The Effect of Wet Weather Driven Dissolved Oxygen Sags on Fishes in Urban Systems – Pilot Study

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ILLINOIS

LimnoTech
Water | Environment | Scientists | Engineers

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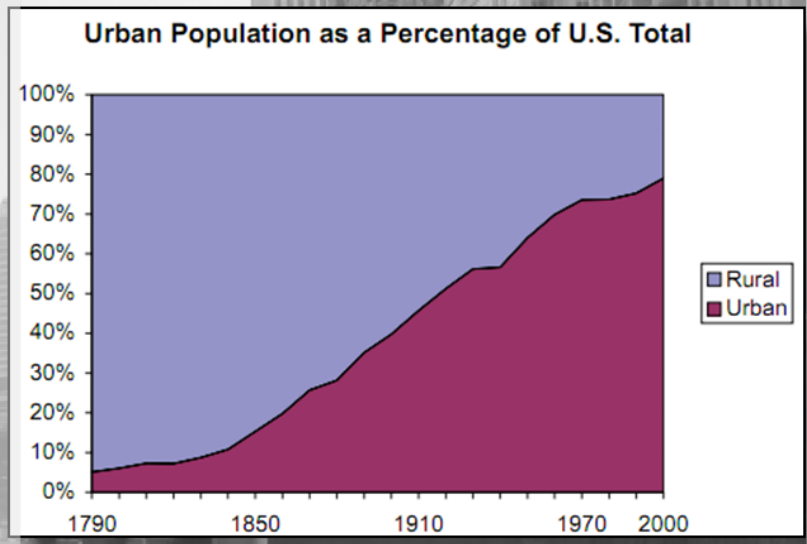
Presentation Goals

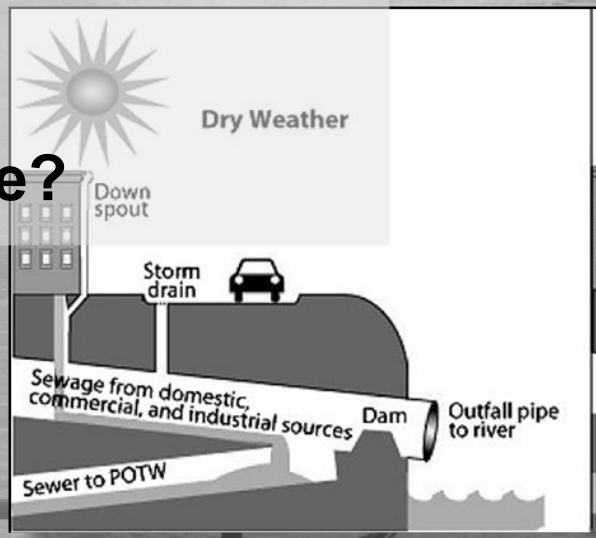
- Background
  - (Why do we care and who does this affect?)
- Objectives
  - (What did we hope to do and learn?)
- Methods/Results
  - (What did we actually do and what did we find/learn?)
- Discussion
  - (What does it mean?)
- Missing bits and next steps?

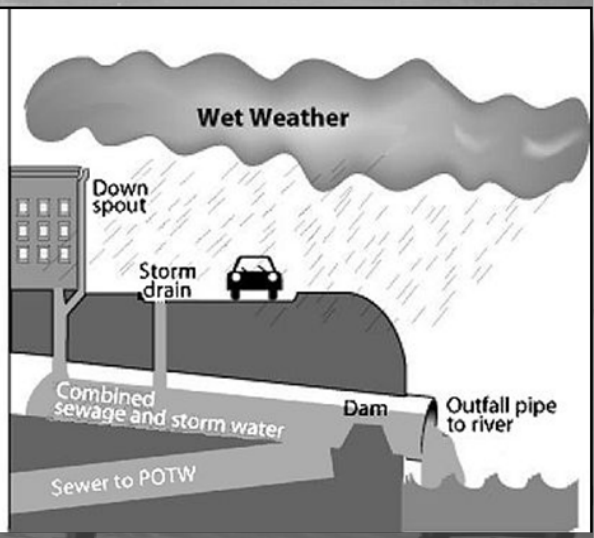
Background

Urban Systems + Rain = Mgmt Headache

- Global issue (Big Cities!)
  - Treatment systems overwhelmed
- Regulatory Pain
  - Episodic (Barton et al, 1987)
  - Regulations on aquatic life effect based on old science (EPA 1986; Kramer 1987)
  - What is fish in-situ exposure/response?





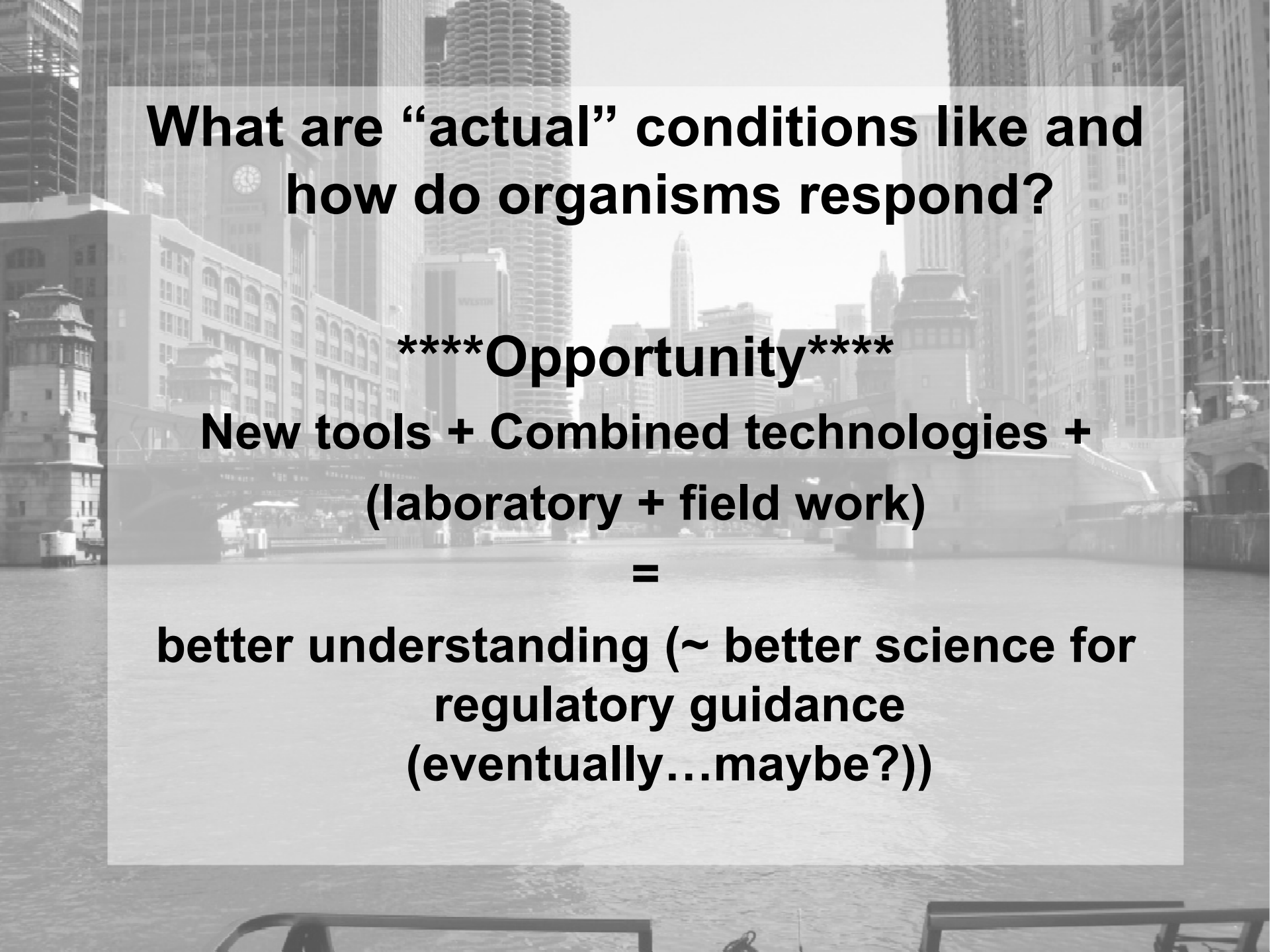


The Real Issue

- Dissolved oxygen (DO) depletion during rain events a leading stressor in urban, aquatic systems (Burton and Pitt, 2002)
- DO criteria based on laboratory findings (EPA 1986; Kramer 1987)
- New tools suggest fish more physiologically plastic than lab studies suggest (Hasler et al. 2009)

