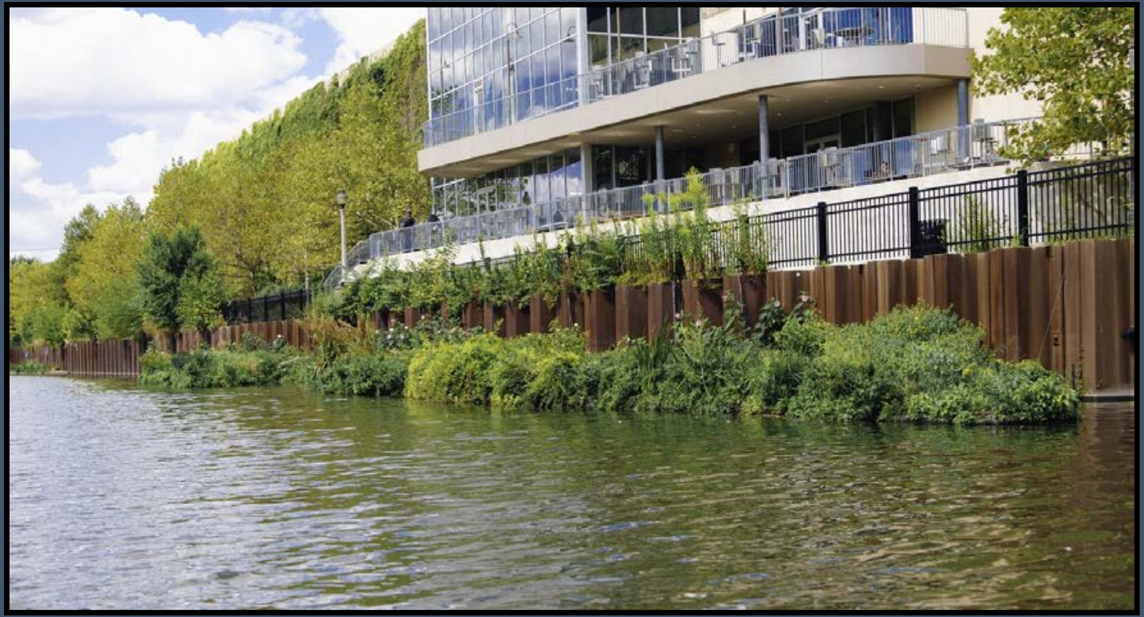
The Role of Floating Gardens to Alter the Water Quality of the Chicago River: Chicago, IL

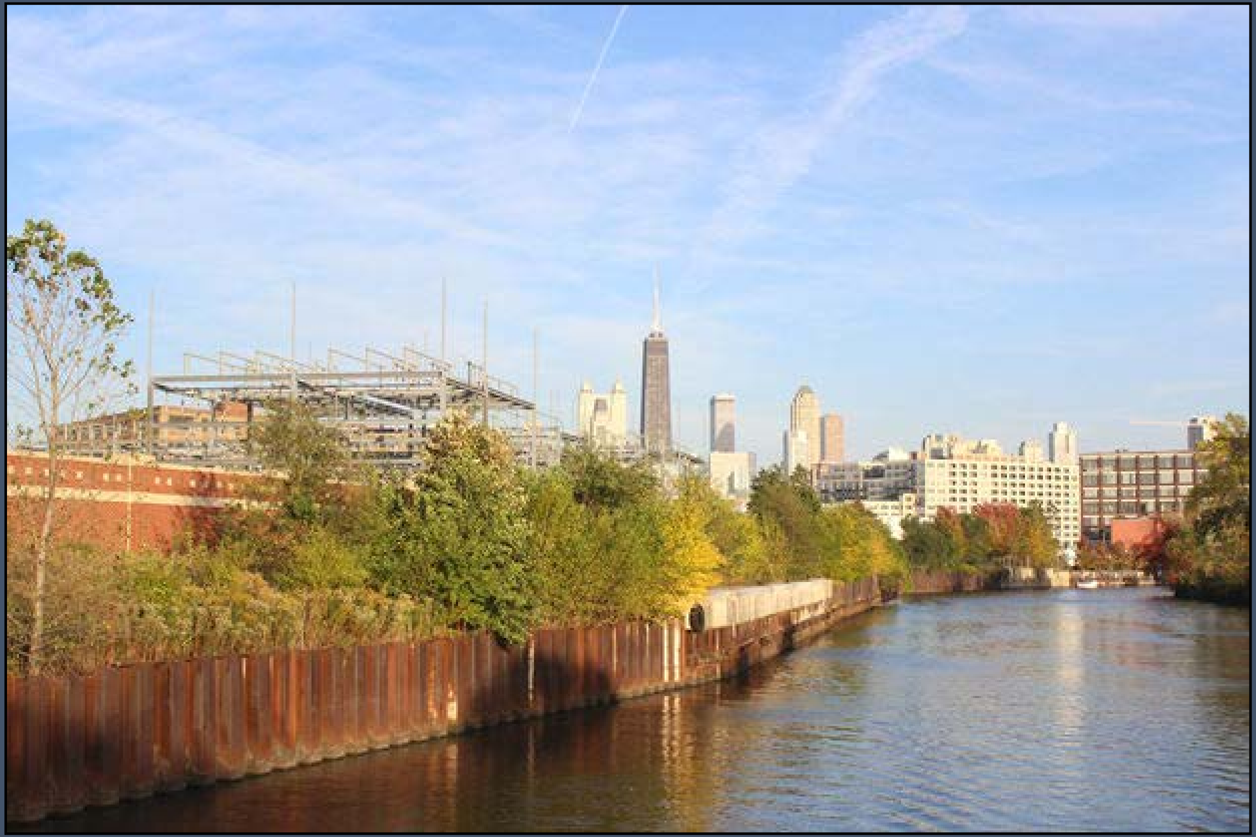
Emmett Spooner



Urban Rivers- https://www.urbanriv.org/research-all

Natural vs Urban Rivers

Daily Saba- https://www.dailysabah.com/gallery/world/the-10-most-beautiful-rivers-in-the-world



