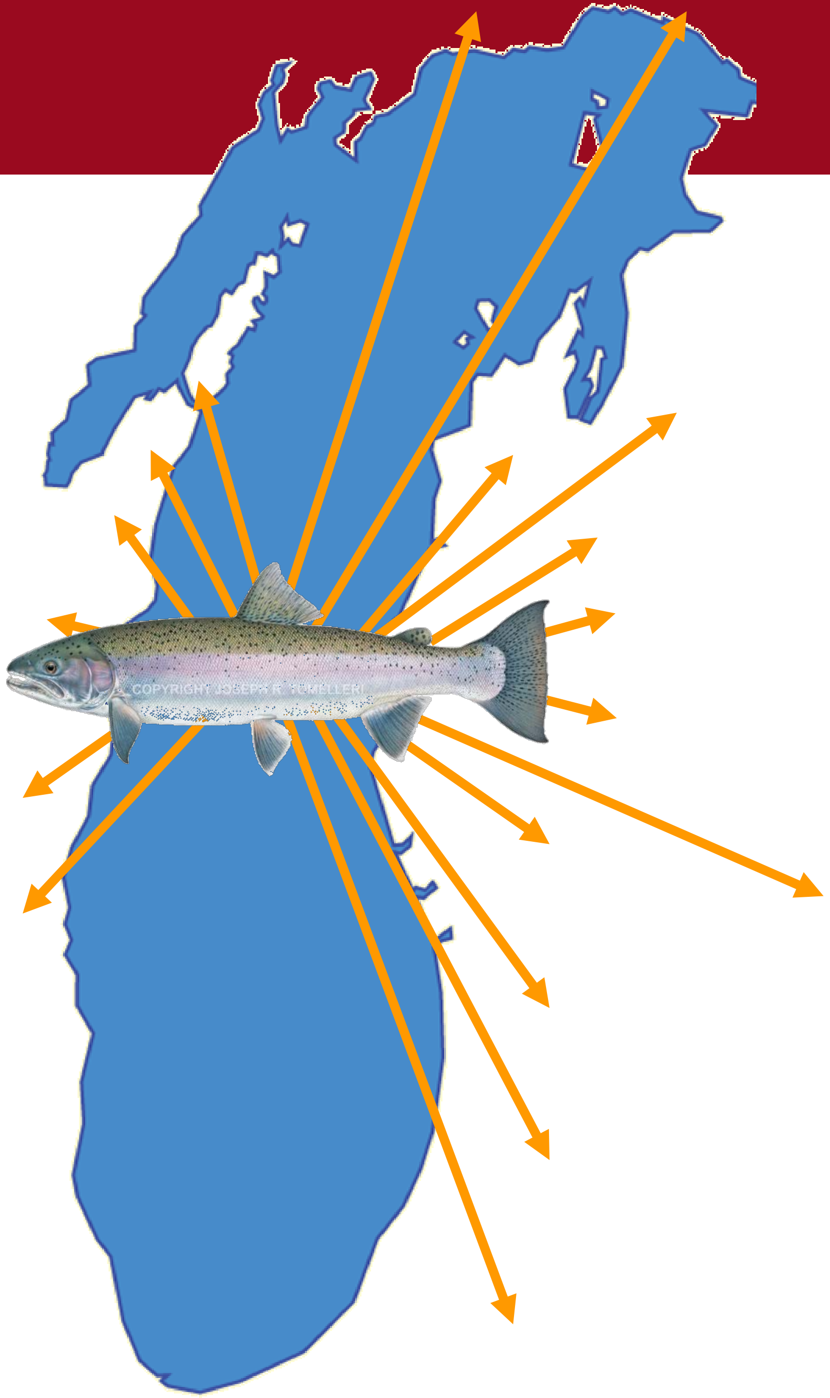
- Many sources of steelhead production

  1. Five hatchery strains: Arlee, Chambers Creek, Ganaraska, Little Manistee, and Skamania

     - Raised among six different hatcheries

Background

- Many sources of steelhead production
  1. Five hatchery strains: Arlee, Chambers Creek, Ganaraska, Little Manistee, and Skamania
     - Raised among six different hatcheries
  2. Wild steelhead from natural reproduction
     - Northwest Lower Peninsula of Michigan and elsewhere



Research questions

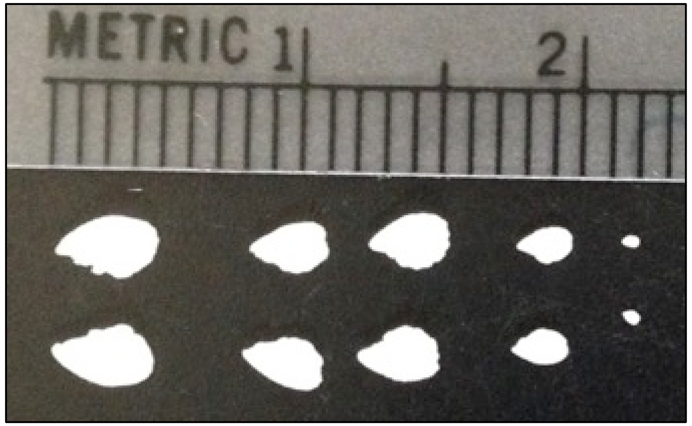
- To what extent can juvenile steelhead be discriminated by natal source using otolith microchemistry?