Regulatory Challenge

- Potential for overly stringent regulatory criteria (Burton and Pitt, 2002)
- Potential for unattainable regulatory requirements
- Wet Weather controls may not make a measurable difference for aquatic community



What are "actual" conditions like and how do organisms respond?

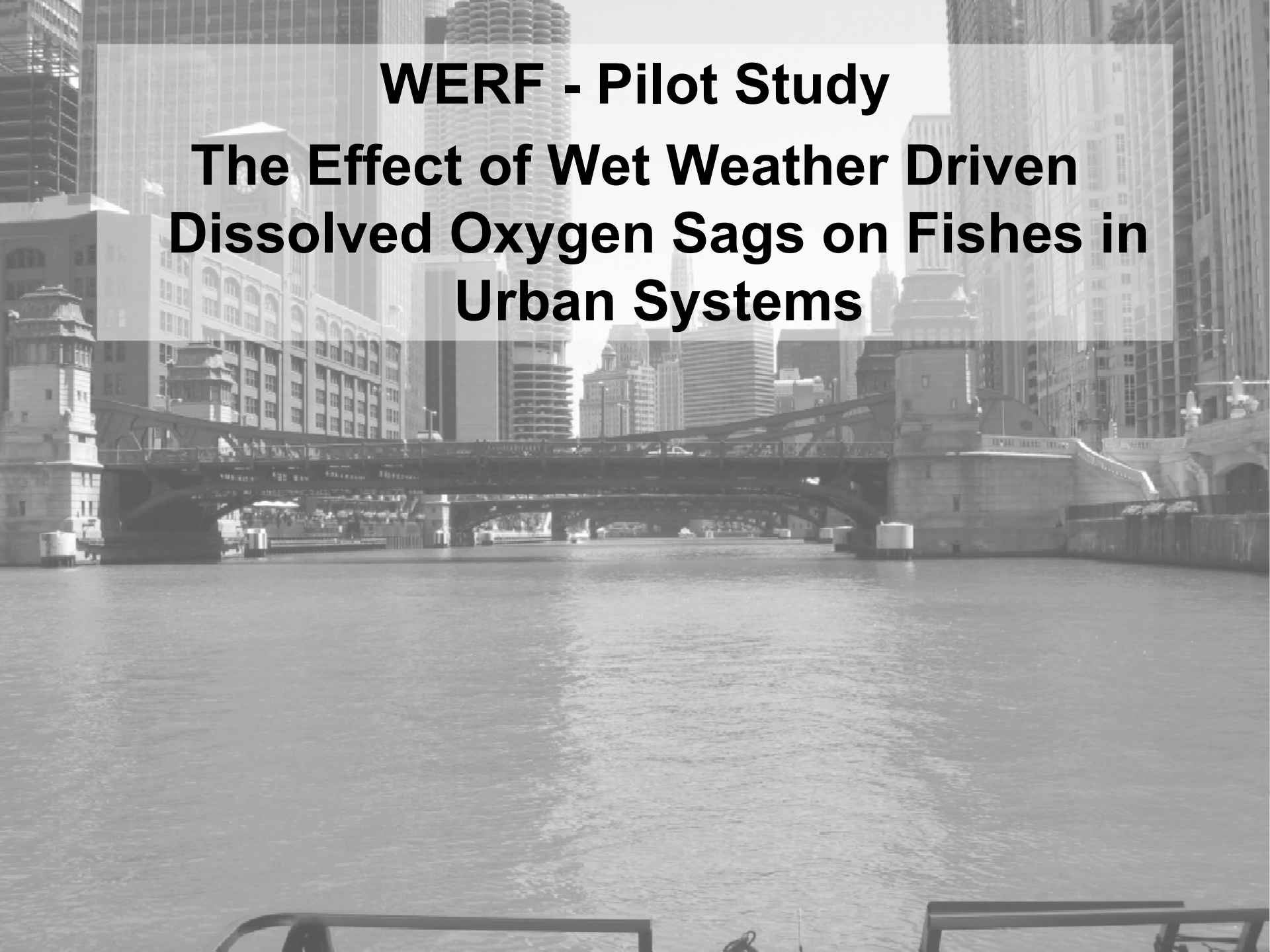
******Opportunity******

New tools + Combined technologies +

(laboratory + field work)

=

better understanding (~ better science for regulatory guidance (eventually…maybe?))



WERF - Pilot Study

The Effect of Wet Weather Driven Dissolved Oxygen Sags on Fishes in Urban Systems

Objectives

Pilot Study Objectives

1) quantify fish responses to dissolved oxygen (DO) drops using field- and laboratory-derived data.
2) determine if fish subjected to regular low DO events are tougher (or weaker) than reference fish
3) Identify a definable low DO limit of fish use

