Post-Stocking Survival and Spatial Spread of Lake Trout Stocked in Lake Michigan

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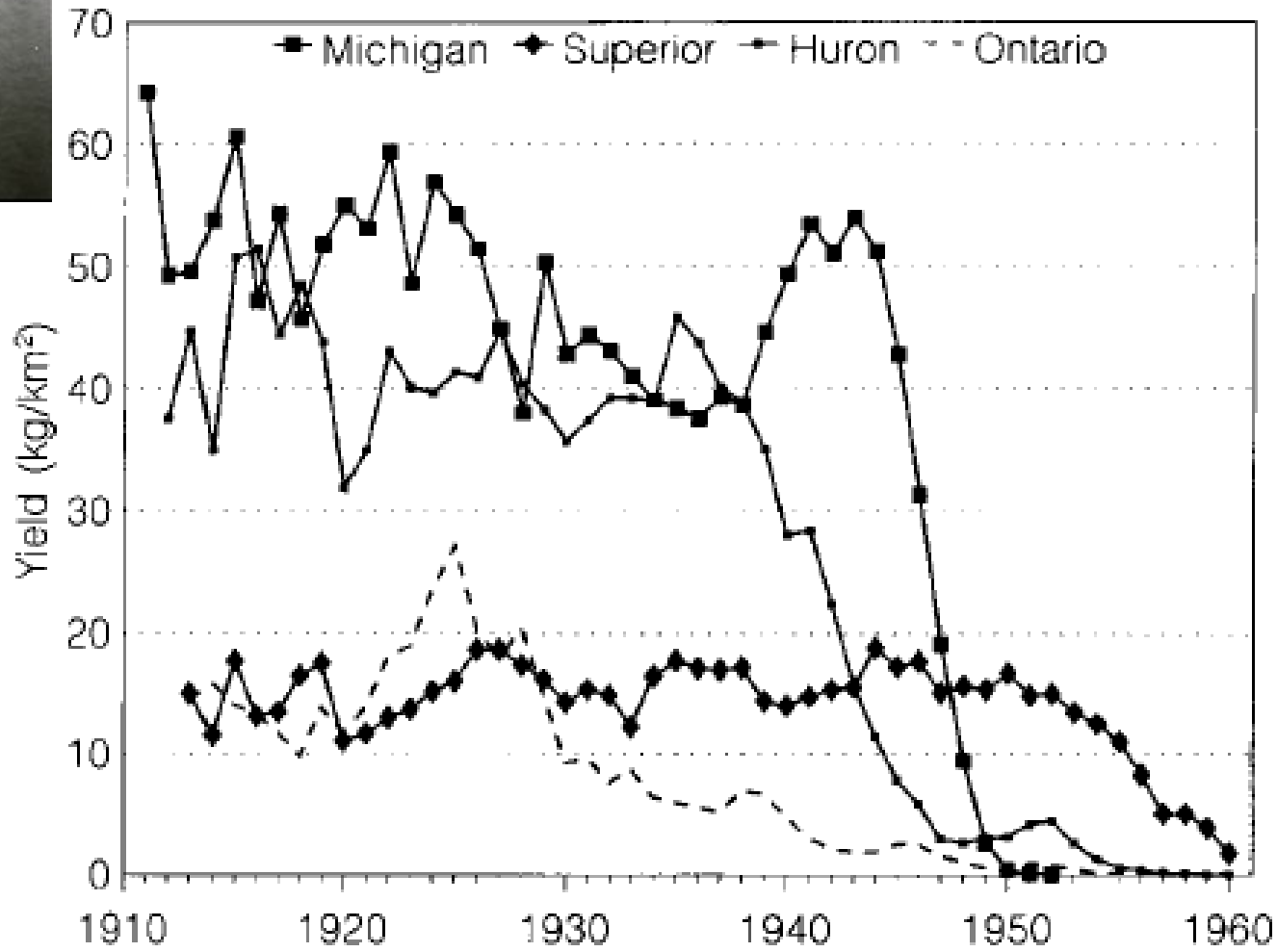
[9]Little River Band of Ottawa Indians, Natural Resources Dept., Manistee, MI, USA

Background – Lake Trout Collapse



Data from Baldwin *et al.* 1979 Figure from Holey *et al.* 1995

Background – Lake Trout Rehabilitation Effort

- Objectives
  - Increase spawning stock biomass
  - Support fisheries
- CWTs since mid-1980s:
  - Stocking location
  - Genetic strain
  - Hatchery of origin
  - Length and condition at stocking

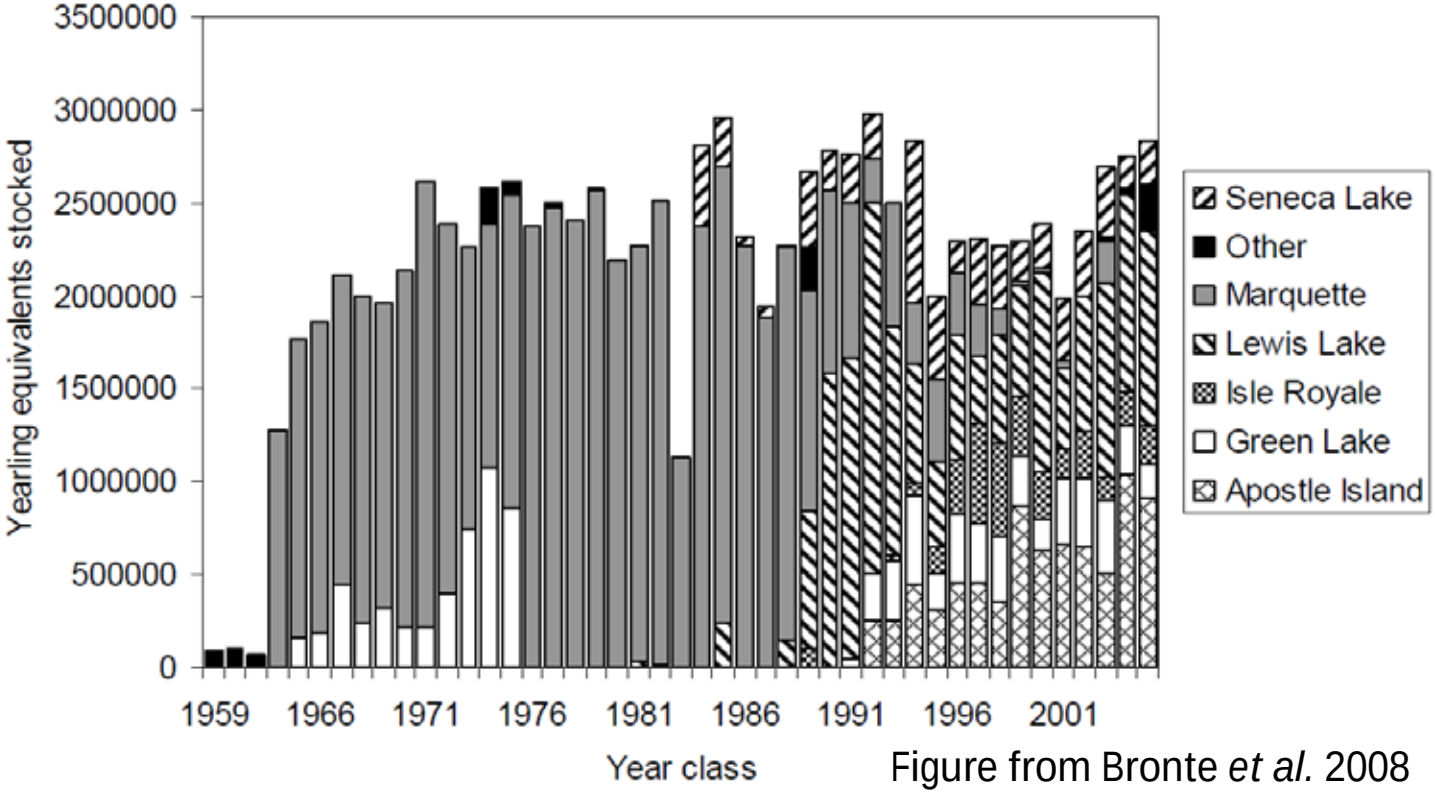


Figure from Bronte *et al.* 2008

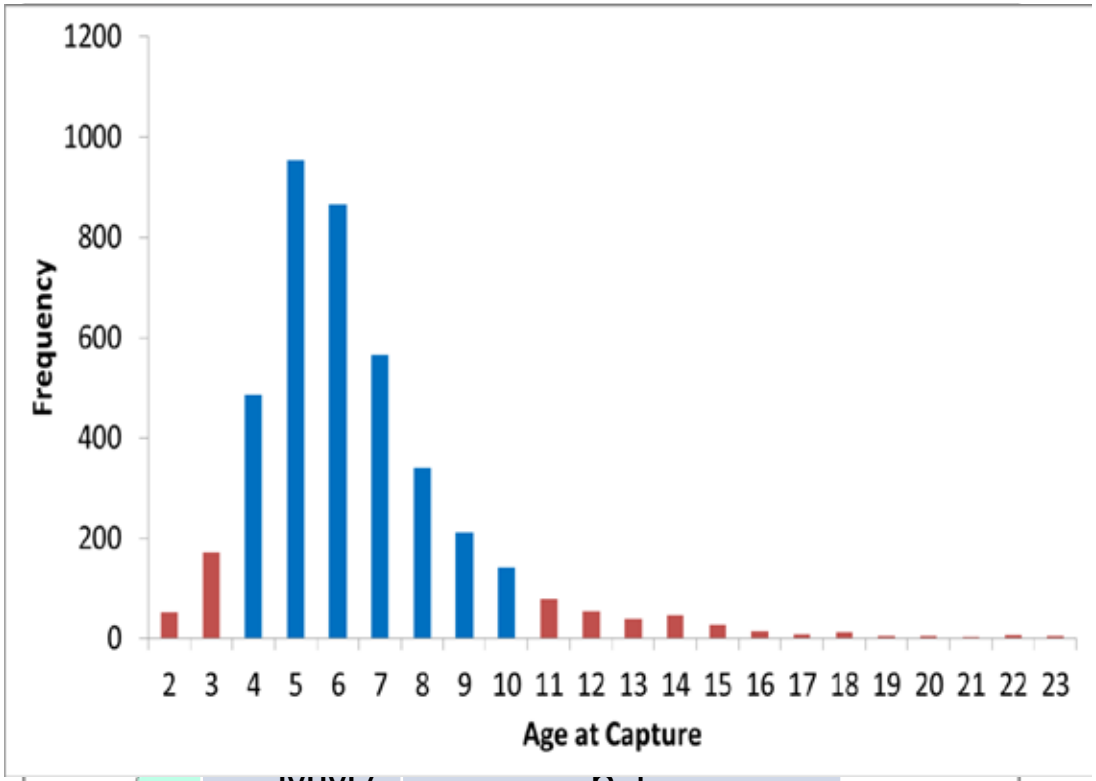
Background – Assessment Surveys

- Since 1998, coordinated inter-agency effort to annually assess relative abundance of lake trout and other select species (LWAP and LWF surveys)

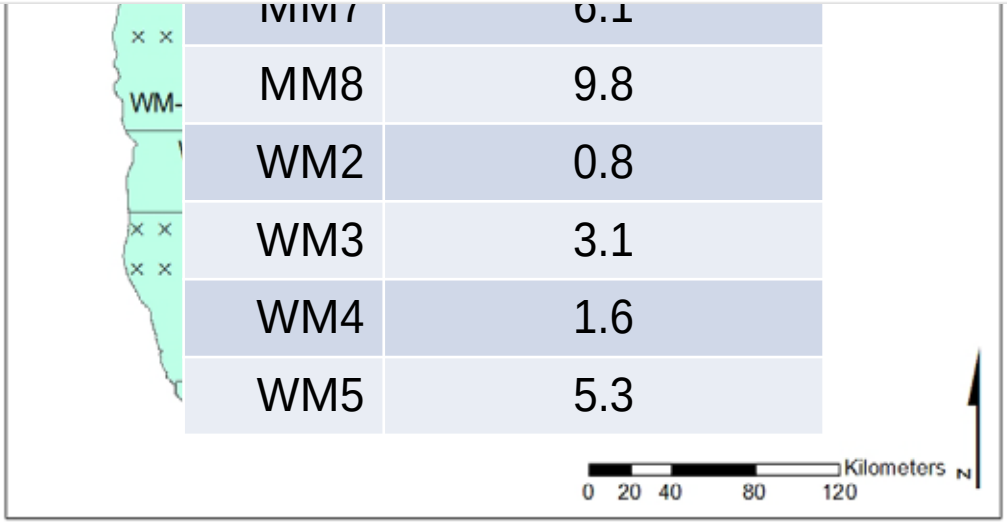
- Graded-mesh gill nets (64 to 152 mm stretched, 8 increments) set on bottom during spring (April-June)

- This analysis focuses on CWT lake trout recovered during these surveys
  - Post-stocking survival
  - Spatial spread of recoveries

Background – Assessment Surveys



MM7	6.1
MM8	9.8
WM2	0.8
WM3	3.1
WM4	1.6
WM5	5.3



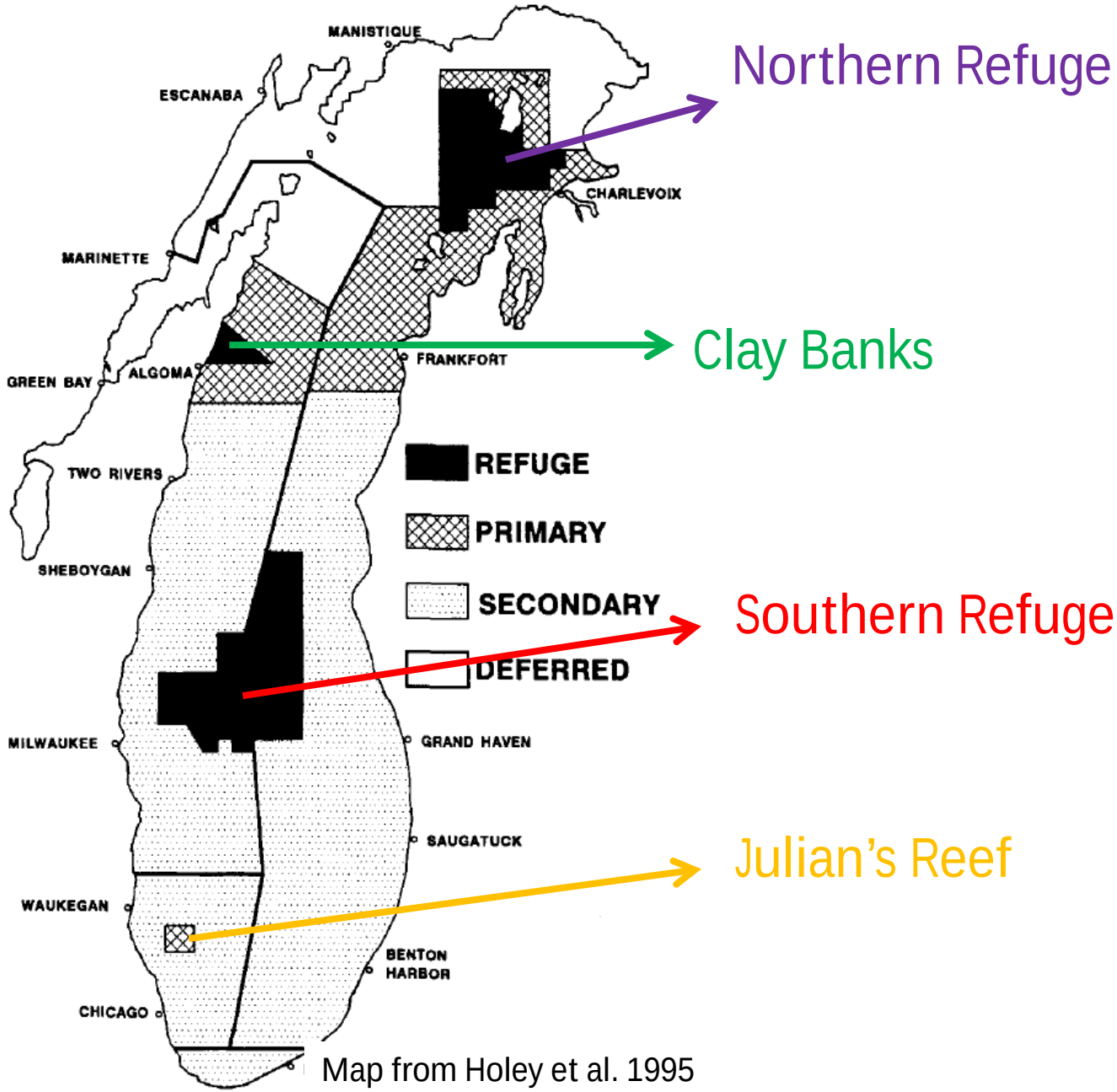
Description of Fish in Analysis

- All pre-mass marking year classes included (1984-85, 1988-2003)
- Core analysis focused on Age 4-10 individuals (year classes 1994-2003)
  - 3563/4089 individuals (87% of recoveries)

Description of Surveys in Analysis

- Recoveries from 1998 – Present included in dataset (both LWAP and LWF surveys included)
- Effort varied by year and by district

Map of Major Stocking Locations with CWT Lake Trout



Map from Holey et al. 1995

- Analysis focused on four stocking locations
- Historical lake trout spawning grounds
- Fish also recovered from nearshore stocking events (1.3 % of CPUEs from east and 5.4% from west) and from Lake Huron (0.07%).
- Most nearshore stocking events not CWT until 2010

Evaluating Post-Stocking Survival – Response Variable

- CWT tag lots were the unit of replication

- For each statistical district, we:
  - Calculated pooled catch of fish from each tag lot at ages 4-10
  - Calculated pooled effort (km*nights) for the corresponding years
    - Example: for a tag lot from the 1994 year class, catch and effort from 1998-2004 were pooled

- Then, we took the average across districts, and expressed average CPUE per 100,000 fish stocked
  - Districts MM1, WM2 (0 trout recoveries); IND (1 trout recovery); and WM1 and WM6 (0 effort) were excluded from averaging

- Thus, CPUEs accounted for year class-specific and district-specific sampling effort, and for number of fish stocked.

- $CPUE_{Age\ 4\text{-}10}$ was standardized (z-scored) within each year class to remove inter-annual variability in factors such as food abundance or temperature.

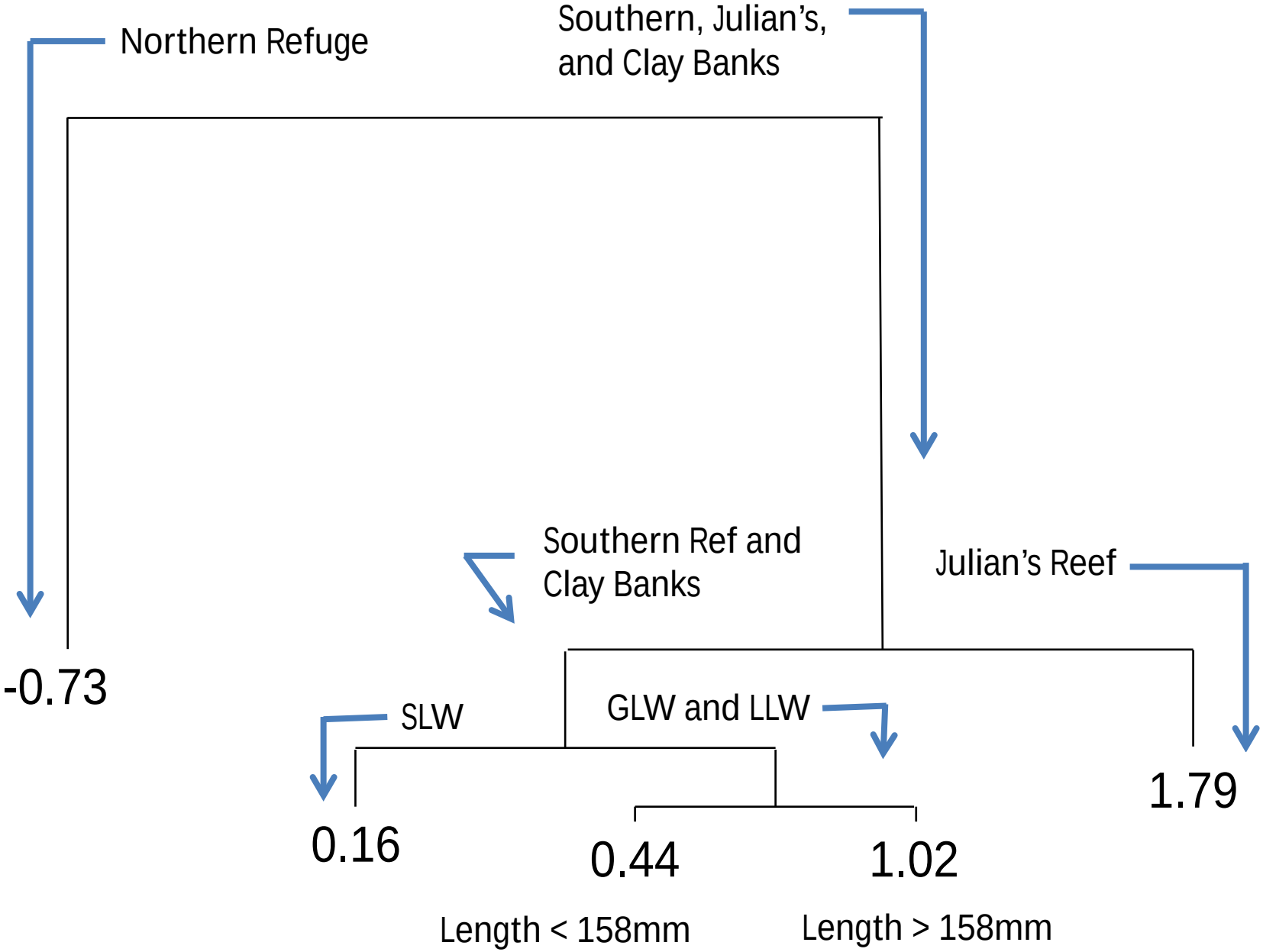
Evaluating Post-Stocking Survival – Analysis

- Standardized $CPUE_{Age\ 4\text{-}10}$ = Response Variable

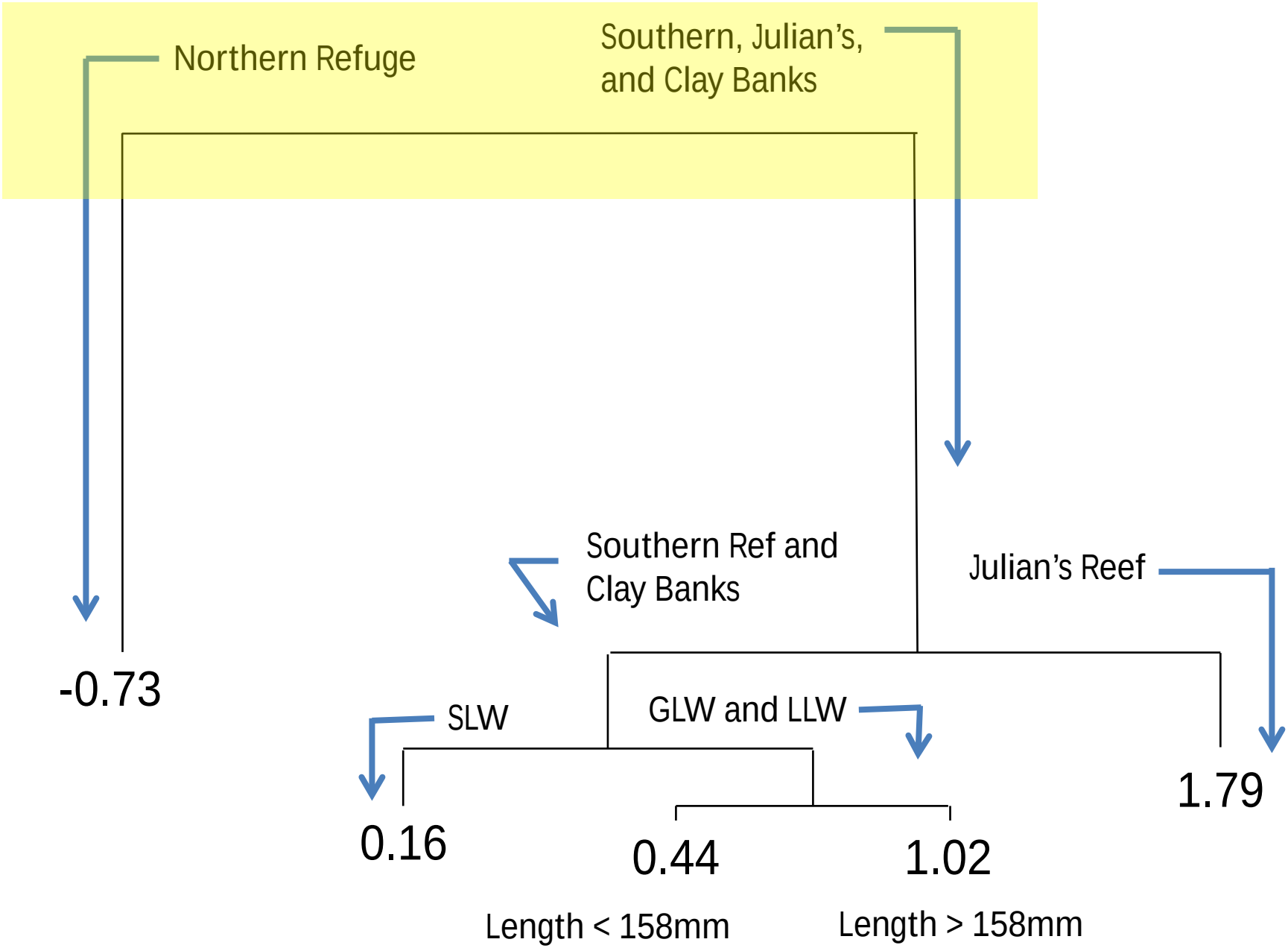
- Potential predictors included: stocking location, strain, length at stocking, condition at stocking, hatchery of origin, and predator density at stocking

- CART analysis
  - Followed by ANOVA and Tukey-Kramer pairwise comparisons on standardized log-transformed data

CART Model of $CPUE_{Age\ 4\text{-}10}$

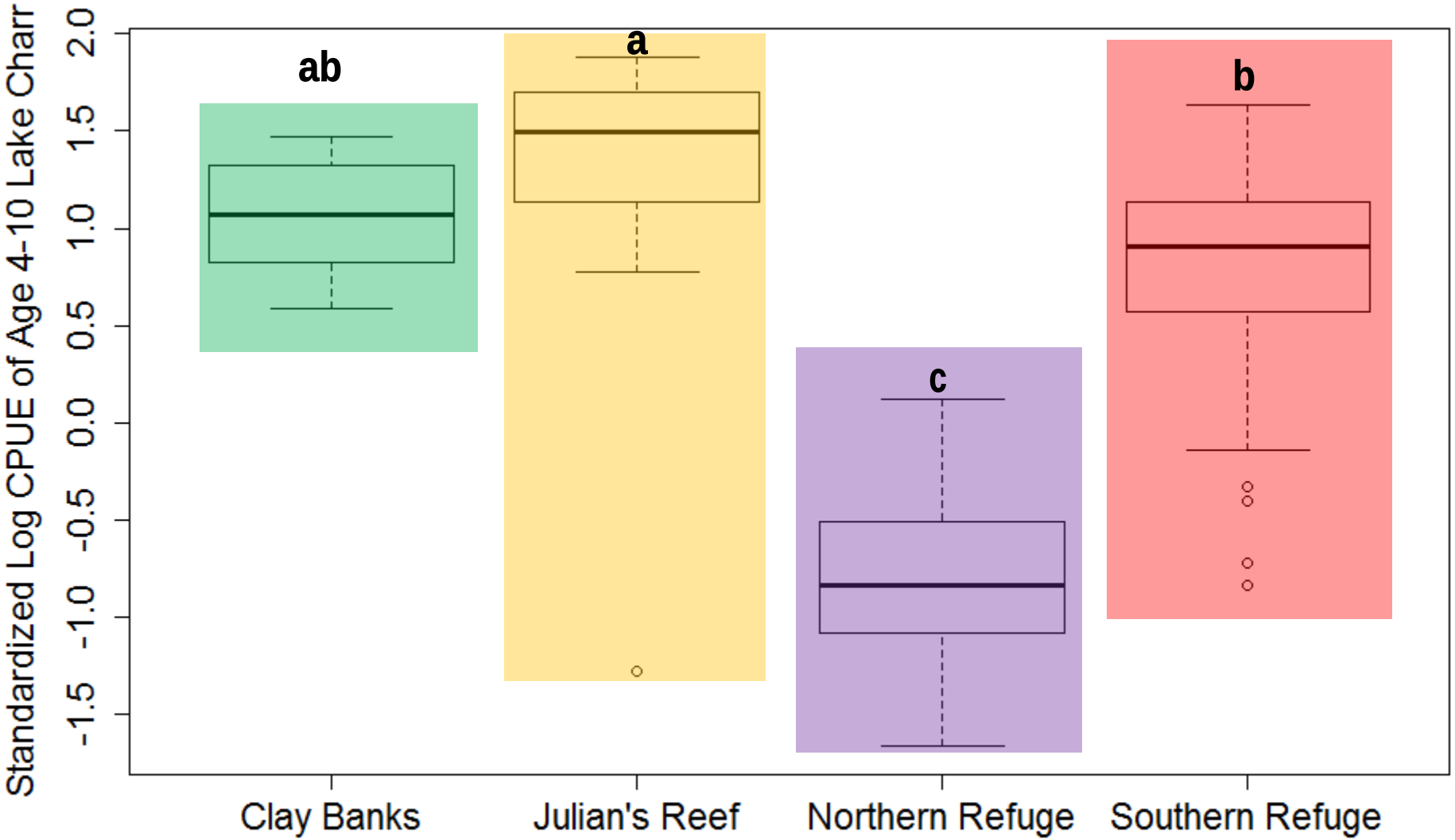


First Node in Tree – Low Recoveries in Northern Refuge



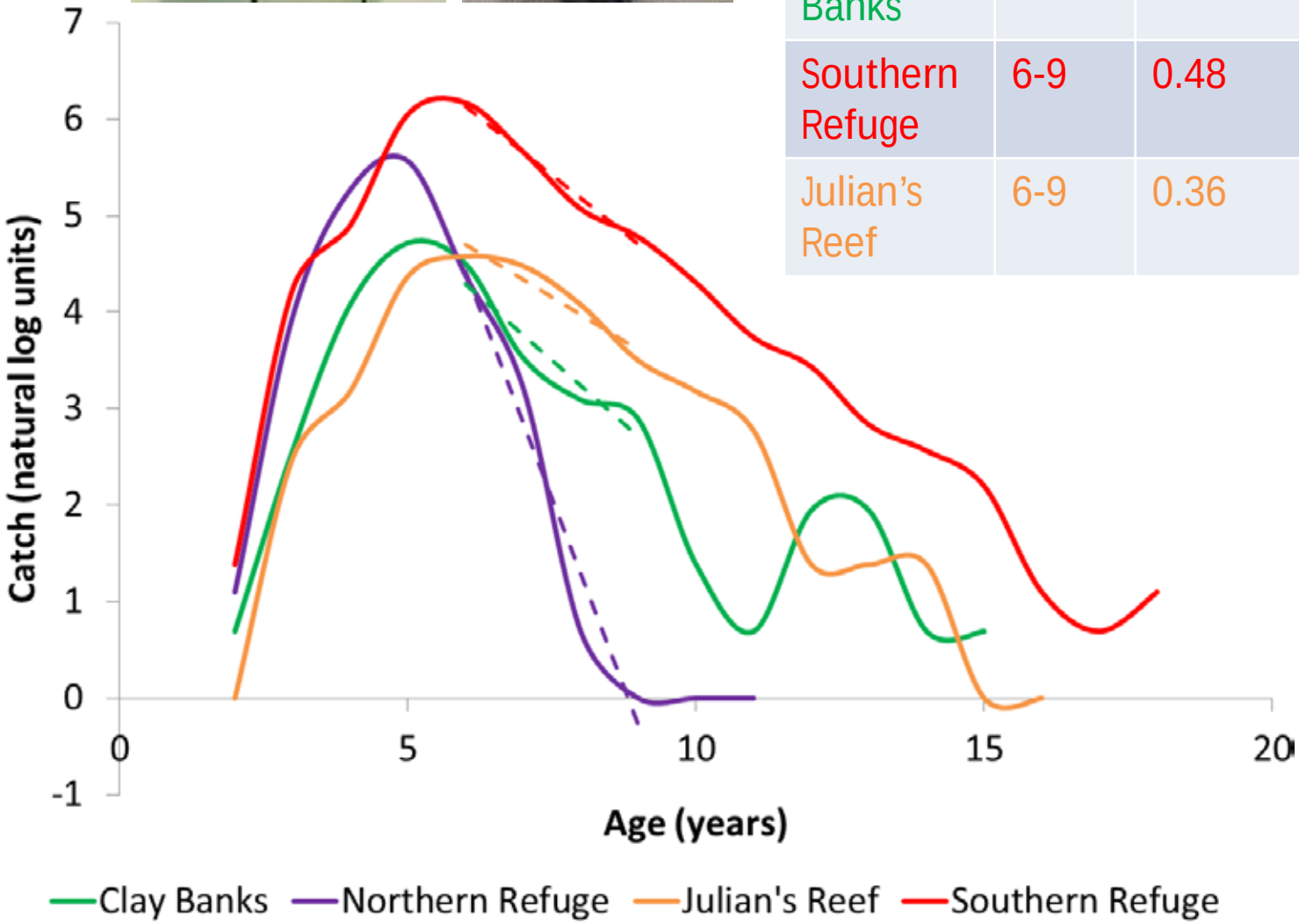
First Node in Tree – Effect of Stocking Location