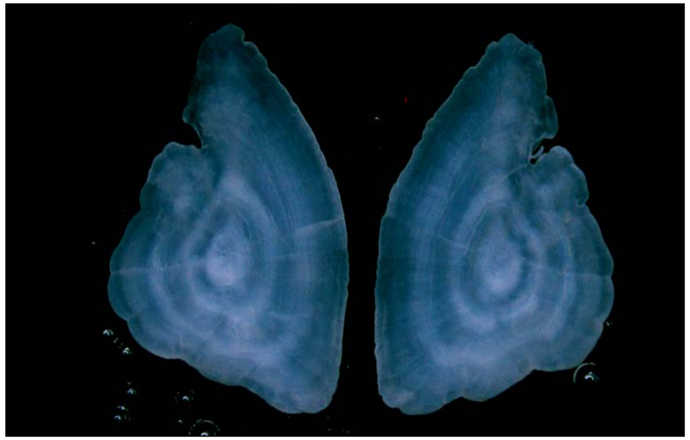
Can the following be distinguished?

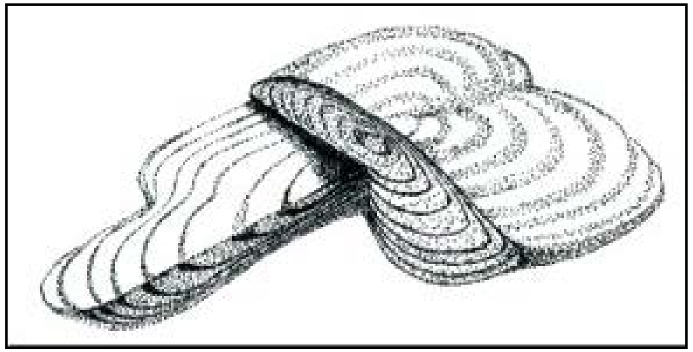
1. Juvenile steelhead from different hatcheries
2. Wild vs. hatchery juvenile steelhead among stocked streams
3. Wild juvenile steelhead among >30 different Lake MI tribs

Otoliths: fish ear bones

- Hard calcium carbonate structures located behind the brain
- Help fish hearing, balance, orientation
- Metabolically inert
- Concentric growth around core
- Reconstruct the environmental history of fish
  - Act as a “natural” marker
  - Journal of fish habitat occupancy

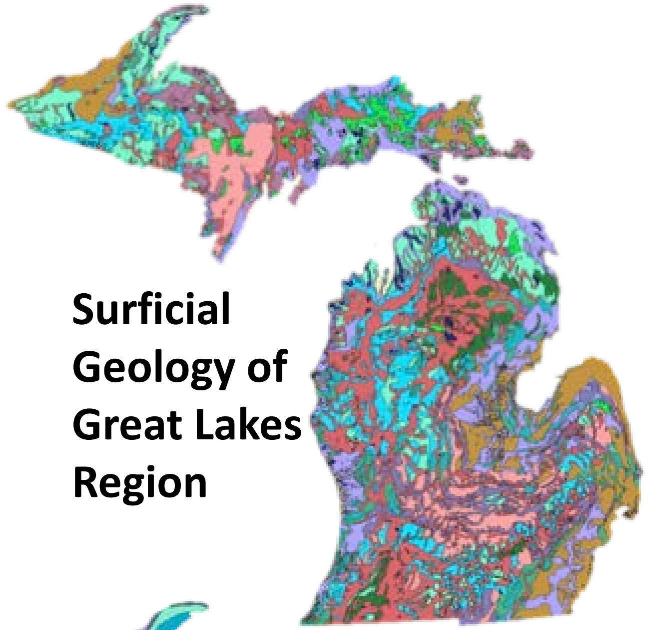




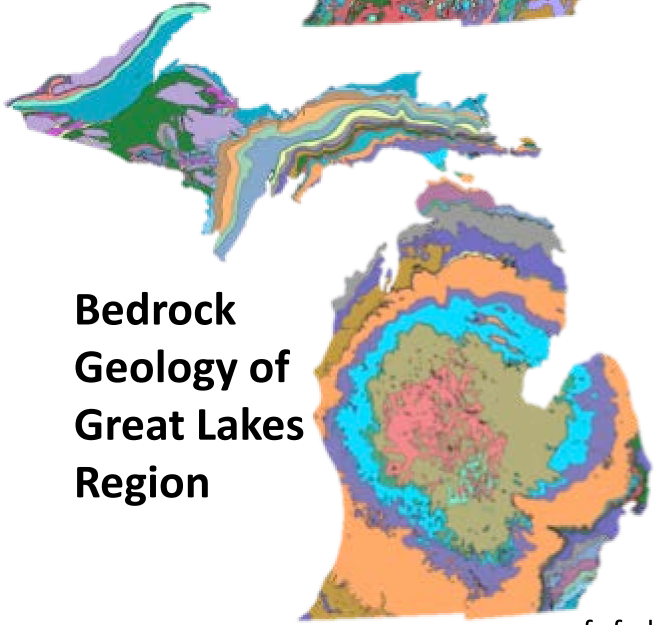


Geology influences otolith microchemistry

- Otolith chemical analysis has the potential to determine natal origins in the Great Lakes
  - Unique geology