Methods/Results

Implementation Spring 2010 – Fall 2011

Final draft report submitted January 31, 2012

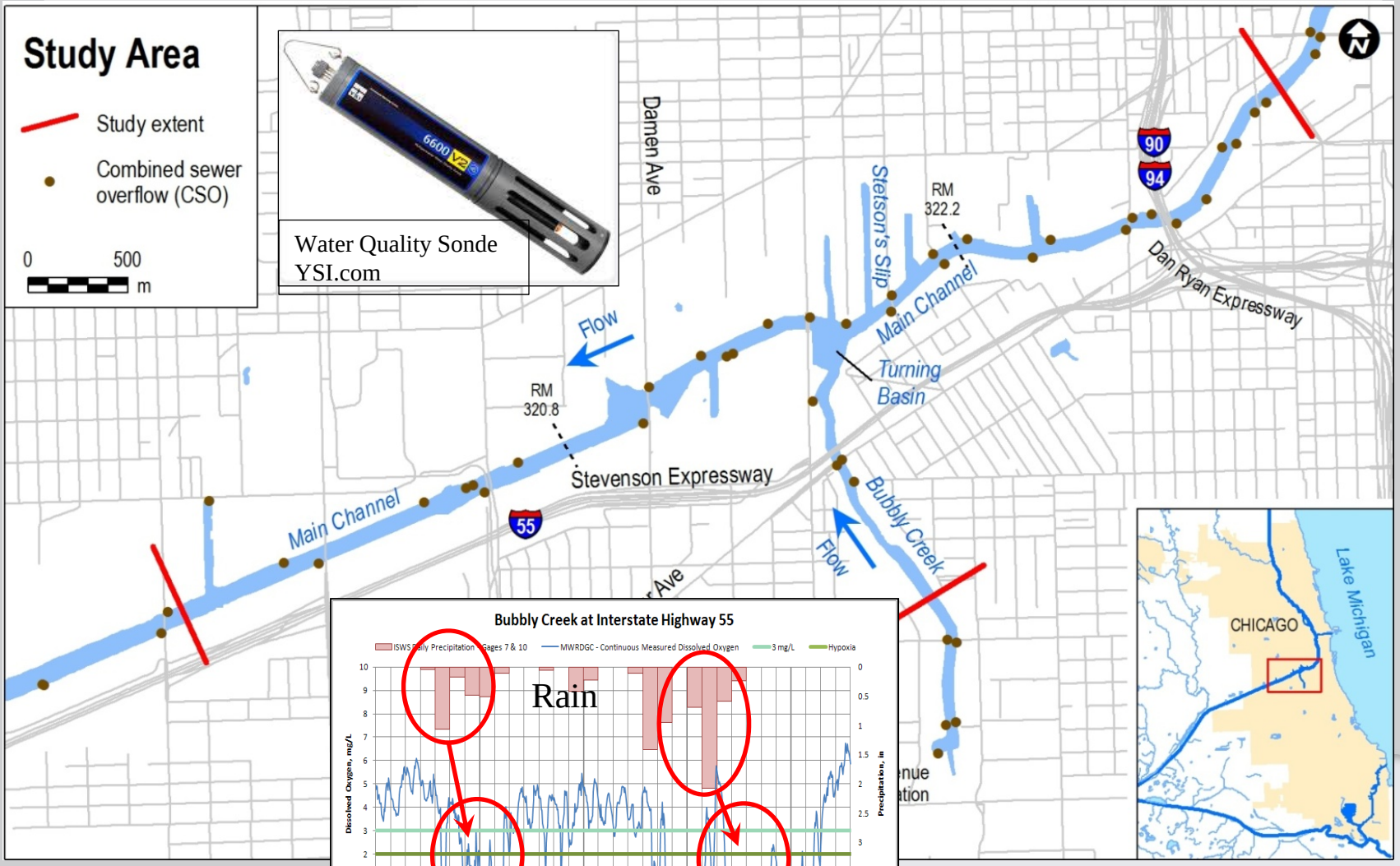
WERF Published October 2012

Study Steps

- Phase I (2010) Testing the Waters
  - Set Up and Fish Movement Field Study;
- *Adjust field study based on Phase I findings*;
- Phase II (2011) The Money Year!
  - Fish Movement/Exposure Field Studies/Health Exam/Lab Stress;
- Many Interim Reports>Final

Pilot Study Site

Location: Bubbly Creek (Chicago Area Waterway System)

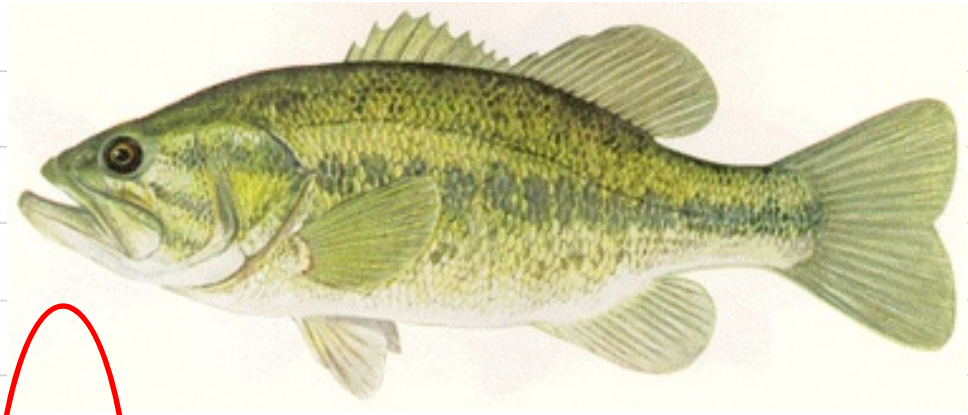


Field Activities	Lab Activities
Water quality monitoring sondes	DO chamber (Hypoxia Tolerance)
Acoustic telemetry •Hydrophones •Position tags (movement) •DO tags (exposure/movement)	Blood/Muscle Samples (health) •Physiology
Blood Samples (health) •Stress •Condition •Physiology	

Fishes in the CAWS (2001-2007)

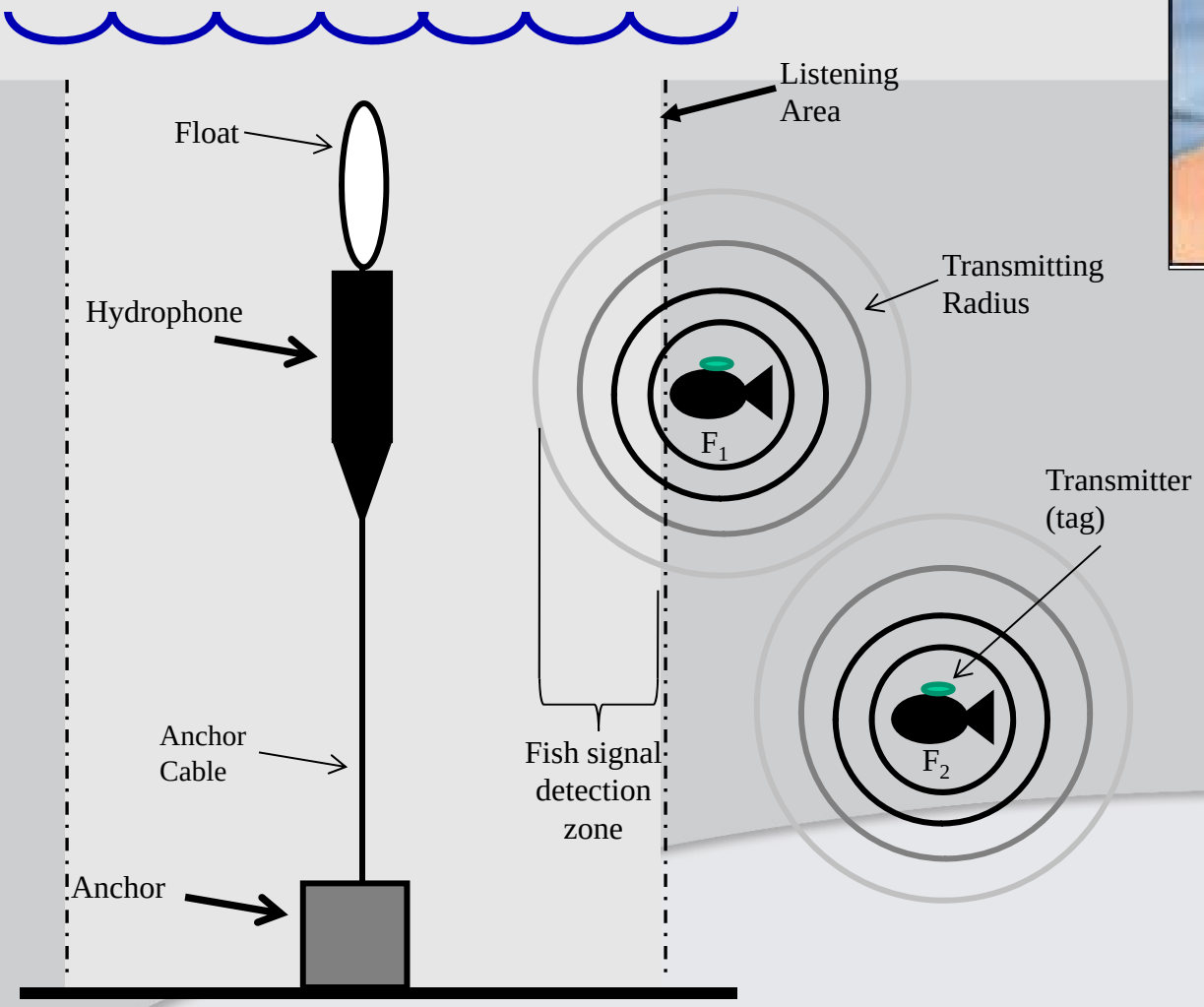
High abundance (> 1000)