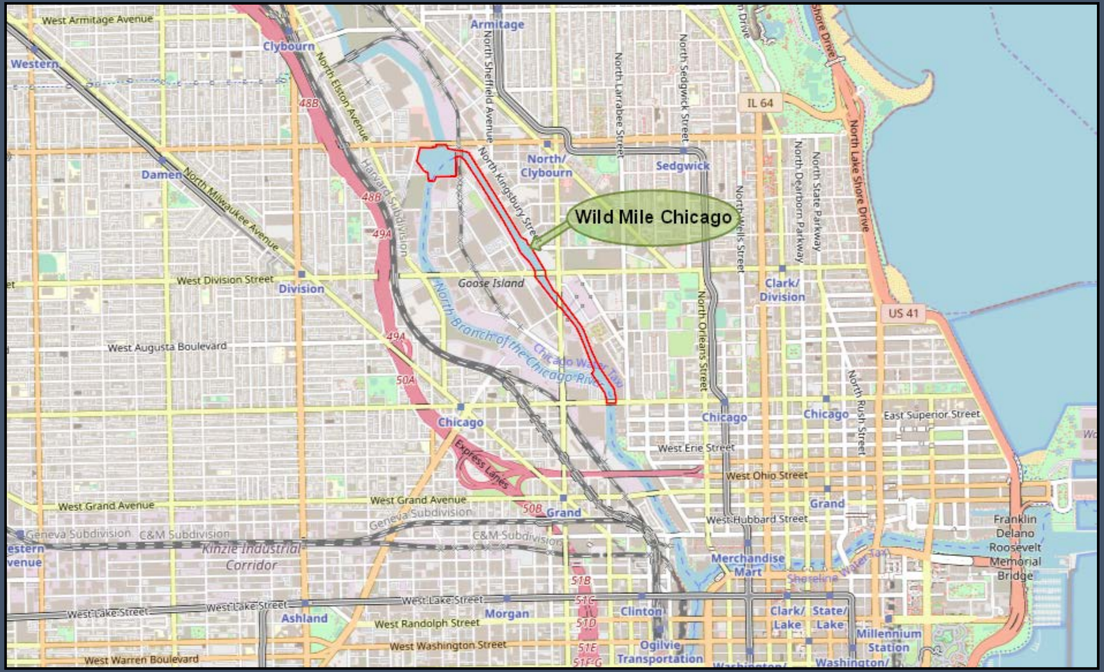
DNA Info- https://www.dnainfo.com/chicago/20161018/downtown/river-trail-bike-patch-action-plan-active-transportation-alliance/

Location

- Mile-long Goose Island Canal of the Chicago River
- Drains urban landscape, industrial sites, and residential and commercial facilities

Goose Island, Chicago, IL

- 1 to 3 meters in depth and ranges from 25 to 37 meters in width
- Loose sediment on top of hard clay



Chicago Sun Times- https://chicago.suntimes.com/news/chicago-river-eco-park-floating-river-worlds-first

Problem

- Increase in urban land cover
  - Changes in water chemistry, hydrology, geomorphology, and ecology of surface waters
- Widespread damage to urban aquatic ecosystems
- Chloride and heavy metal pollution

Chicago Curbed- https://chicago.curbed.com/2016/5/5/11601564/goose-island-transformation-chicago-river

Road Salts & Chloride Pollution

- Increasing application since the 1940s

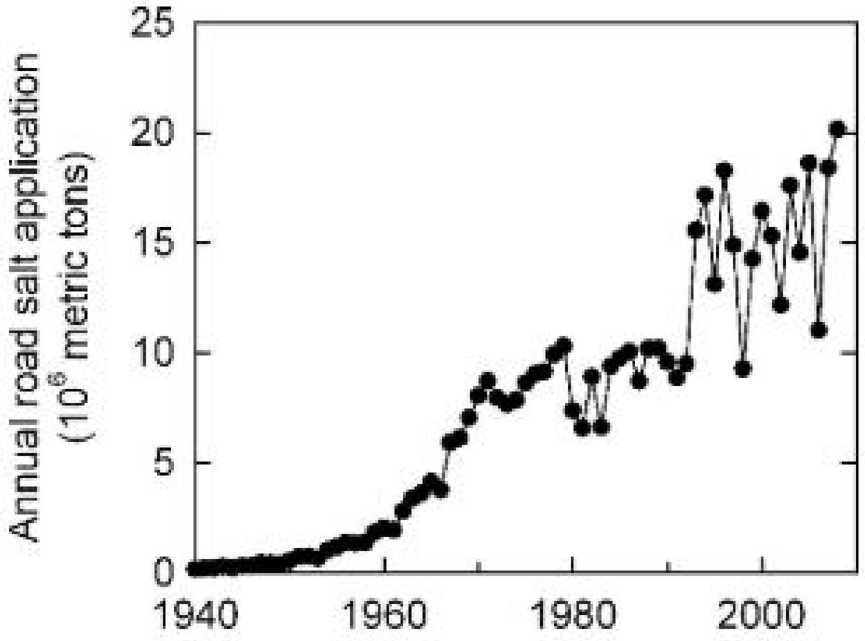


Figure 1. Yearly U.S. highway salt sales. Data are from Salt Institute (2009).

Kelly et al., 2012

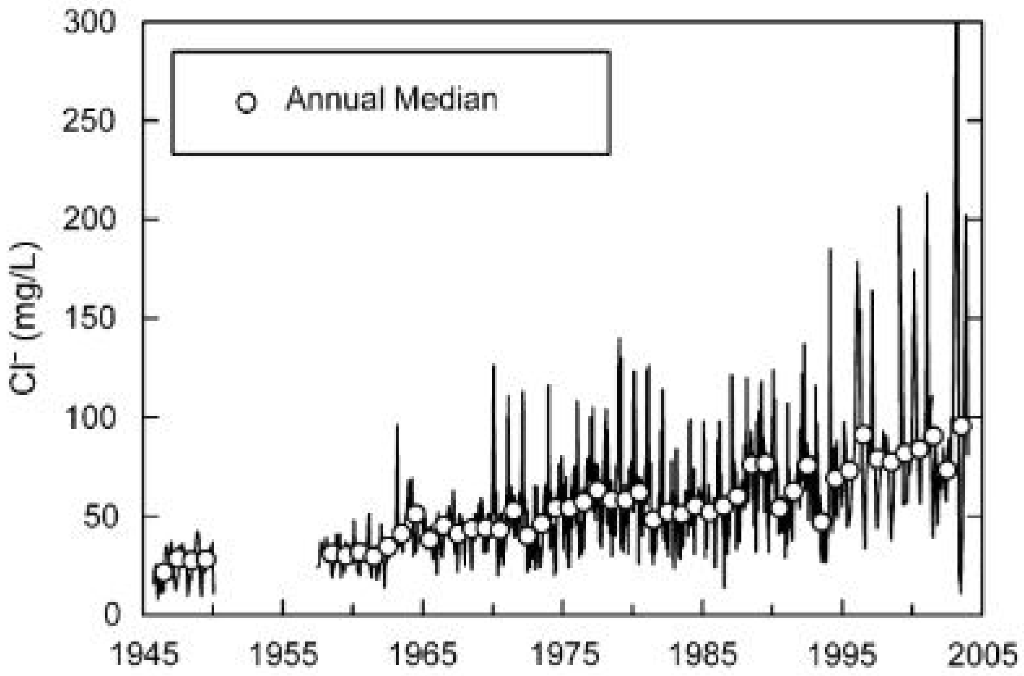


Fig. 8. Chloride concentrations and annual medians in Illinois River at Peoria from 1945 through 2005.