Surficial Geology of Great Lakes Region

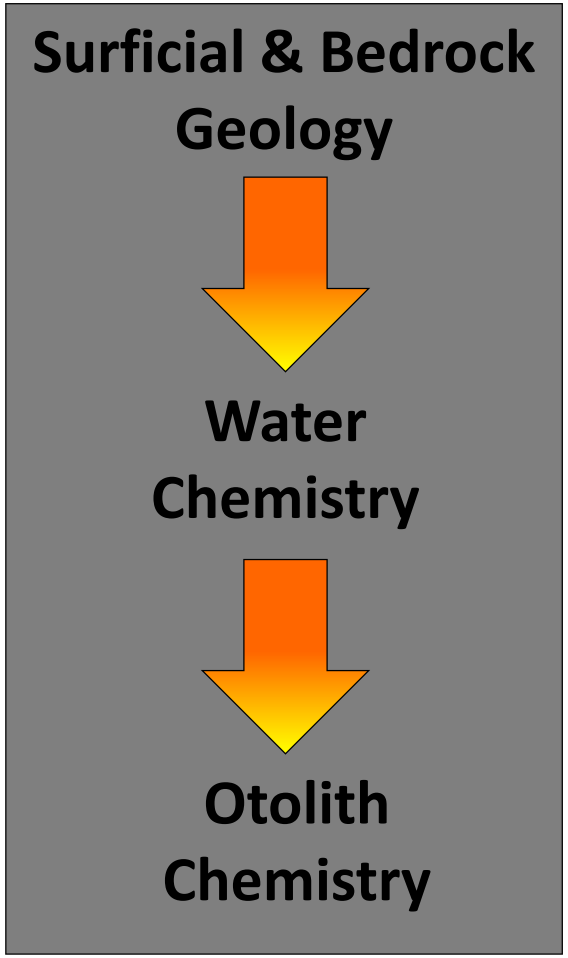


Bedrock Geology of Great Lakes Region

www.ncrs.fs.fed.us

Geology influences otolith microchemistry

- Otolith chemical analysis has the potential to determine natal origins in the Great Lakes
  - Unique geology
- Strontium (Sr) and Barium (Ba)
  - Others of importance: magnesium (Mg), manganese (Mn), iron (Fe), lead (Pb), copper (Cu)