Medium abundance (<1000, >50)

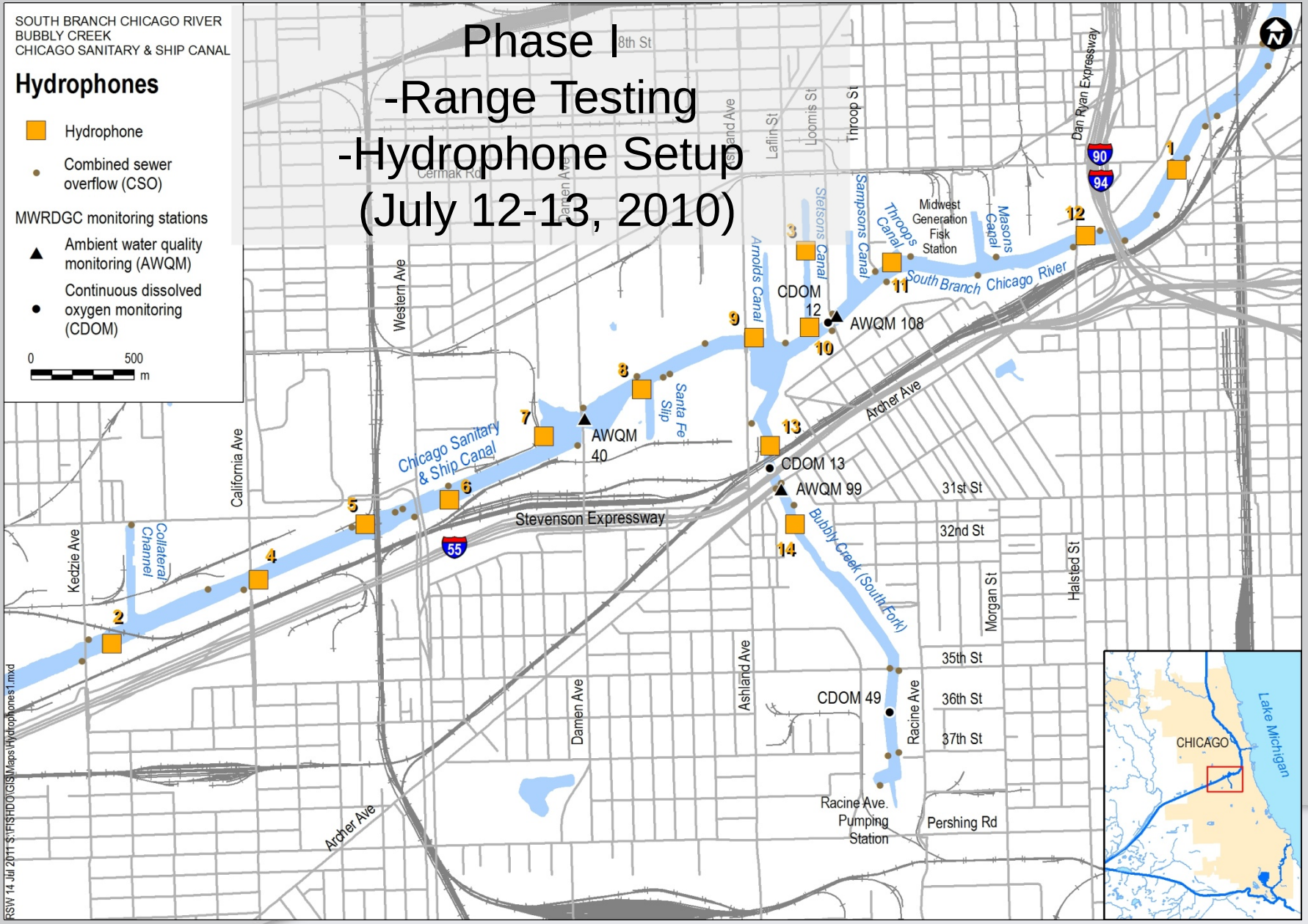


What is Acoustic Telemetry?

(The Nickel Tour)



Phase I
-Range Testing
-Hydrophone Setup
(July 12-13, 2010)



Phase I

Fish Collection and Tagging

July 14-17, 2010

Largemouth Bass

- Electrofished and collected 20 fish for tag study
- Size/Health determination (Target-225-350 mm, normal looking, normally active, no external anomalies)

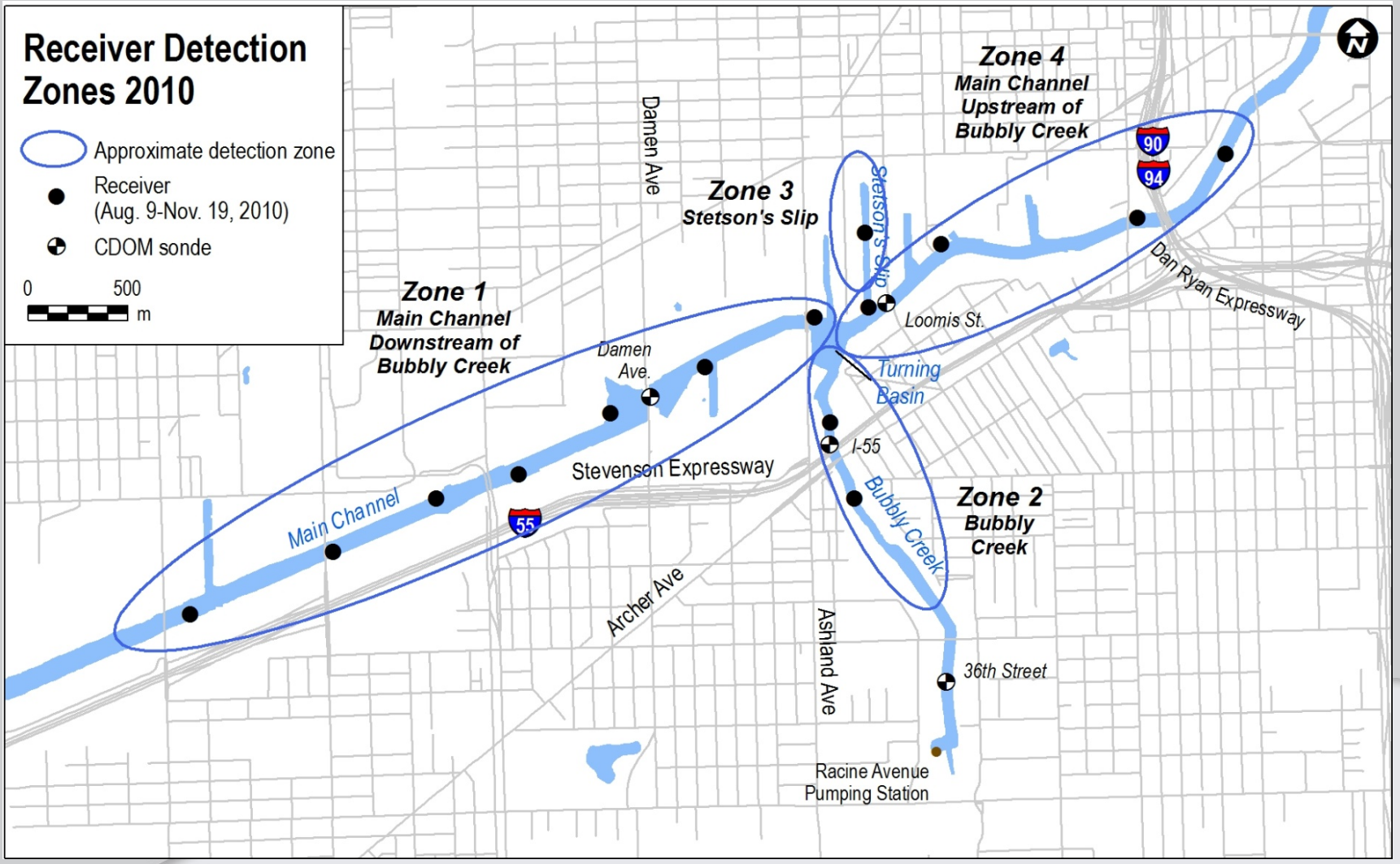
- Fish length ranged from 224 mm to 350 mm (~274 mm)
- Fish weight ranged from 180 g to 653 g (~326 g)

- Implanted tags > post surgery recovery released fish in study area.