Kelly et al., 2010

Road Salts & Chloride Pollution

- Projected to increase in the future

The Federalist- http://thefederalist.com/2018/02/09/governments-need-stop-subsidizing-road-salt/

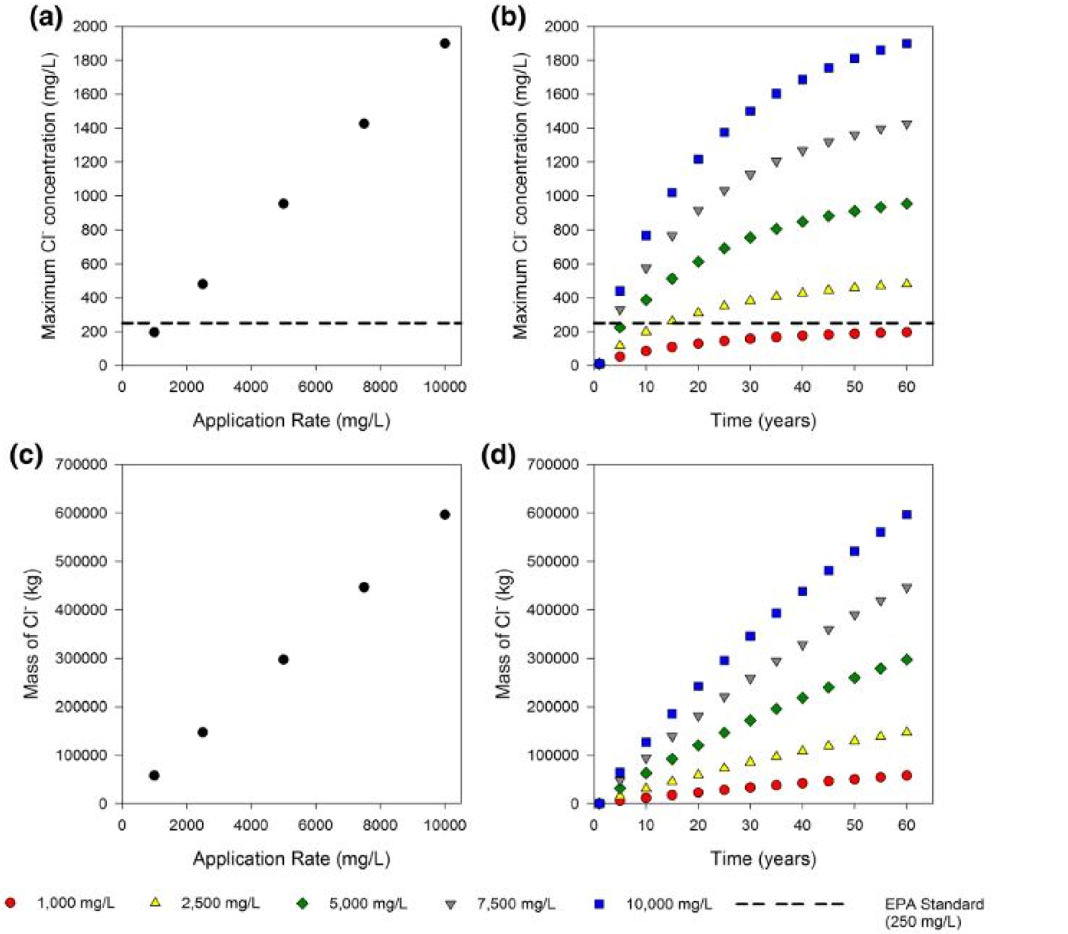
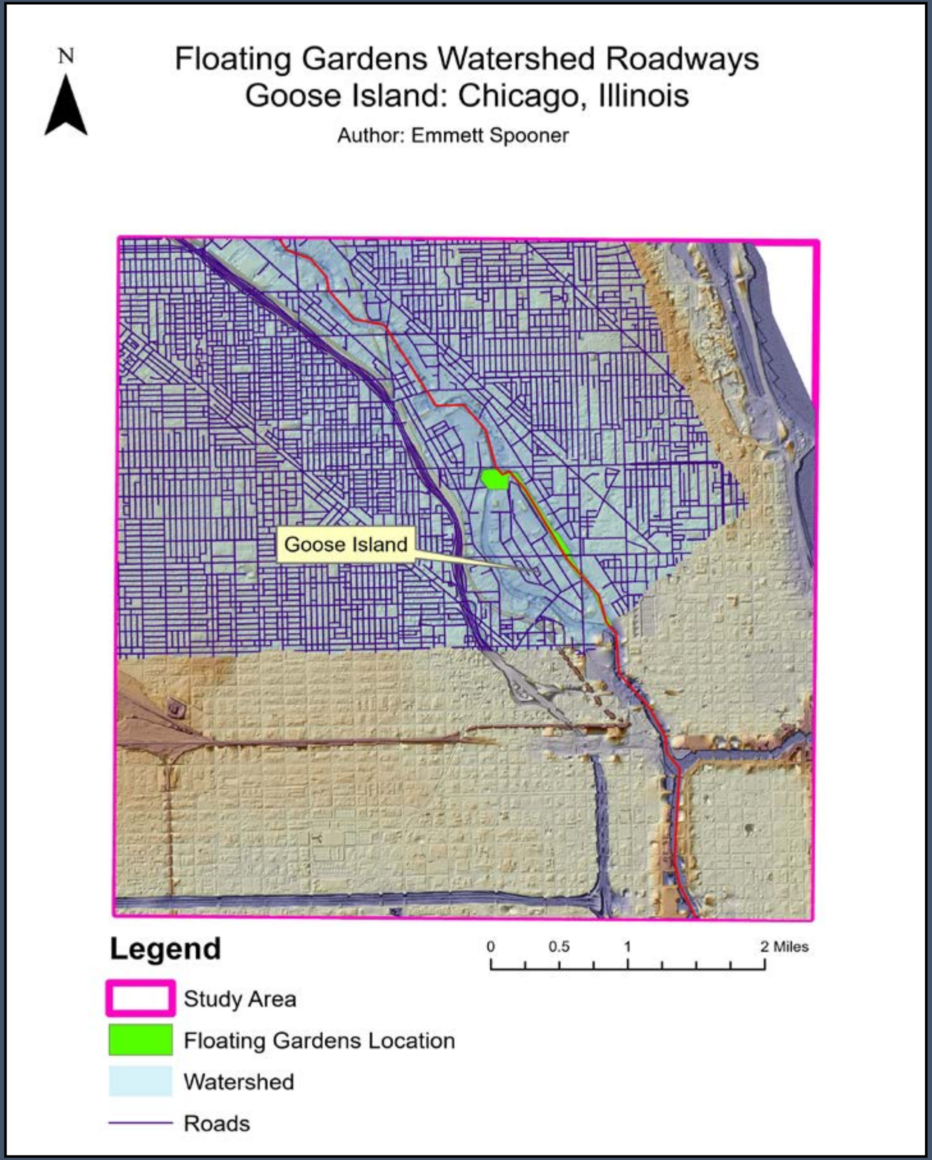


Fig. 5 Build-up model results, wherein road salt was applied for 60 winter seasons. **a** Relationship between the application rate and the maximum Cl^- concentration at the end of the 60-year simulation. **b** Maximum Cl^- concentrations (mg/L) at the end of each 5-year period. **c** Relationship between the application rate and the mass of Cl^- within the system. **d** Net mass of Cl^- at the end of each 5-year period. Represented as a dashed line, the EPA secondary drinking water standard (250 mg/L) is provided for reference (cf. **a–b**)

Ludwikowski and Peterson, 2018

Road Salts in Chicago, IL

- Annually, 270,000 tons of roads salts
- 36 of the 41 stations have increased in Cl^- from 1975 to 2008 (Kelly et al. 2012)
- 7,500 lbs. of Cl^- deposited within 18 km^2 watershed surrounding the Gardens