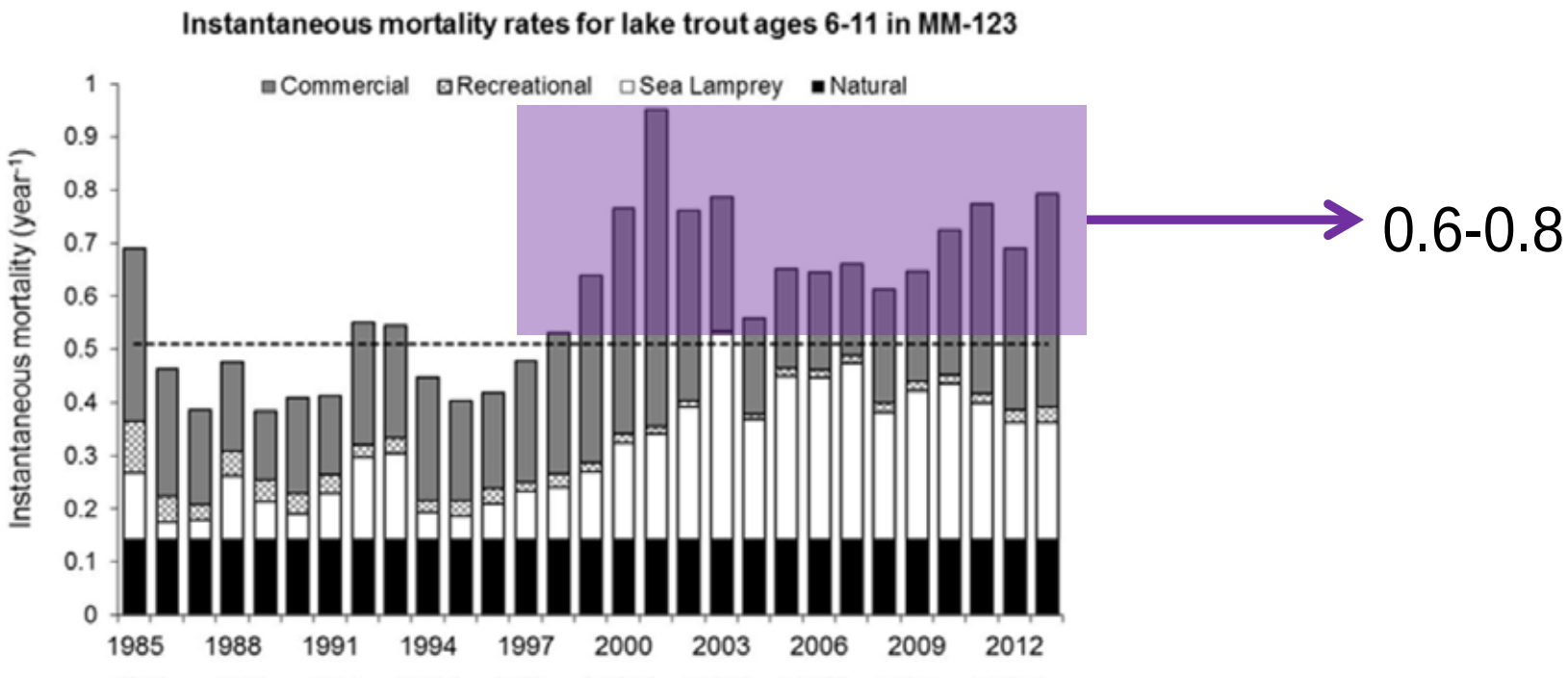
***p* < 0.0001 (ANOVA)**
Northern < all others (*p* <0.001); Southern < Julians (*p* = 0.003) (Tukey)

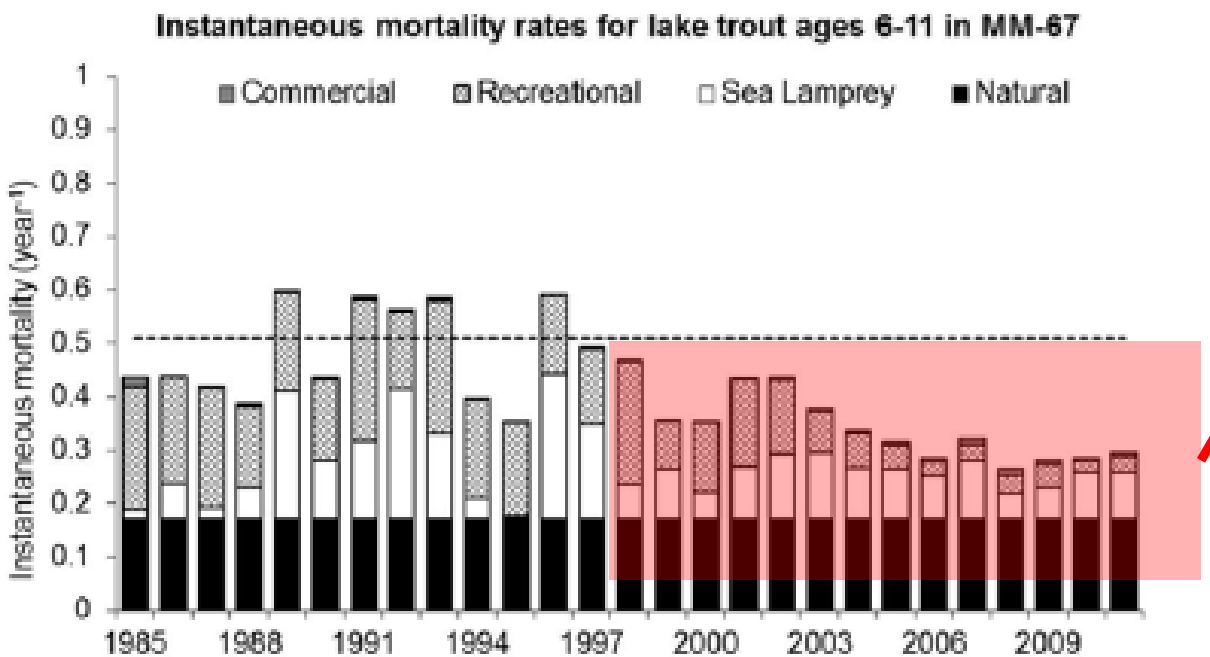


Mortality in the North

Stocking Location	Ages	Instantaneous Mortality	Annual Mortality
Northern Refuge	6-9	1.57	79.2%
Clay Banks	6-9	0.53	41.1%
Southern Refuge	6-9	0.48	38.1%
Julian's Reef	6-9	0.36	30.2%



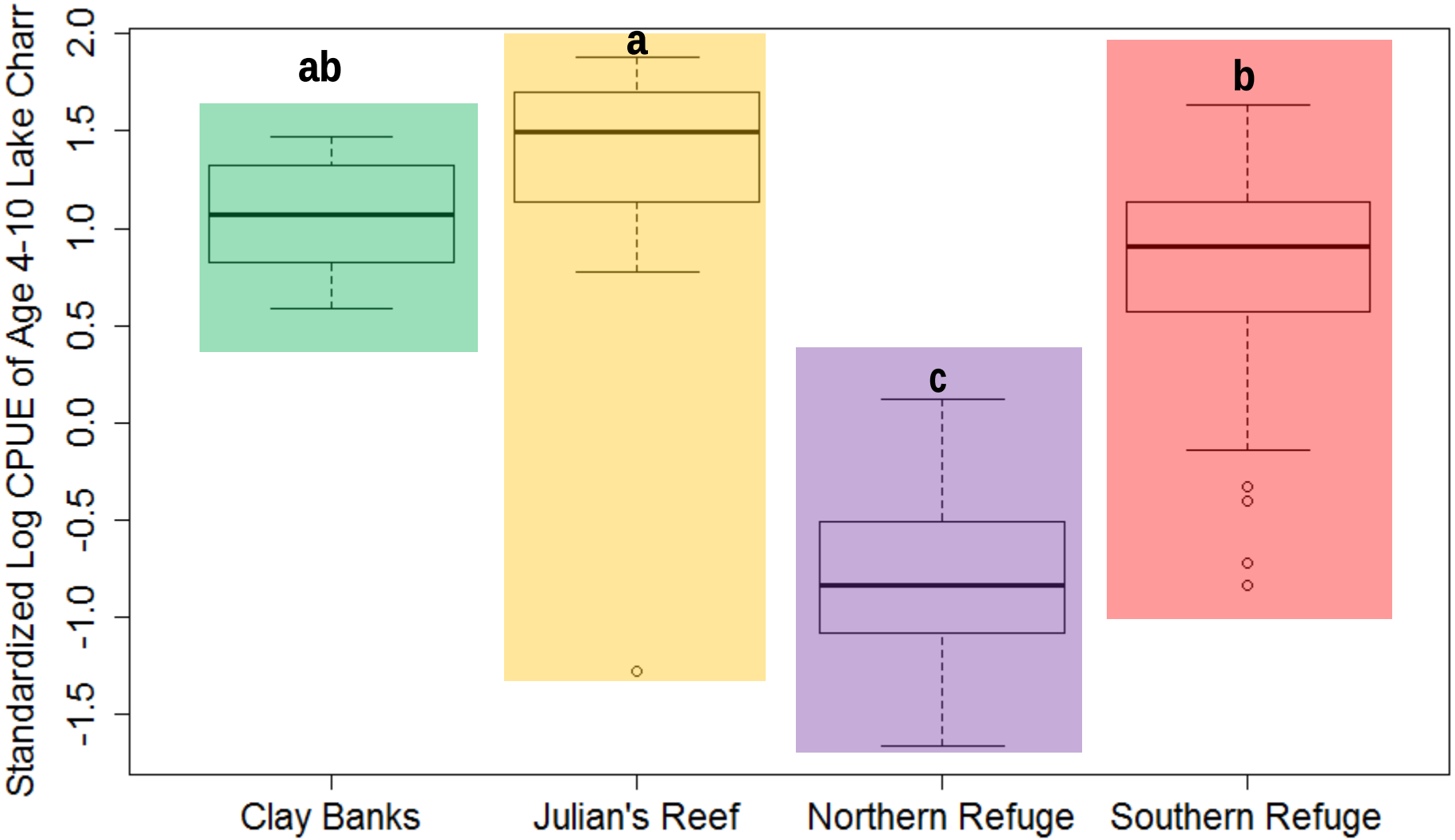




Figures from 2014 Report of the Technical Fisheries Committee to the Executive Council 2000 Consent Decree

First Node in Tree – Effect of Stocking Location

***p* < 0.0001 (ANOVA)**
Northern < all others (*p* <0.001); Southern < Julians (*p* = 0.003) (Tukey)

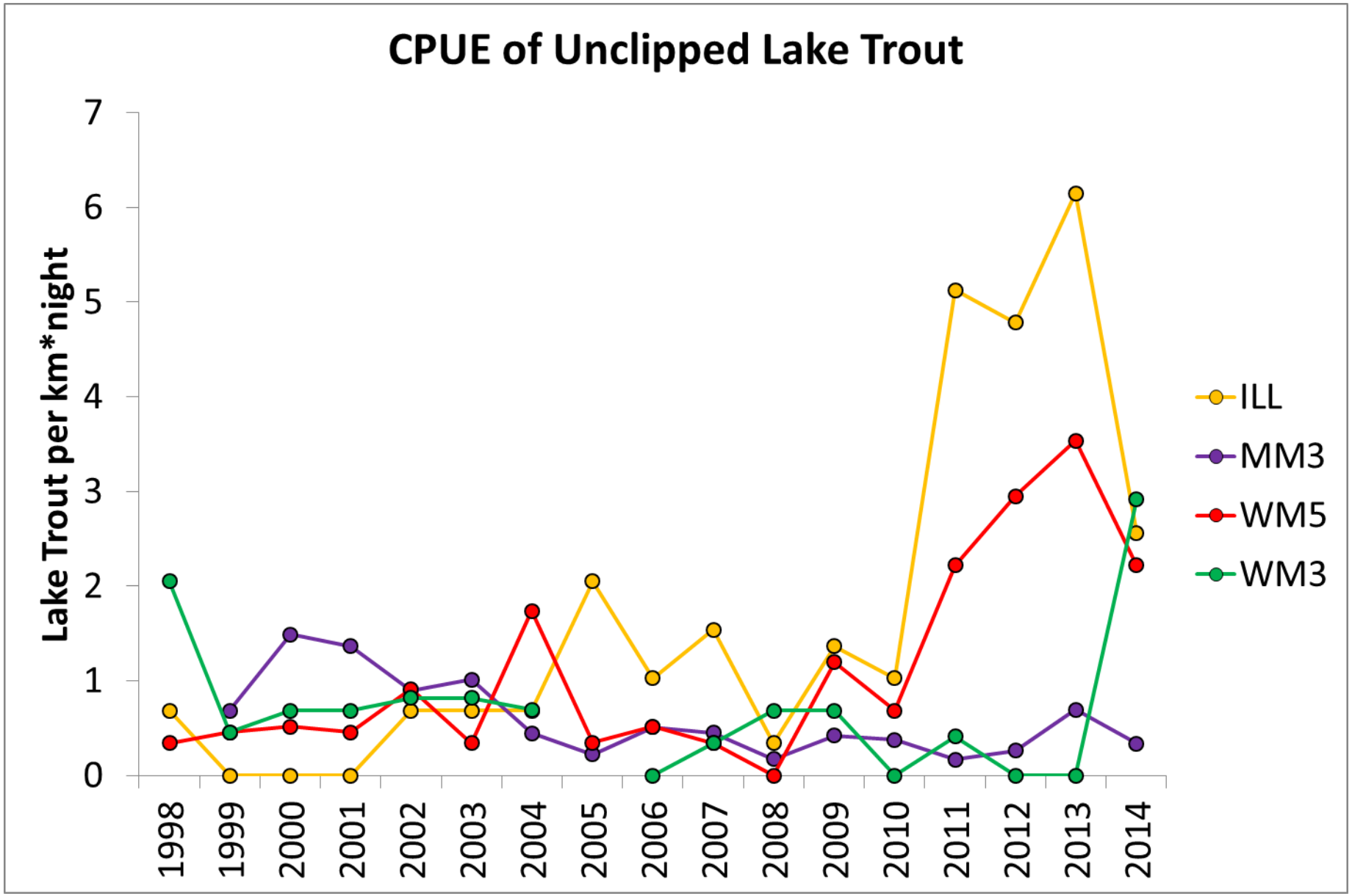


Proportion of Unclipped Lake Trout by Survey

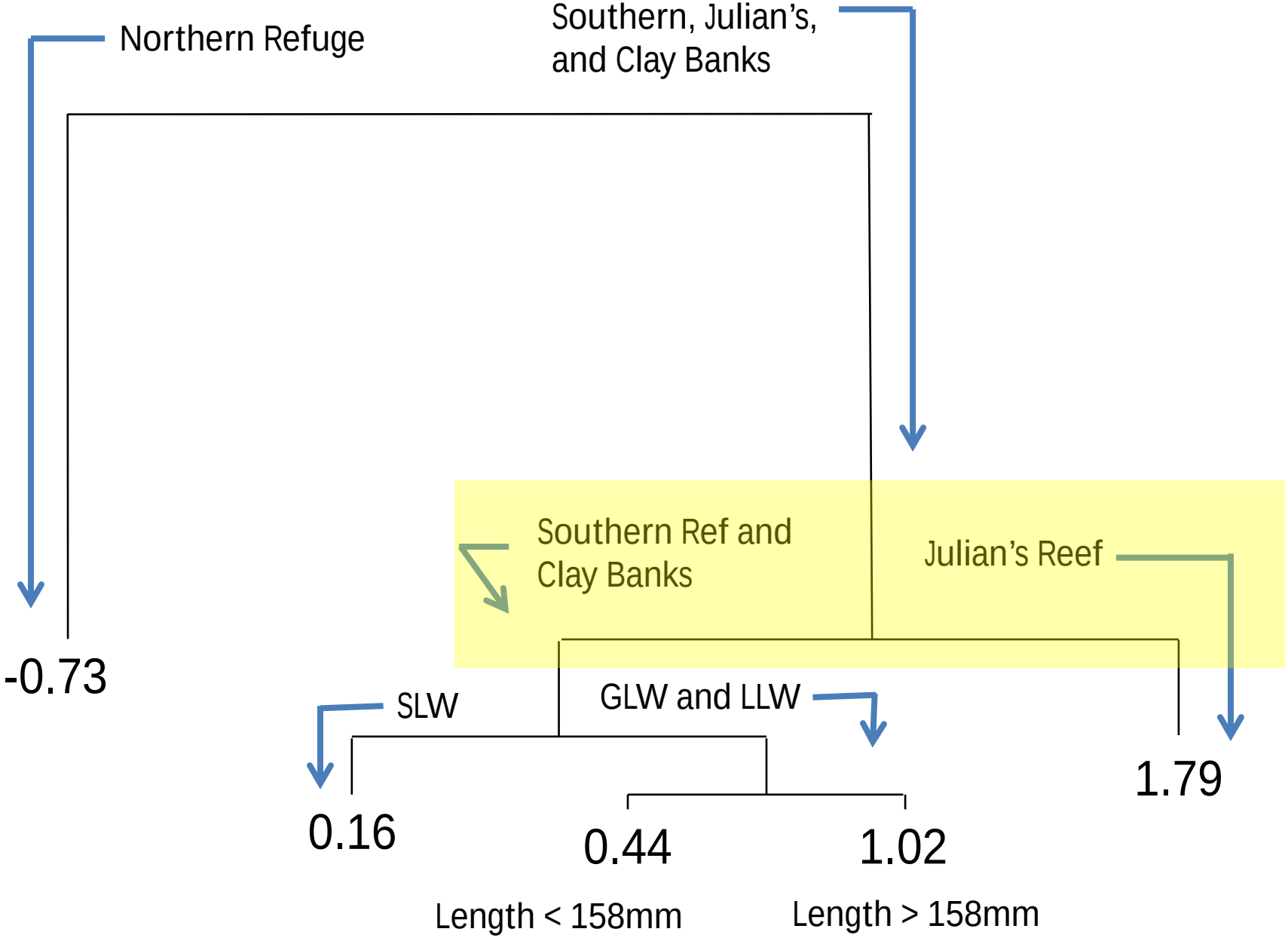
Areas with High CWT Returns Also had High Proportions of Wild Fish in 2014

District (Location)	Spring Assessment	Spawning Survey (fall)	Great Lakes Mass Marking Program (angler recoveries)
Julian's Reef (ILL)	19%	54%	39%
Southern Refuge (WM5/MM7)	11%	22%	19%
Clay Banks (WM3)	7%	n/a	0%
Northern Refuge (MM3)	3%	11%	3%

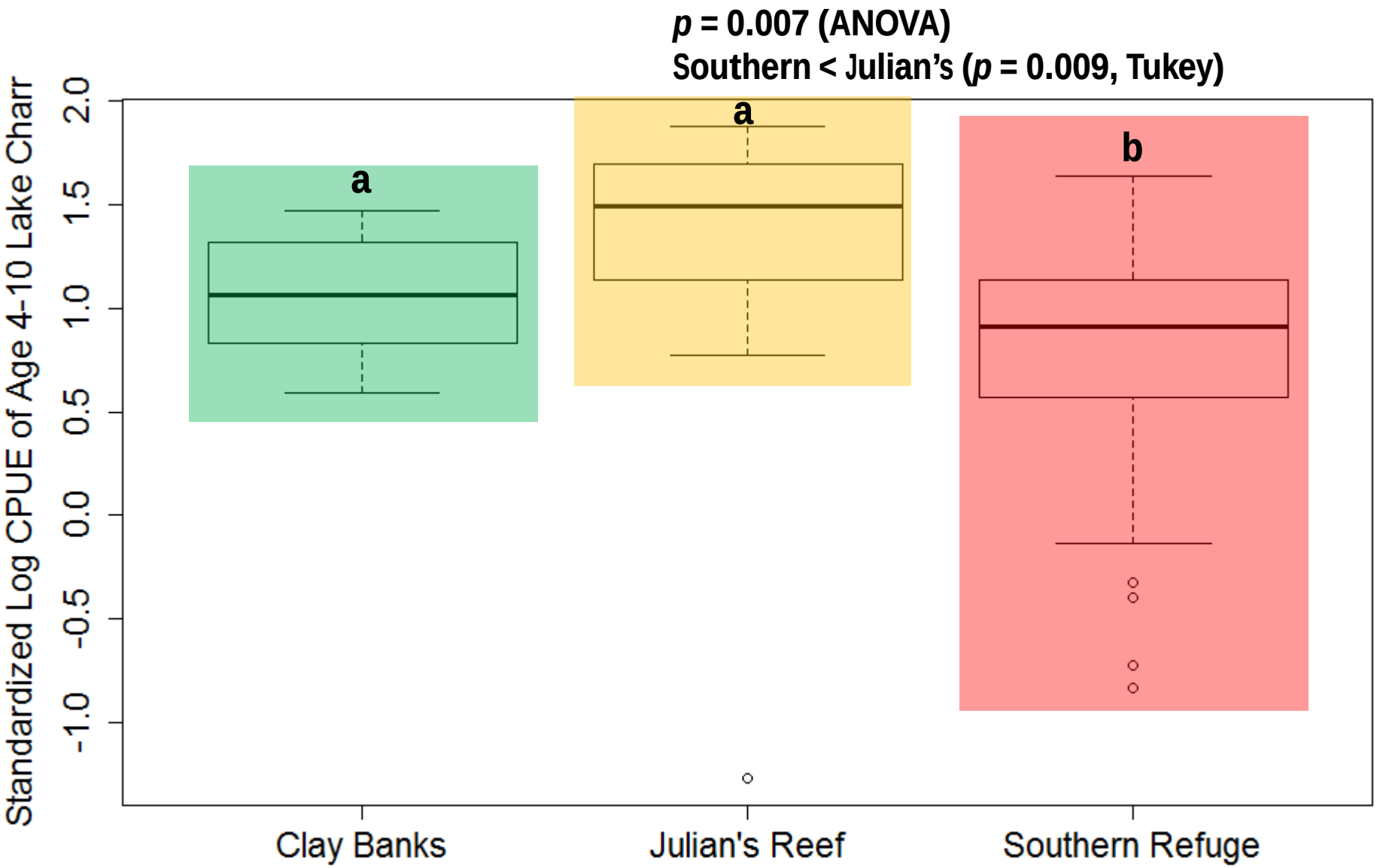
Data from 2014 Lake Michigan Lake Trout Working Group Report


CPUE of Unclipped Lake Trout
Lake Trout per km*night
0
1
2
3
4
5
6
7
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
ILL
MM3
WM5
WM3

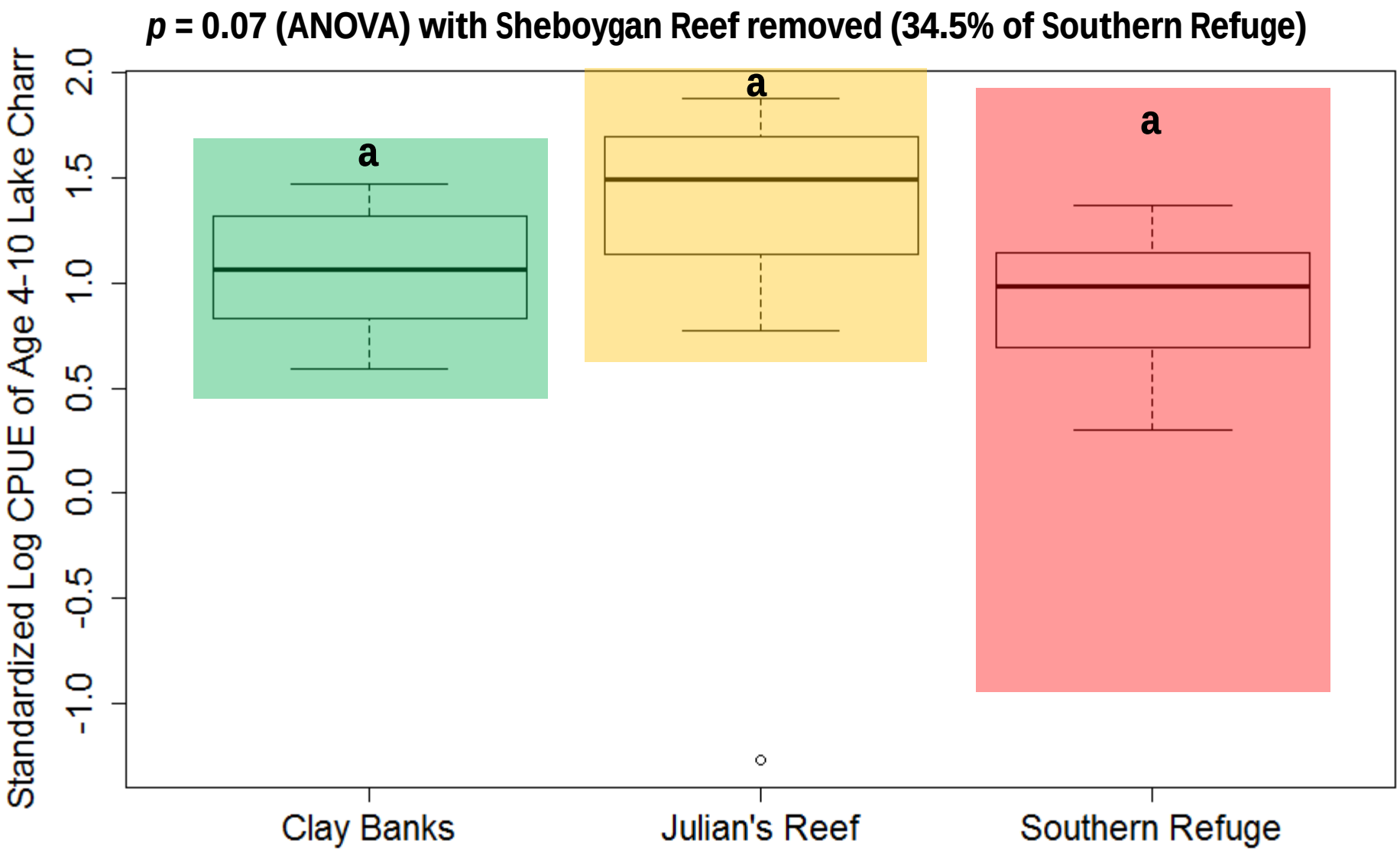
Second Node in Tree – High Recoveries at Julian's Reef



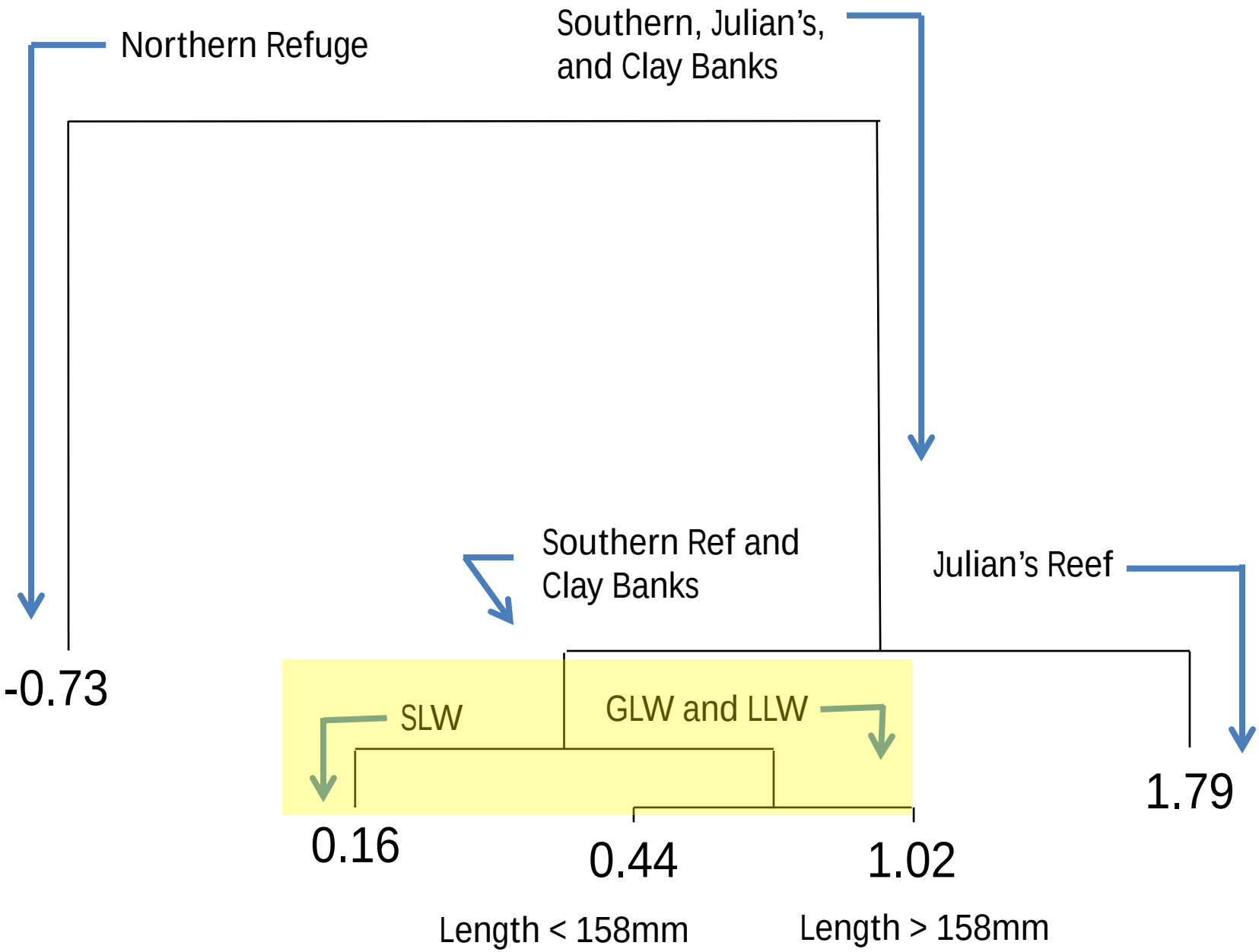
Second Node in Tree – Julian's Reef Splits Off