- 19/20 fish stayed within study area

Phase I (Fish Movement)

Wet Weather Event – Trigger local CSOs
Hypoxia (stressful to fish)- < 2 mg/l



Phase I Results

Study Period – July 14 – November 19, 2010

DO Data
3 Sondes – July 14 – November 19, 2010
Hourly data collected
Six wet weather events ***hypoxic focused

DO conc. (mg/L)	Bubbly Creek DS BC Zone 1	Zone 2	US BC Zone 4
< 2.0	3 (0.1%)	627 (21 %)	14 (0.5 %)
2.1-6.0	1526 (67 %)	2185 (73 %)	1384 (46 %)
> 6.0	738 (32 %)	164 (6%)	1578 (53 %)
Total	2267	2976	2976

Phase I Results

Study Period – July 14 – November 19, 2010

Hypoxic Events - daily mean dissolved oxygen of 2.0 mg/L or lower for 4 consecutive days or more

Three Events During the 2010 Study Period

Event No.	Location	Duration (days)			No. fish before	No. fish during	No. fish after	No. fish total
		Before	During	After				
1[b]	Bubbly Creek	2	4	2	4	2	1	16
2[b]	Bubbly Creek	2	6	2	1	1	1	16
3[a]	Bubbly Creek	2	7	2	1	1	1	17

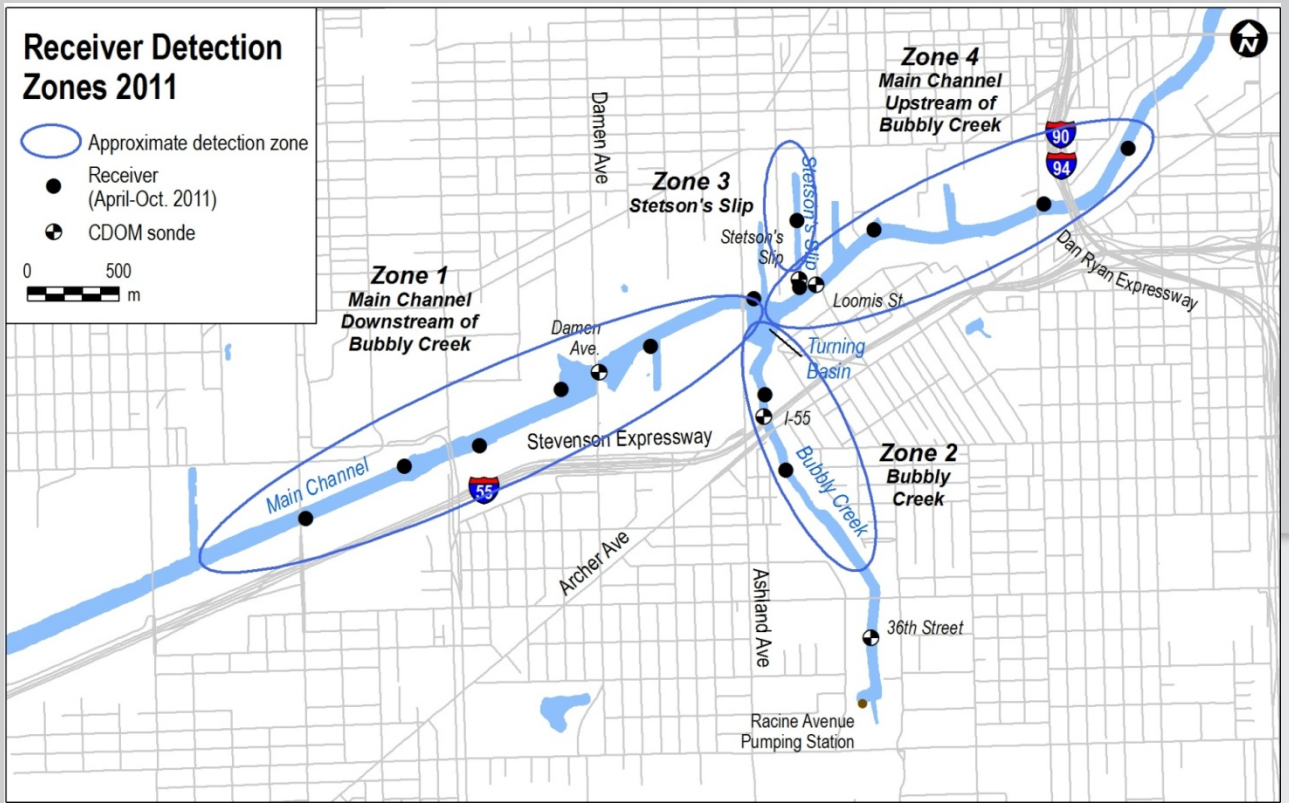
Phase I Take Home Message

Fish stayed in Bubbly Creek during hypoxic events

Phase II

(Study Period – May 20 – September 30, 2011)

Fish Movement (similar to Phase I)
Fish Exposure (testing external DO tags)
Fish Condition (blood stress/health)
Hypoxia Tolerance (lab stress test)



Phase II Results – Fish Movement

Six Hypoxic Events During the 2011 Study Period

Hyp No.	Location	Duration (d) Before	During	After	Propn fish before	Propn. fish during	Propn fish after	No. fish total
4[b]	Downstream	2	5	2	1	5	2	11
5[c]	Bubbly Creek	2	22	2	2	6	2	18
6[b]	Downstream	2	10	2	0	3	0	13
7[c]	Bubbly Creek	2	22	2	2	1	2	11
8[b]	Downstream	2	9	2	3	0	1	10
9[b]	Bubbly Creek	2	4	2	1	2	2	7

Phase II Fish Movement Take Home Message
Some fish stayed, some moved out, some moved into areas during hypoxic events

Fish Exposure/Movement

Dissolved Oxygen Transmitter Specs

Manufacturer - Loligo® Systems (Denmark)

Sensor – Galvanic-type DO sensor

Acoustic transmitting signal (~ VEMCO)

Size – l =57 mm, d = 12.5 mm, w = 16 g

Measures % Sat. DO (%DO and Temp)[1]

Transmits DO corresponding pulsed signal

(0-200% DO ~ 1000-3000ms)

Life expectancy ~ 30 d

(@1 mg/l)