Effects of Chloride Pollution

- Highly soluble: easily transported into waterbodies
- Toxic to many species of aquatic life
- USEPA chronic value: 230 mg/L
- USEPA acute value: 860 mg/L

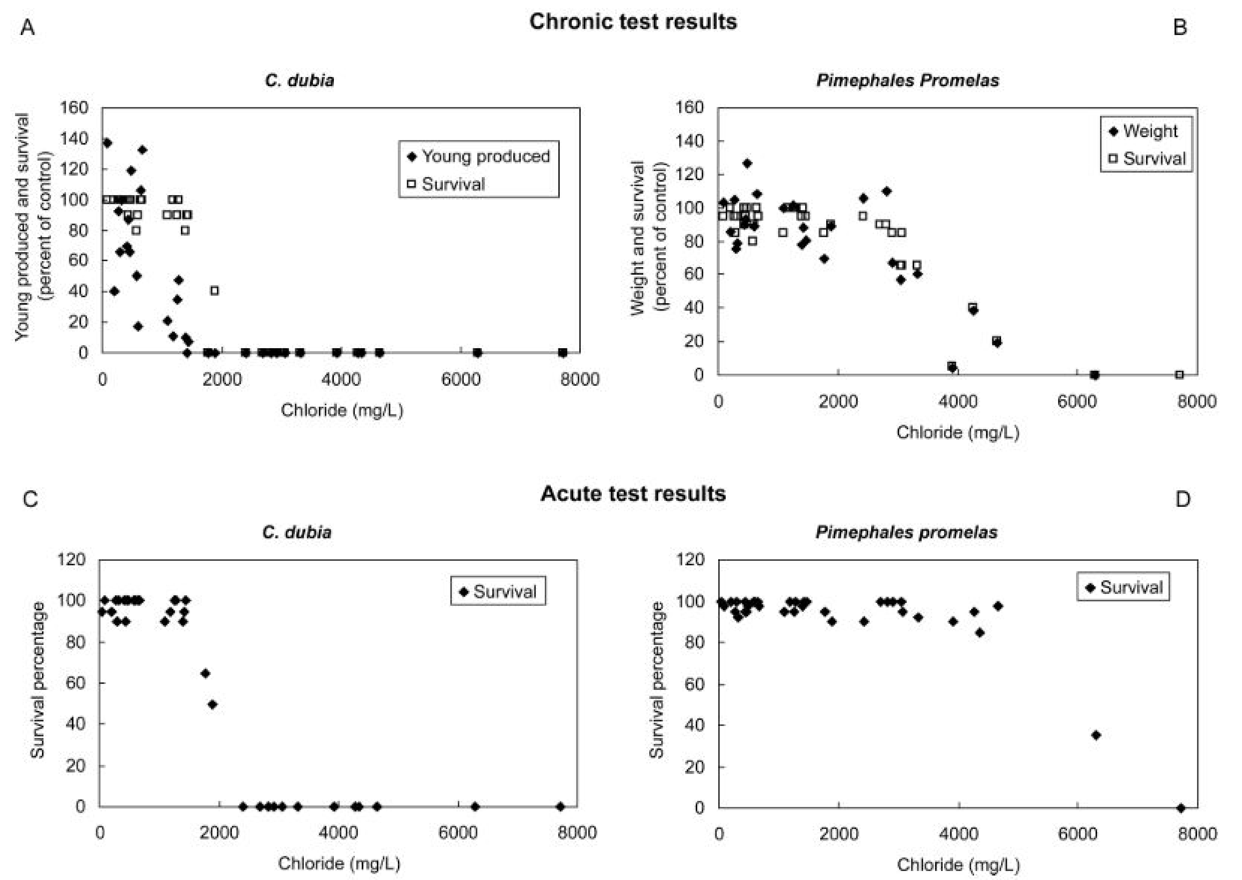


FIGURE 4. Bioassay results in relation to chloride concentration in samples collected from Wilson Park Creek in Milwaukee, Wisconsin, 1997–2007: (A) *C. dubia* survival and mean young produced in chronic bioassays, (B) *P. promelas* survival and mean weight in chronic bioassays, (C) *C. dubia* survival in acute bioassays, and (D) *P. promelas* survival in acute bioassays.