Note – Site Effect in Southern Refuge

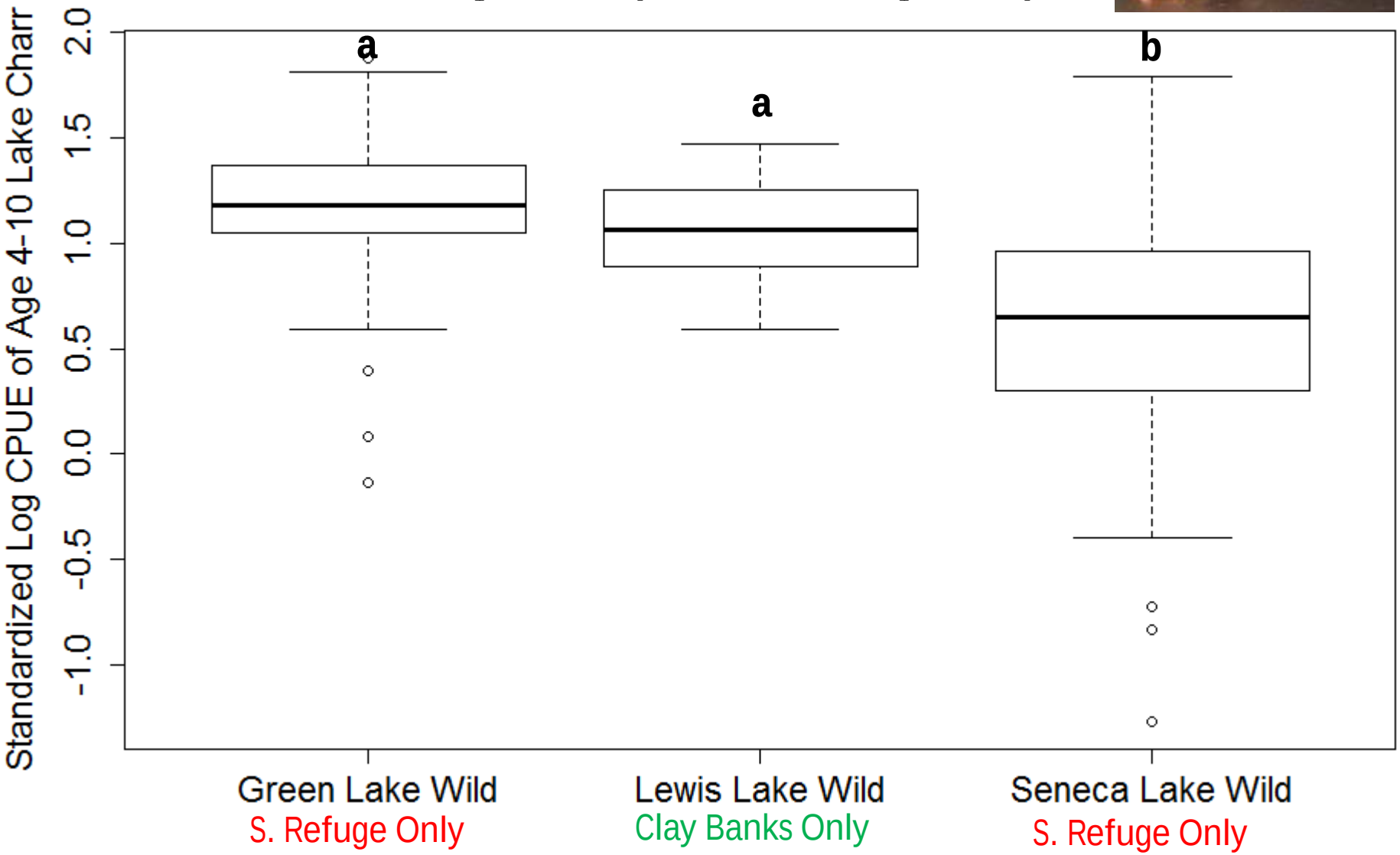


Third Node in Tree – Location-Specific Strain Effect



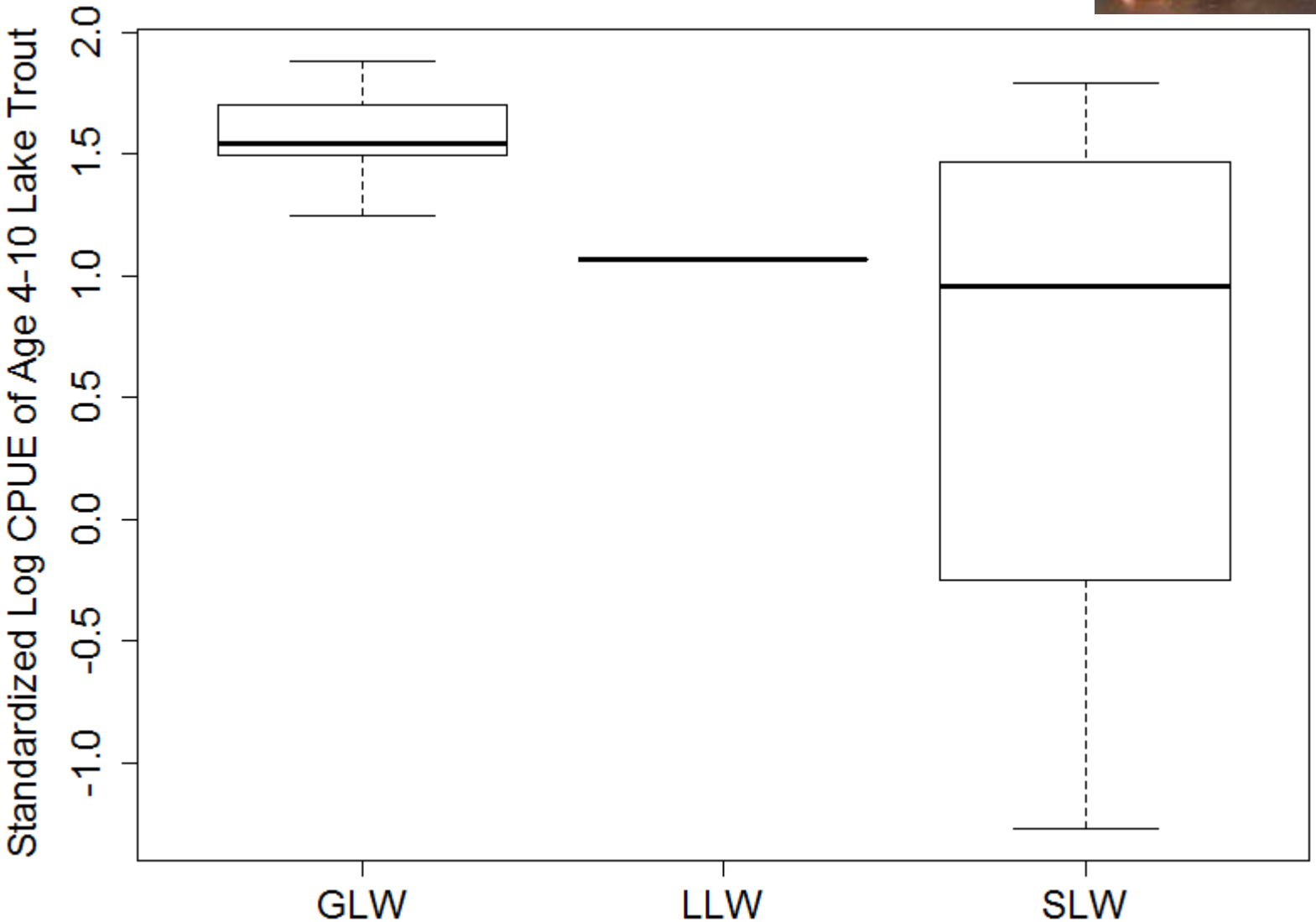
Third Node – Strain Effect in Southern Refuge and Clay Banks

***p* < 0.0001 (ANOVA)**
Seneca < Green Lake (*p* < 0.0001) and Lewis Lake (*p* = 0.01).

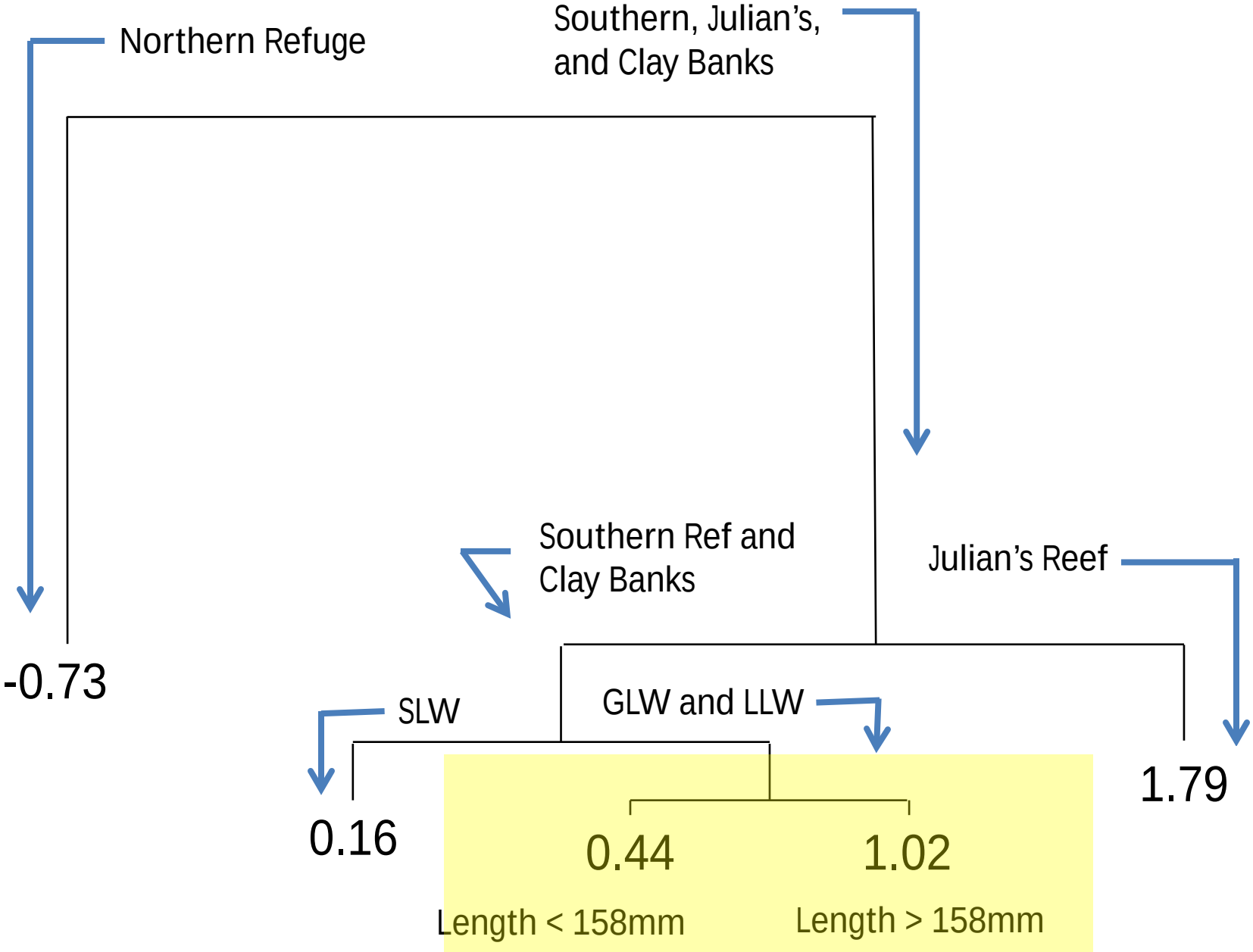


Note: Strain Effect Similar at Julian's Reef

***p* < 0.11 (ANOVA)**

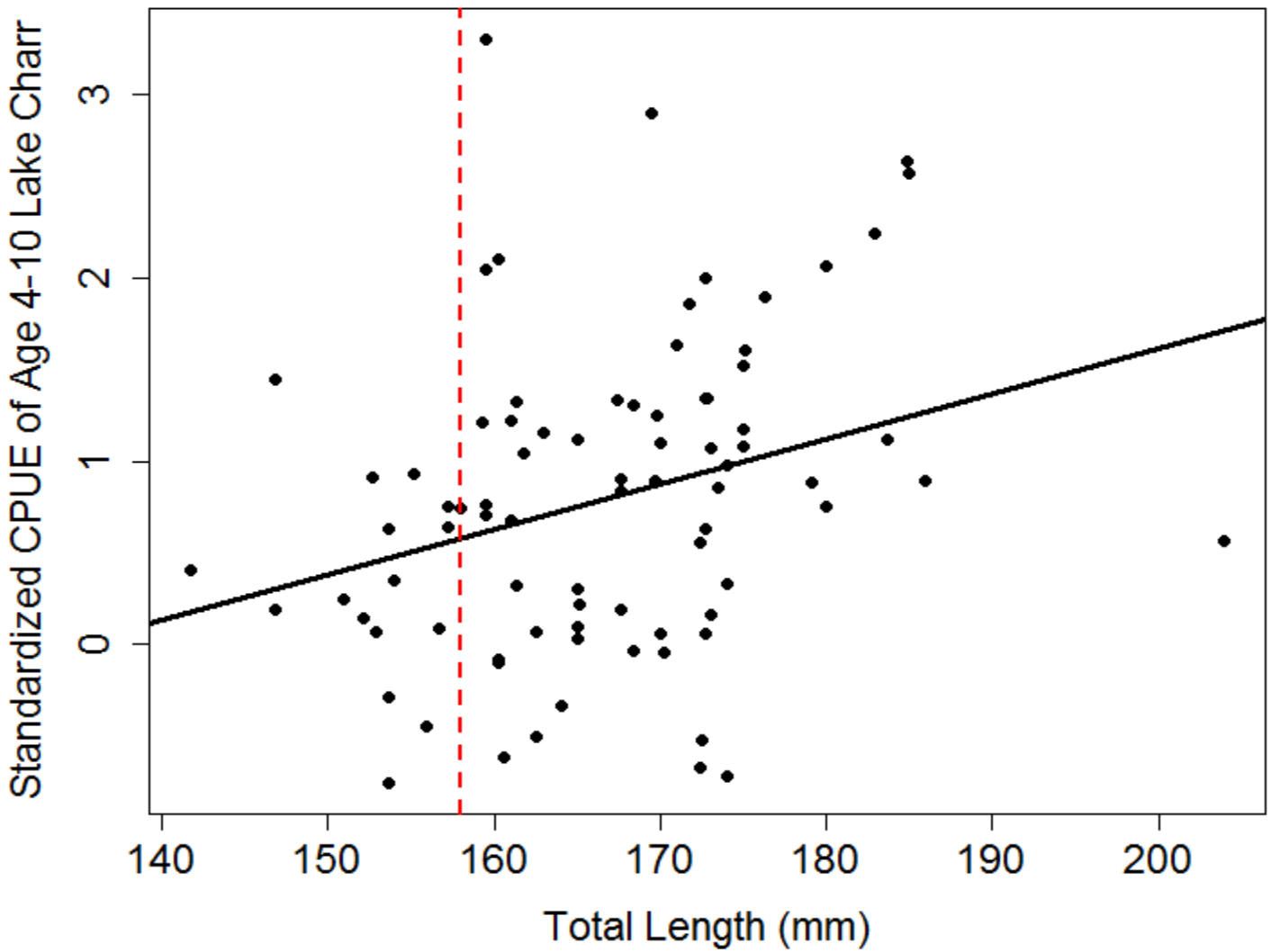


Fourth Node in Tree – Length-at-Stocking Effect

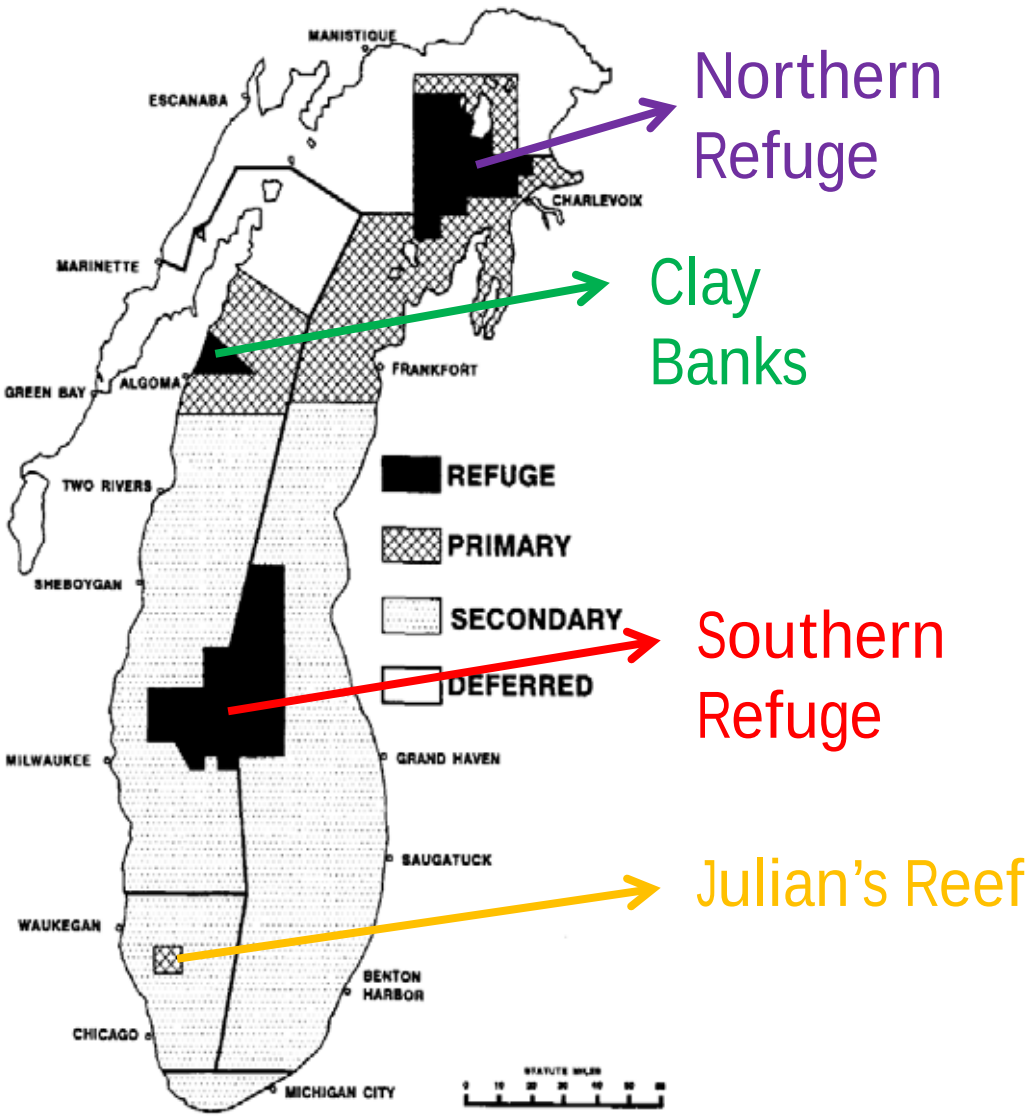


Fourth Node in Tree – Length-at-Stocking Effect

For fish not in Northern Refuge: p = 0.002, R^2 = 0.11
Dashed red line is the CART identified threshold of 158 mm
Note: All fish stocked after lake trout stocking size increased from ~44 fish/kg to 22-26 fish/kg (Bronte et al. 2006)

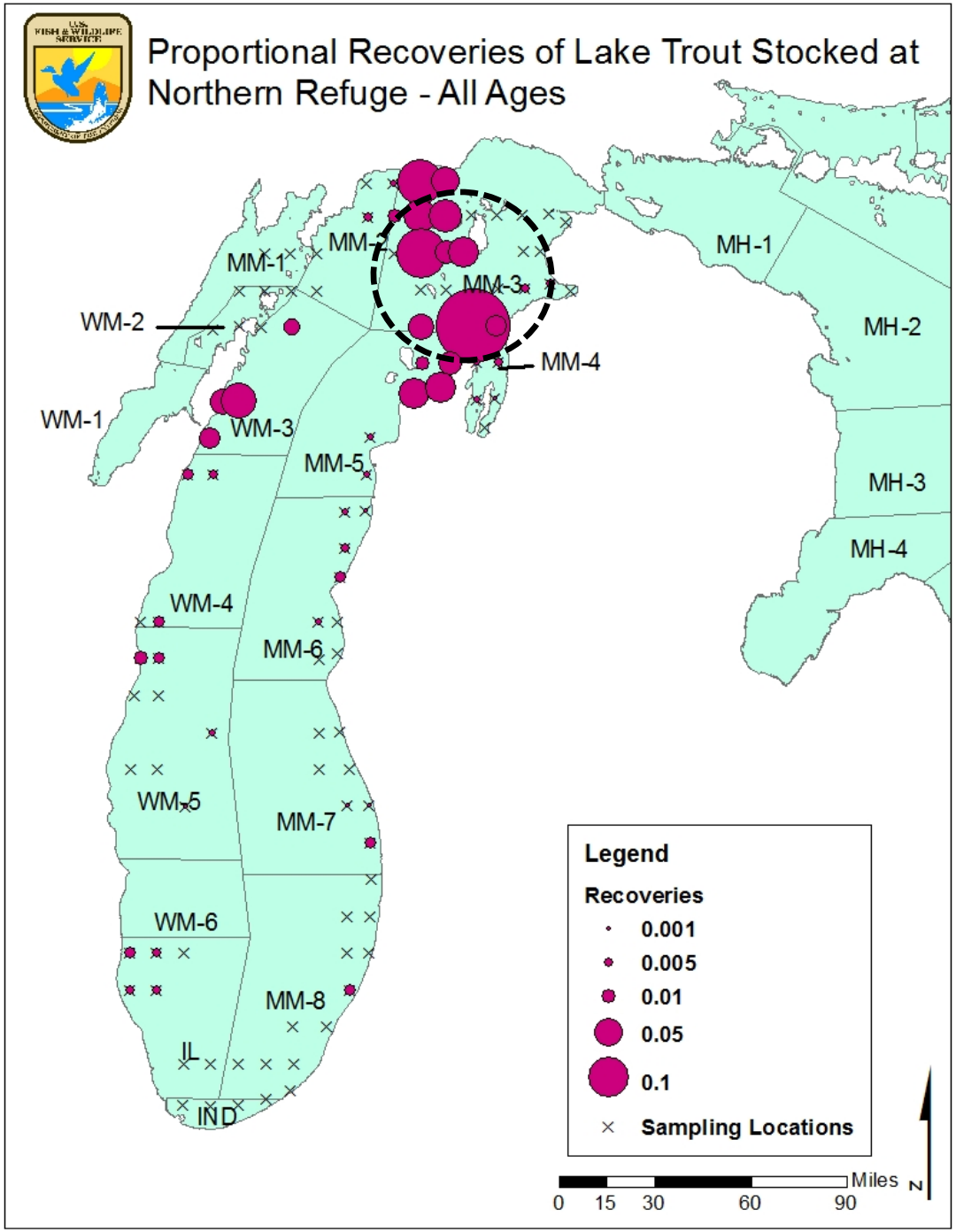


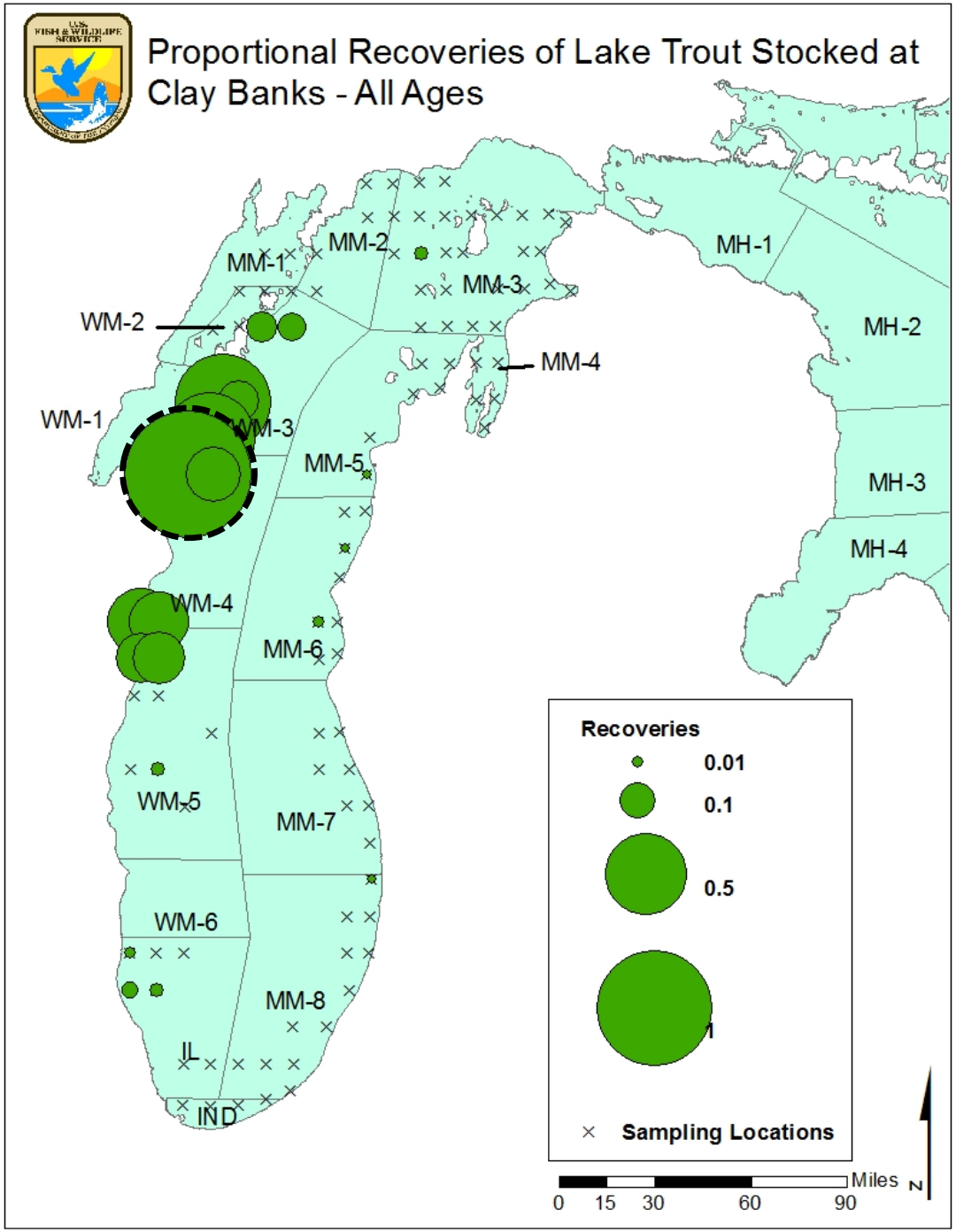
Spatial Spread of Fish from Major Stocking Locations

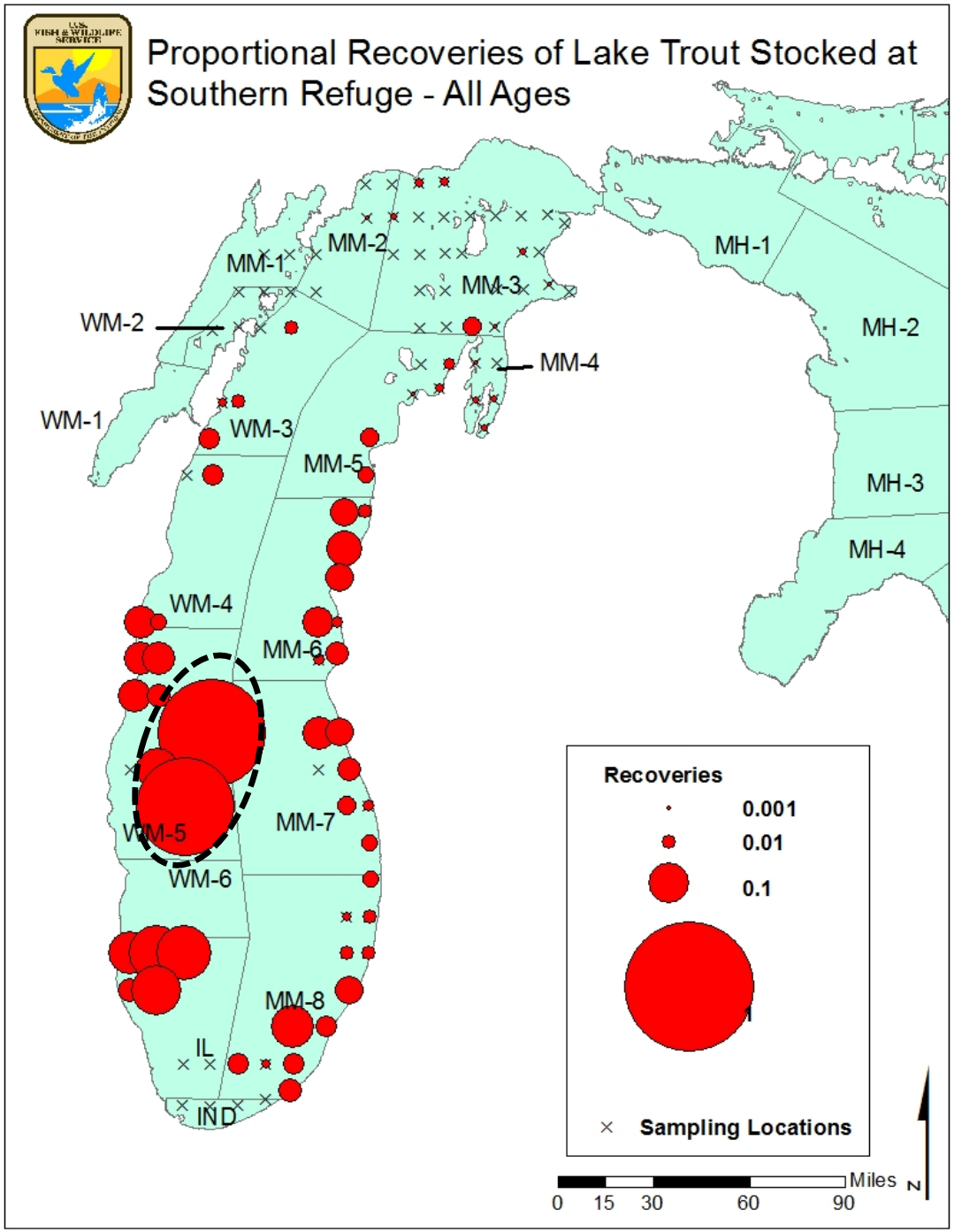


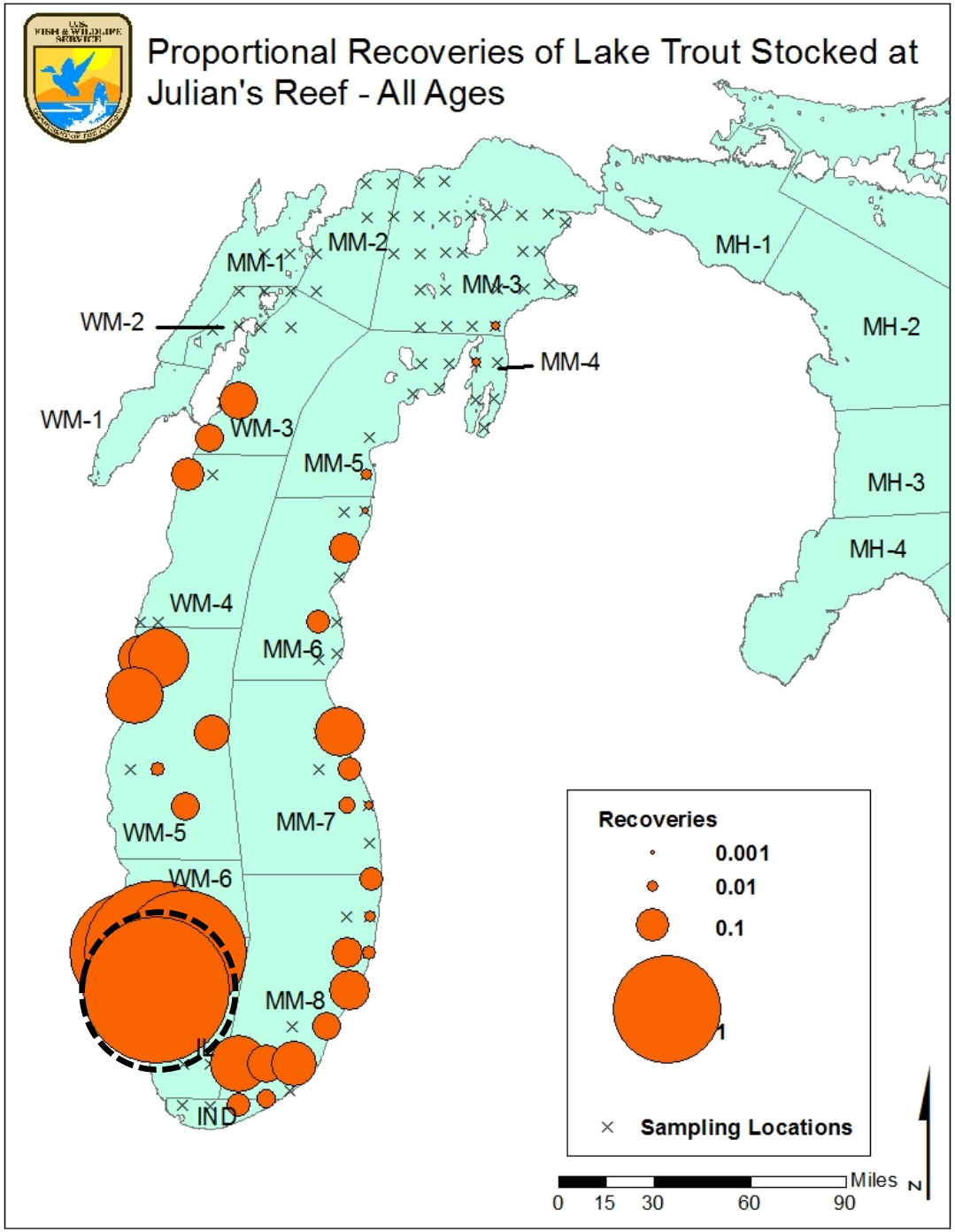
Map from Holey et al. 1995

- Mapped values are CPUEs corrected for number of fish stocked and for grid-specific sampling effort.
- Values are mapped at the 10' grid scale.
- The stocking refuge in each map is circled in black dashed line
- Dot sizes are on equal scales between four maps.