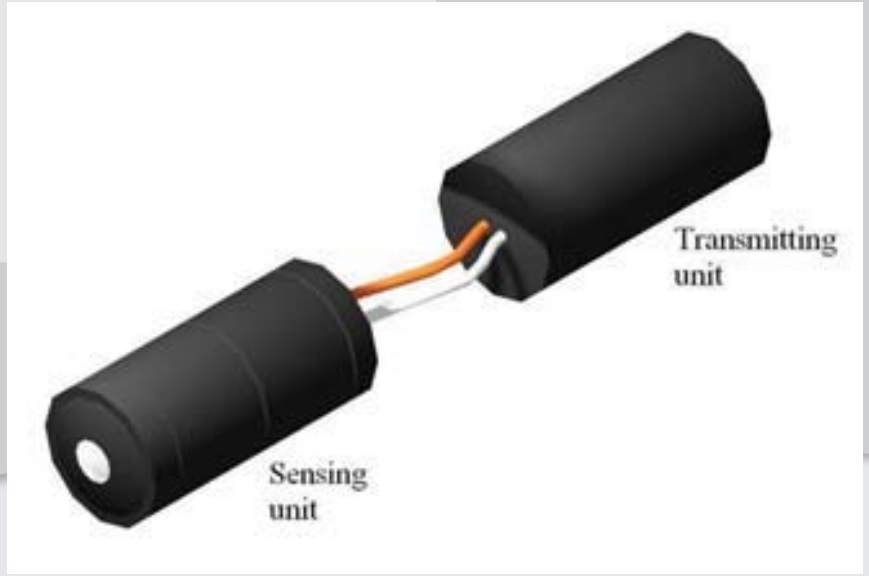


Image from Svendsen et al. 2006

Purchased 10 DO tags

Deployed 9, 1 for lab testing

Lab- calibrated for accuracy (n=1)

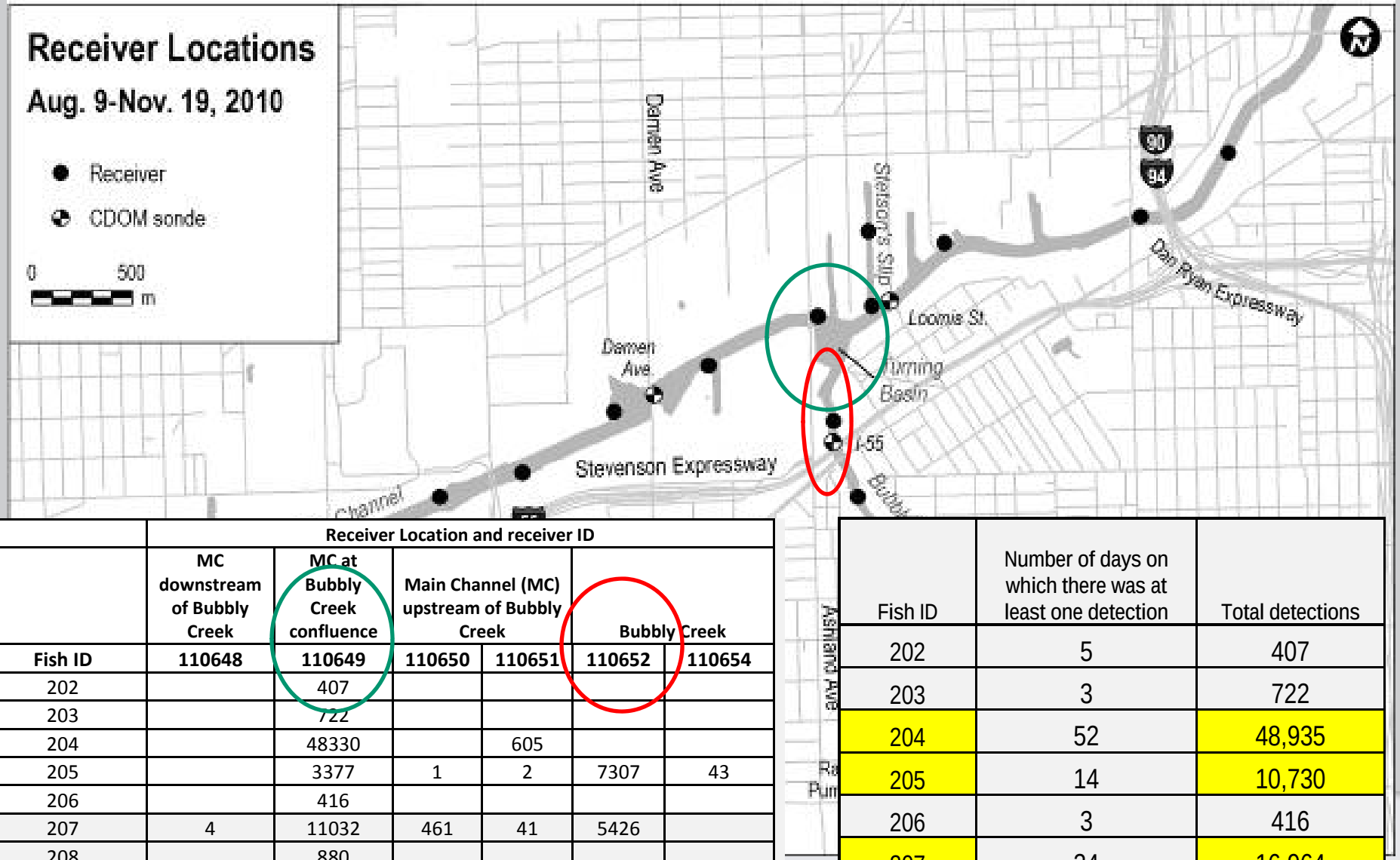
- high/low DO
- temporal drift

Tagged LMB (n=9)

- External Mount
  - Dorsal musculature (dorsal fin)
- Actual body burden ave (1.8%)
  - 30 minute observation pre-release

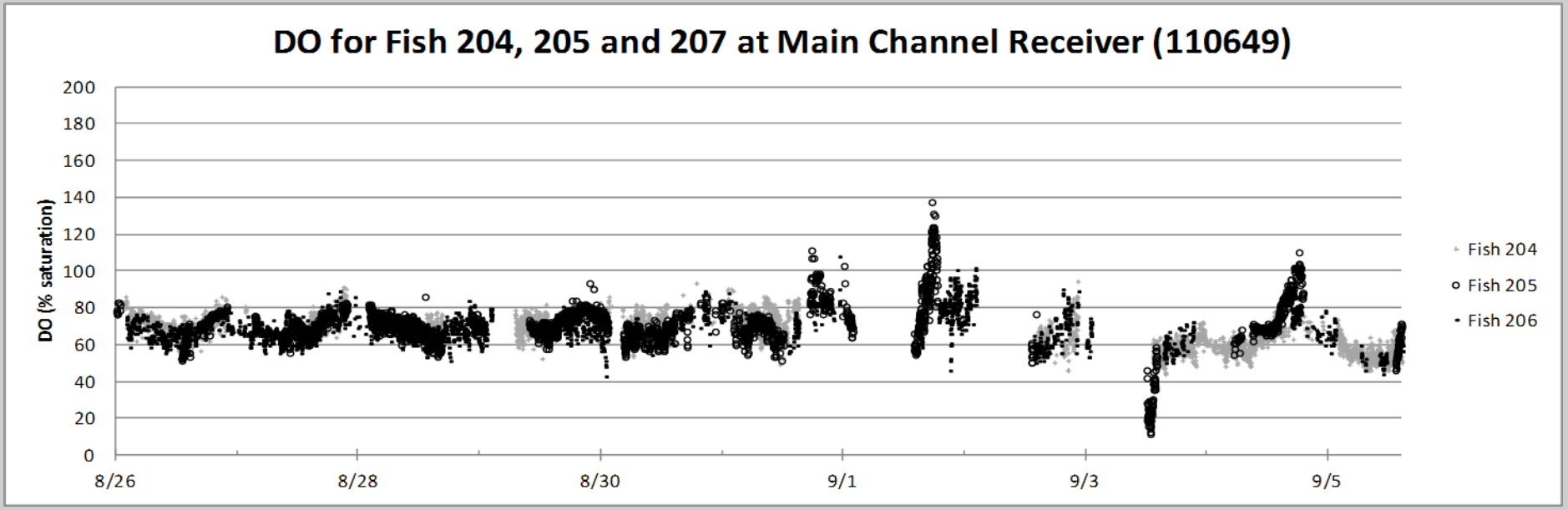
Transmitter ID	Fish Length (mm)	Fish Weight (g)	Tag Burden (%)
202	421	1152	1.4
203	346	950	1.7
204	380	1047	1.5
205	415	1132	1.4
206	330	666	2.4
207	374	816	2.0
208	360	907	1.8
209	330	771	2.1