Corsi, et al. 2010

Chloride and Heavy Metals

- Chloride releases heavy metals from sediment

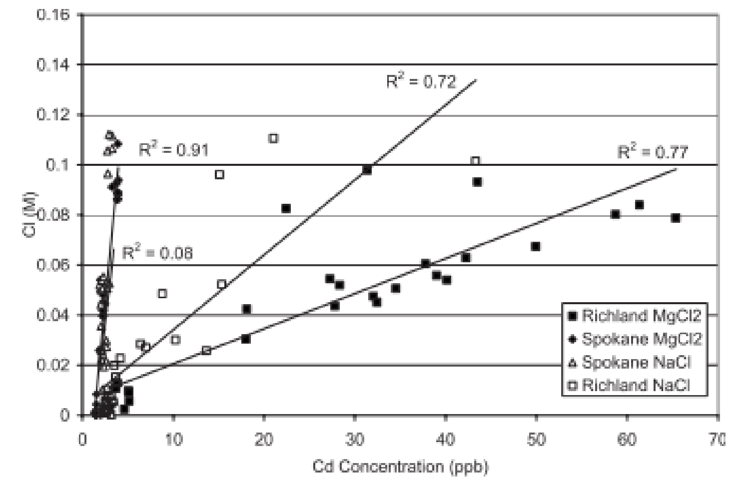


Fig. 9. Correlation of cadmium to chloride in the presence of $MgCl_2$ and NaCl

Nelson et al., 2009

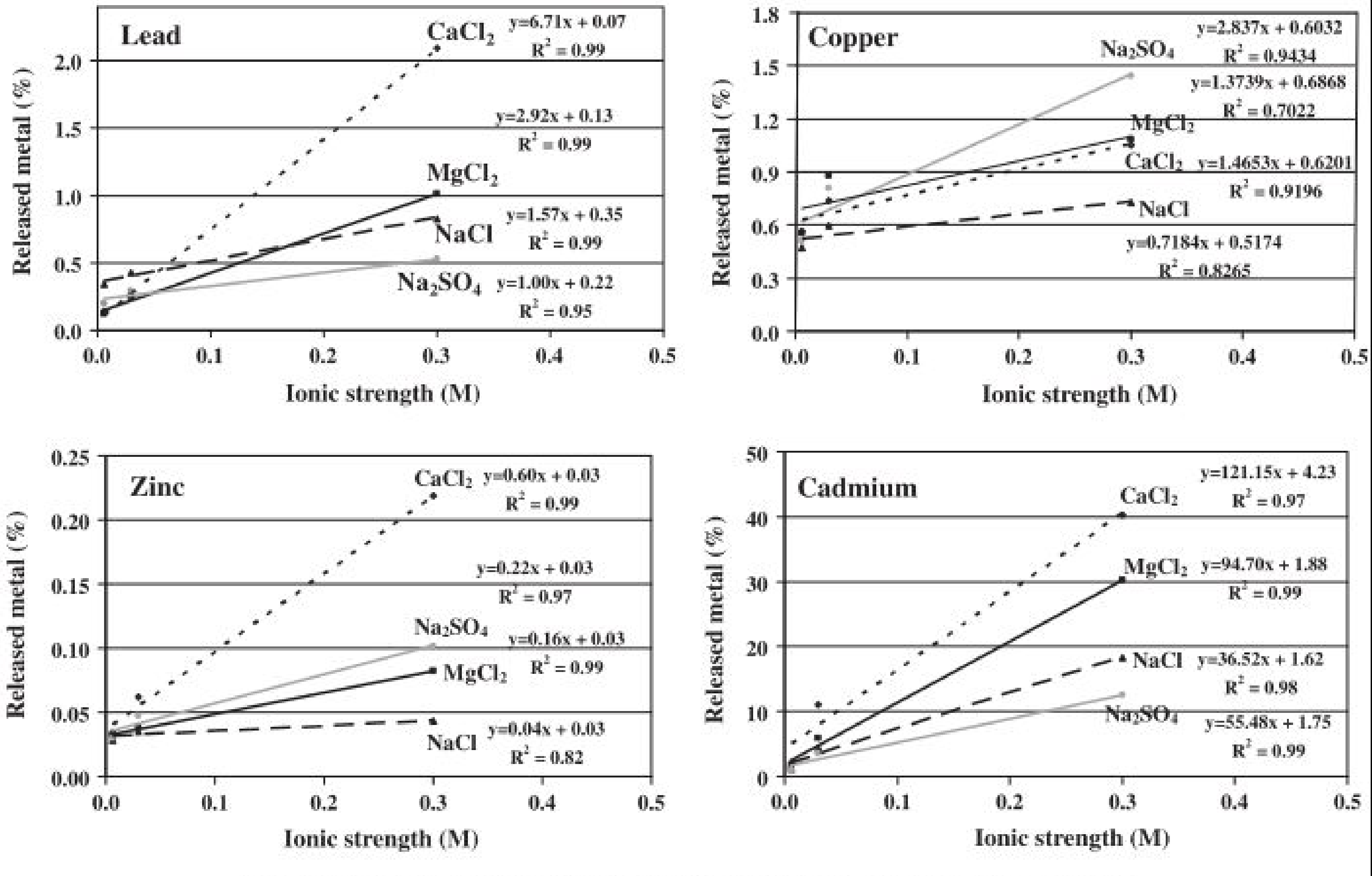


Fig. 3. Effect of salts on metal mobilization, each point is the average of the nine soil samples.

Acosta et al., 2011

Anthropogenic Sources of Heavy Metal Pollution

- Industrial waste
- Road Dust
- Water treatment wastewater
  - Combined Sewage Overflows

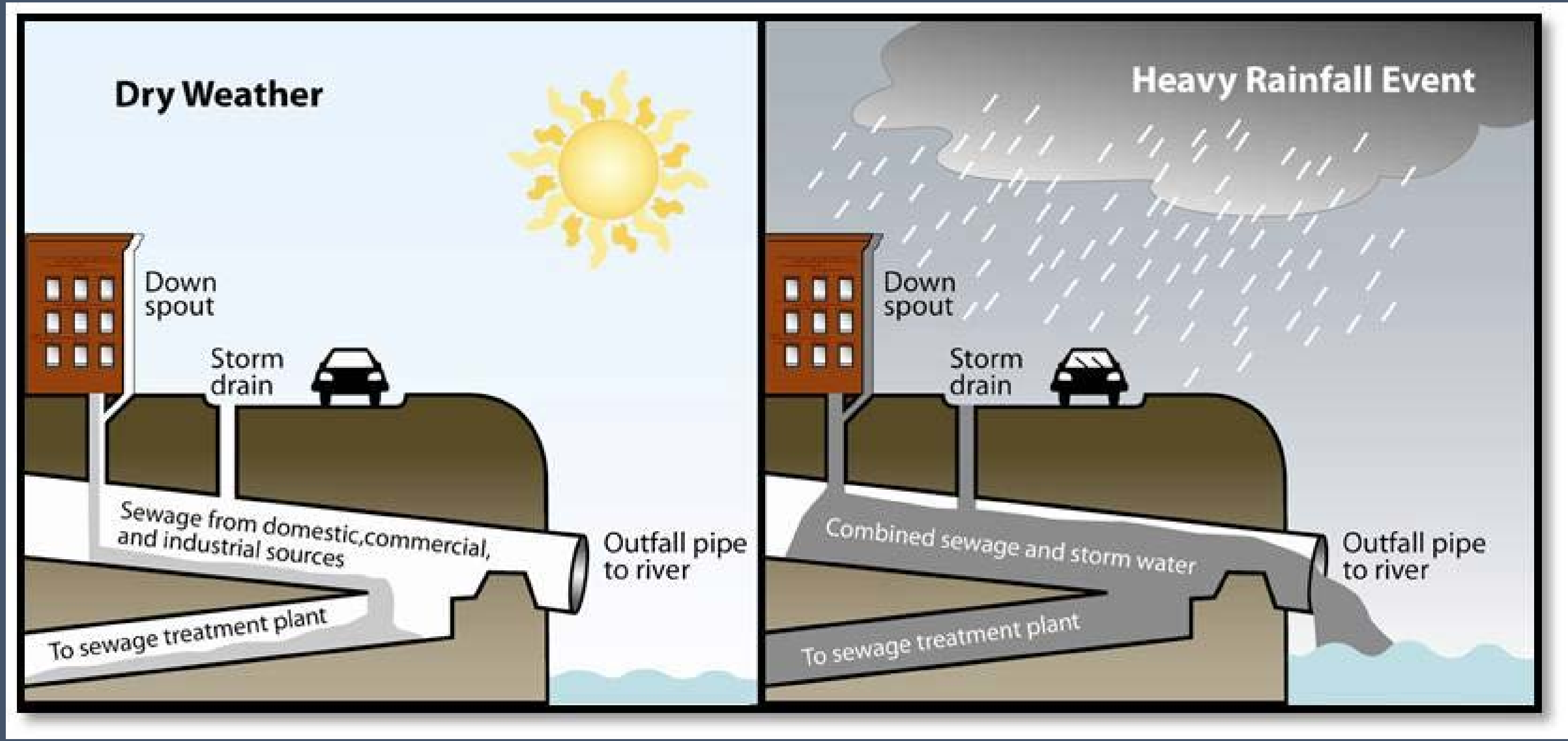
Anthropogenic sources of specific heavy metals in the environment.