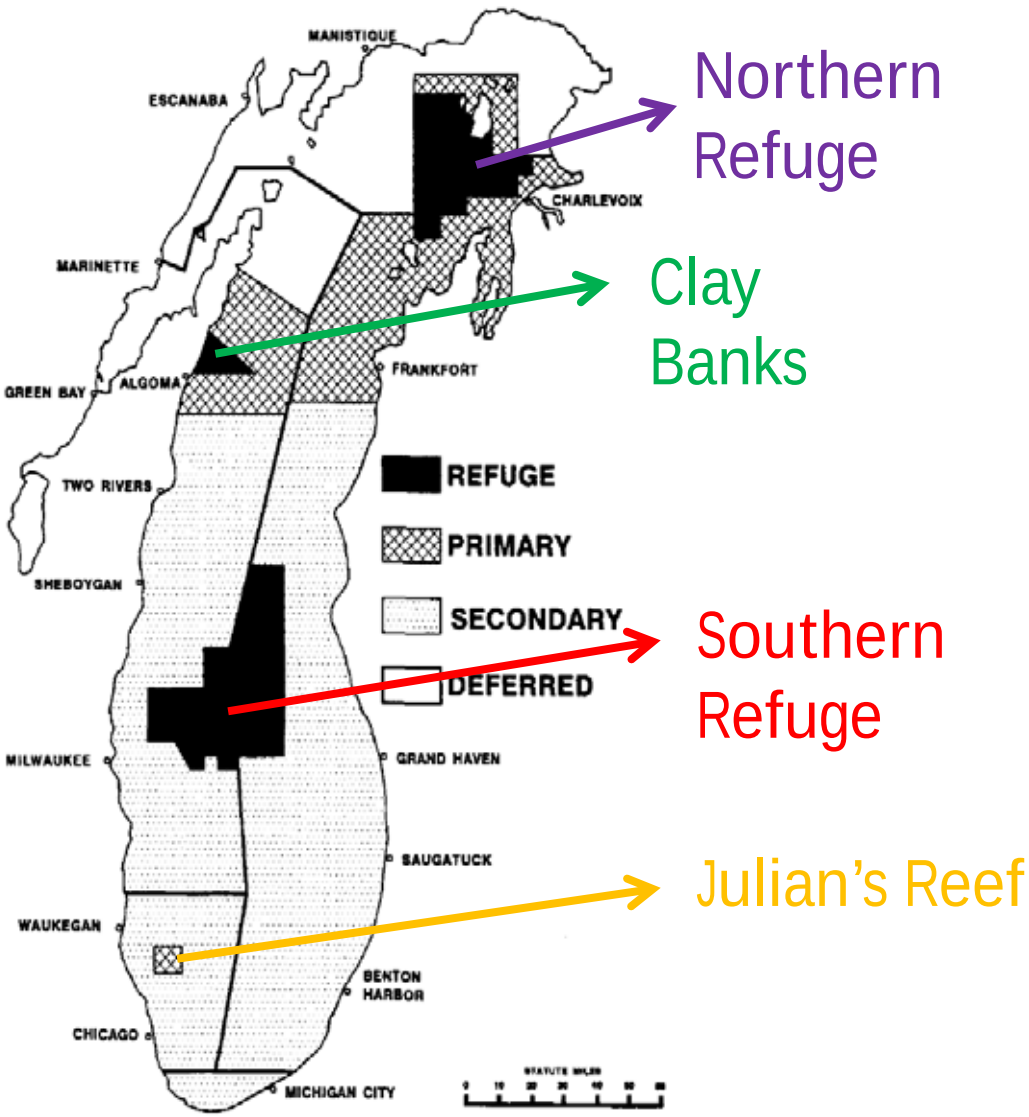

Proportional Recoveries of Lake Trout Stocked at Northern Refuge - All Ages
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
MH-1
MH-2
MH-3
MH-4
IL
IND
Legend
Recoveries
0.001
0.005
0.01
0.05
0.1
Sampling Locations
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Clay Banks - All Ages
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
Recoveries
0.01
0.1
0.5
1
Sampling Locations
Miles
0
15
30
60
90
N


Proportional Recoveries of Lake Trout Stocked at Southern Refuge - All Ages
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
Recoveries
0.001
0.01
0.1
1
Sampling Locations
Miles
0
15
30
60
90
N

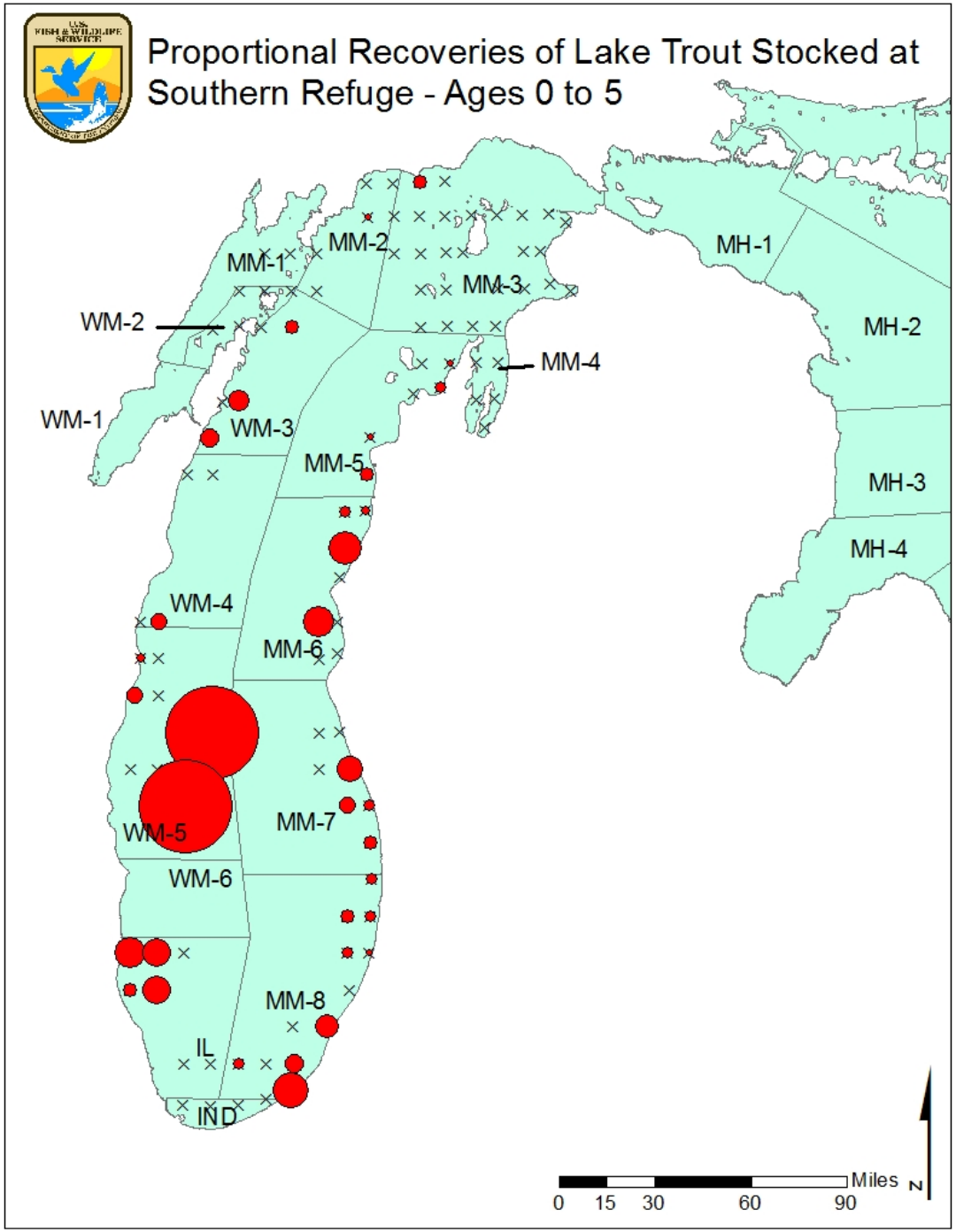

Proportional Recoveries of Lake Trout Stocked at Julian's Reef - All Ages
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
MH-1
MH-2
MH-3
MH-4
IND
Recoveries
0.001
0.01
0.1
1
Sampling Locations
0 15 30 60 90
Miles
N

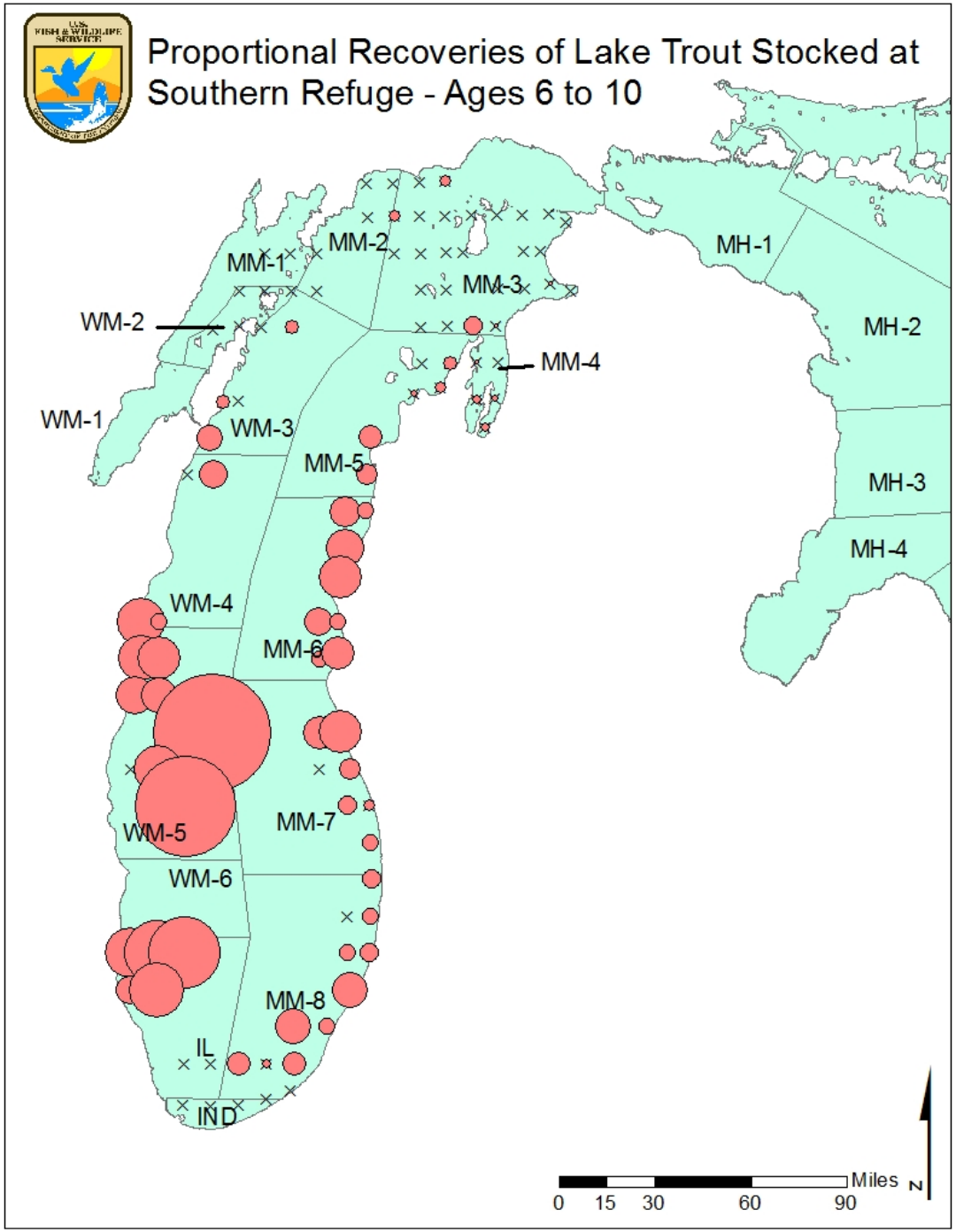
Spatial Spread of Fish from Major Stocking Locations by Age

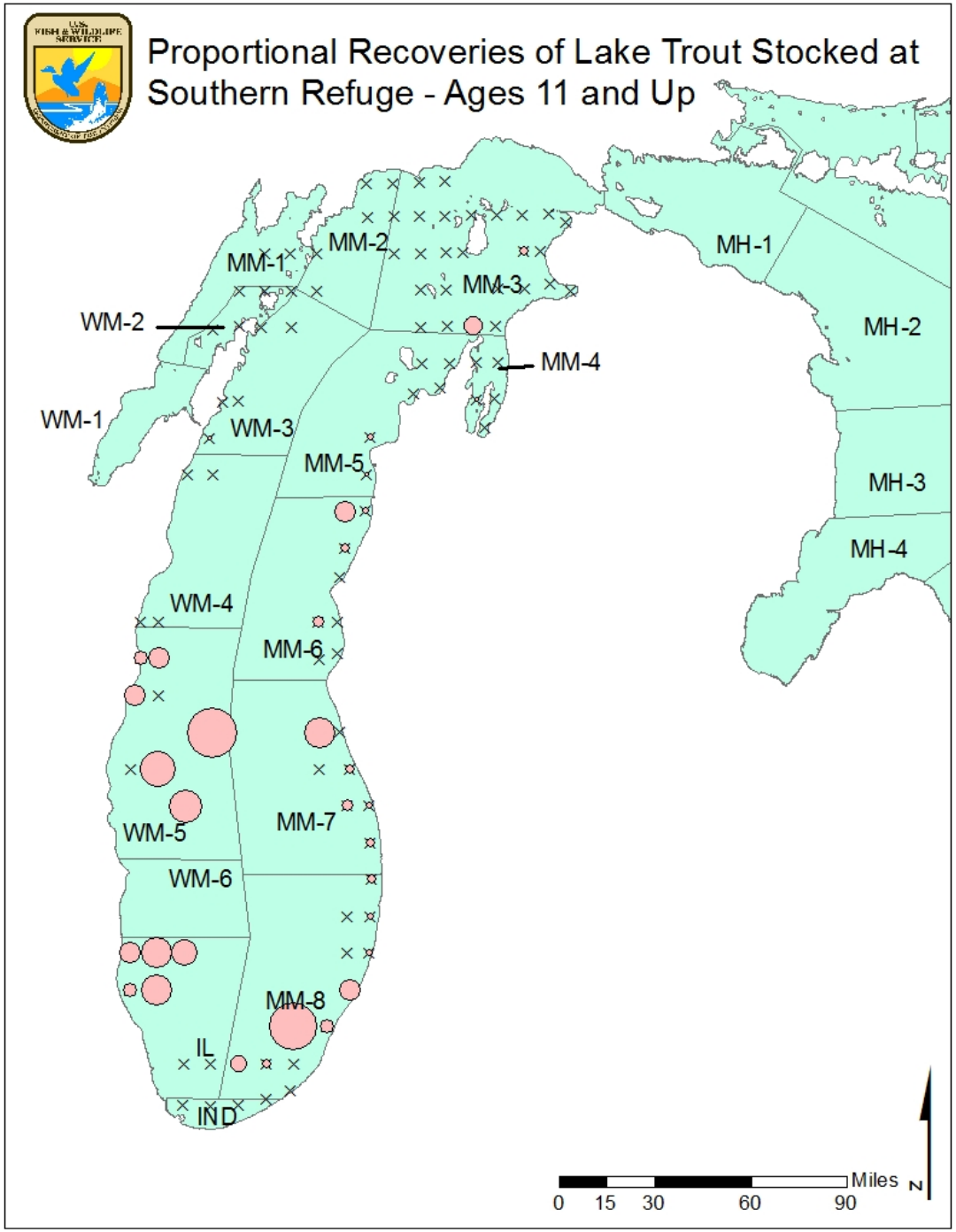


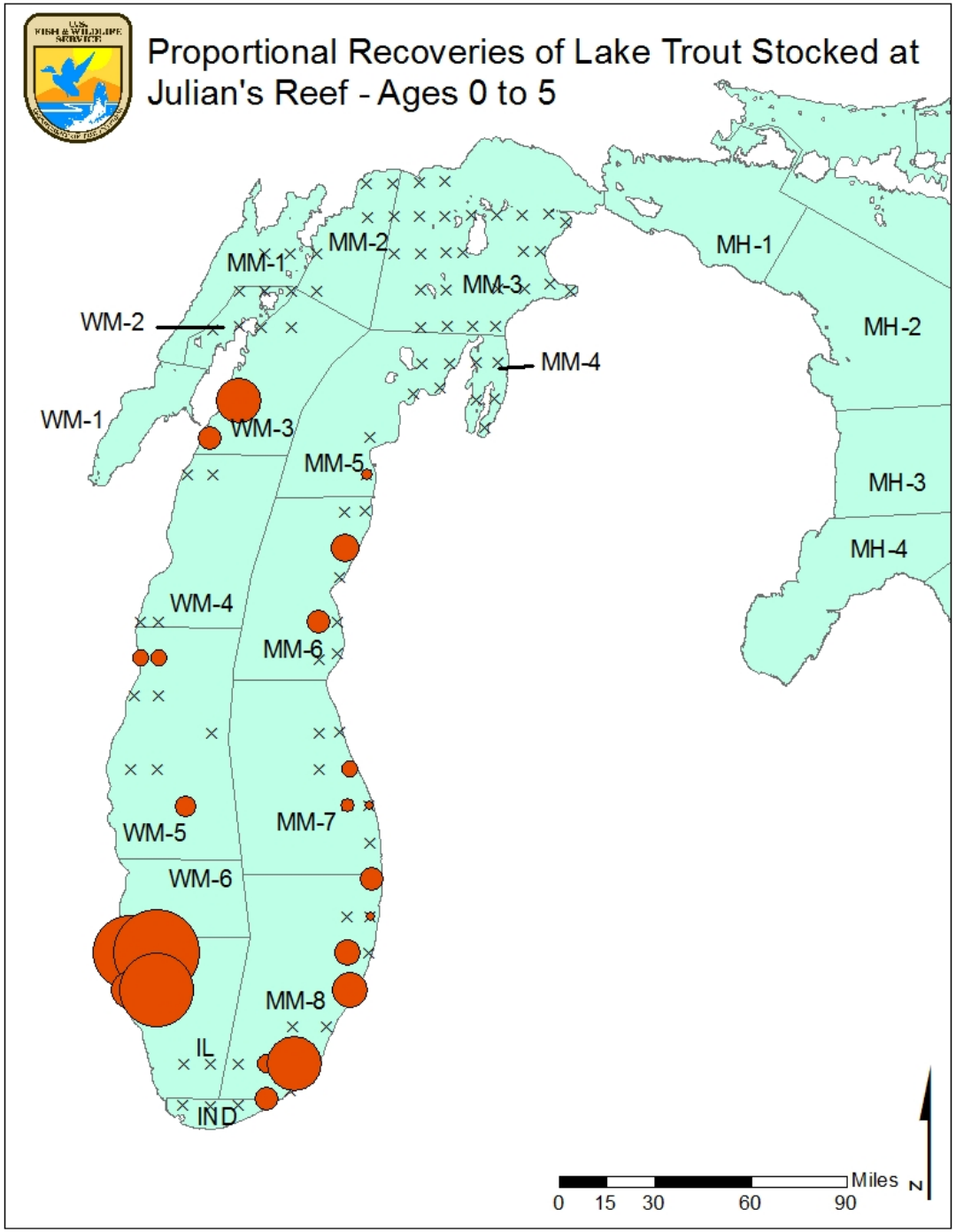
Map from Holey et al. 1995

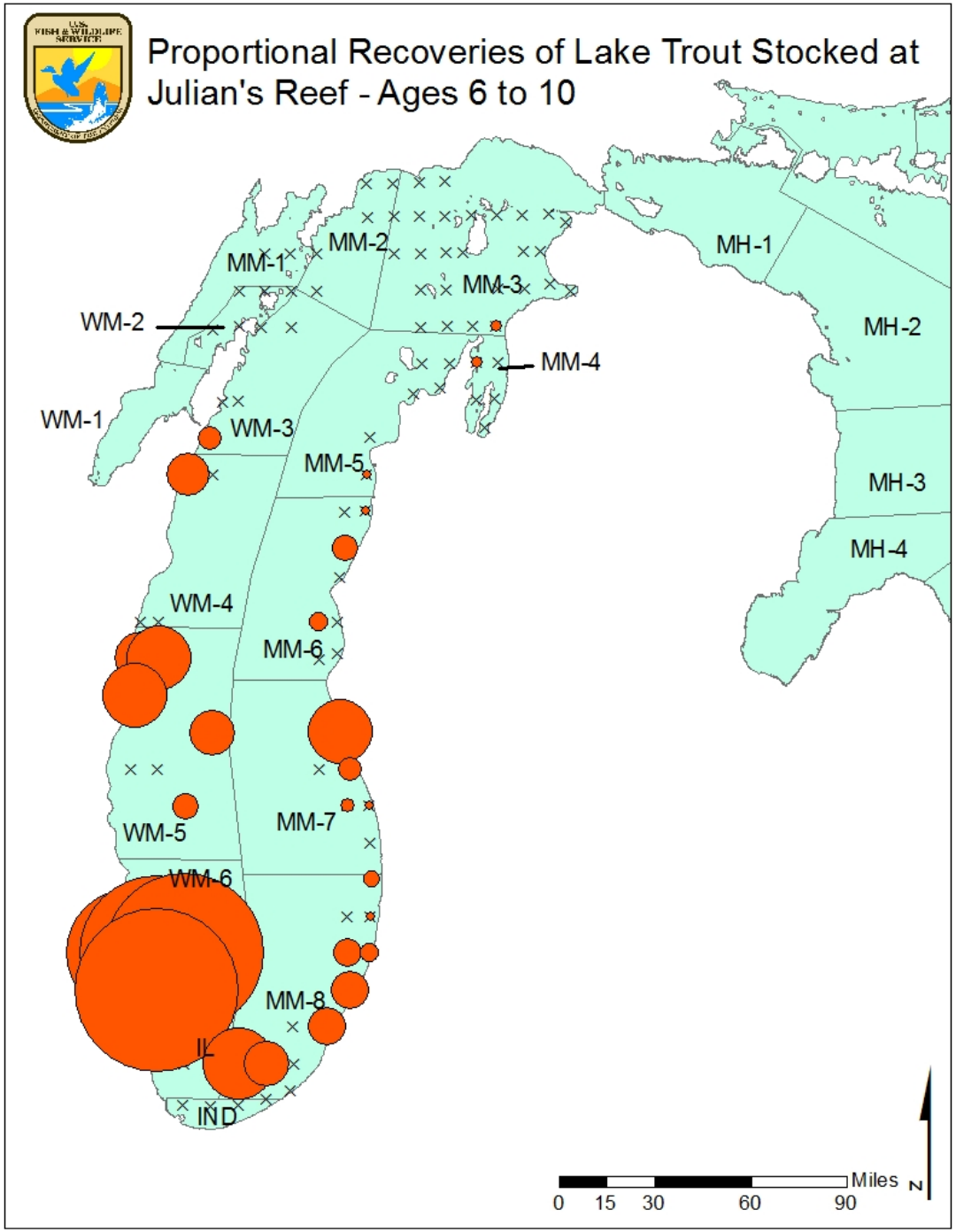
- Mapped values are corrected CPUEs in three age groups:
  - 2-5
  - 5-10
  - 11+

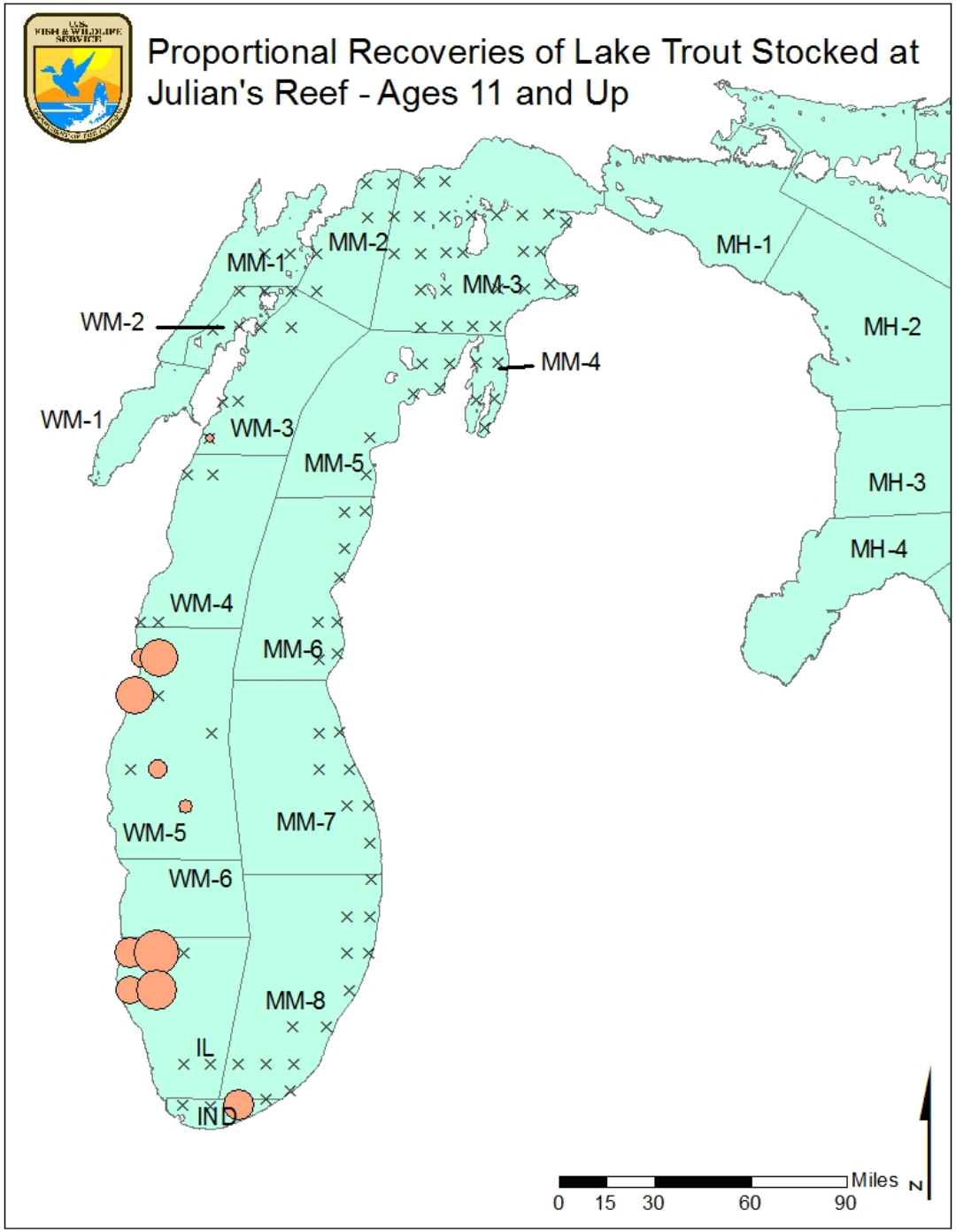

Proportional Recoveries of Lake Trout Stocked at Southern Refuge - Ages 0 to 5
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
MH-1
MH-2
MH-3
MH-4
IL
IND
0 15 30 60 90
Miles
N

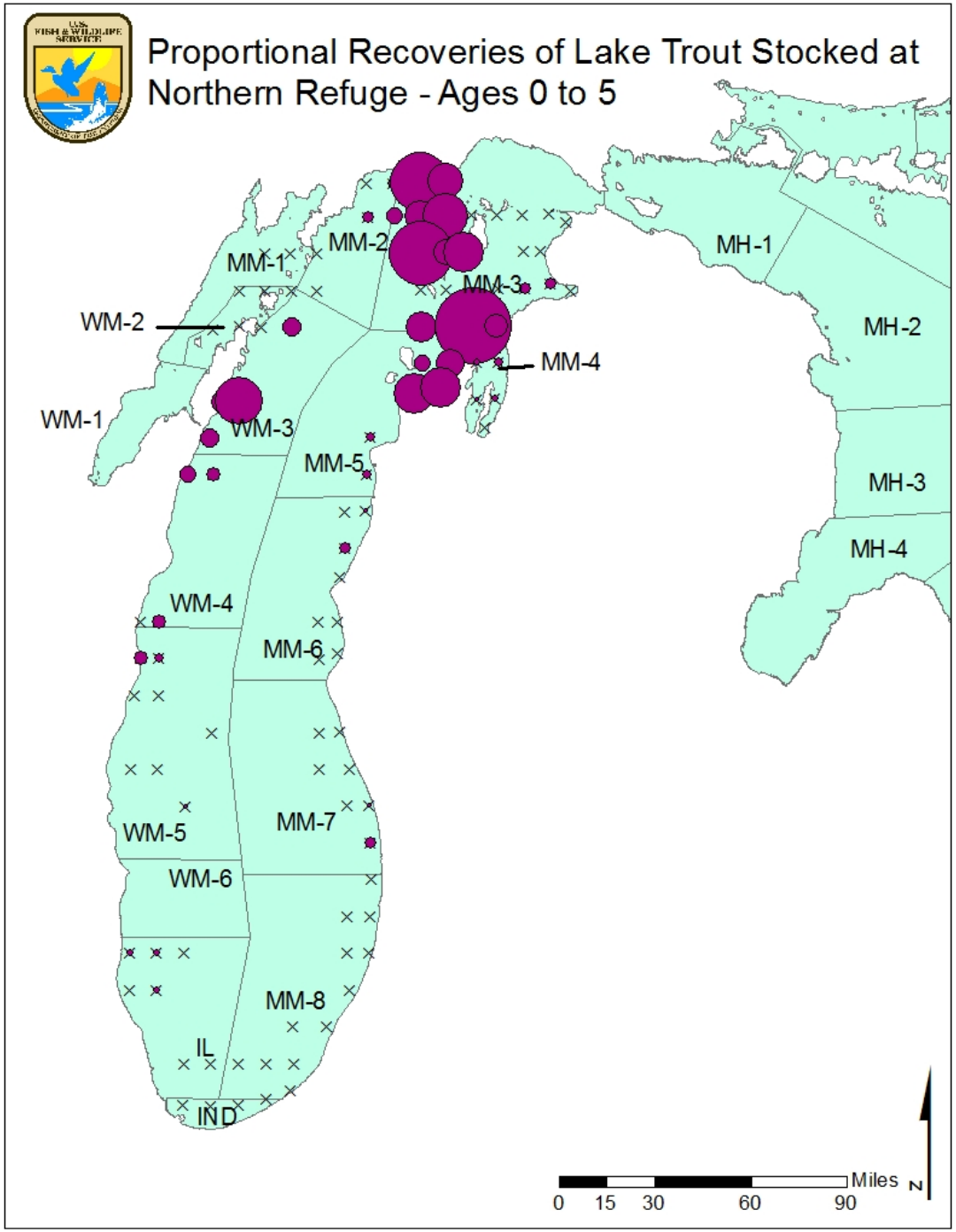

Proportional Recoveries of Lake Trout Stocked at Southern Refuge - Ages 6 to 10
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N

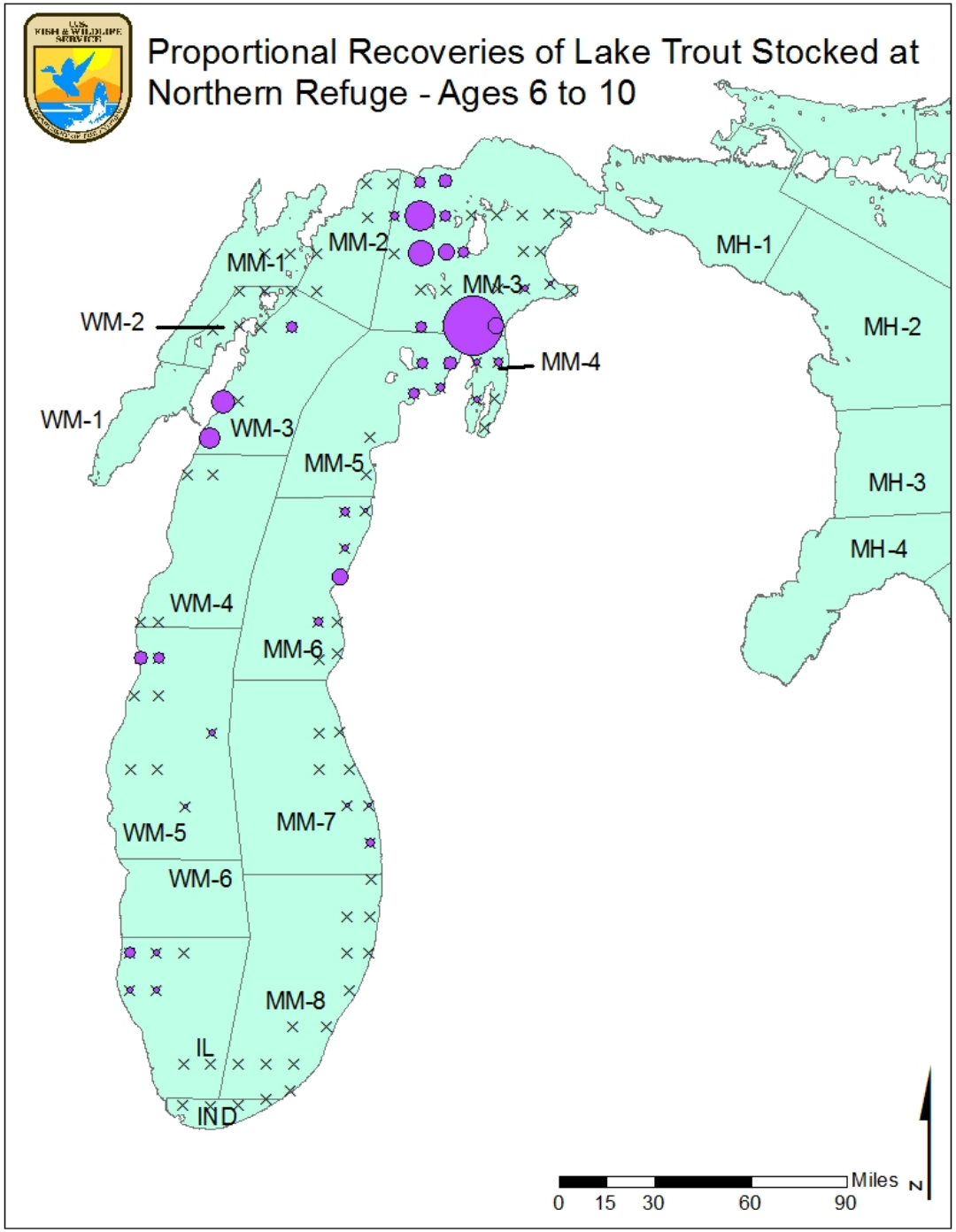

Proportional Recoveries of Lake Trout Stocked at Southern Refuge - Ages 11 and Up
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Julian's Reef - Ages 0 to 5
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Julian's Reef - Ages 6 to 10
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
MH-1
MH-2
MH-3
MH-4
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Julian's Reef - Ages 11 and Up
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
Miles
0
15
30
60
90
N