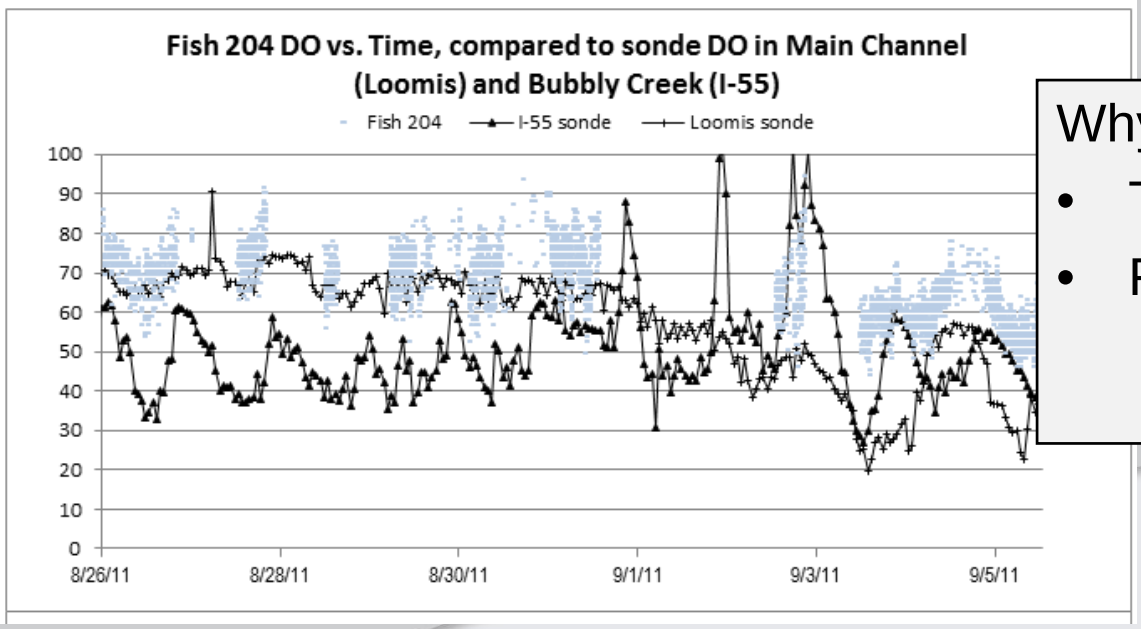
DO Tag Results



	Receiver Location and receiver ID					
	MC downstream of Bubbly Creek	MC at Bubbly Creek confluence	Main Channel (MC) upstream of Bubbly Creek		Bubbly Creek	
Fish ID	**110648**	**110649**	**110650**	**110651**	**110652**	**110654**
202		407				
203		722				
204		48330		605		
205		3377	1	2	7307	43
206		416				
207	4	11032	461	41	5426	
208		880				
209		102			10	
% total detections	0%	82%	1%	1%	16%	0%

Fish ID	Number of days on which there was at least one detection	Total detections
202	5	407
203	3	722
204	52	48,935
205	14	10,730
206	3	416
207	34	16,964
208	3	880
209	2	112





Why the difference?

- Tag vs sonde calibrations
- Fish actually in higher DO areas
  - Fish seeking refugia?
  - Fish position vs sonde position

Exposure Take Home Messages

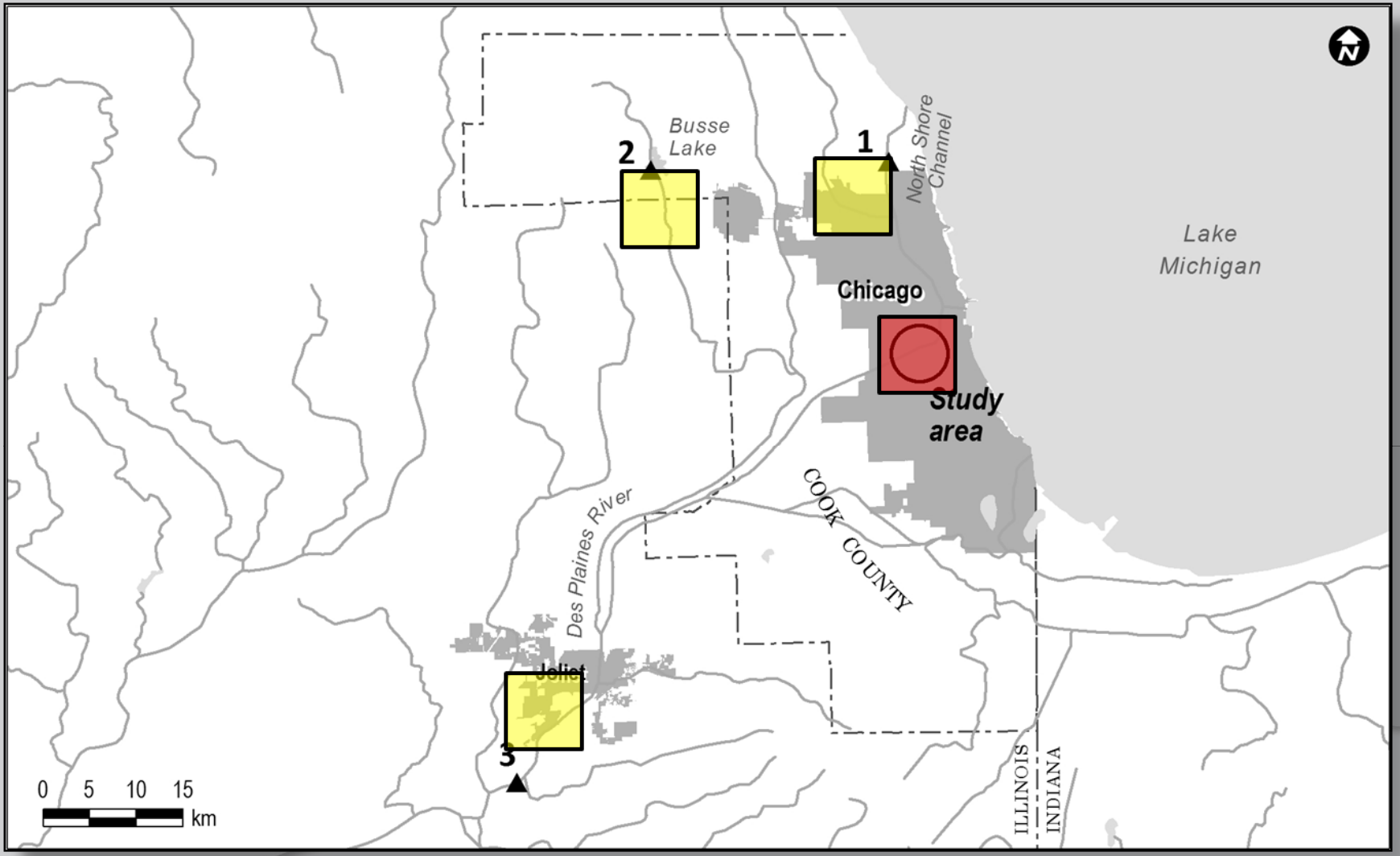
- Cool tool!
- Tag data appears to be sending a reasonable representation of DO data (for a limited period)
- Tagged fish signals appeared to show similar results when “near” one another
- Tag DO levels appeared to track representative sonde DO patterns
- Tag DO appears to be slightly higher than representative sonde DO data