Heavy metal	Sources	Reference
As	Pesticides and wood preservatives	Thangavel and Subbhuraam (2004)
Cd	Paints and pigments, plastic stabilizers, electroplating, incineration of cadmium-containing plastics, phosphate fertilizers	Salem et al. (2000); Pulford and Watson (2003)
Cr	Tanneries, steel industries, fly ash	Khan et al. (2007)
Cu	Pesticides, fertilizers	Khan et al. (2007)
Hg	Release from Au–Ag mining and coal combustion, medical waste	Memon et al. (2001), Wuana and Okieimen (2011), and Rodrigues et al. (2012)
Ni	Industrial effluents, kitchen appliances, surgical instruments, steel alloys, automobile batteries	Tariq et al. (2006)
Pb	Aerial emission from combustion of leaded petrol, battery manufacture, herbicides and insecticides	Thangavel and Subbhuraam (2004), Wuana and Okieimen (2011)

Ali et al., 2013

Combined Sewage Overflows (CSOs)

- Manage the mixture of urban runoff and municipal wastewater
- Use one pipe to transport storm water and wastewater
- Four CSO locations on the canal



Akron Waterways Renewed- http://www.akronwaterwaysrenewed.com/about-us/combined-sewer-overflow-cso.aspx

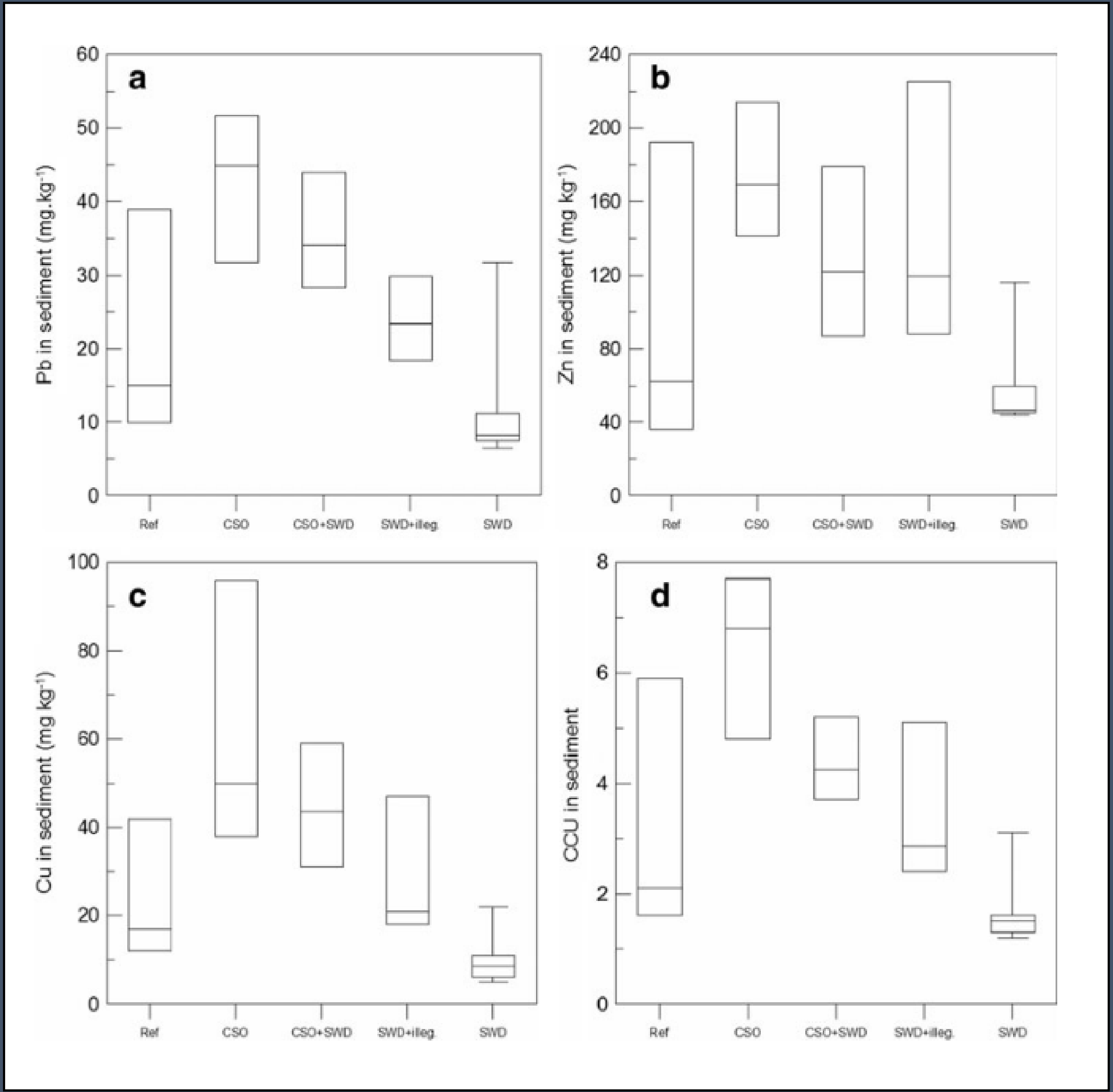
Effects of CSO

- High concentrations of Cu, Zn, and Pb released into streams and rivers

Table 2 Cumulative criterion unit (Clements et al. 2000)

Level	CCU	Impact on biota
Background	<1	No effect
Low	1–2	No risk for biota, although adverse effect may occur
Medium	2–10	Higher mortality of sensitive species, changes in macroinvertebrate diversity
High	>10	Significant decrease of macroinvertebrate diversity

Komínková et al. 2016



Komínková et al. 2016

Effects of Heavy Metal Pollution

- Human life effects:
  - Hair loss (Cr)
  - Brain and kidney damage (Cu)
  - Cancer of the lungs (Ni)
  - Impaired development in children (Pb)

- Marine life affects:
  - Wrinkled cell membrane
  - Cell nucleus damage and shifting
  - Nucleus destruction
  - Anemia or death in fish species

Harmful effects of specific heavy metals on human health.

Heavy metal	Harmful effects	References
As	As (as arsenate) is an analogue of phosphate and thus interferes with essential cellular processes such as oxidative phosphorylation and ATP synthesis	Tripathi et al. (2007)
Cd	Carcinogenic, mutagenic, and teratogenic; endocrine disruptor; interferes with calcium regulation in biological systems; causes renal failure and chronic anemia	Degraeve (1981), Salem et al. (2000), and Awofolu (2005)
Cr	Causes hair loss	Salem et al. (2000)
Cu	Elevated levels have been found to cause brain and kidney damage, liver cirrhosis and chronic anemia, stomach and intestinal irritation	Salem et al. (2000), Wuana and Okieimen (2011)
Hg	Anxiety, autoimmune diseases, depression, difficulty with balance, drowsiness, fatigue, hair loss, insomnia, irritability, memory loss, recurrent infections, restlessness, vision disturbances, tremors, temper outbursts, ulcers and damage to brain, kidney and lungs	Neustadt and Pieczenik (2007), Ainza et al. (2010), and Gulati et al. (2010)
Ni	Allergic dermatitis known as nickel itch; inhalation can cause cancer of the lungs, nose, and sinuses; cancers of the throat and stomach have also been attributed to its inhalation; hematotoxic, immunotoxic, neurotoxic, genotoxic, reproductive toxic, pulmonary toxic, nephrotoxic, and hepatotoxic; causes hair loss	Salem et al. (2000), Khan et al. (2007), Das et al. (2008), Duda-Chodak and Baszczyk (2008), and Mishra et al. (2010)
Pb	Its poisoning causes problems in children such as impaired development, reduced intelligence, loss of short-term memory, learning disabilities and coordination problems; causes renal failure; increased risk for development of cardiovascular disease.	Salem et al. (2000), Padmavathiamma and Li (2007), Wuana and Okieimen (2011) and Iqbal (2012)
Zn	Over dosage can cause dizziness and fatigue.	Hess and Schmid (2002)