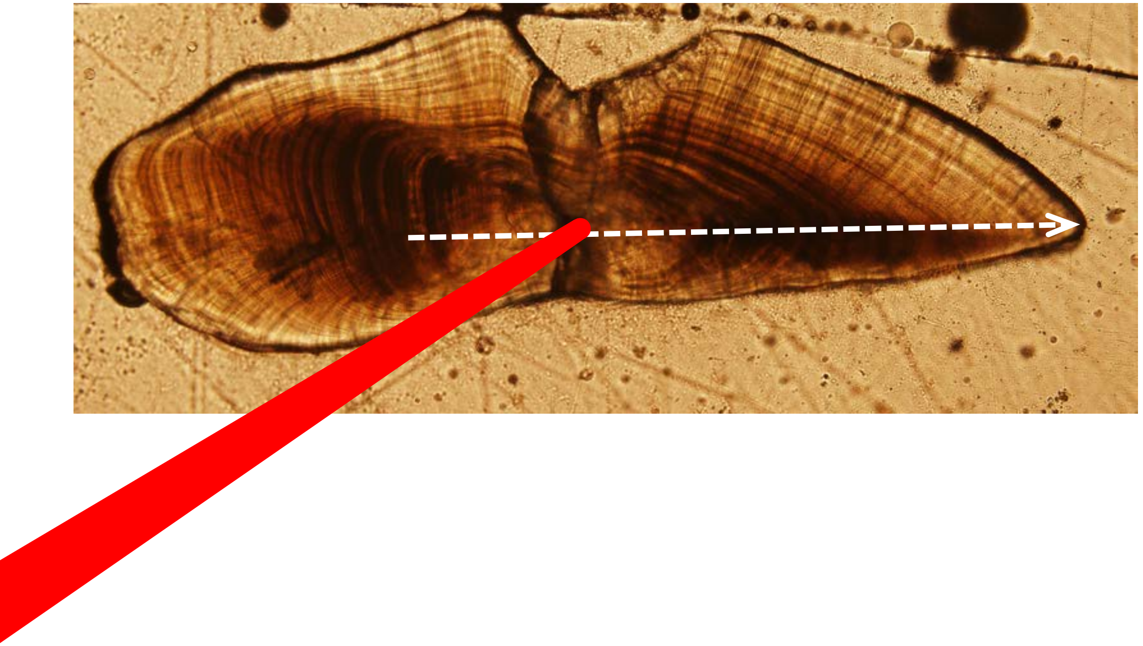
Elements analyzed with LA-ICPMS

1. Similar charge and/or size to Ca^{+2}
2. Detectable abundance

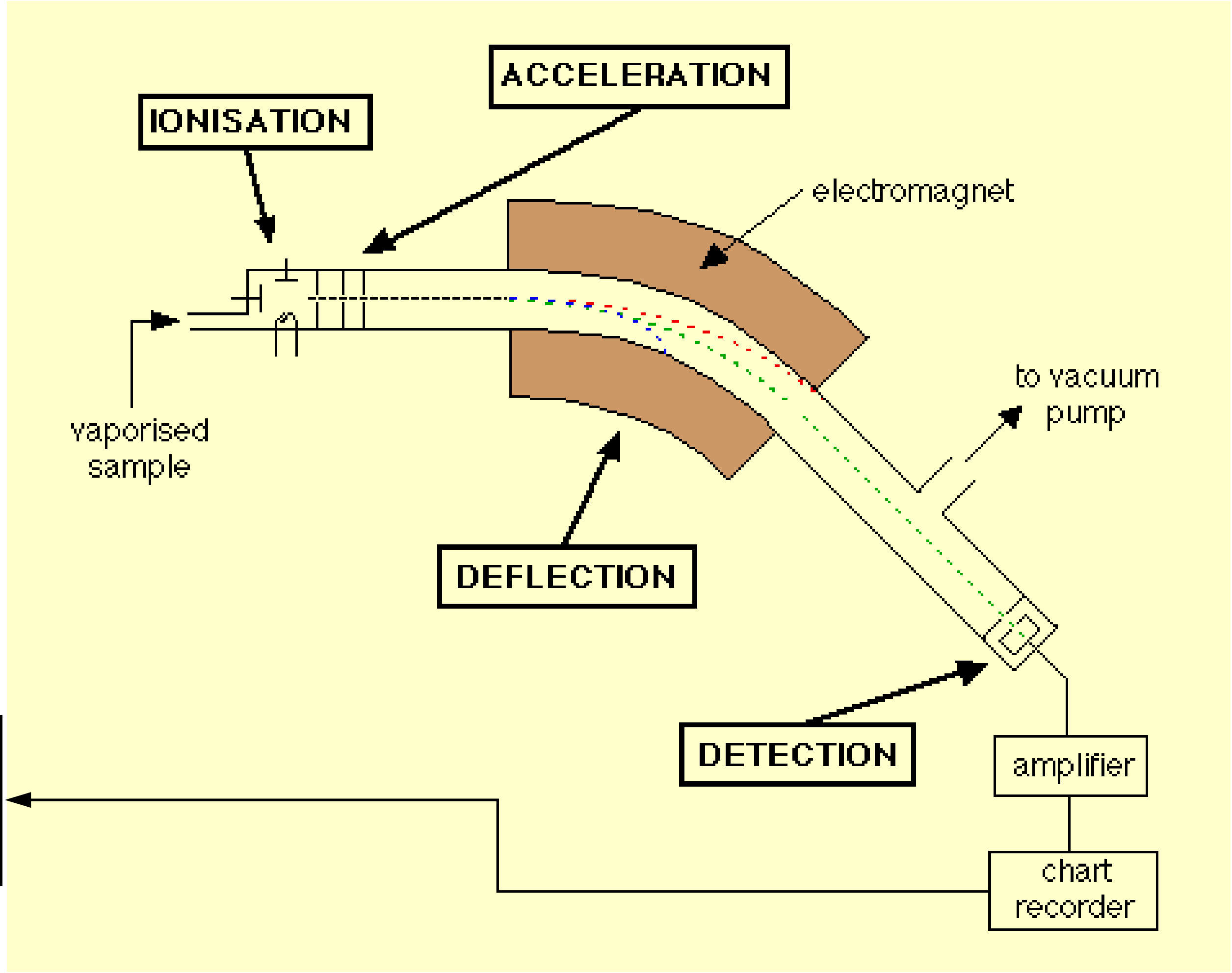
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.008																	2 He 4.0026
3 Li 6.94	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	**Mg**											13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06	17 Cl 35.45	18 Ar 39.948
19 K 39.098	**Ca**	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	**Mn**	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	**Cu**	**Zn**	31 Ga 69.723	32 Ge 72.630	33 As 74.922	34 Se 78.97	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	**Sr**	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.95	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	**Ba**	57-71 *	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	**Pb**	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89-103 #	104 Rf (265)	105 Db (268)	106 Sg (271)	107 Bh (270)	108 Hs (277)	109 Mt (276)	110 Ds (281)	111 Rg (280)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (294)	118 Og (294)

* Lanthanide series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
# Actinide series	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

How LA-ICPMS measures elements



Data (ppm of elements)



http://www.chemguide.co.uk/analysis/masspec/howitworks.html

Objective 1: Hatchery analysis

- To what extent can juvenile steelhead from different hatcheries be discriminated using otolith microchemistry?

Lake Michigan steelhead stocking, 2015

	Fingerlings	Yearlings	Proportion
Clipped	64,092	164,370	0.136
Unclipped	373,929	1,087,763	0.865
Total	438,021	1,252,133	1

Objective 1: Hatchery analysis

Hatchery steelhead samples

Hatchery description	Sample date	Year class	*n*
Bodine State Fish Hatchery, IN	10 Apr 2014	2013	8
	17 Nov 2015	2015	10
Jake Wolf Memorial Fish Hatchery, IL	20 Oct 2015	2015	10
Kettle Moraine Springs Hatchery, WI	1 Nov 2015	2015	10
Thompson State Fish Hatchery, MI	25 Apr 2014	2013	10
	13 Apr 2015	2014	10
Wolf Lake State Fish Hatchery, MI	28 Aug 2015	2015	10

Results: Model performance

	Misclassification (%)		
Model	$m_{try} = 0.5p^{0.5}$	$m_{try} = p^{0.5}$	$m_{try} = 2p^{0.5}$
Hatchery ~ Mg, Mn, Cu, Zn, Sr, Ba, Pb	4.41	7.35	10.29
Hatchery ~ Mg, Mn, Zn, Sr, Ba	7.35	7.35	10.29
Hatchery ~ Mn, Sr, Ba	5.88	8.82	10.29
Hatchery ~ Zn, Sr, Ba	8.82	10.29	10.29
Hatchery ~ Sr, Ba	7.35	5.88	10.29
Hatchery ~ Sr	13.24	14.71	17.65
Hatchery ~ Ba	22.06	22.06	25.00

Results: Classifications among hatchery fish

	Predicted origin					
Known origin	BSFH	ILFH	KMFH	TSFH	WLFH	% Misclassified
BSFH						
ILFH						
KMFH						
TSFH						
WLFH						