Proportional Recoveries of Lake Trout Stocked at Northern Refuge - Ages 0 to 5
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Northern Refuge - Ages 6 to 10
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
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WM-1
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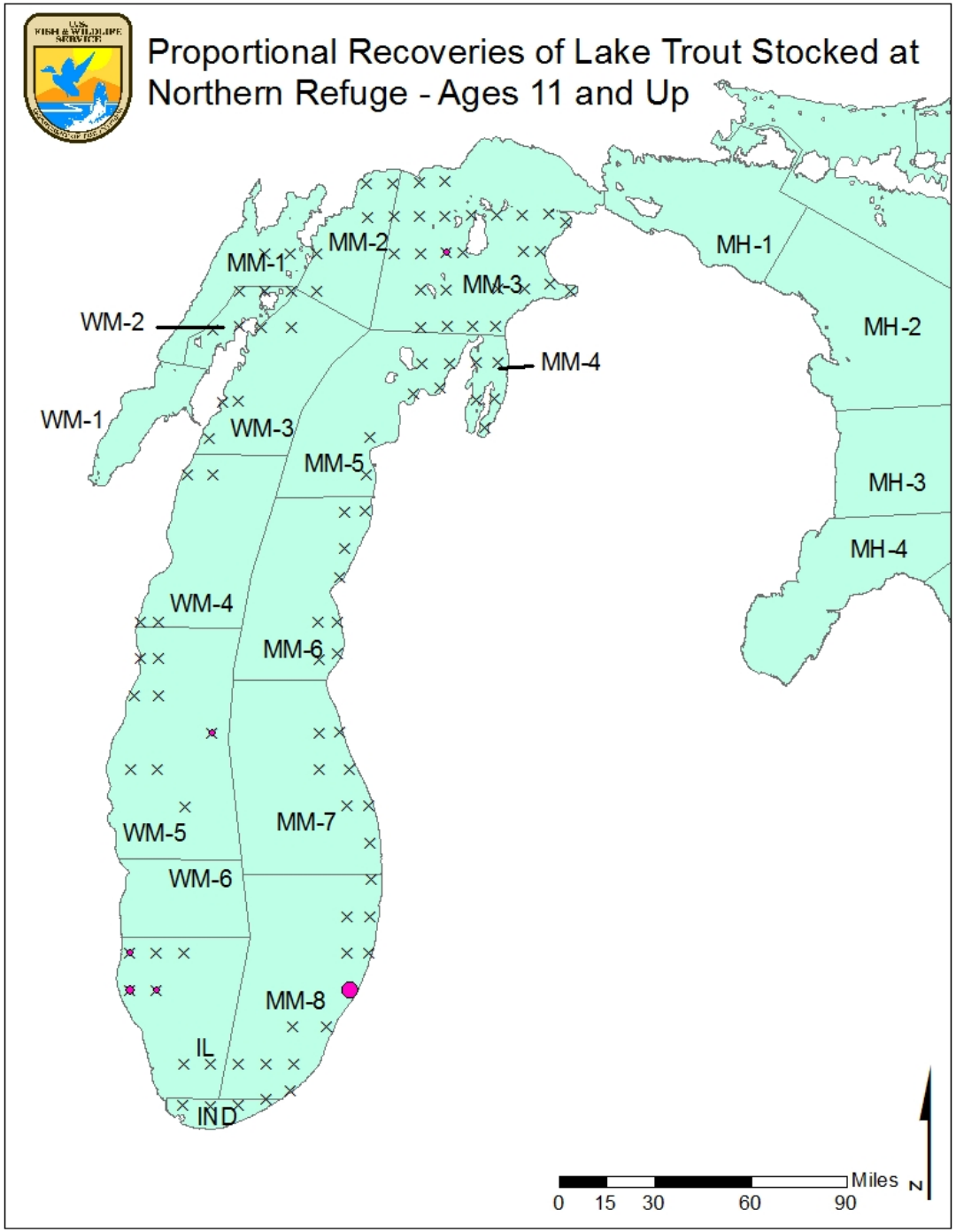
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Northern Refuge - Ages 11 and Up
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
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IND
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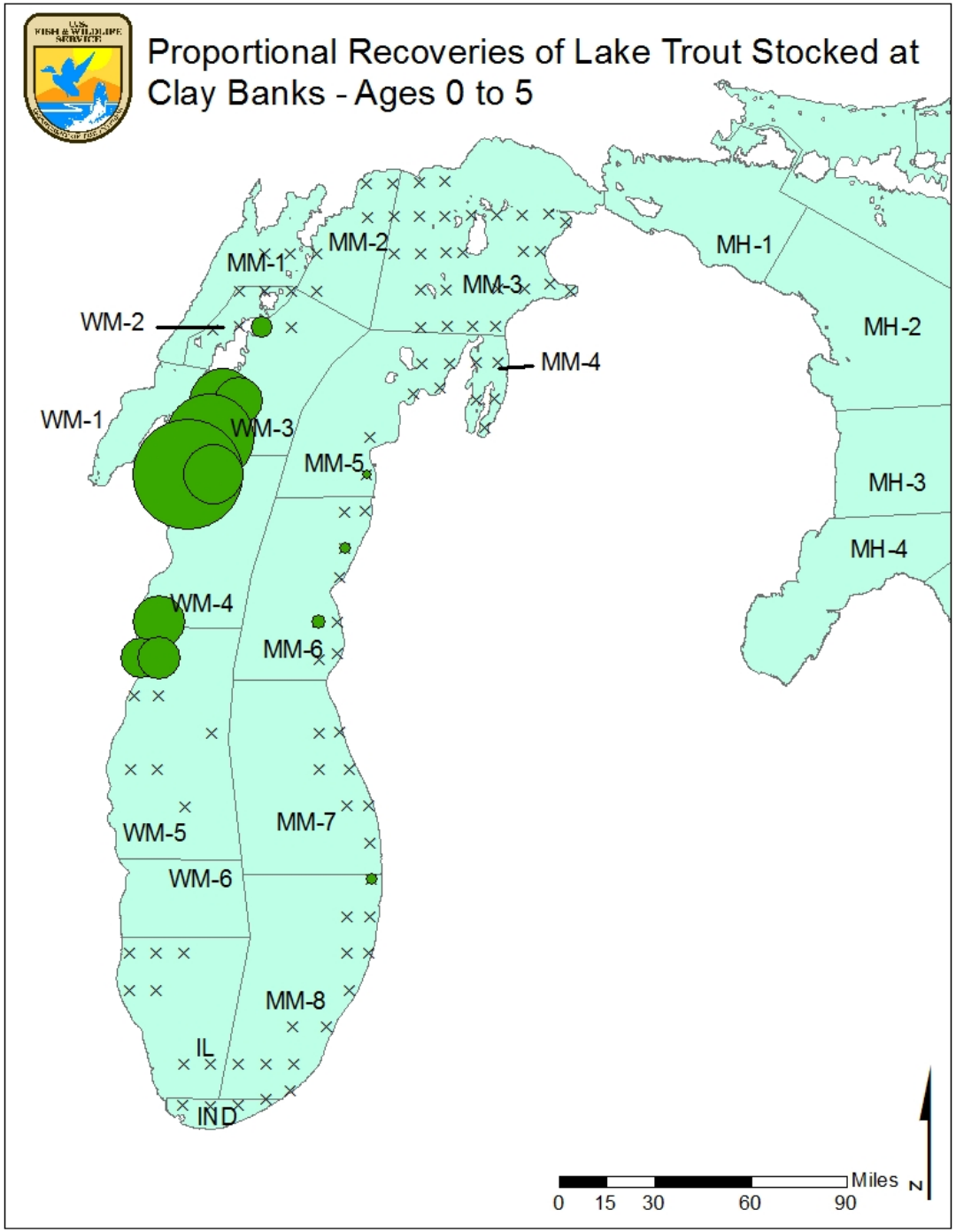
Miles
N


Proportional Recoveries of Lake Trout Stocked at Clay Banks - Ages 0 to 5
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MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
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WM-4
WM-5
WM-6
IL
IND
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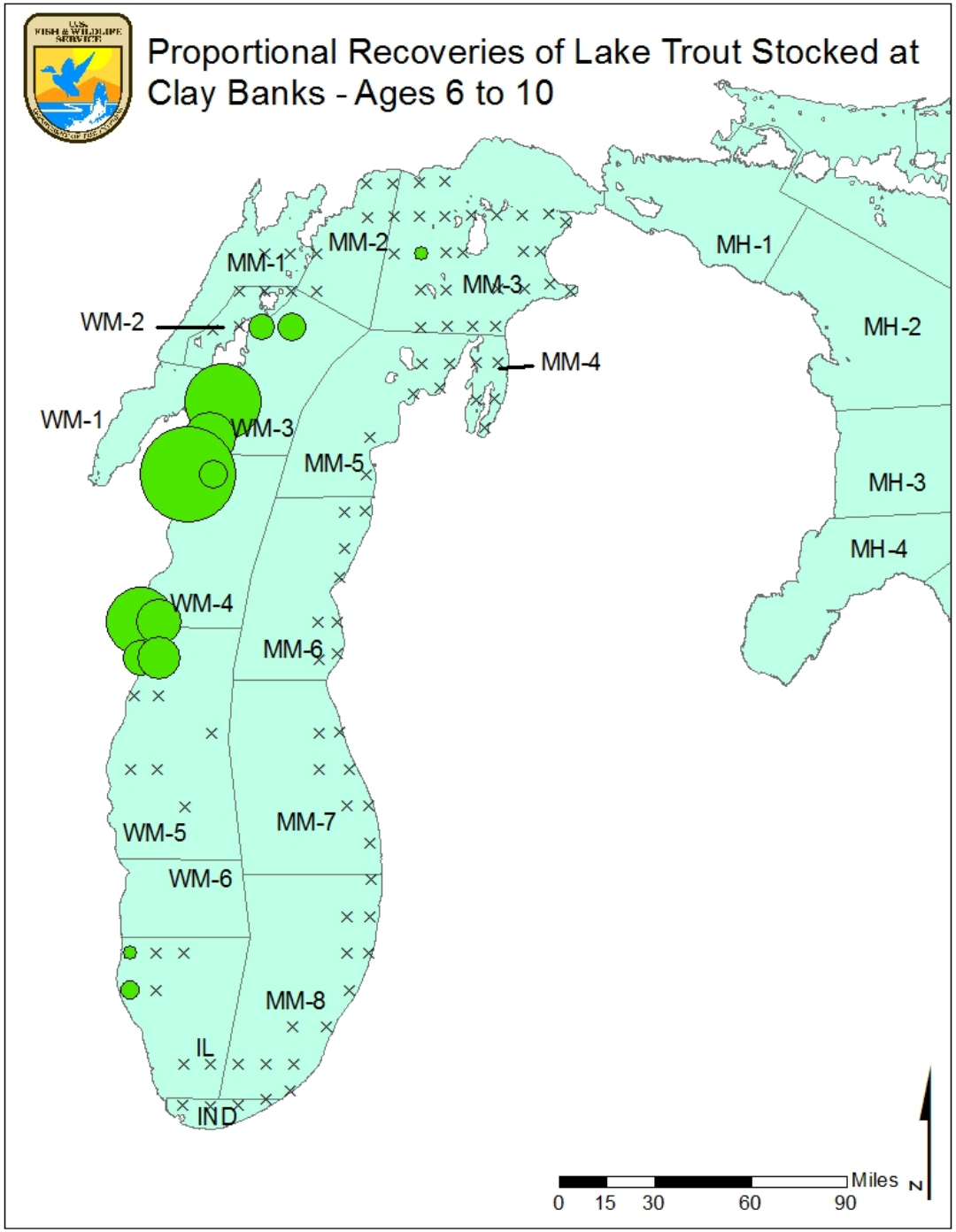
Miles
N


Proportional Recoveries of Lake Trout Stocked at Clay Banks - Ages 6 to 10
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MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
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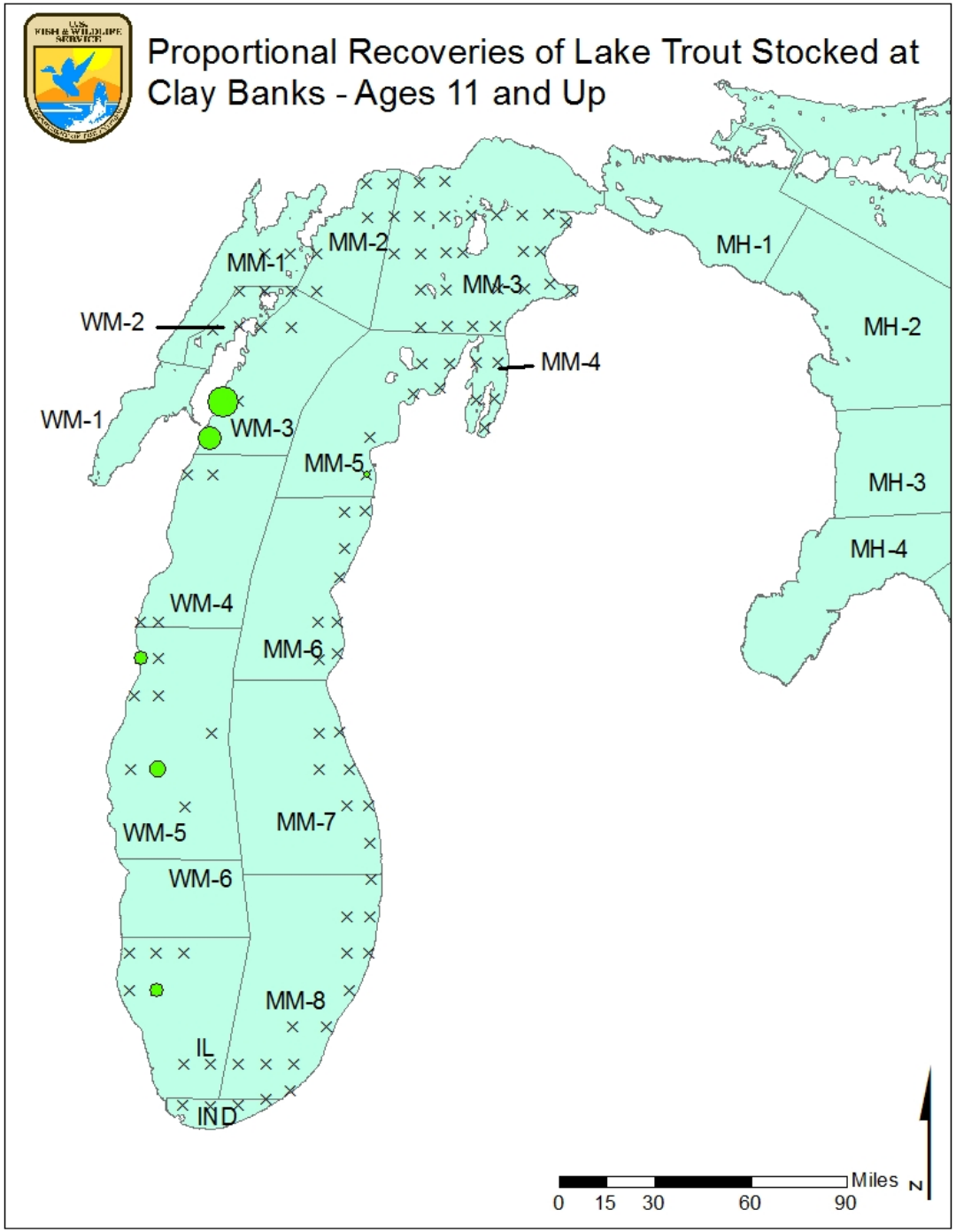
Miles
N


Proportional Recoveries of Lake Trout Stocked at Clay Banks - Ages 11 and Up
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N

Conclusions

- Stocking location / mortality most important for post-stocking survival
- CPUE and spatial spread were greatest for fish stocked in Southern Lake Michigan
  - Mounting evidence of wild recruitment of lake trout in southern Lake Michigan suggests progress toward rehabilitation
  - Frequent recoveries of stocked lake trout in nearshore waters, where they are accessible to the recreational fishery
- In areas with low mortality, genetic strains from remnant Lake Michigan populations had highest recoveries
- Positive effect of length-at-stocking in areas with low mortality

Acknowledgements

Hatcheries Staff

Field Biologists

Tag Extraction Techs

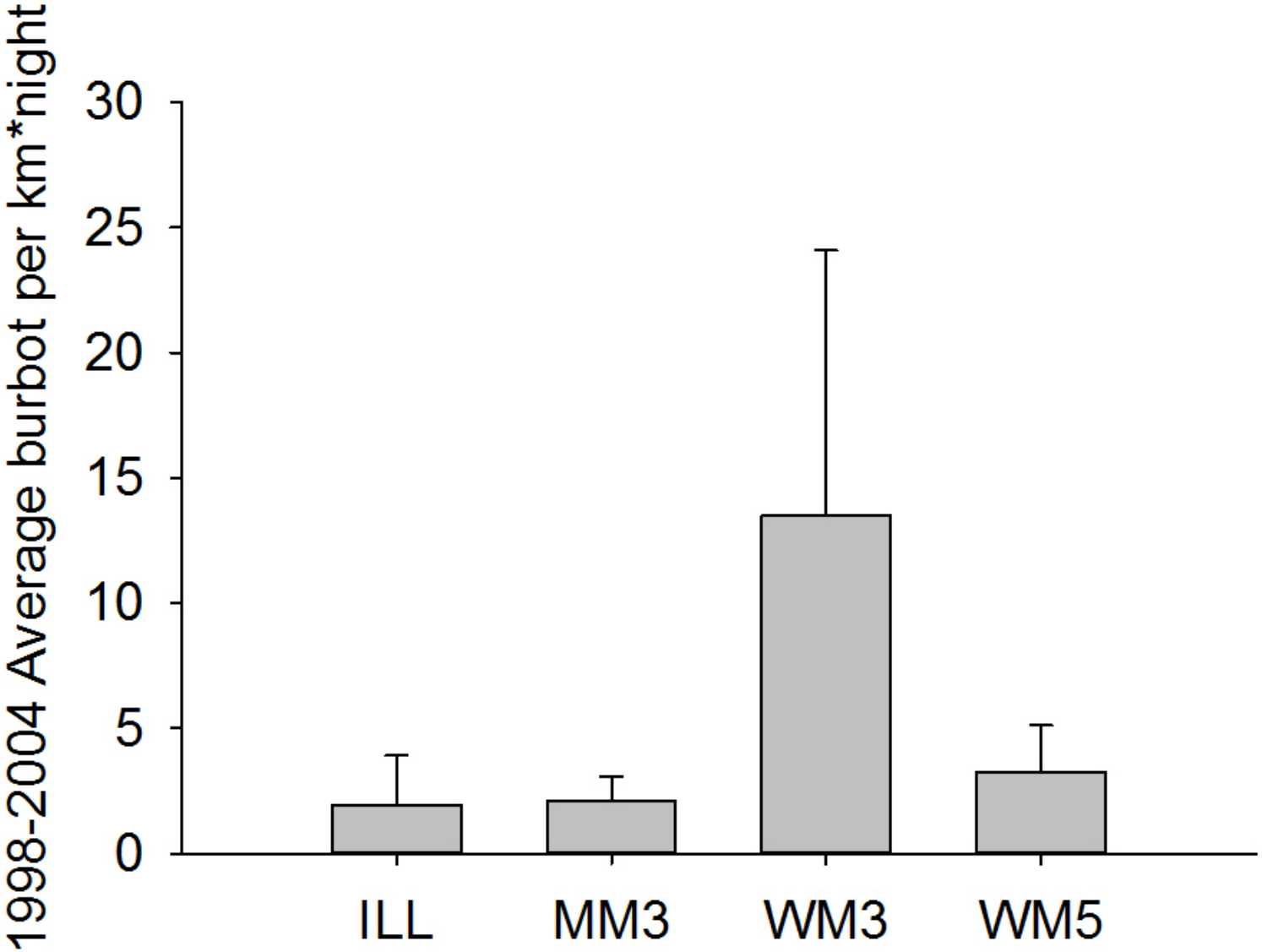
Lake Committees

Lake Michigan Lake Trout Working Group

Contact Matt: matthew_kornis@fws.gov

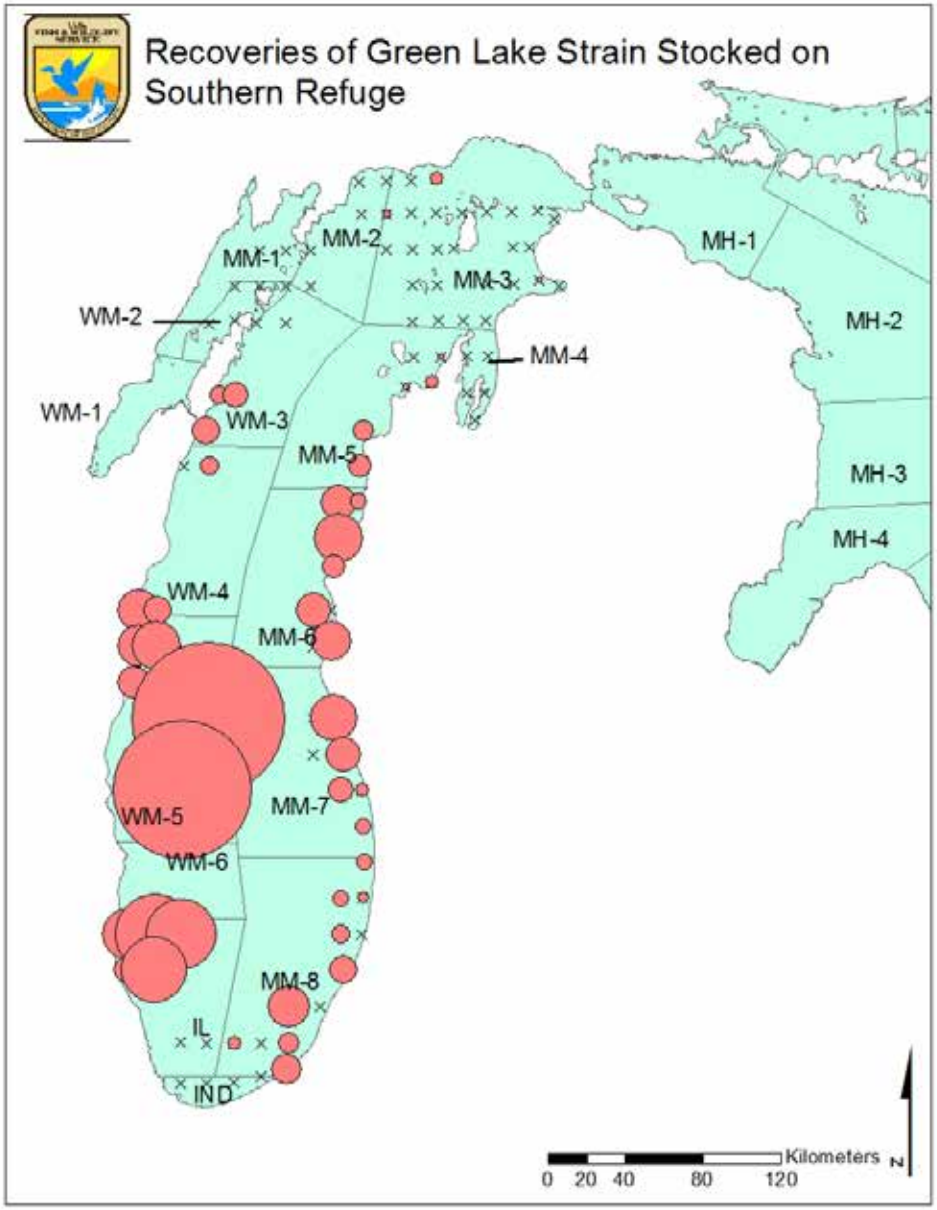
Sideboard

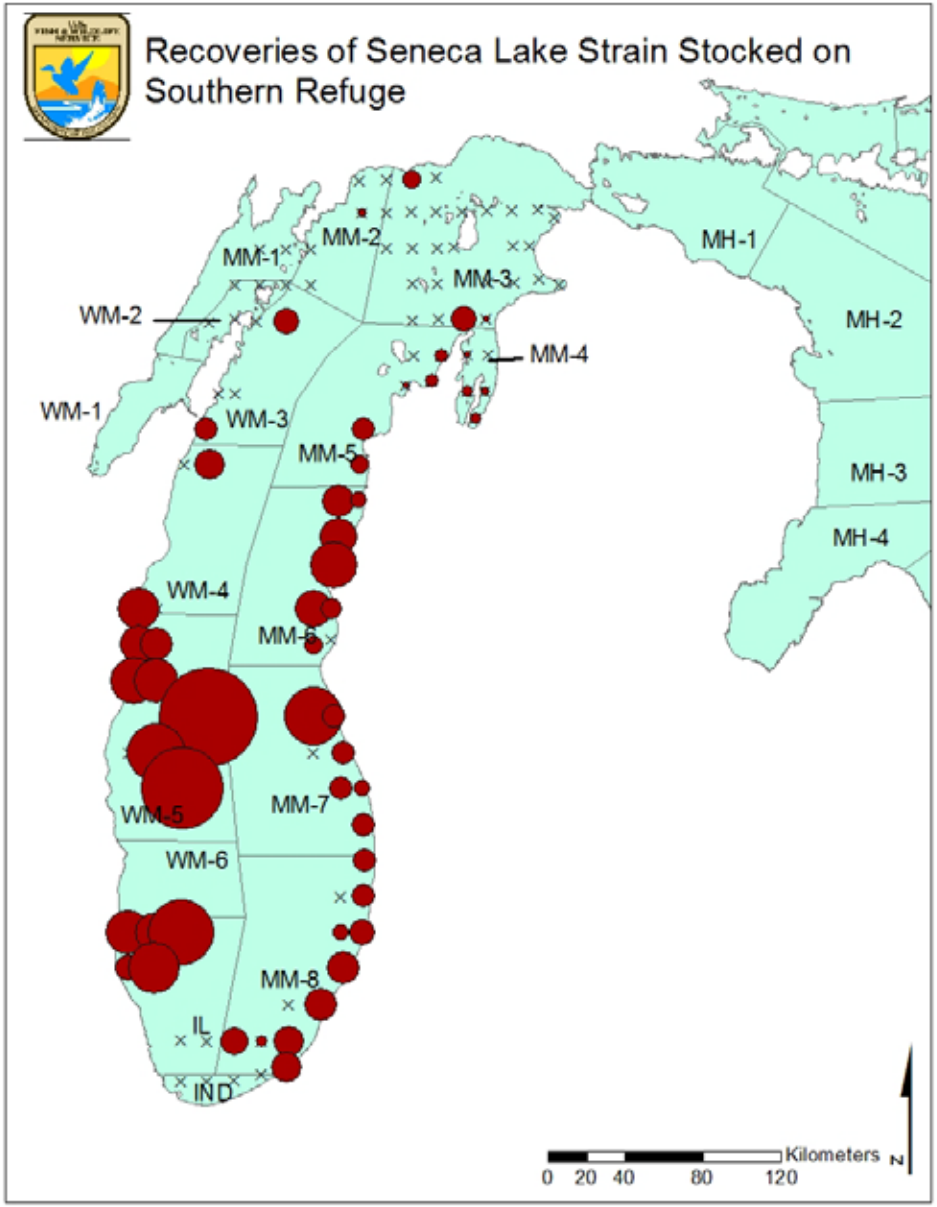
Mortality Does Not Appear to Be Related to Predator Density At Time of Stocking



Spatial Spread of Fish – Strain Effect from Southern Refuge

Effect on CPUE, but not on spread

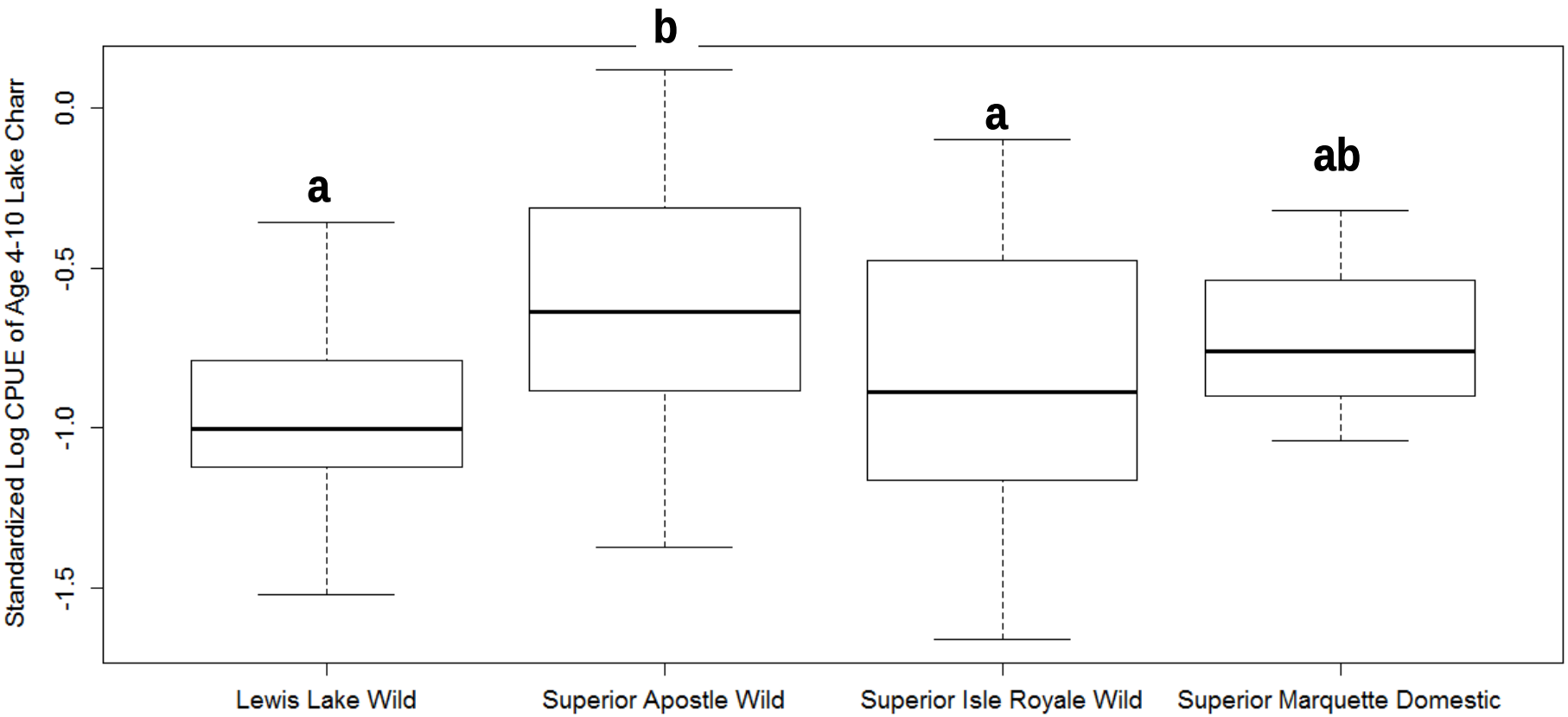




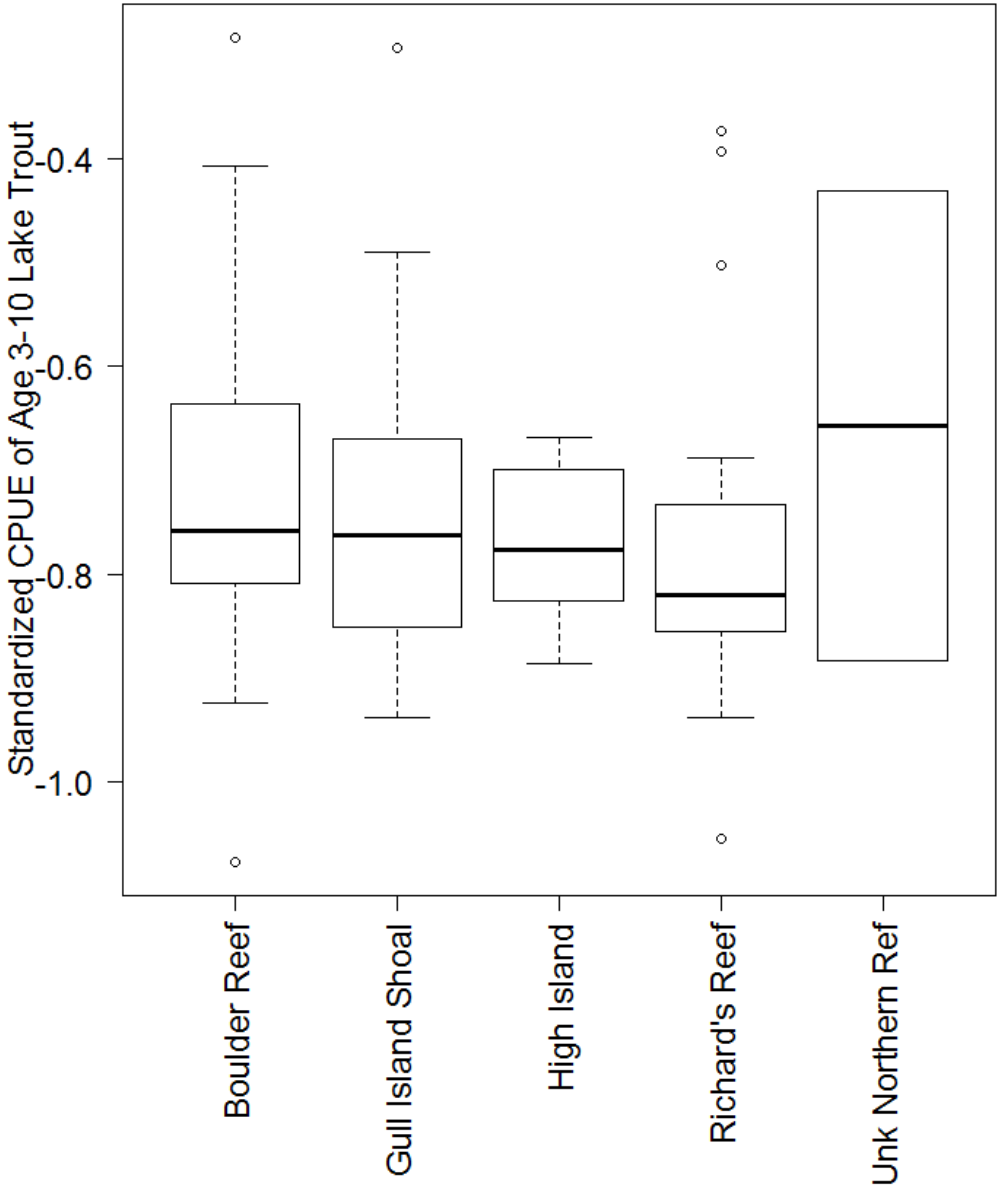
Not in Tree – Small Strain Effect in Northern Refuge