Ali et al., 2013

Solution: Floating Gardens

- Successful application on
  - Stormwater (Headley and Tanner, 2007)
  - CSO (Tao et al., 2014)
  - Sewage (Shahid et al. 2018)
  - Acid Mine Drainage (Headley and Tanner, 2007)
  - Water Supply Reservoirs (Garbett, 2007)

Urban Rivers- https://www.kickstarter.com/projects/1996859969/floating-gardens-in-the-chicago-river

Floating Gardens Construction

- Made of four long tubes covered in coconut husk
- Filled with mulch and native Illinois plants

The Mike Nowak Show- https://mikenowak.net/radio/july-16-2017-floating-gardens-trash-talking-pr

Species Name	Common Name
Acorus calamus	Sweet flag
Caltha palustris	Marsh-marigold
Carex bromoides	Brome sedge
Carex comosa	Bristly sedge
Carex stricta	Tussock sedge
Decodon verticillatus	Waterwillow
Filipendula rubra	Queen of the prairie
Hibiscus moscheutos	Rose mallow
Iris virginica var. shrevei	Southern blue flag
Juncus effusus	Common rush
Justicia americana	American water-willow
Rumex altissimus	Pale dock
Saururus cernuus	Lizards tail
Scirpus cyperinus	Woolgrass
Verbena hastata	Blue vervain
Carex comosa	Longhair sedge
Rumex altissmus	Pale dock

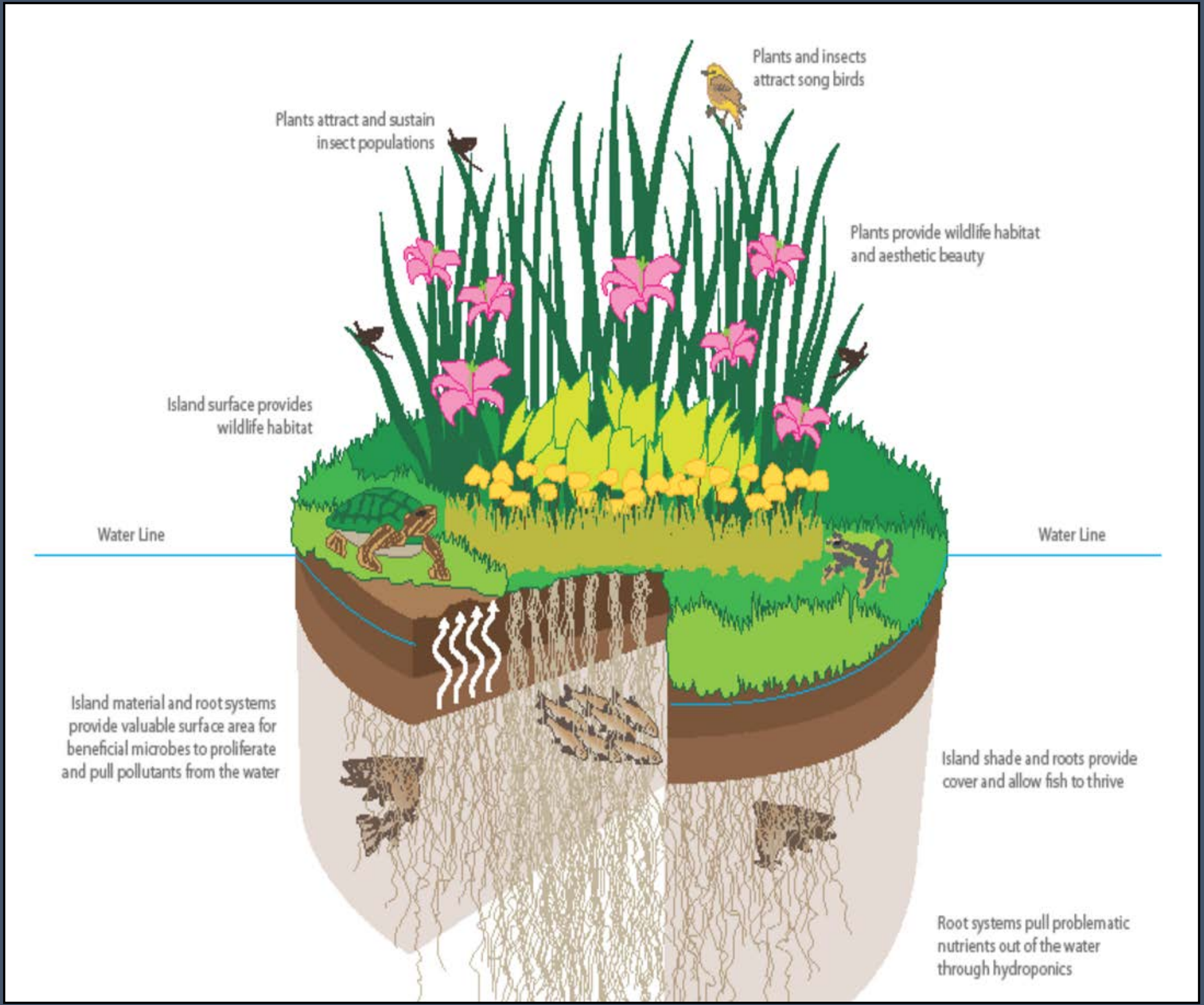
Floating Garden Benefits

- Aesthetically pleasing
- Sanctuary for aquatic organisms
- Plants can thrive off the nutrients in the garden
- Remove nutrients directly from water column

Urban Rivers- https://twitter.com/UrbanRiv/status/1040447671427903488

Urban Rivers- https://www.kickstarter.com/projects/1996859969/floating-gardens-in-the-chicago-river/posts/2400379

How do floating gardens work?