Results: Classifications among hatchery fish

	Predicted origin					
Known origin	BSFH	ILFH	KMFH	TSFH	WLFH	% Misclassified
BSFH	18	0	0	0	0	0.0
ILFH	0	9	1	0	0	10.0
KMFH	0	1	9	0	0	10.0
TSFH	0	0	0	20	0	0.0
WLFH	1	0	0	0	9	10.0

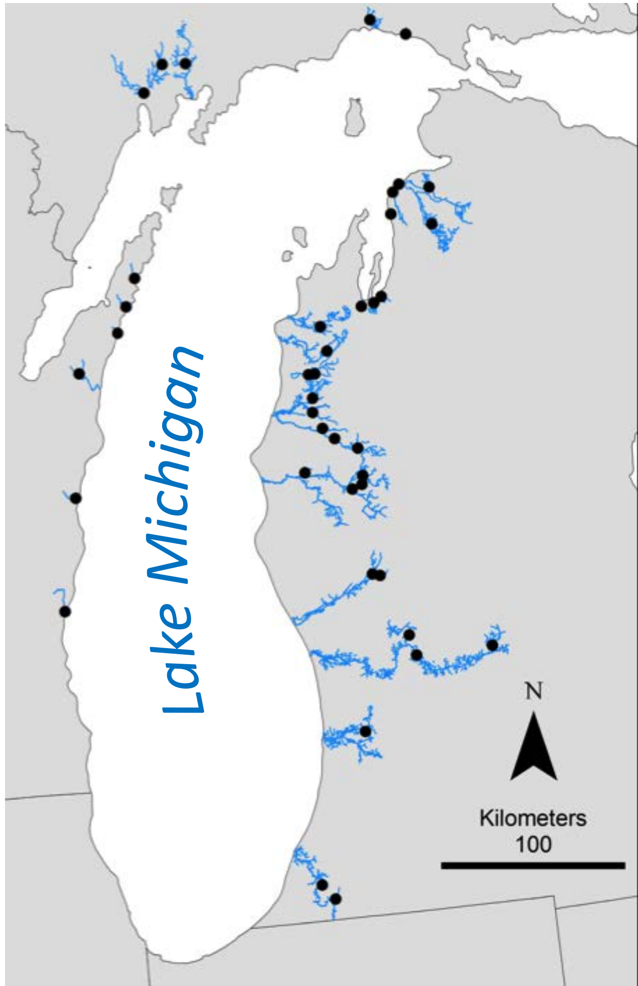
Objective 1: Implications

- Each hatchery imparts a unique microchemical signature on juvenile steelhead otoliths
- If all stocked steelhead were fin-clipped, we could reliably assign to correct natal origin

Objective 2: Hatchery vs. wild analysis

- To what extent can wild vs. hatchery juvenile steelhead be discriminated among stocked streams?

- Methods:
  - Streams sampled for age-0 wild juvenile steelhead
  - Classification models (n = 25) built using otolith chemistry inputs from:
    1. Known wild-origin juvenile steelhead
    2. Hatchery steelhead from hatchery(s) that source stockings of each respective watershed



Objective 2: Hatchery vs. wild analysis

	KMFH			TSFH					WLFH										TSFH & WLFH		BSFH, TSFH & WLFH				
Assignment	Fischer Creek	Hibbard Creek	Sauk Creek	Days River	Eighteen Mile Creek	Haymeadow Creek	Horton Creek	Jordan River	Bigelow Creek	Egypt Creek	Honey Creek	Little S Br Pere Marquette River	Middle Br Pere Marquette River	Prairie Creek	Sanborn Creek	Silver Creek	Muskegon R trib	Weldon Creek	Kids Creek	Platte River	Bear Creek	Lemon Creek	Pine Creek	Townsend Creek	Dowagiac River trib.
W→W																									
W→H																									
H→H																									
H→W																									
Misclassification (%)																									