***p* = 0.002 (ANOVA)**

Superior Apostle > Lewis Lake (*p* = 001) and Superior Isle Royale (*p* = 0.04) (Tukey)



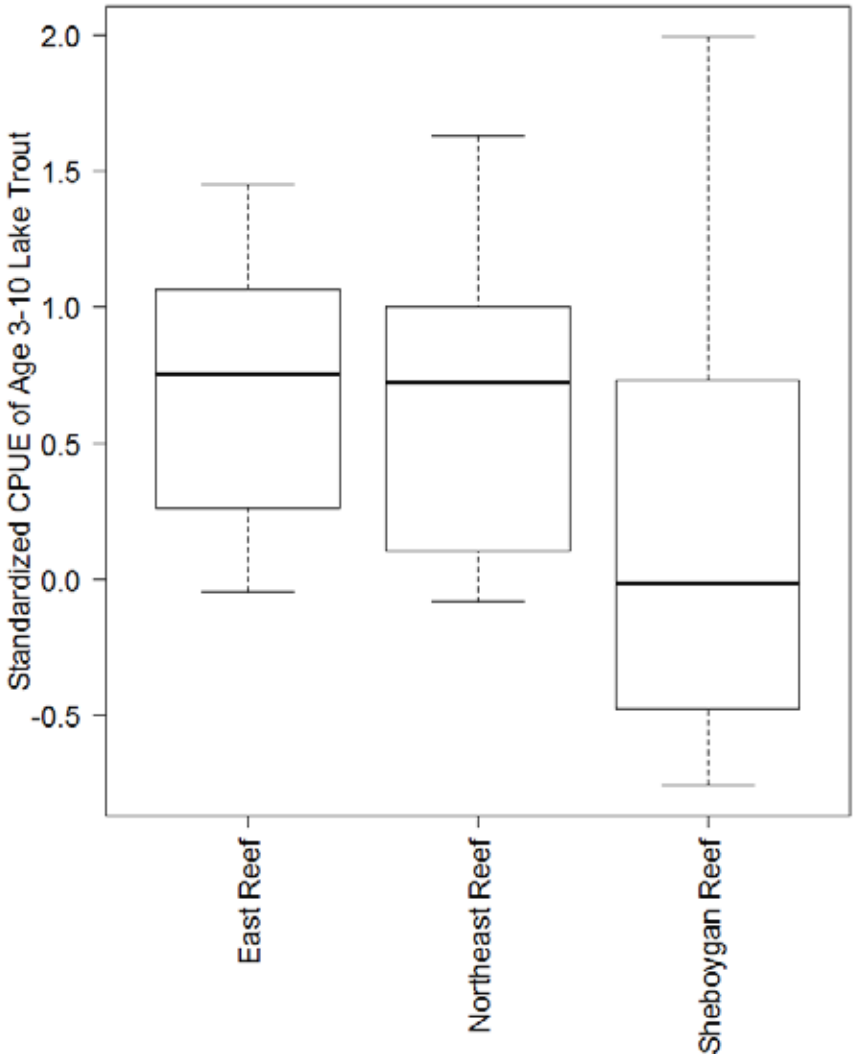
Stocking Site Differences Within the Northern Refuge None. ANOVA $F_{4,83} = 0.49$, $p = 0.74$



Site Differences Within the Southern Refuge

ANOVA $F_{2,55} = 4.9$, $p = 0.01$

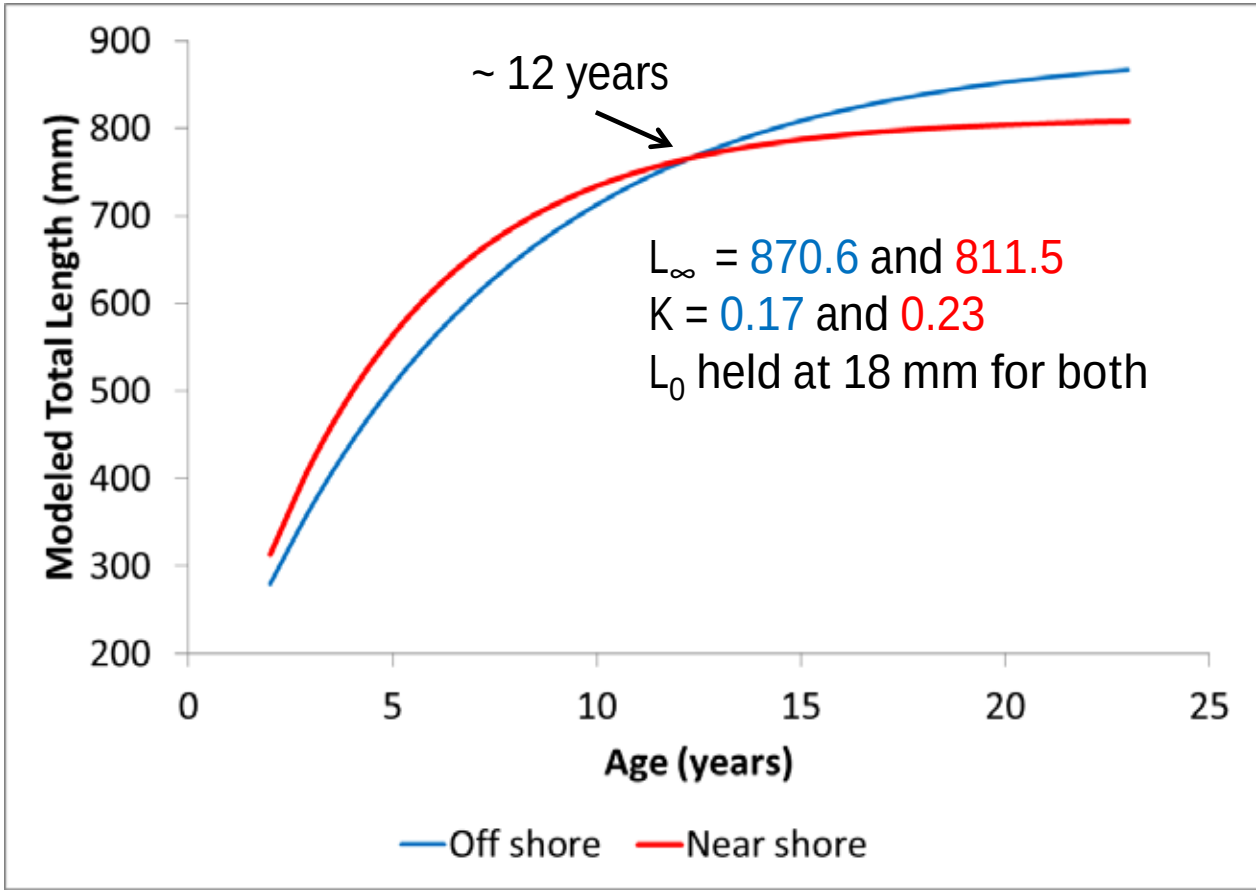
Tukey: Sheboygan < East Reef (p = 0.02) and Northeast Reef (p = 0.04).
Northeast and east reef similar (p= 0.98)



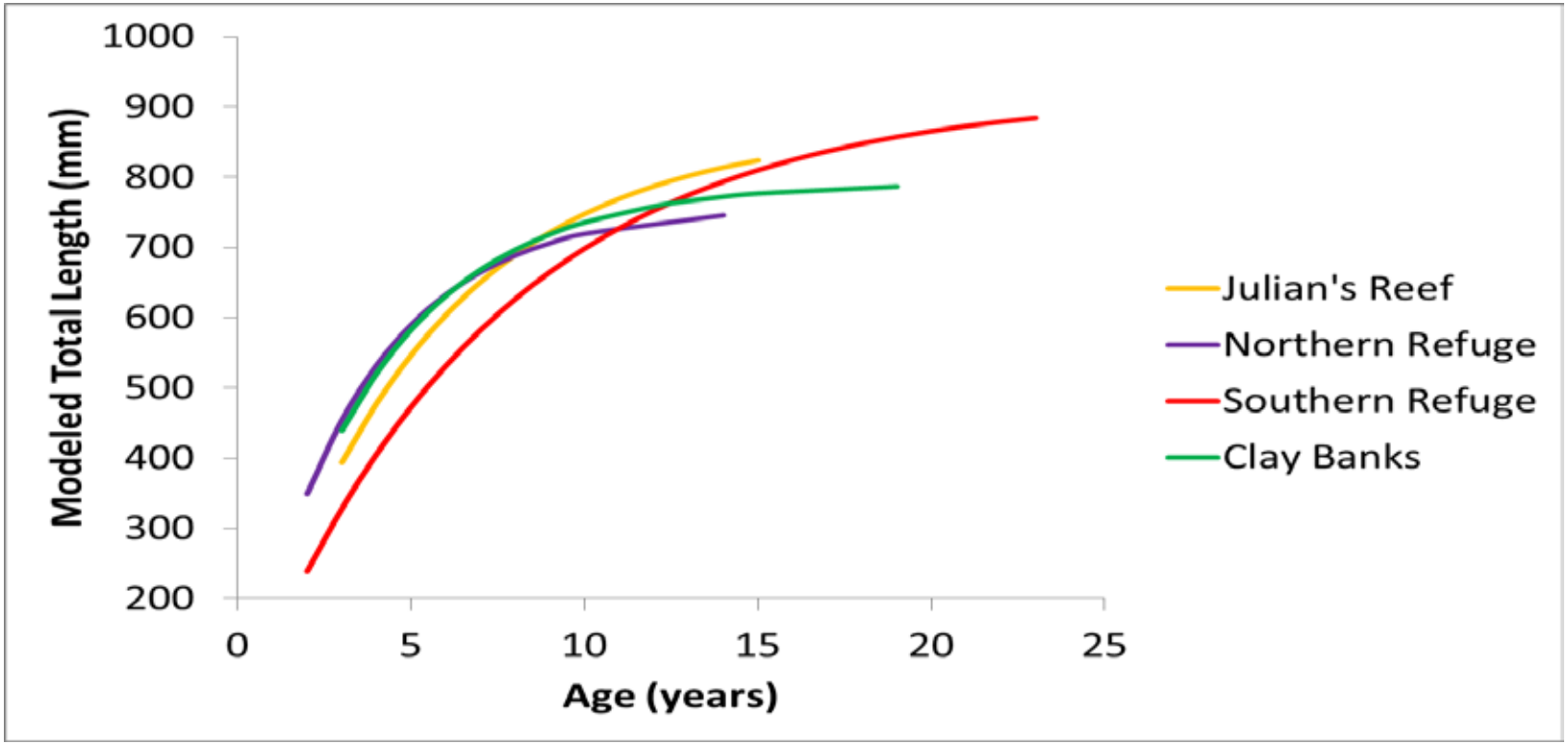
Other Notes

Length-at-Age Higher for Trout Recovered Near Shore

- Fit von Bertalanffy growth functions to length-at-age data at time of capture
- Lake trout recovered near shore were 44 mm longer on average than offshore recovered fish of the same age, up to Age 9
- More variability in length-at-age for ages 14+
- Madenjian et al. 1998 found similar results, attributable to food and temperature differences



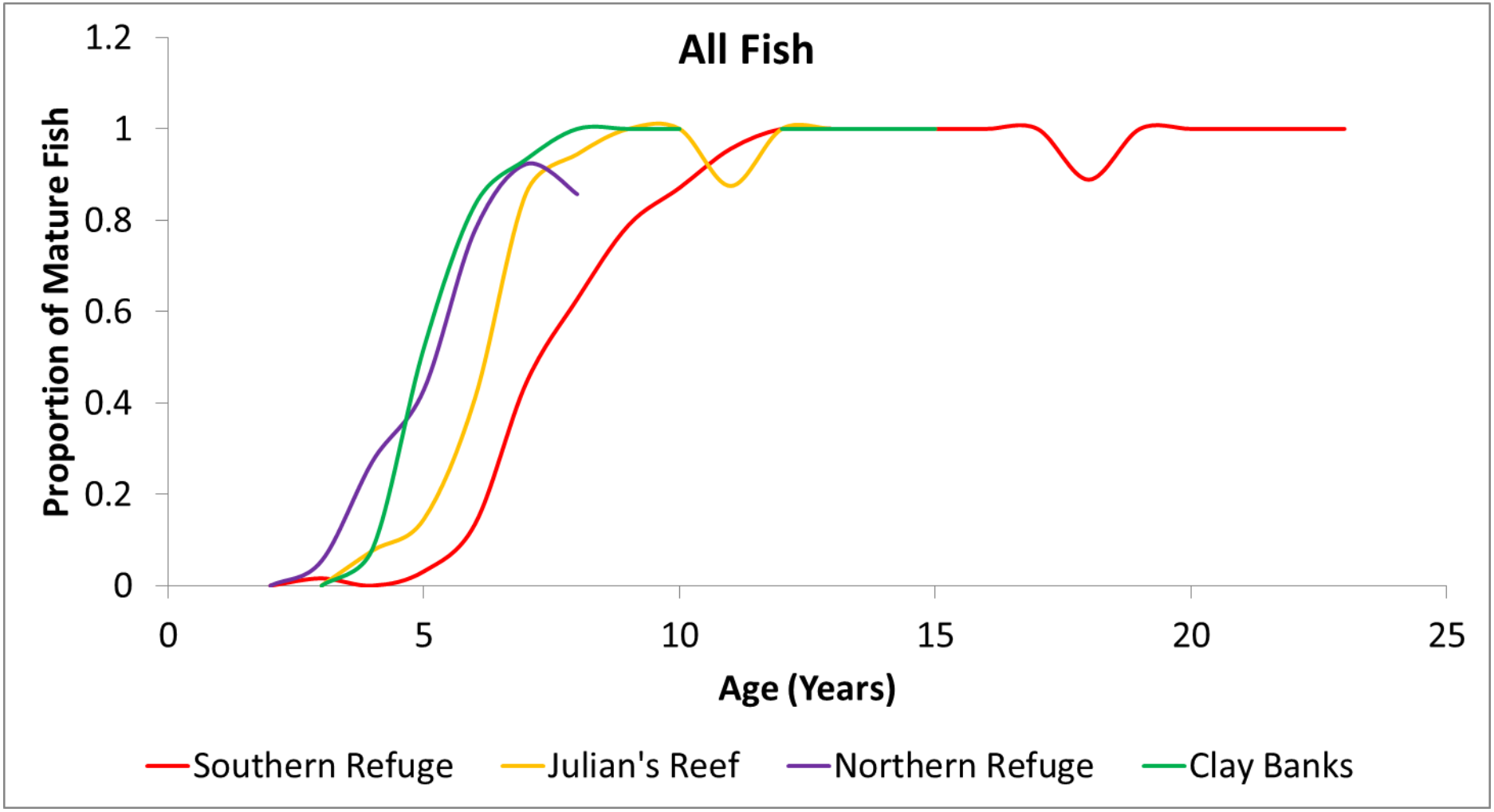
Length-at-Age Differed By Location



- Only fish captured at their stocking location were included
- Higher growth at Northern Refuge may be due to lower density
- Higher growth at Clay Banks probably due to nearshore location

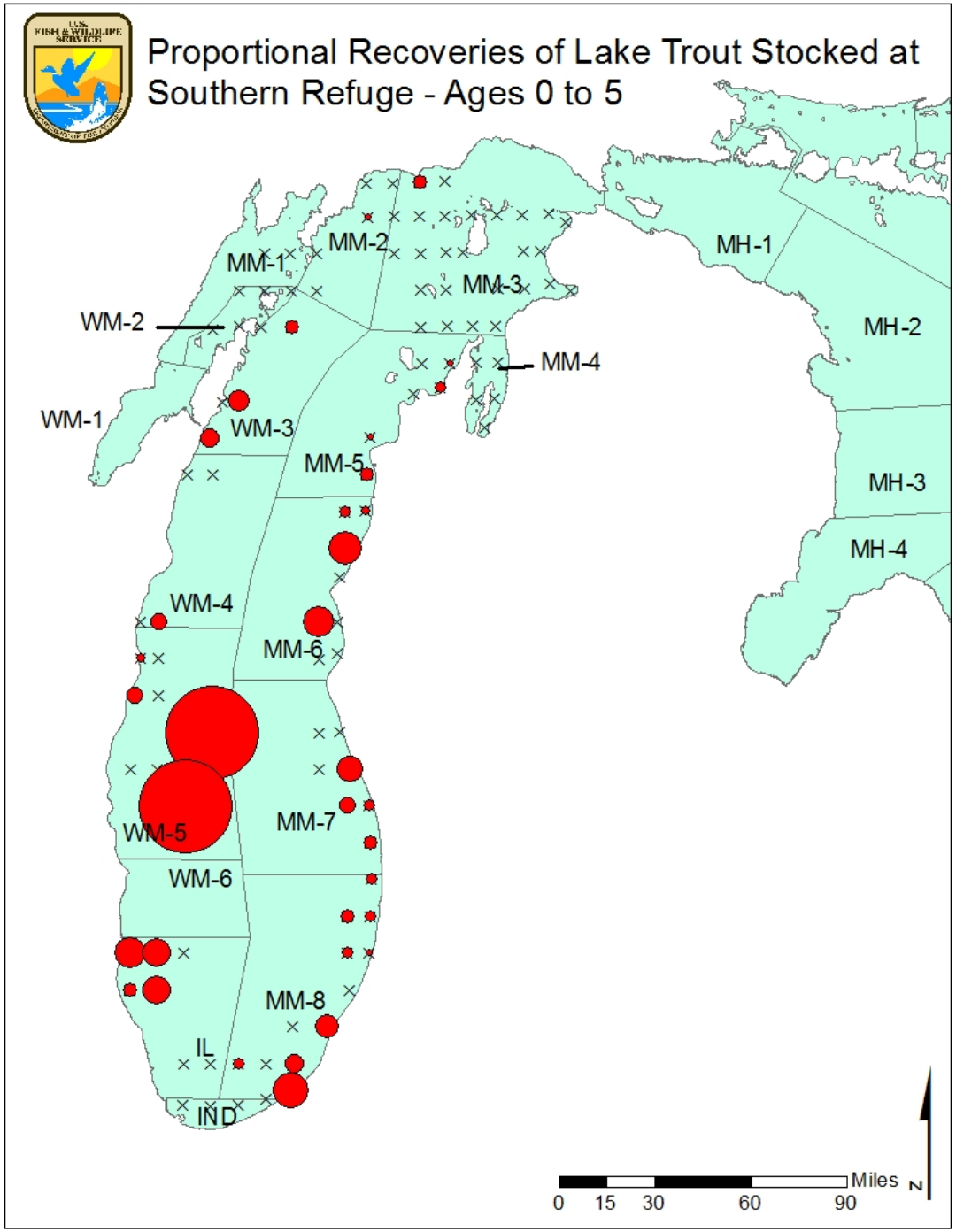
Location	K	L_∞ (mm)	L_0 (mm)
Northern Refuge	0.30	757.4	18
Clay Banks	0.26	792.1	18
Julian's Reef	0.19	870.9	18
Southern Refuge	0.14	920.1	18

Maturity-at-Age Differed by Location



I will break this down by sex and look at maturity-at-length in the very near future.

Spatial Patterns in CPUE in three age groups (0-5, 6-10 and 11+)