Fish Condition

Field Condition Assessment

- Examine and compare health & condition of CAWS largemouth bass to reference sites not experiencing hypoxia
- Study site (CAWS) and 3 nearby reference sites
- Electrofished
  - 8 largemouth bass collected from each site
  - Immediately sampled for blood and tissues

CAWS and Reference sites



Field sampling results

Variable	BubblyCr	Reference#1	Reference#2	Reference#3	P
Cortisol (ng/mL)	15 ± 11				0.17
Lactate (mM)	2 ± 0.7				0.42
Triglycerides	3 ± 0.6	4			0.13
Total Protein	7 ± 0.7				0.34
Condition (Wr)	102 ± 3**B**	114		**B**	**<0.05**
Hematocrit (%)	31 ± 1**A**	26			**<0.05**
Hemoglobin (g/dL)	11 ± 2**A**				**<0.05**

Measures of Health Stress

Measures of Health Condition (fatness)

Measures of Oxygen Transport Ability

Field sampling results

Variable	Study Area	Reference#1	Reference#2	Reference#3	P
Cortisol (ng/mL)	15 ± 11	31 ± 17	4 ± 0.6	7 ± 2	0.17
Lactate (mM)	2 ± 0.7	3 ± 1.2	2 ± 0.3	2 ± 0.5	0.42
Triglycerides	3 ± 0.6	4 ± 1	4 ± 0.5	2 ± 0.7	0.13
Total Protein	7 ± 0.7	9 ± 0.9	6 ± 0.5	8 ± 0.6	0.34
Condition (Wr)	102 ± 3**B**	114 ± 3**A**	106 ± 3**AB**	103 ± 3**AB**	**<0.05**
Hematocrit (%)	31 ± 1**A**	26 ± 0.5**B**	-	28 ± 1**AB**	**<0.05**
Hemoglobin (g/dL)	11 ± 2**A**	7 ± 0.5**B**	7 ± 0.5**B**	8 ± 0.1**AB**	**<0.05**

Field sampling results

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Condition (Wr)	102 ± 2**B**	114 ± 3**A**	106 ± 3**AB**	103 ± 3**AB**	**<0.05**
Hematocrit (%)	21 ± 1**A**	26 ± 0.5**B**	-	28 ± 1**AB**	**<0.05**
Hemoglobin (g/dL)	6 ± 2**A**	7 ± 0.5**B**	7 ± 0.5**B**	8 ± 0.1**AB**	**<0.05**

Take Home Message

Little evidence that study fish are stressed or are in poorer condition than ref sites

Some evidence of improved tolerance in oxygen transport for study fish?

Lab Study – Hypoxia tolerance

- Quantify measures of hypoxia tolerance in study site relative to reference sites
- N=8 from study site and 3 reference sites
- Fish placed in individual chambers
  - 24hr acclimation
- Treatments:
  - 6 hr exposure to 2.0 mg/L DO (hypoxia)
  - 6 hr 8 mg/L DO (control)
- Sample for blood and muscle

Oxygen shock – Lab results

Variable		Study Area	Ref #1	Ref#2	Ref#3
Lactate (mmol/L)	Control	0.5 ±			: 0.6**A**
	Hypoxia	6 ± 1.6**B**			5 ± 2**B**
Hematocrit	Control	36 ±			2**A**
	Hypoxia	35 ± 1**A**			44 ± 2**A**

Reaction Test

Stress Test

Oxygen shock – Lab results

Variable		Study Area	Ref #1	Ref#2	Ref#3
Lactate (mmol/L)	Control	0.5 ± 0.2**A**	0.6 ± 0.3**A**	1.2 ± 0.1**A**	1.2 ± 0.6**A**
	Hypoxia	6 ± 1.6**B**	12 ± 2**B**	6 ± 1**B**	5 ± 2**B**
Hematocrit	Control	36 ± 1**A**	32 ± 2**A**	33 ± 1**A**	37 ± 2**A**
	Hypoxia	35 ± 1**A**	42 ± 0.5**B**	45 ± 1**B**	44 ± 2**A**

All Responded

Least Response

Take Home Message
Least hematocrit response for fish from study sites – lowest stress under stress

Summary of Pilot Study Findings

Movement/Exposure Work

- No influence of hypoxia on large-scale movements
  - Fish did not entirely vacate hypoxic areas during prolonged exposure
  - Fish may seek/find microrefugia during hypoxic events

Health & condition

- No evidence for chronic stress or poorer condition

Physiology

- Slightly improved tolerance (acclimation) - oxygen transport?
- Study fish appear to exhibit less hypoxic exposure stress

Pilot Study Objectives

1) quantify fish responses to dissolved oxygen (DO) drops using field- and laboratory-derived data. √

2) determine if fish subjected to regular low DO events are tougher (or weaker) than reference fish √

3) Identify a definable low DO limit of fish use X

Study Caveats

1) many unmeasured variables

reduced growth, impaired reproduction, reduced immune function, increased parasite loads, oxidative stress, endocrine disruption, or truncated life expectancy

2) co-occuring affects

elevated carbon dioxide, high hydrogen sulfide or methane, toxic organics, and heavy metals

3) Limited spp and size class

large fish may have a metabolic advantage over smaller fish during periods of low oxygen although laboratory studies with largemouth bass showed that smaller fish can utilize water with lower oxygen concentration than larger fish

Study Value

1) applied science

In-situ approach supported by laboratory finding

Evaluation of exposure tool to understand spatial heterogeneity of fish use in DO stressed environments

Potentially valuable tool for tracking climate change dynamics in fishes/communities

2) Basic science

First test of external DO tags on free roaming fish

Identify DO environments that fish actually inhabit and physio responses to that exposure

The Future

1) More Fish/other tolerances
2) DO tag performance testing
3) Expand scale
4) Fine scale/3-D performance
5) Increase sonde density
6) Other systems (urban and rural)

Search Results

Title: The Effect of Wet Weather Driven Dissolved Oxygen Sags on Fishes in Urban Systems

PROJECT NUMBER: U3R09

PROJECT MANAGER: Jeff Moeller
Water Environment Research Foundation
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PRINCIPAL INVESTIGATOR: John Wolfe, Ph.D., P.E.
LimnoTech
Jwolfe@limno.com

http://www.werf.org/

STATUS: Completed

LAST UPDATED: 9/25/2012

TOTAL FUNDING: $575,882.00

REPORT DESCRIPTION: This study is the first known field deployment of externally mounted dissolved oxygen (DO) transmitters on fish. The transmitters were used to track fish movement in response to changes in DO levels, in particular as relates to CSO discharges in the Chicago Area Waterway System (CAWS). DO-sensing transmitters attached to fish permit the generation of data that have the potential to demonstrate the DO concentration in which the fish inhabits. Concentrations of DO within the CAWS appeared to exert only a moderate influence on the movement or habitat choice of largemouth bass. The fish (largemouth bass) were quite tolerant of low DO. Data from this study will provide a benchmark for data quality review and analysis that can be referenced by future studies and will provide improved understanding of how fish respond to and are impacted by wet weather CSO events and associated low DO. Published by WERF. 124 pages. Online PDF. (2012)