Objective 2: Hatchery vs. wild analysis

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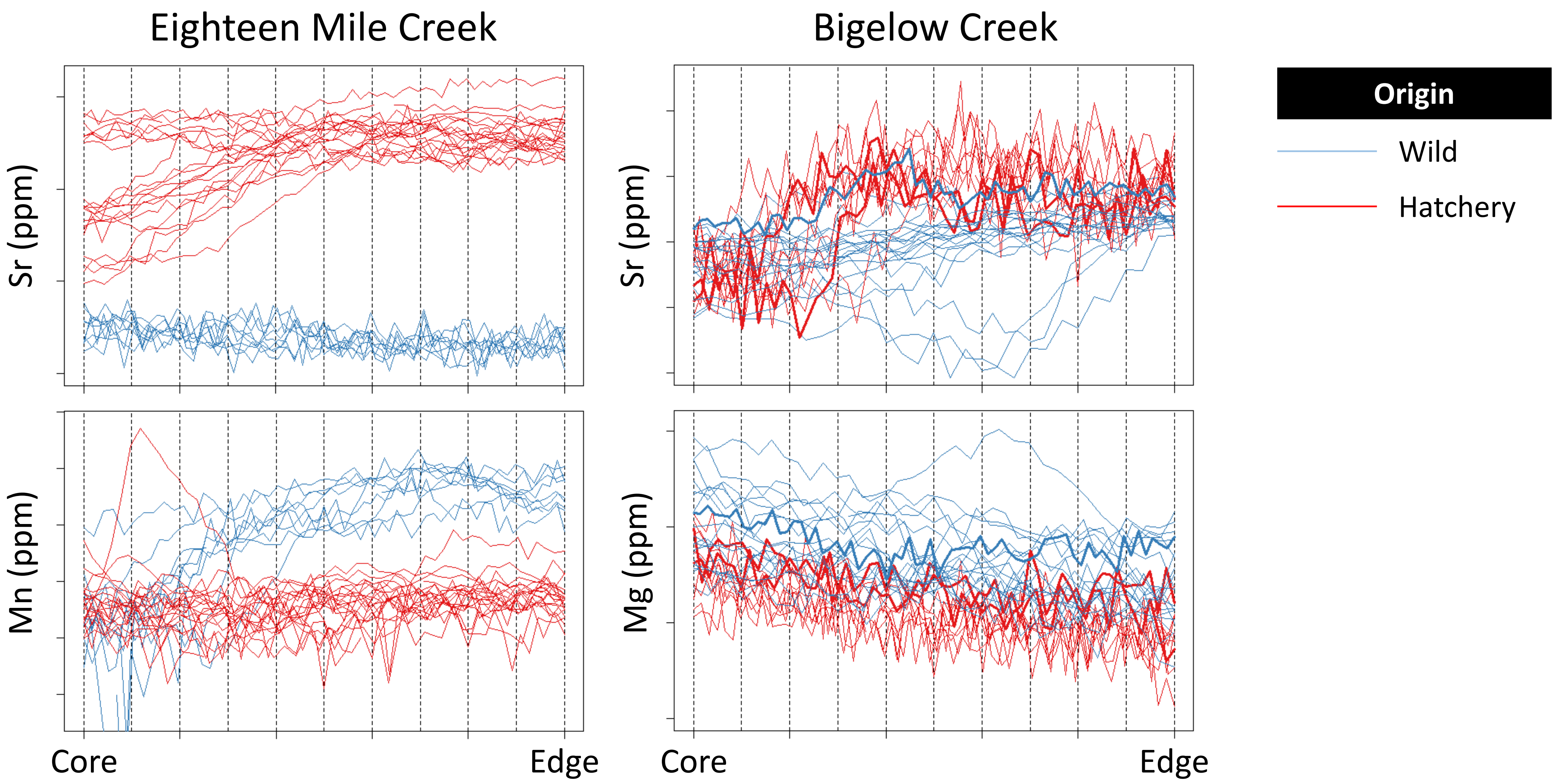
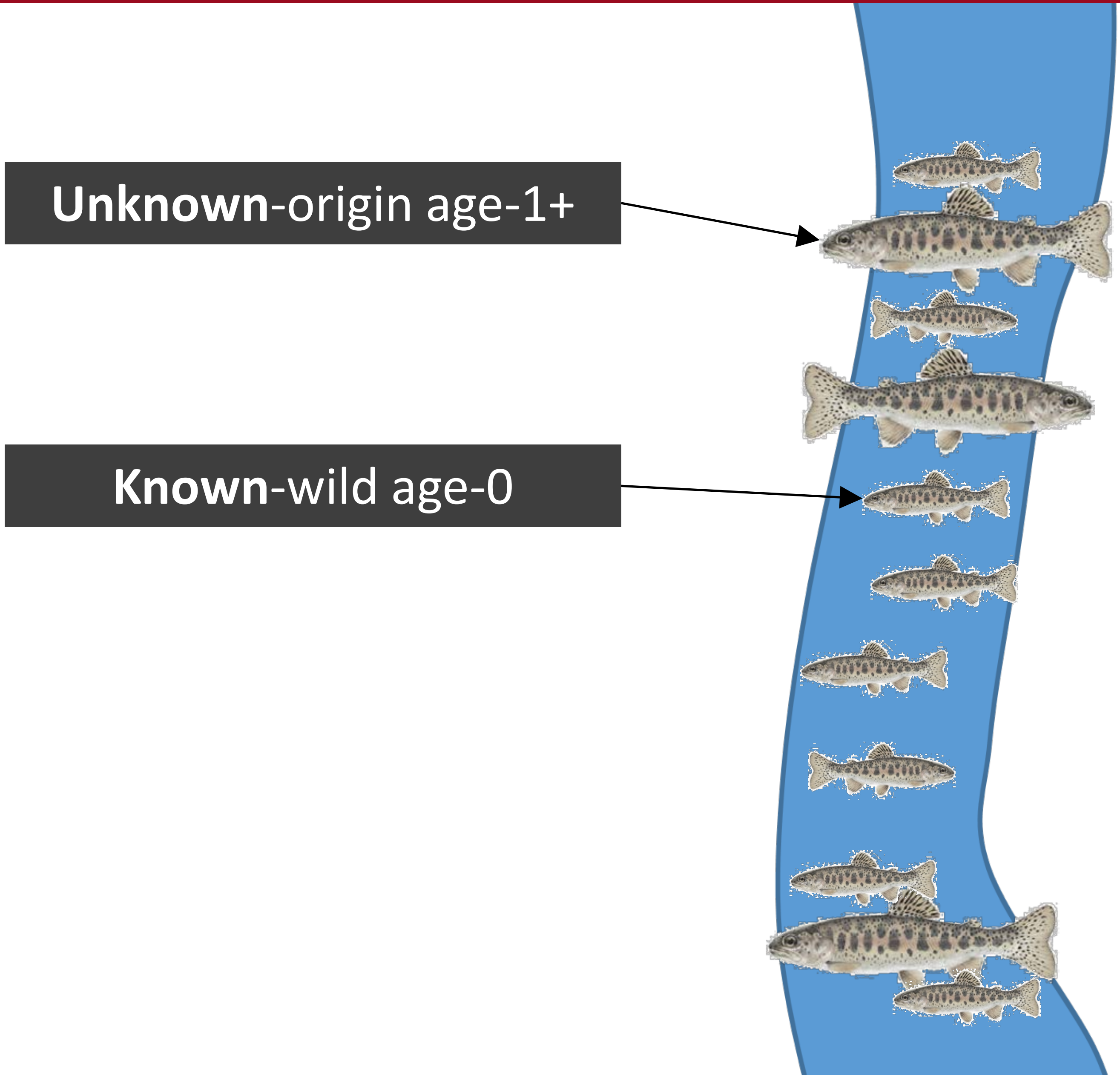
W→W	13	19	20	10	9	10	10	10	19	13	10	20	20	20	15	21	10	9	21	10	20	9	22	20	8
W→H	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
H→H	10	10	10	20	20	20	20	20	8	10	10	10	10	10	10	10	10	10	30	30	47	47	48	46	48
H→W	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0
Misclassification (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.4	0.0	2.9	3.4