Proportional Recoveries of Lake Trout Stocked at Southern Refuge - Ages 0 to 5
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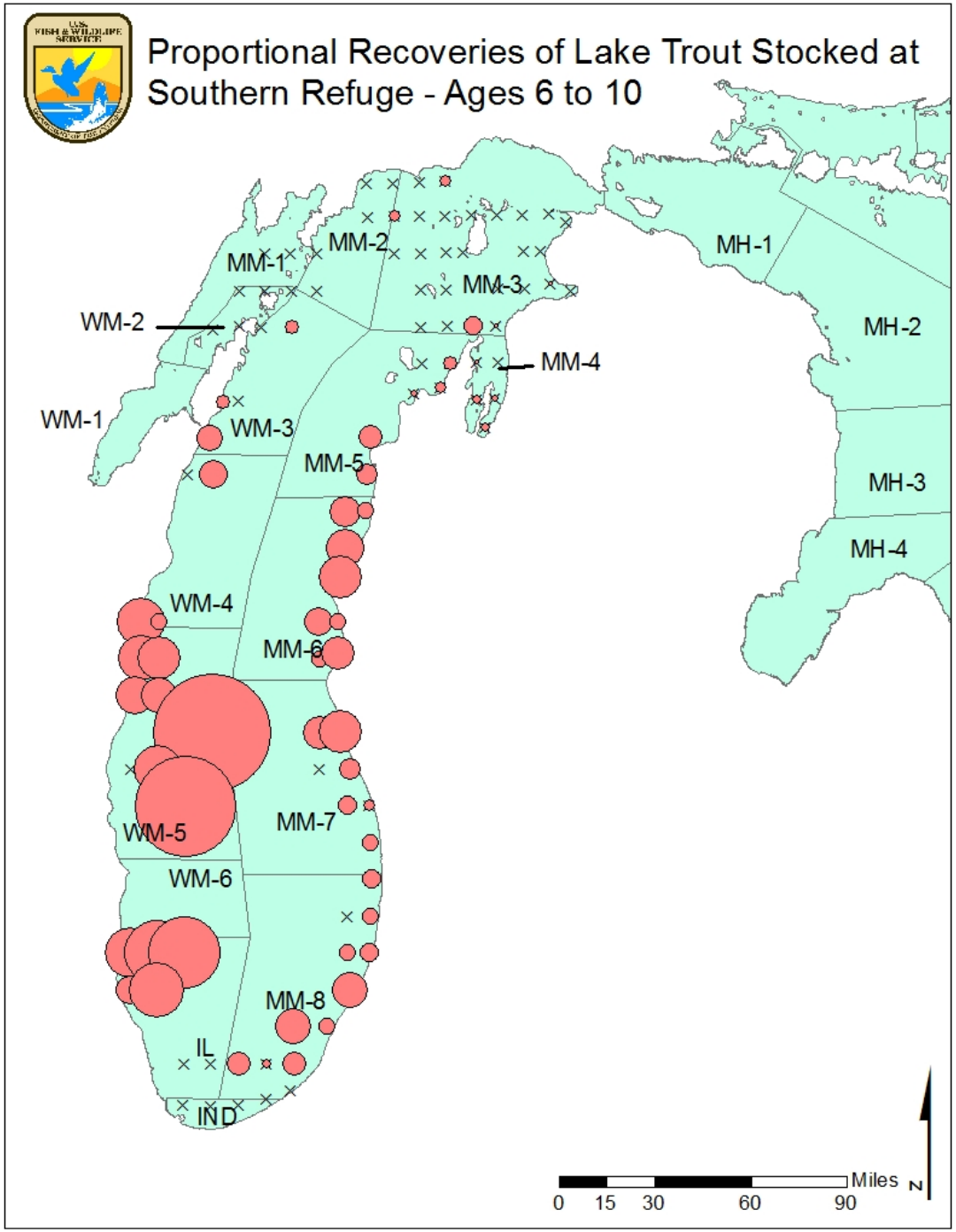
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
MH-1
MH-2
MH-3
MH-4
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Southern Refuge - Ages 6 to 10
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MM-2
MM-3
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MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
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WM-4
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WM-6
IL
IND
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Miles
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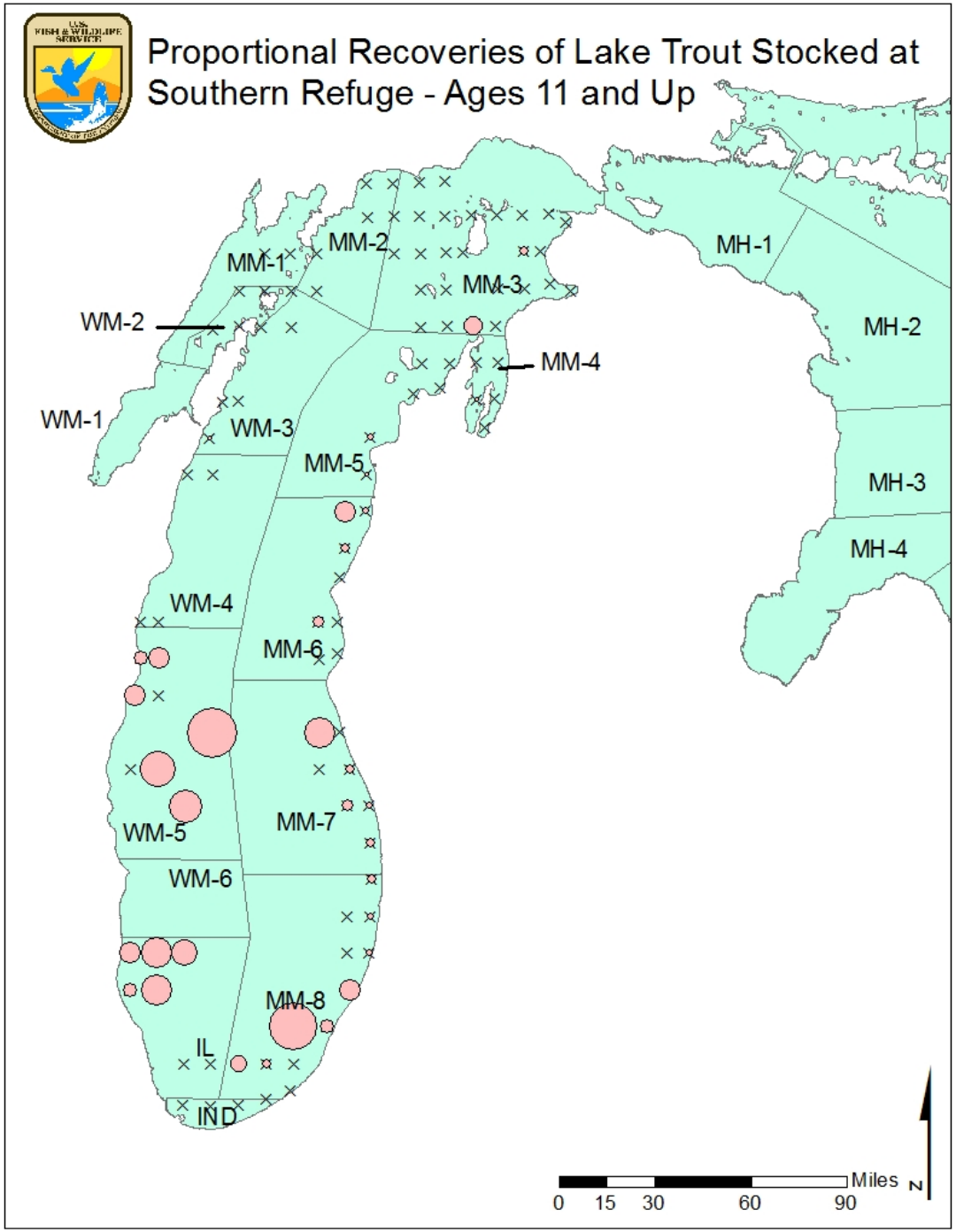
Proportional Recoveries of Lake Trout Stocked at Southern Refuge - Ages 11 and Up
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MM-7
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MH-2
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WM-3
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IL
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Miles
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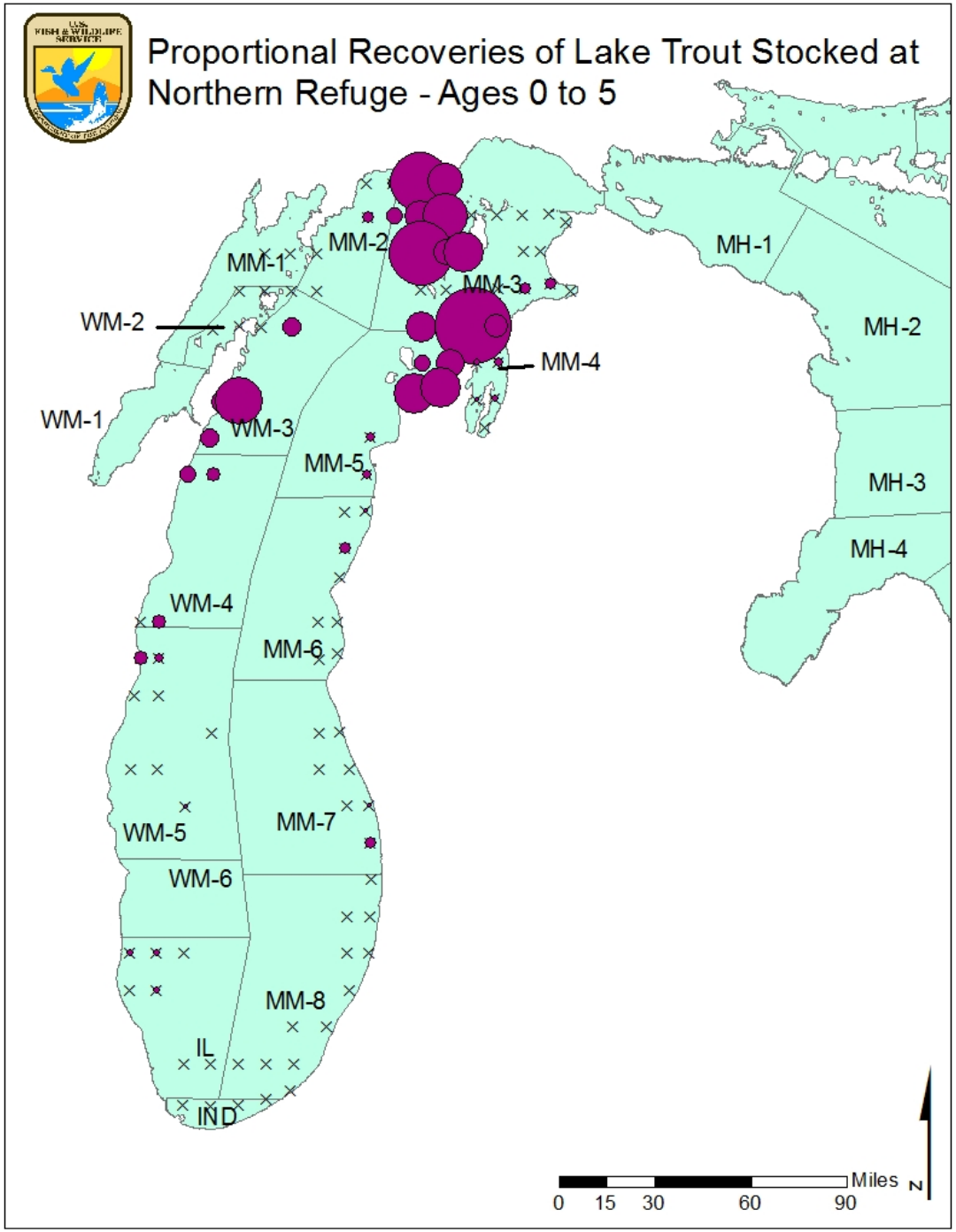
Proportional Recoveries of Lake Trout Stocked at Northern Refuge - Ages 0 to 5
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MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
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WM-1
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WM-3
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WM-5
WM-6
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Miles
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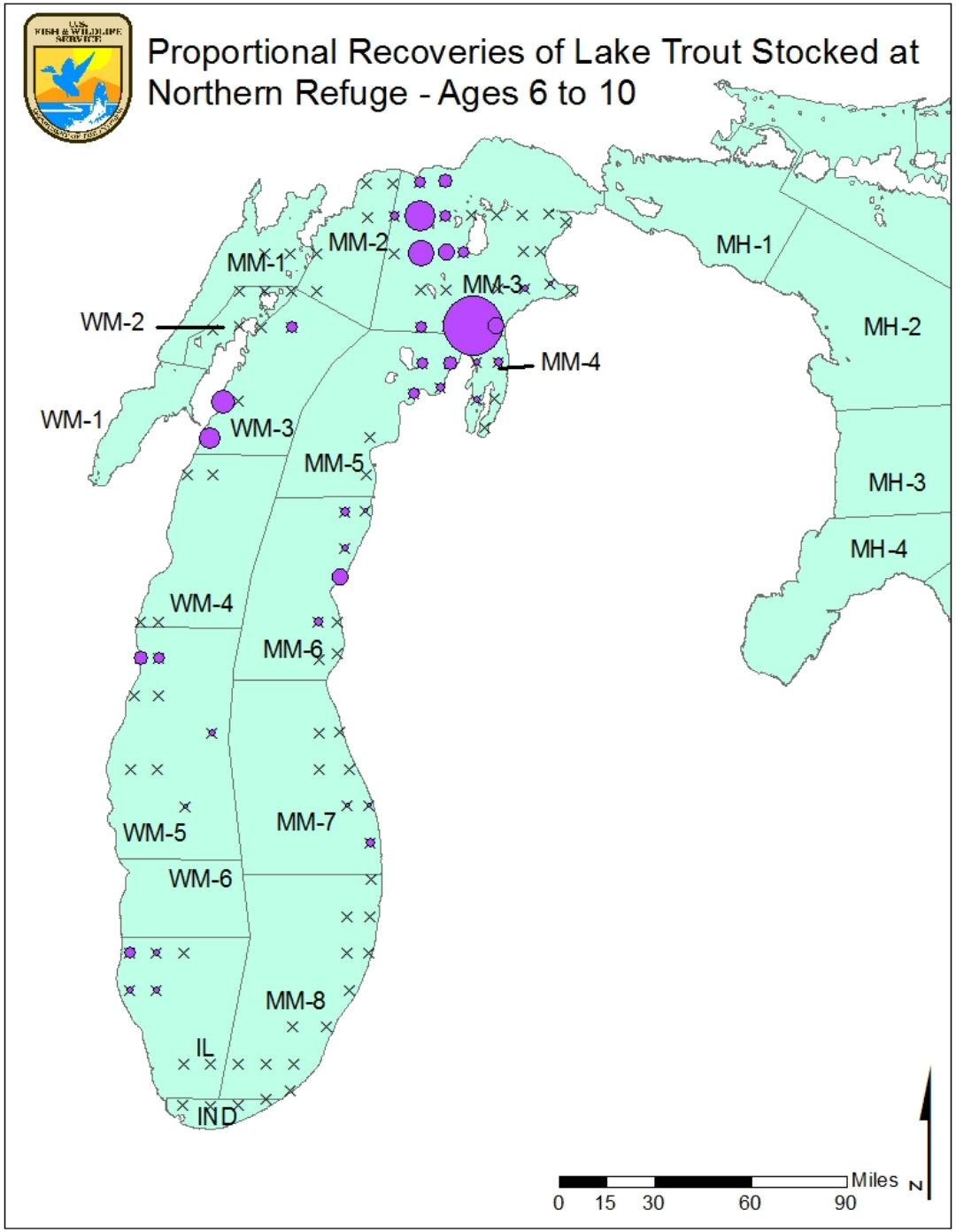
Proportional Recoveries of Lake Trout Stocked at Northern Refuge - Ages 6 to 10
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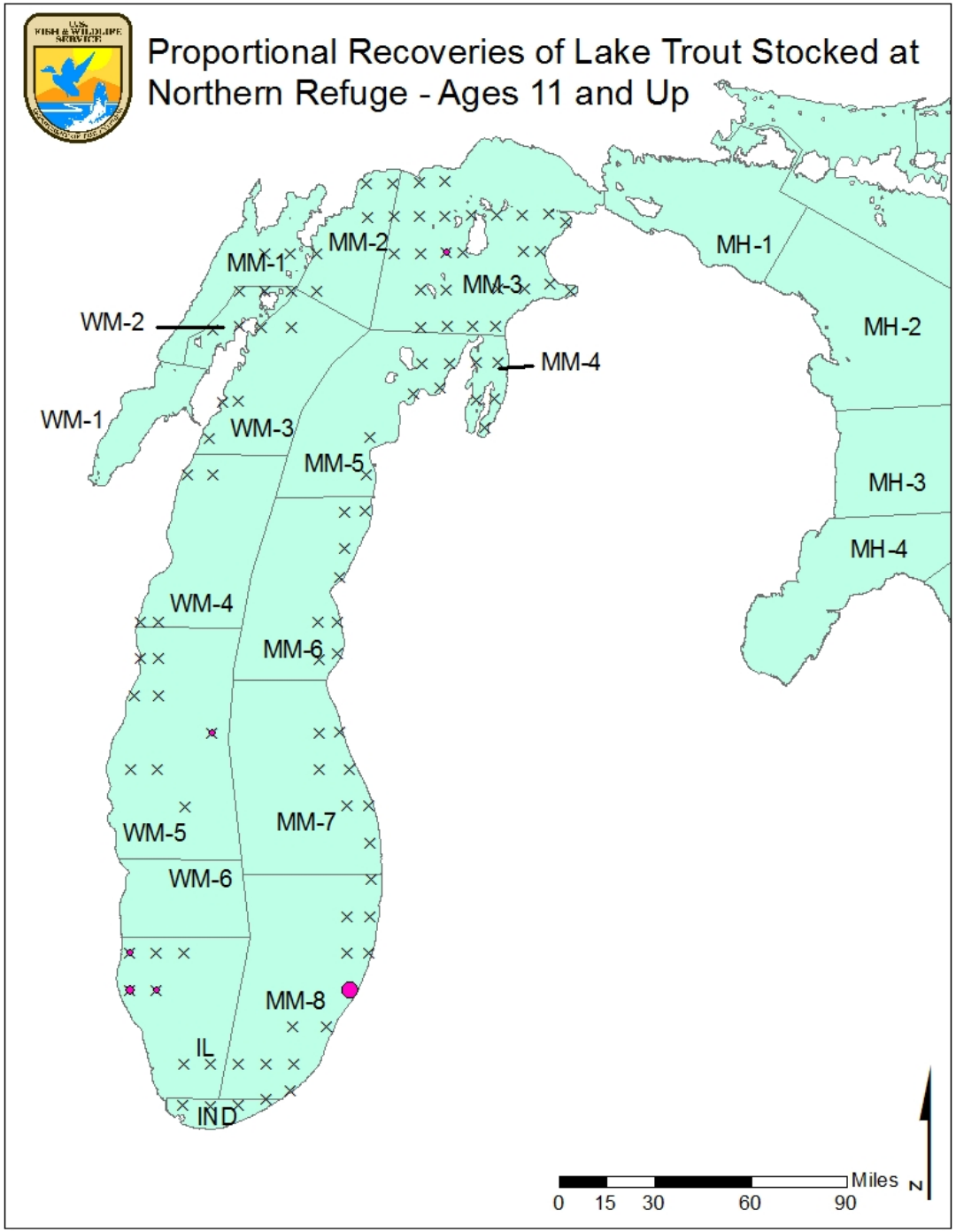
Proportional Recoveries of Lake Trout Stocked at Northern Refuge - Ages 11 and Up
MM-1
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MM-4
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MM-6
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MH-1
MH-2
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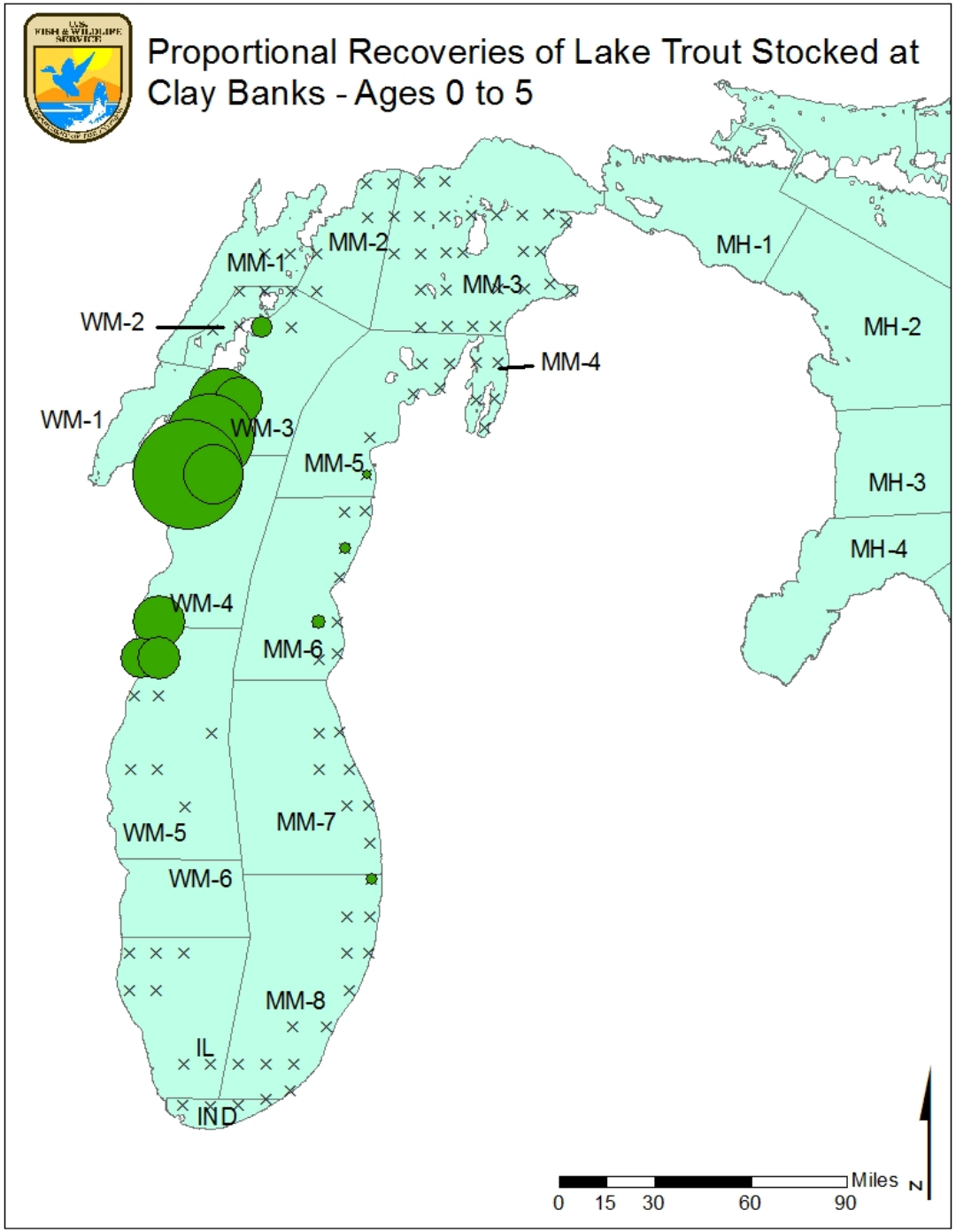
Proportional Recoveries of Lake Trout Stocked at Clay Banks - Ages 0 to 5
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MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
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IL
IND
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Miles
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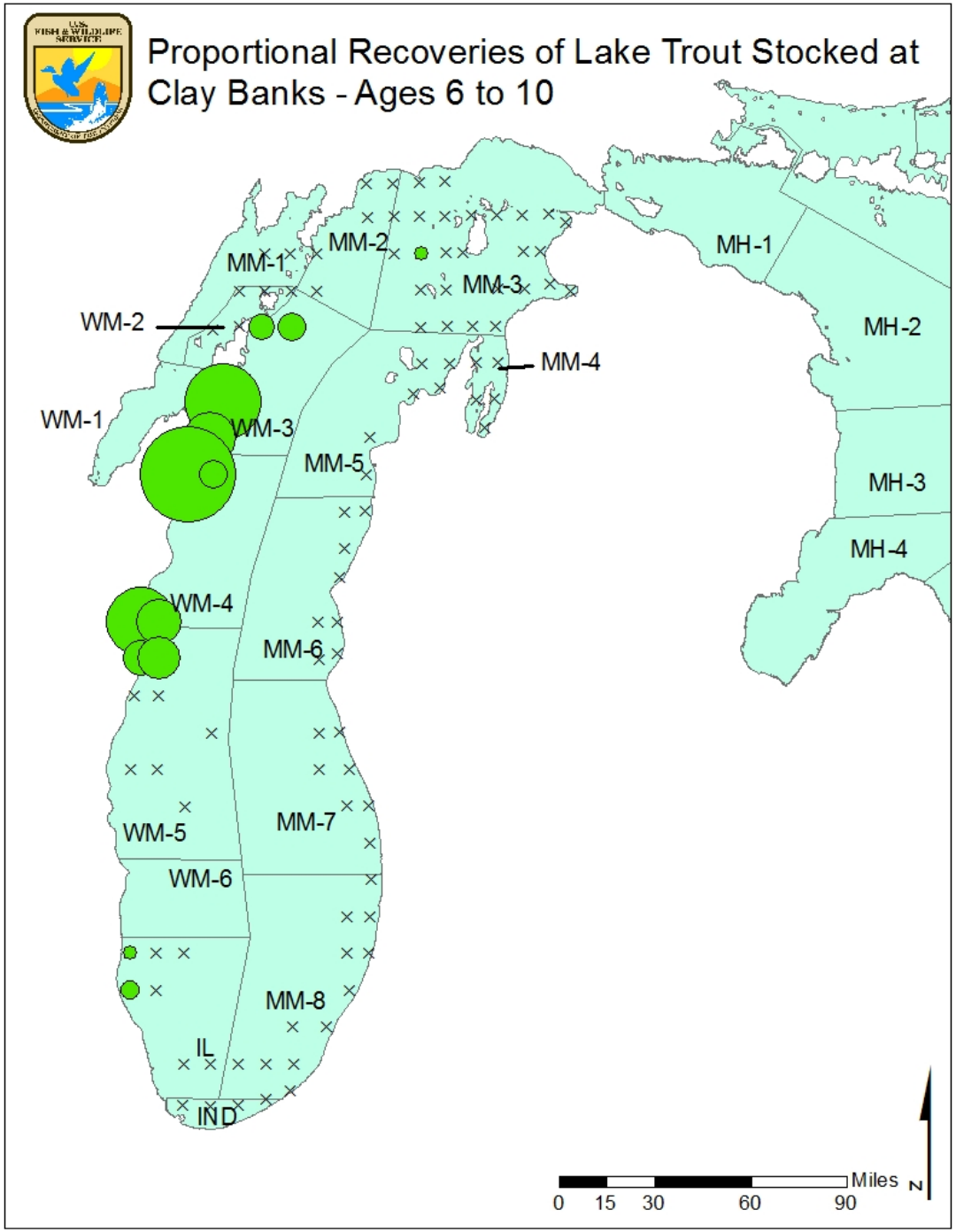
Proportional Recoveries of Lake Trout Stocked at Clay Banks - Ages 6 to 10
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MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
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MH-2
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MH-4
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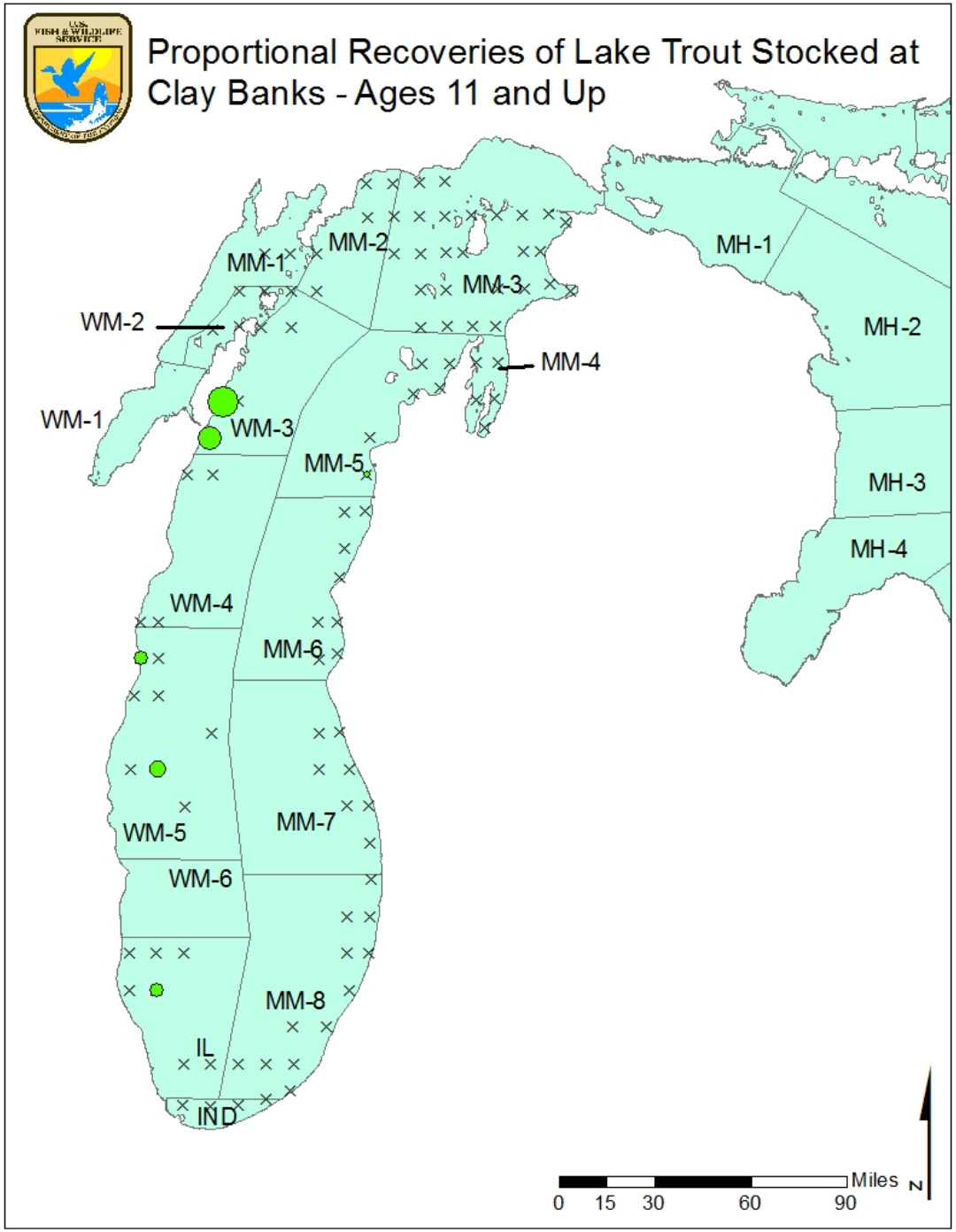
Proportional Recoveries of Lake Trout Stocked at Clay Banks - Ages 11 and Up
MM-1
MM-2
MM-3
MM-4
MM-5
MM-6
MM-7
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MH-1
MH-2
MH-3
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WM-2
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WM-5
WM-6
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IND
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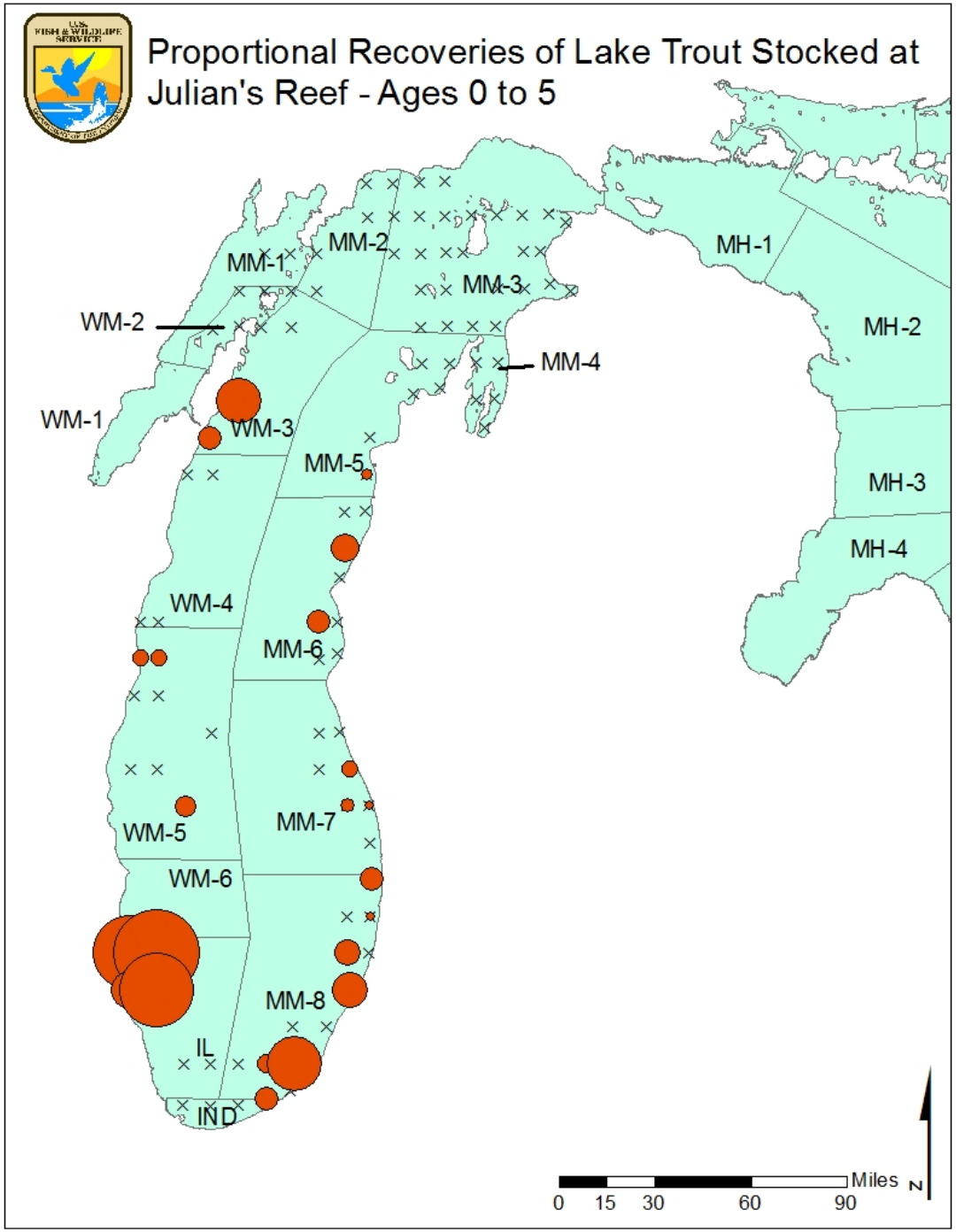
Miles
N


Proportional Recoveries of Lake Trout Stocked at Julian's Reef - Ages 0 to 5
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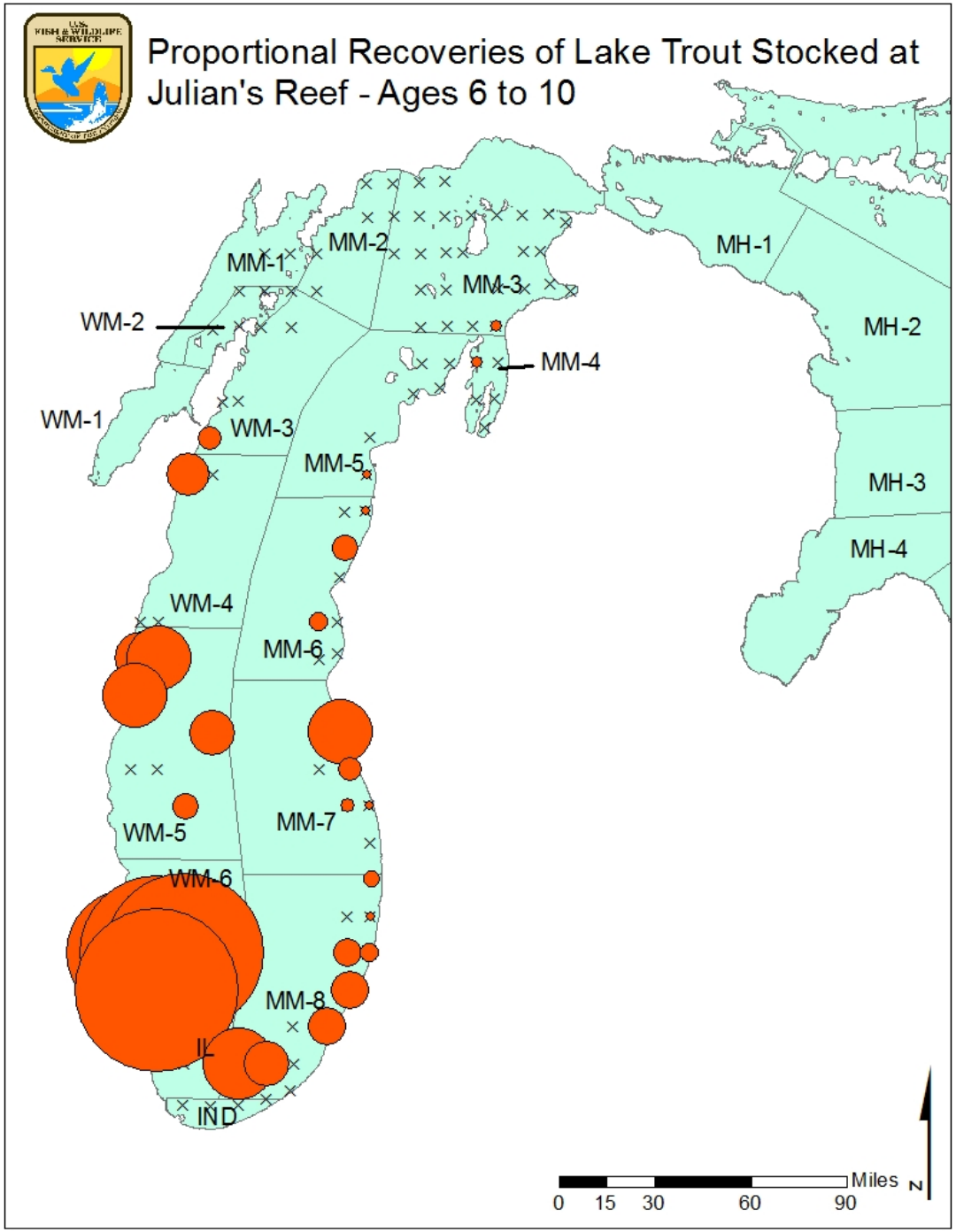
MM-3
MM-4
MM-5
MM-6
MM-7
MM-8
MH-1
MH-2
MH-3
MH-4
WM-1
WM-2
WM-3
WM-4
WM-5
WM-6
IL
IND
0 15 30 60 90
Miles
N