Objective 2: Hatchery vs. wild analysis

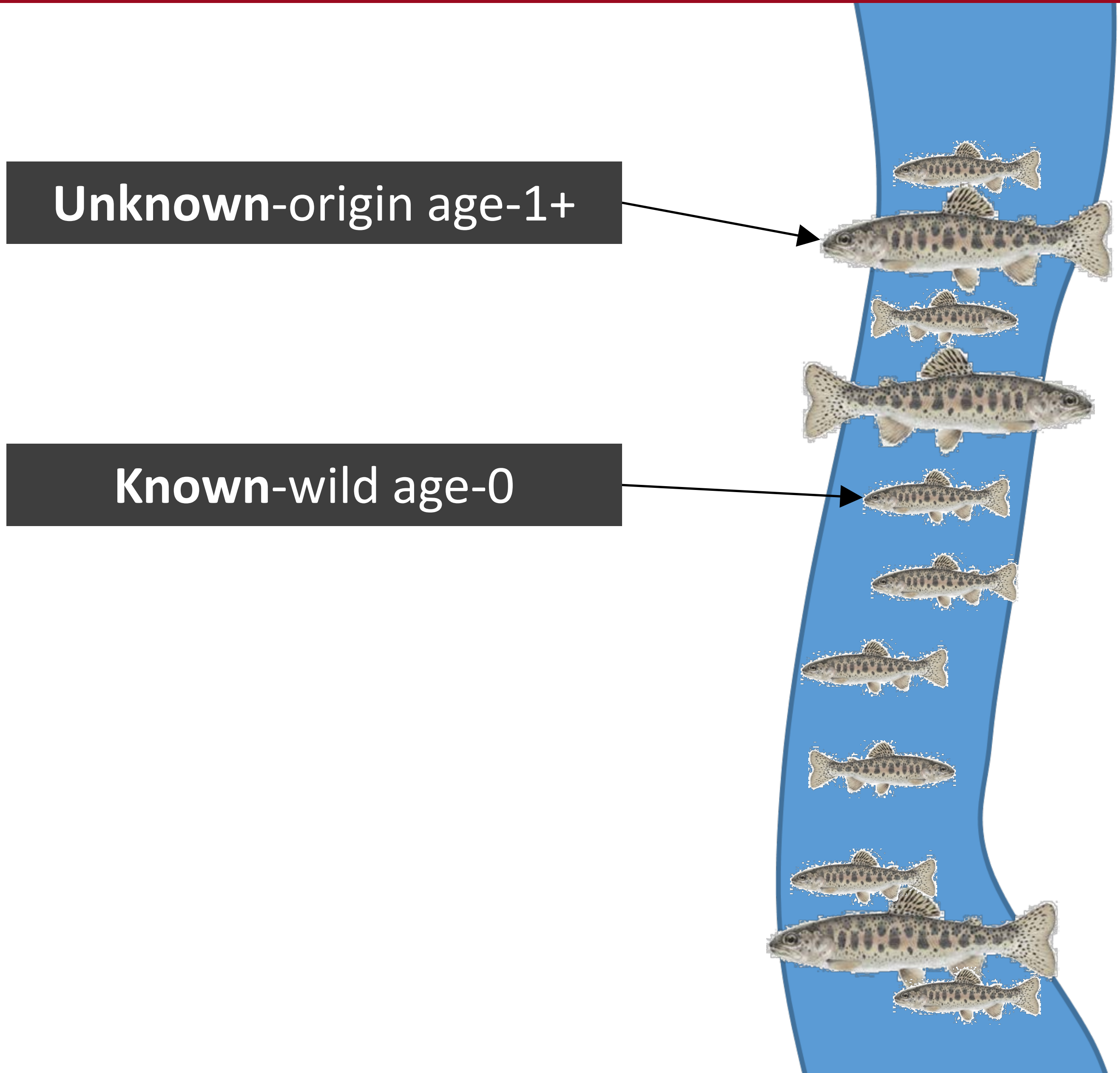


Unknown-origin assignment: Proof of concept



Site	Sample date	Age-1 assignment (*n*)		
		wild	KMFH	WLFH
Fischer Creek, WI	2-Sep-14			
	28-Apr-15			
Prairie Creek, MI	24-Jun-14			
	18-Sep-14			
	11-May-15			
	9-Oct-15			
Sanborn Creek, MI	30-Jun-14			
	25-Oct-14			
	14-Jul-15			
	16-Oct-15			