Proportional Recoveries of Lake Trout Stocked at Julian's Reef - Ages 6 to 10
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MM-5
MM-6
MM-7
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WM-1
WM-2
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Miles
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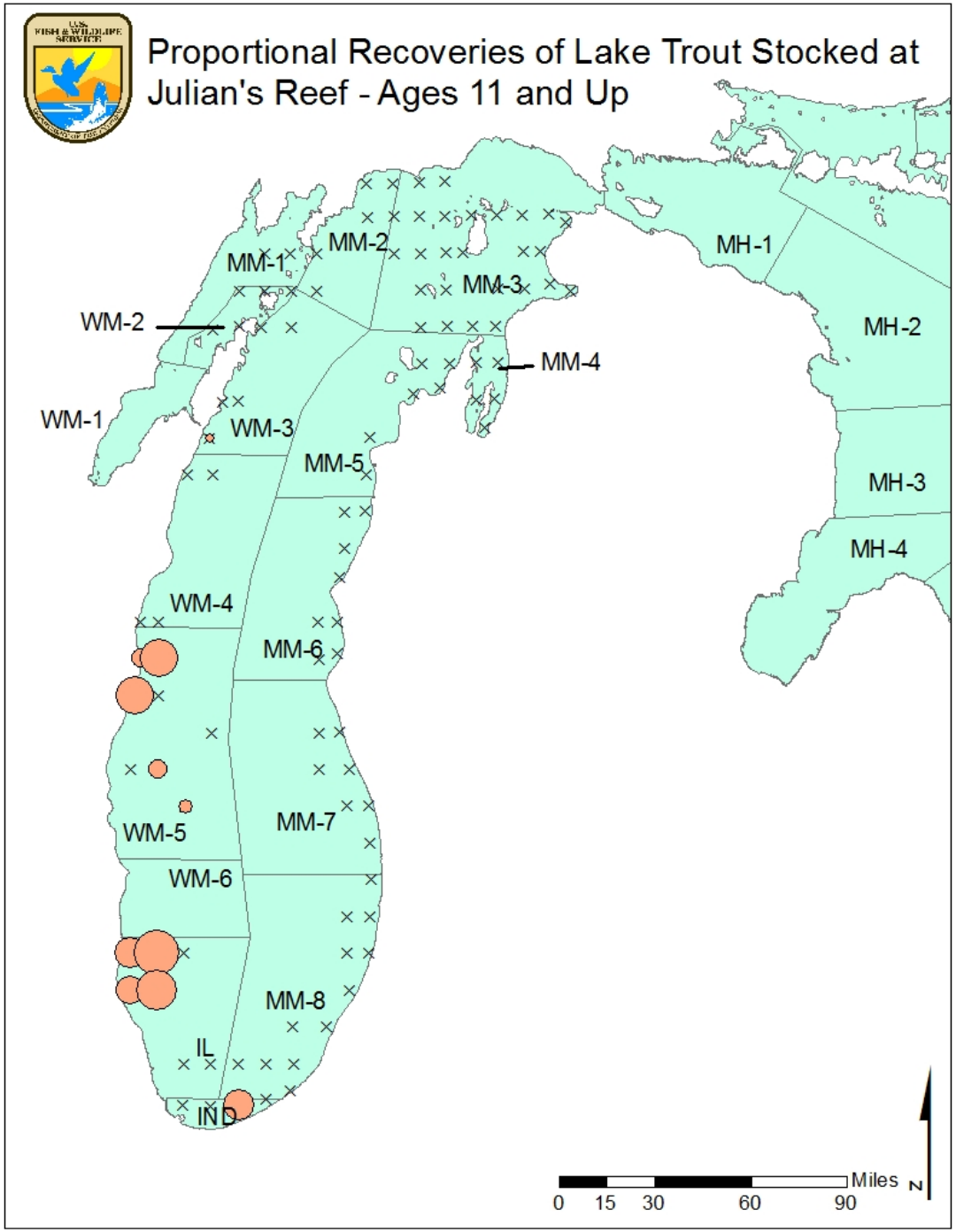
Proportional Recoveries of Lake Trout Stocked at Julian's Reef - Ages 11 and Up
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MM-3
MM-4
MM-5
MM-6
MM-7
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MH-1
MH-2
MH-3
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WM-1
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WM-6
IL
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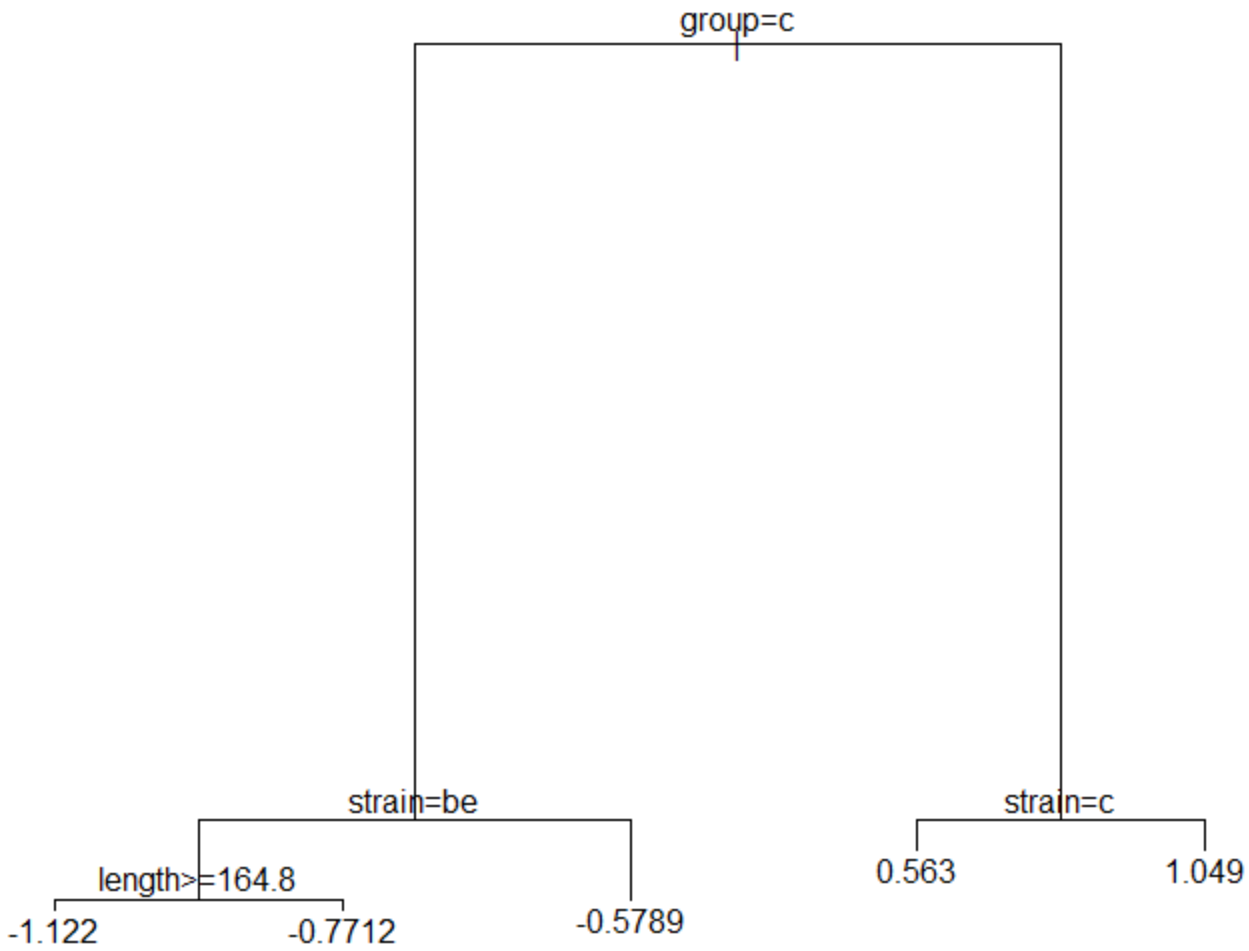
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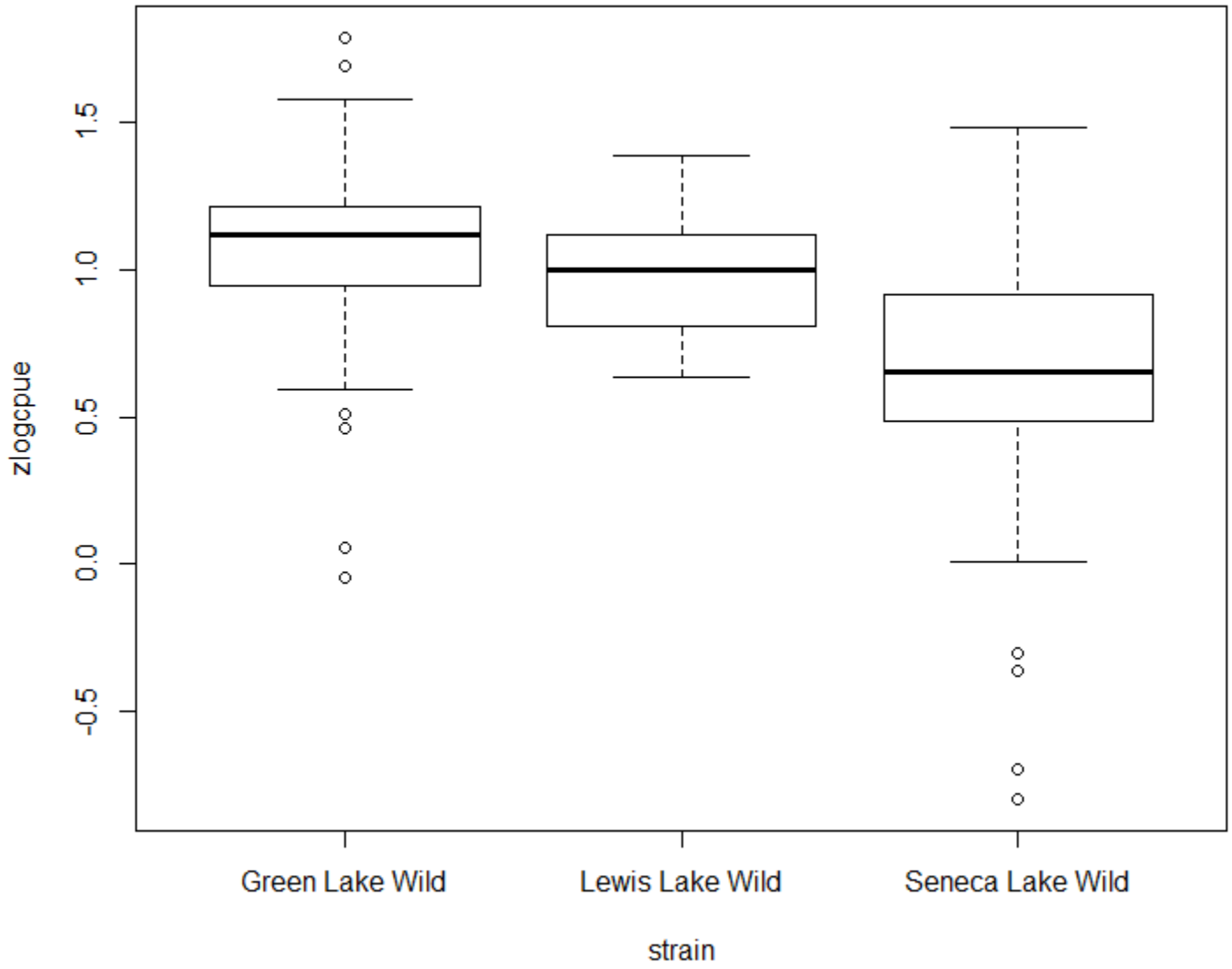
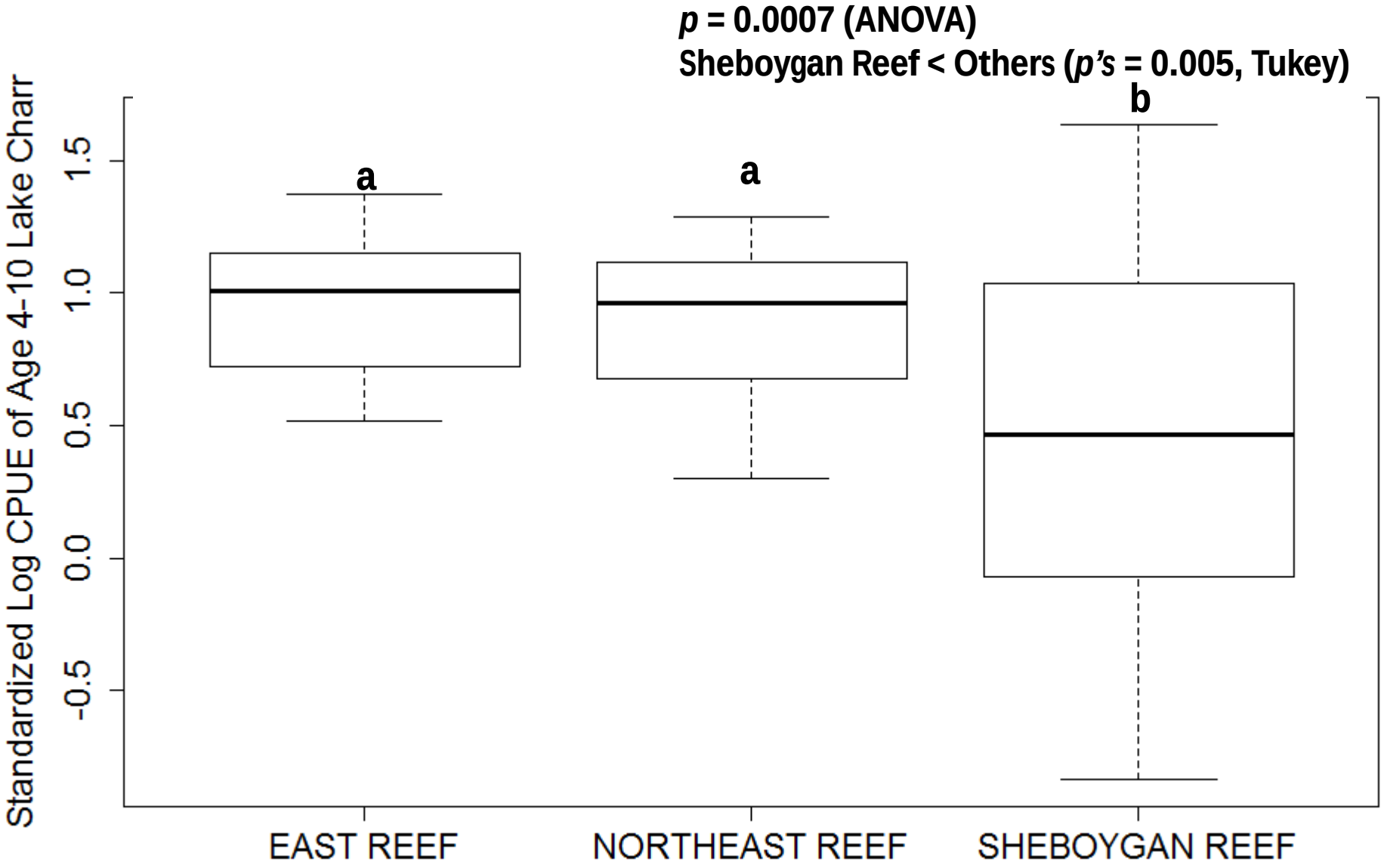


Aov

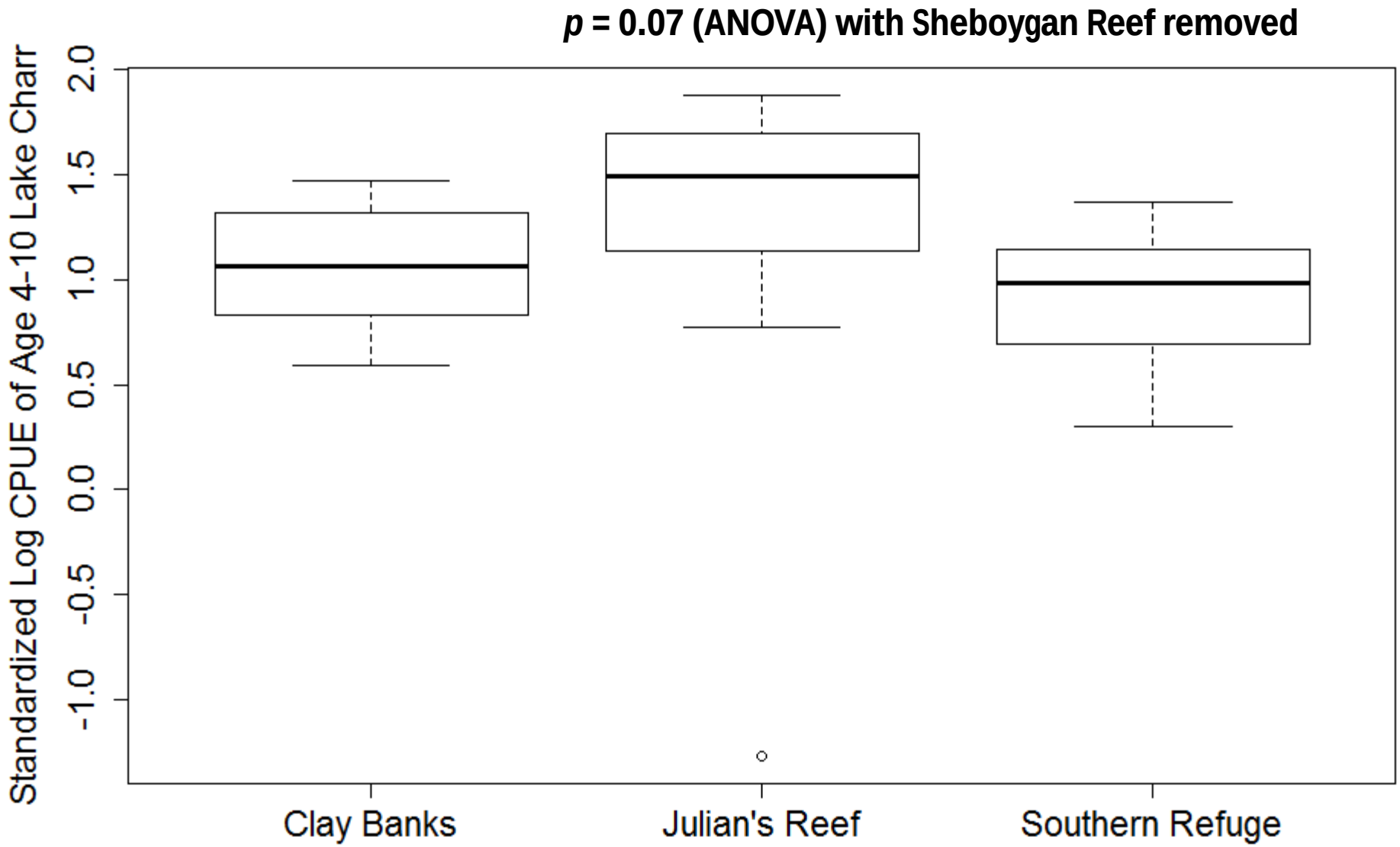
$F_{2,81} = 13.9$, $p < 0.0001$

GLW and LLW p = 0.78
SLW and LLW p=0.01
GLW and SLW p < 0.0001

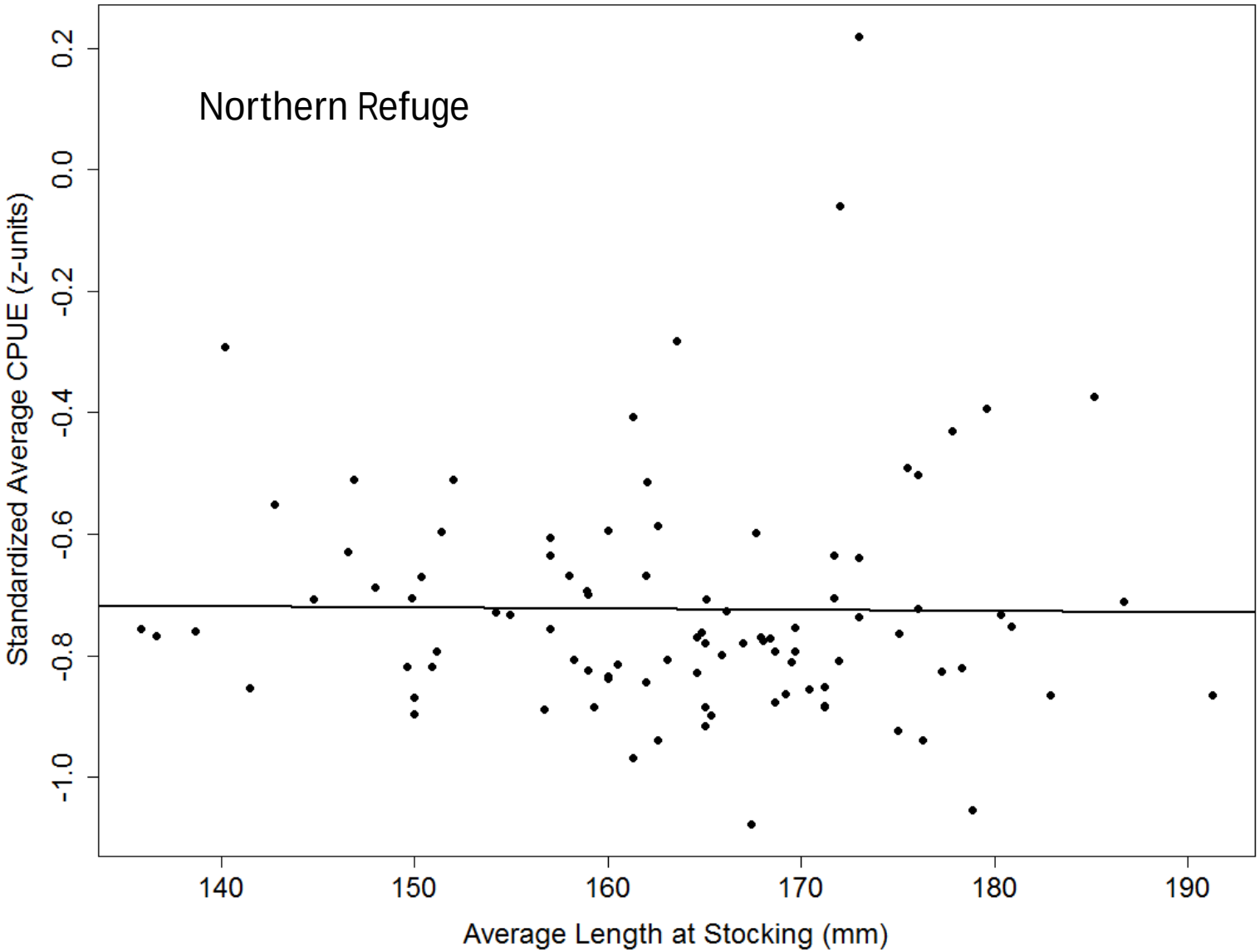
Note – Site Effect in Southern Refuge



Note – Site Effect in Southern Refuge



Not in Tree - Length-at-stocking not a factor in locations that have poor CPUE returns



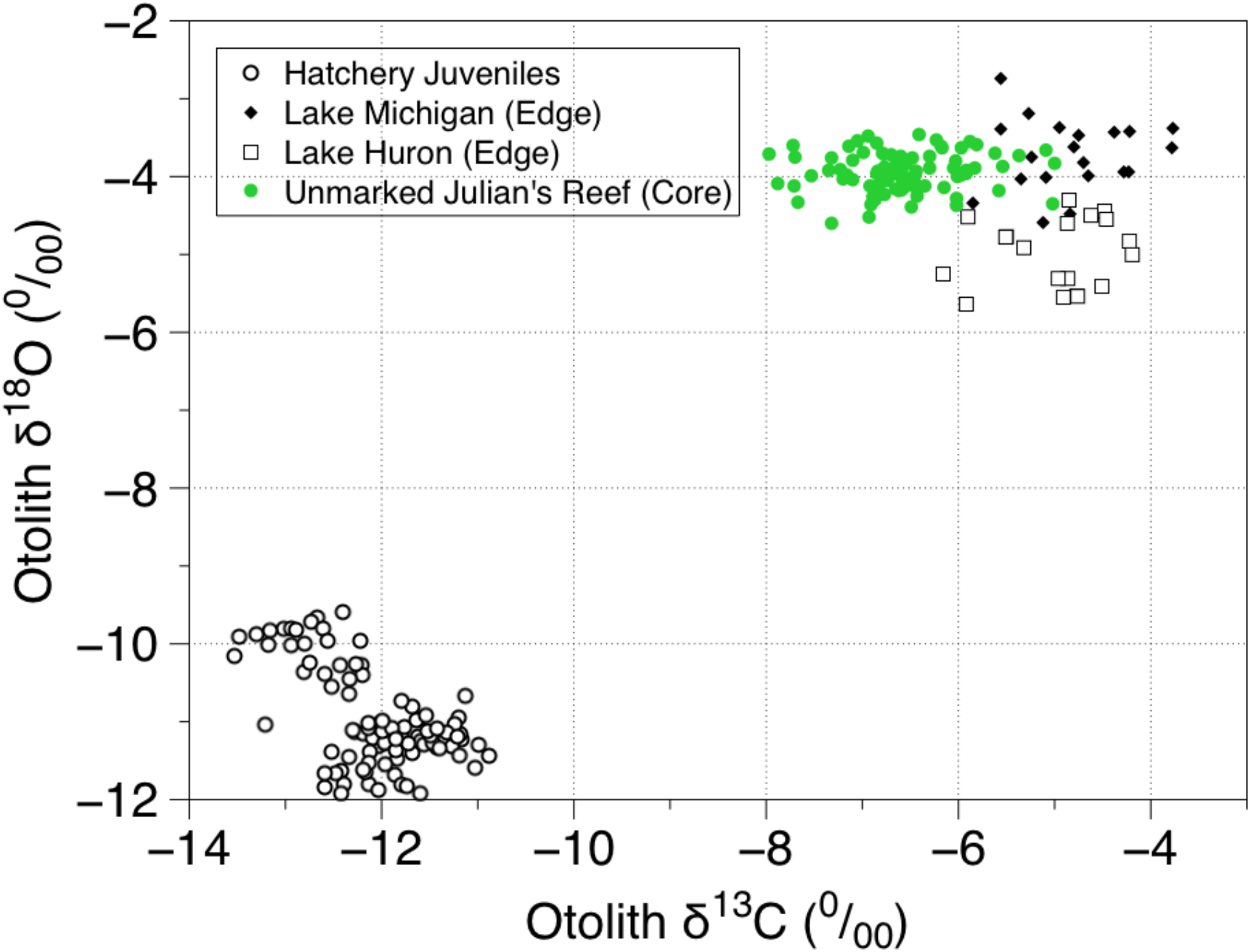
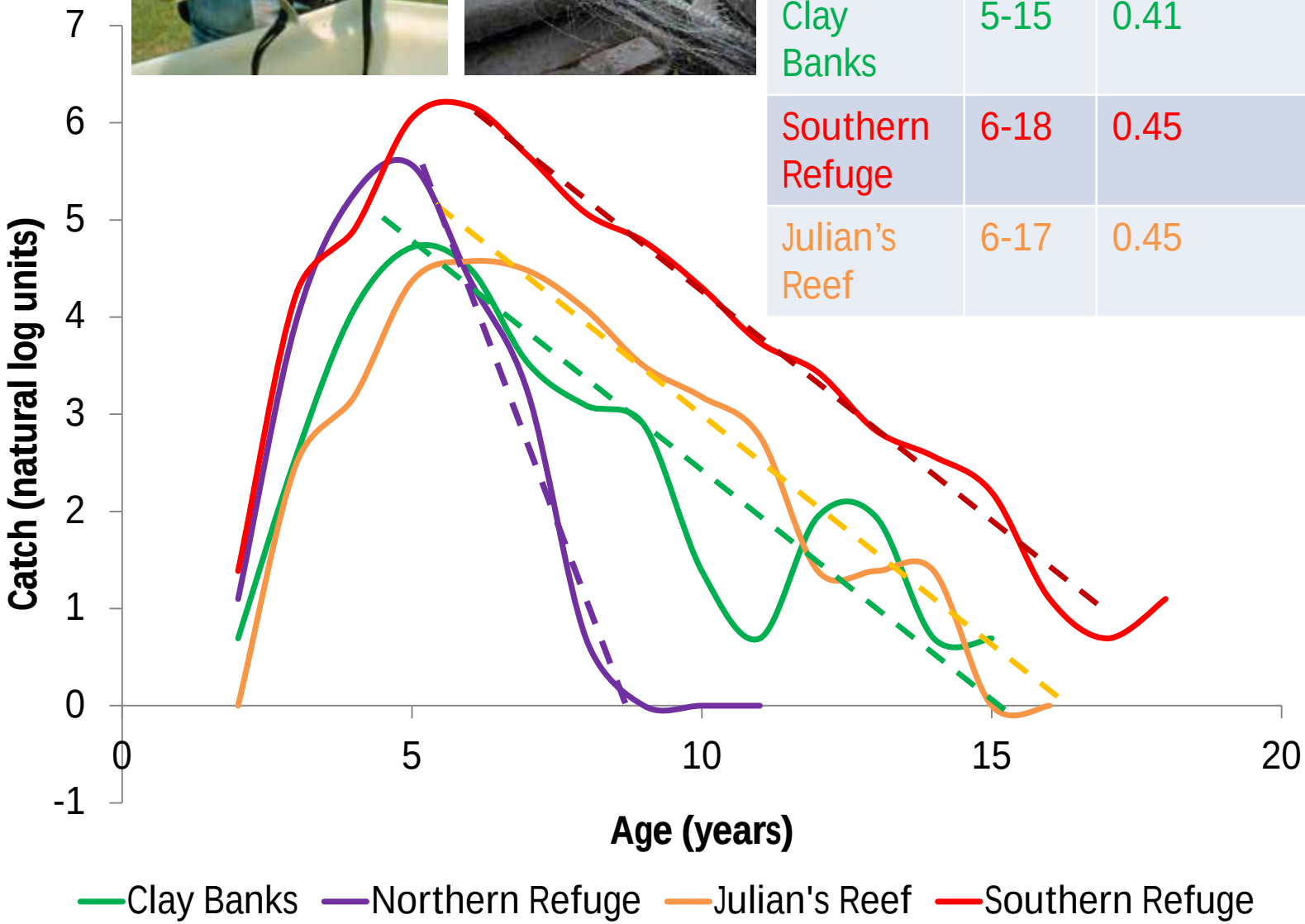


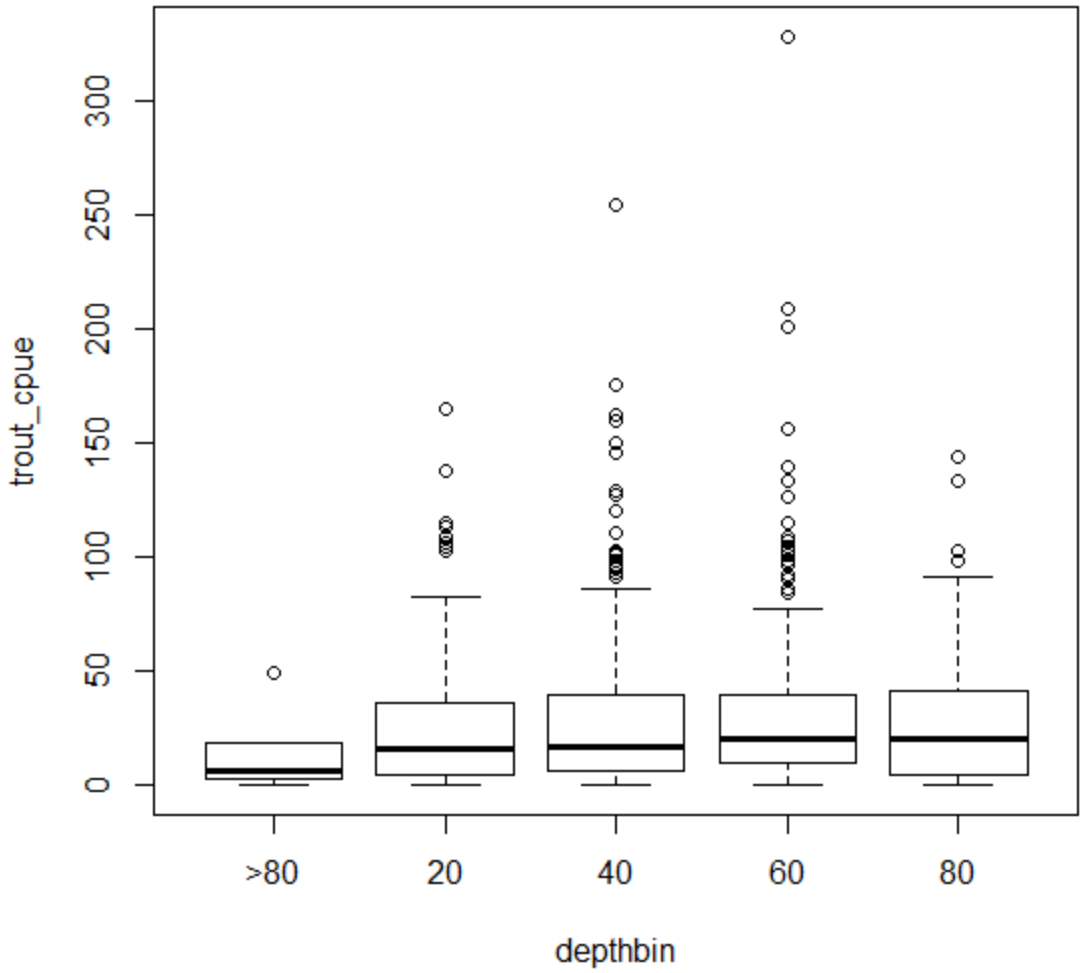
Figure from Jeff Stein et al. *in prep*

Mortality in the North

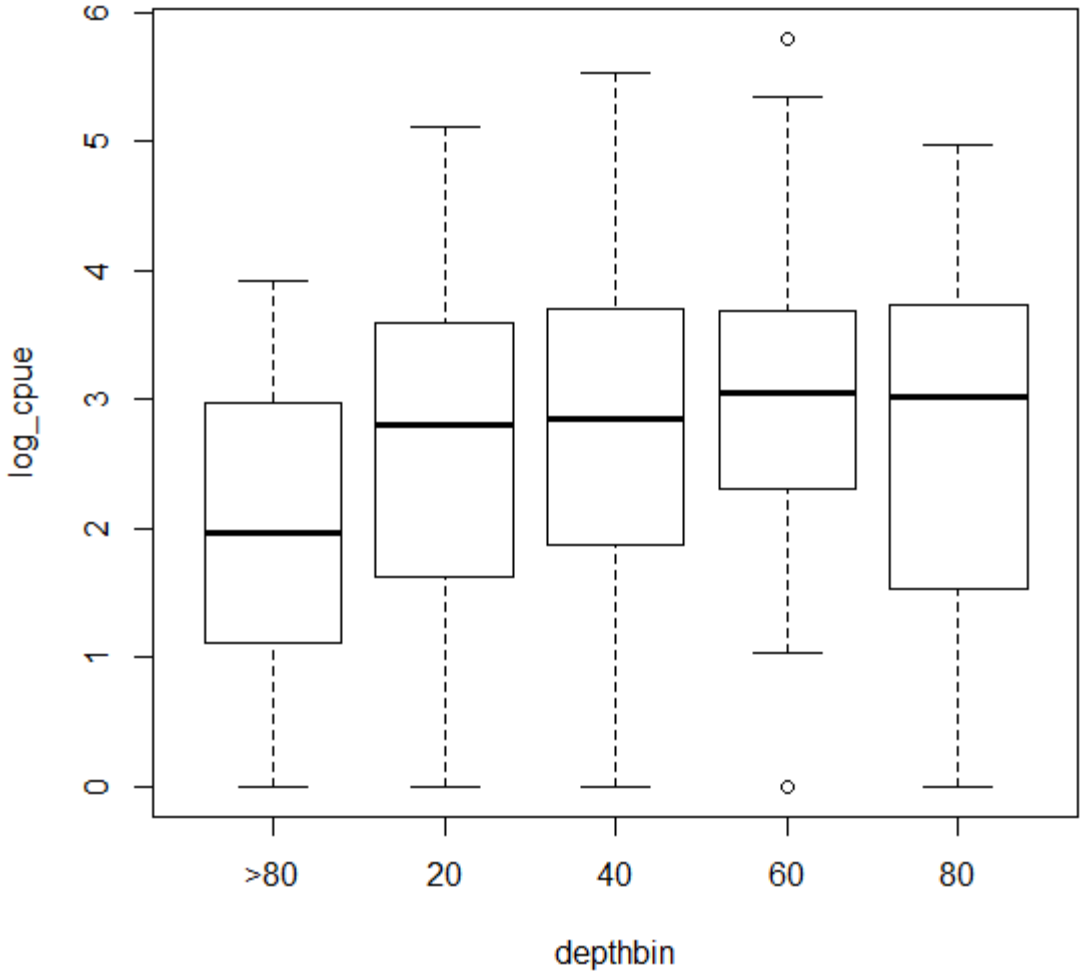
Stocking Location	Ages	Instantaneous Mortality	Annual Mortality
Northern Refuge	5-9	1.48	77.2%
Clay Banks	5-15	0.41	33.6%
Southern Refuge	6-18	0.45	36.2%
Julian's Reef	6-17	0.45	36.2%



DEPTH



ANOVA $F_{4,1145}$=1.4, p = 0.22
Without >80, ANOVA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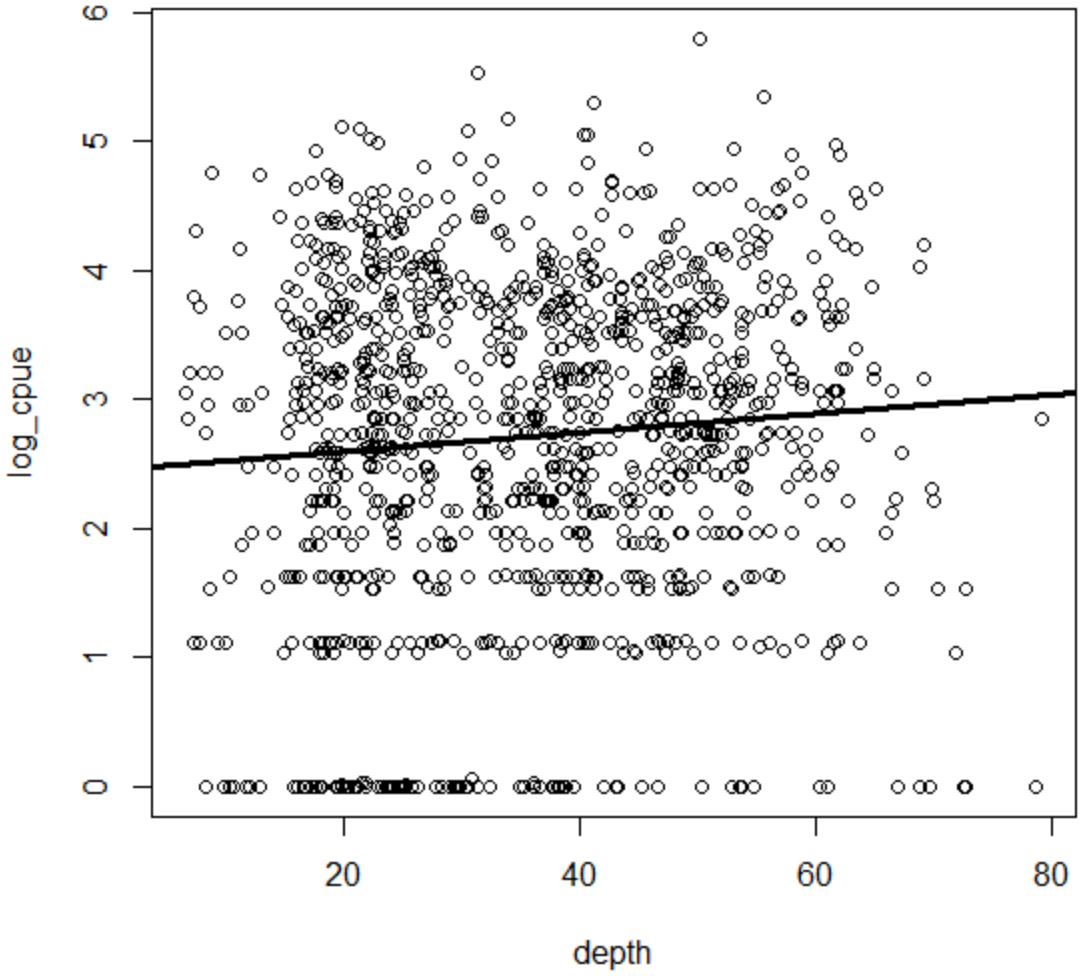
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