Unknown-origin assignment: Proof of concept



		Age-1 assignment (*n*)		
Site	Sample date	wild	KMFH	WLFH
Fischer Creek, WI	2-Sep-14	7	3	NA
	28-Apr-15	8	1	NA
Prairie Creek, MI	24-Jun-14	3	NA	0
	18-Sep-14	3	NA	0
	11-May-15	1	NA	2
	9-Oct-15	5	NA	0
Sanborn Creek, MI	30-Jun-14	5	NA	0
	25-Oct-14	2	NA	0
	14-Jul-15	7	NA	0
	16-Oct-15	3	NA	0

Objective 2: Implications

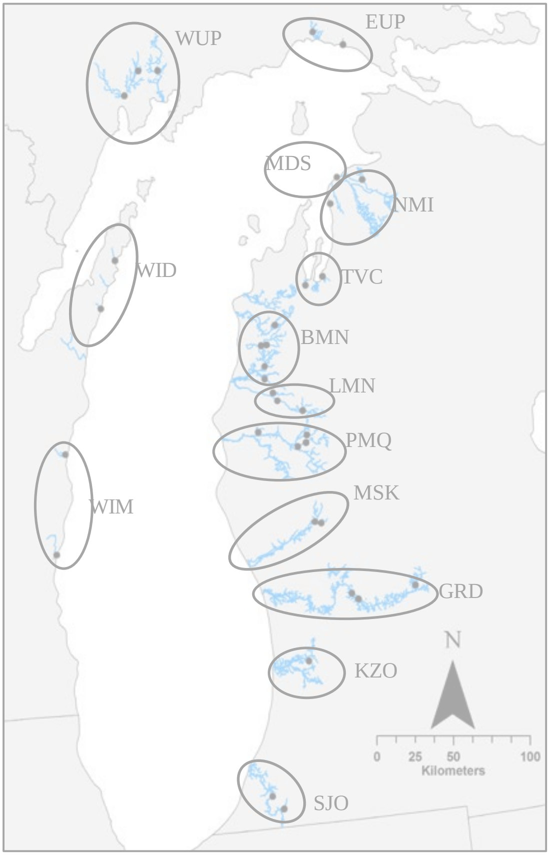
- Among streams analyzed, hatchery- and wild-origin otolith signatures tend to differ
  - Likely can discriminate wild- from hatchery-origin unmarked adults
- Stream-collected adults could be correctly classified for streams analyzed (assuming negligible straying)

Objective 3: Wild juvenile assignment

- To what extent can wild juvenile steelhead from different Lake Michigan tributaries be discriminated using otolith microchemistry?
  - How does assignment accuracy vary with spatial scale?

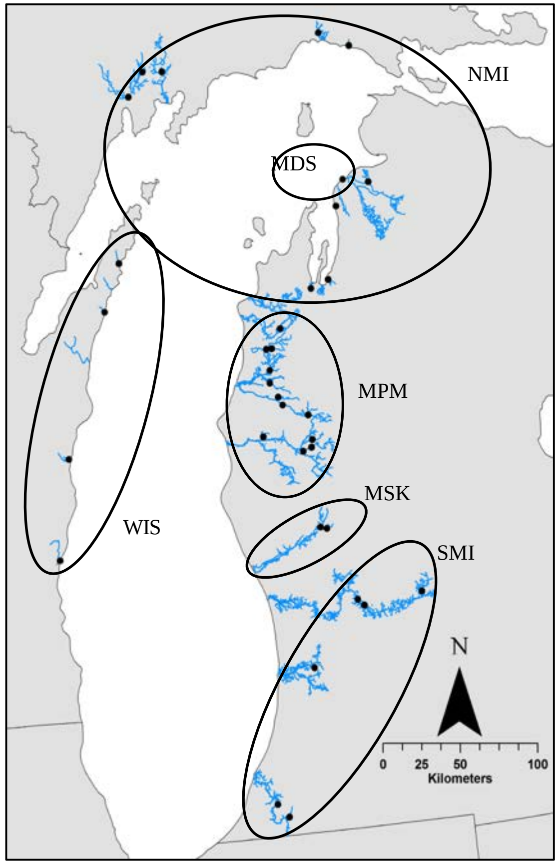
Broader spatial scale improves accuracy

13 Regions



Year-class	Region (fine)
2014 (*n* = 179)	88%
2015 (*n* = 325)	89%
Combined years	89%

6 Regions



Year-class	Region (coarse)
2014 (*n* = 179)	91%
2015 (*n* = 325)	92%
Combined Years	92%

Summary

1. Can discriminate between hatcheries with >95% accuracy
2. Stream-specific known wild- and hatchery-origin assignment models range in accuracy from 90%-100%
3. Broader spatial scales improve assignment accuracy
   - >90% at coarse geographic scale (6 regions)

Ongoing research

1. Comparison of otolith chemistries between resident sculpin and juvenile steelhead and coho salmon
   - Can resident sculpin serve as surrogates for anadromous spp.?
   - Does inter-year-class chemistry variation in coho and steelhead correlate with inter-annulus variation in sculpin?
2. Origin assignments of adult, unmarked steelhead from 2016 open-water fishery
   - Coordinated with USFWS to obtain otoliths of >600 steelhead

Questions

Acknowledgements:

Evidence of inter-annual variation

Year-class$_{t1}$ ~ year-class$_{t2}$ (*y* predicted by *x*)	Site	Region (fine)	Region (coarse)
2014 ~ 2015	43%	49%	57%
2015 ~ 2014	55%	63%	66%

Objective 2: Hatchery vs. wild analysis