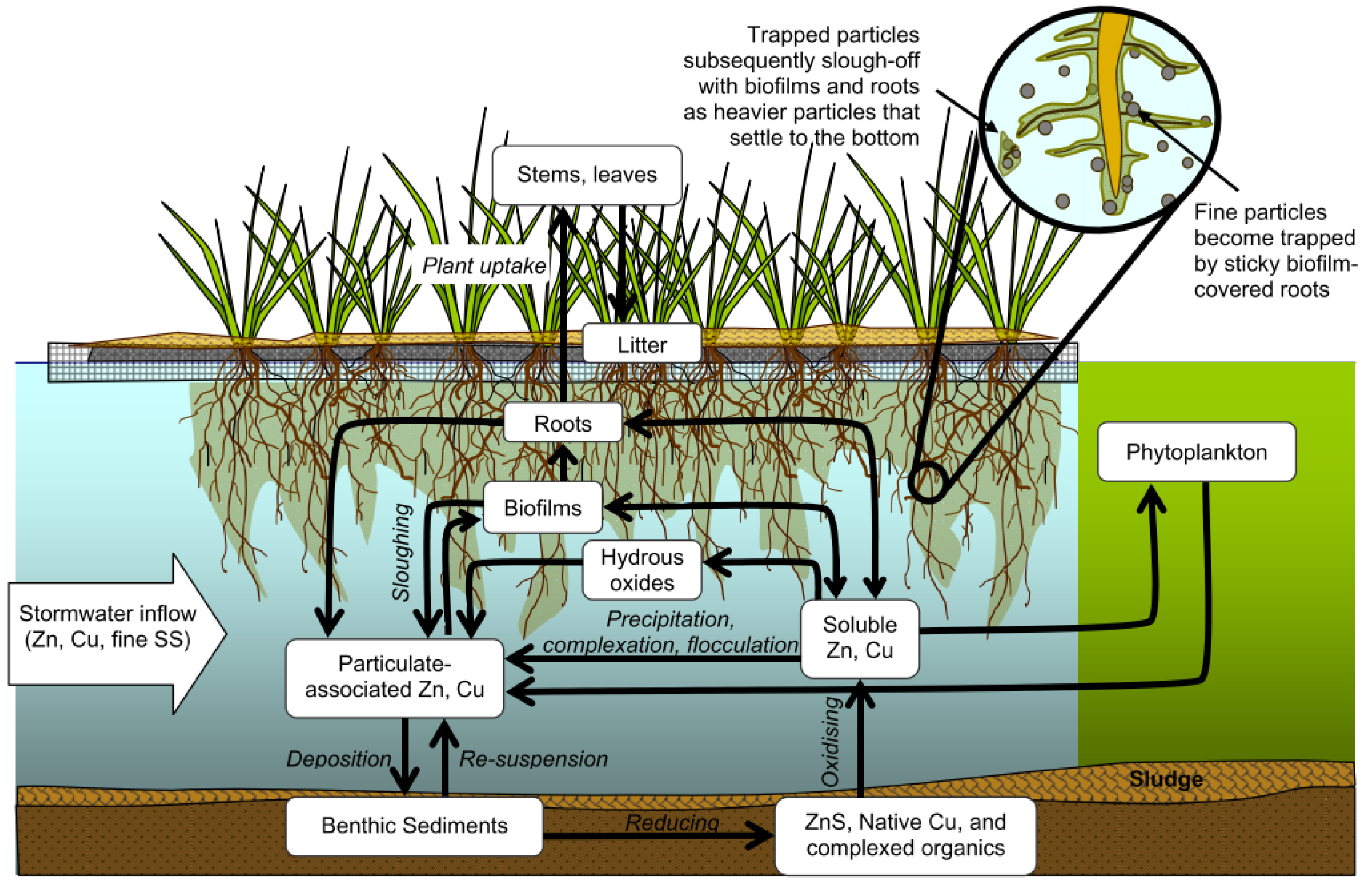
Floating Islands International- http://www.floatingislandinternational.com/technology/

Urban Rivers- https://www.urbanriv.org/

Heavy Metal Removal

- Capture of fine suspended particulates
- Sinking of heavier particles
- Deposition of sediments and immobilization
- Biologic processes

Conceptual model of copper and zinc pathways and interactions within a floating wetland stormwater treatment system.



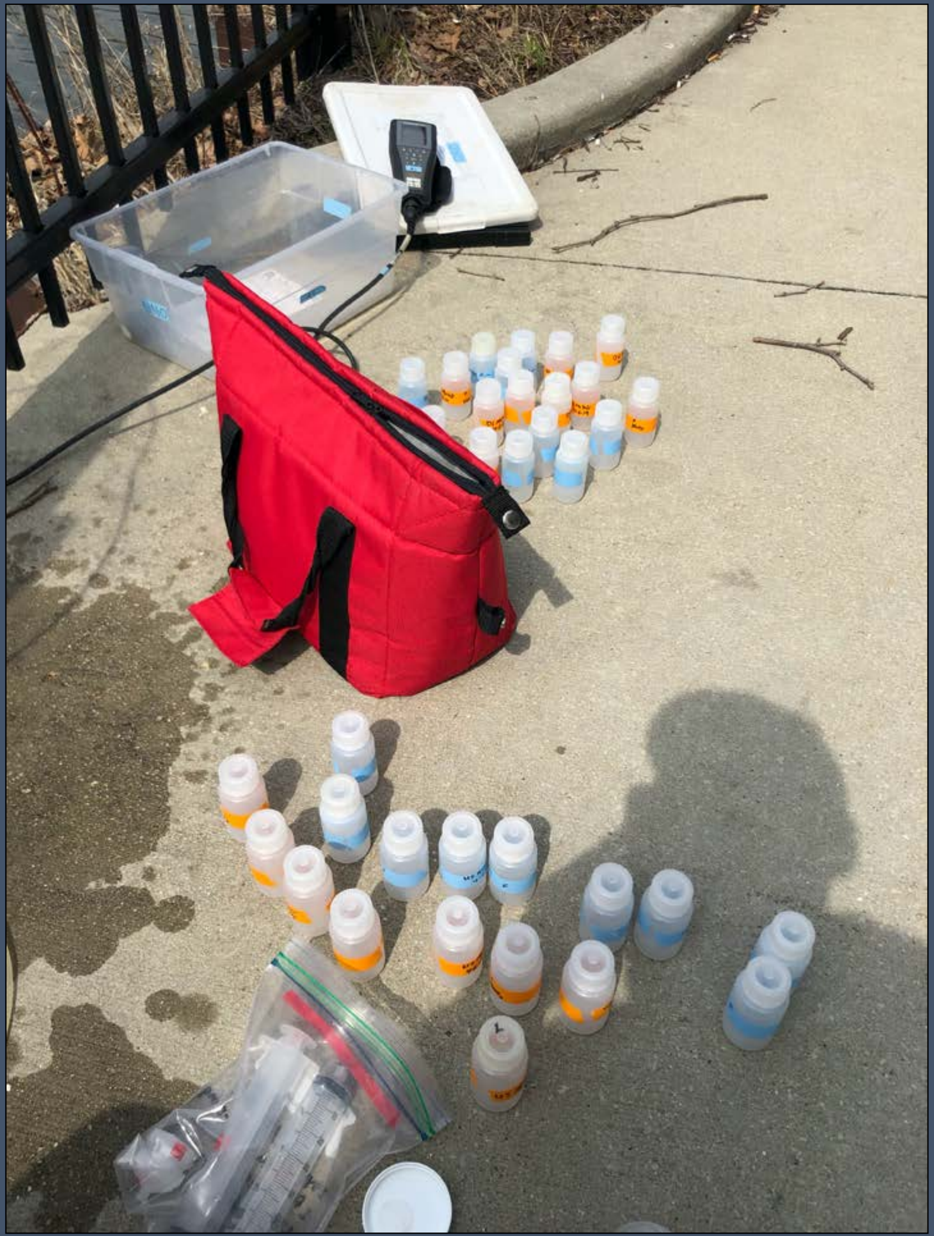
Headely and Tanner, 2006

Research Questions and Hypotheses

- Research Question:
  - Do floating gardens alter the heavy metal concentrations of the river water?
- Hypotheses

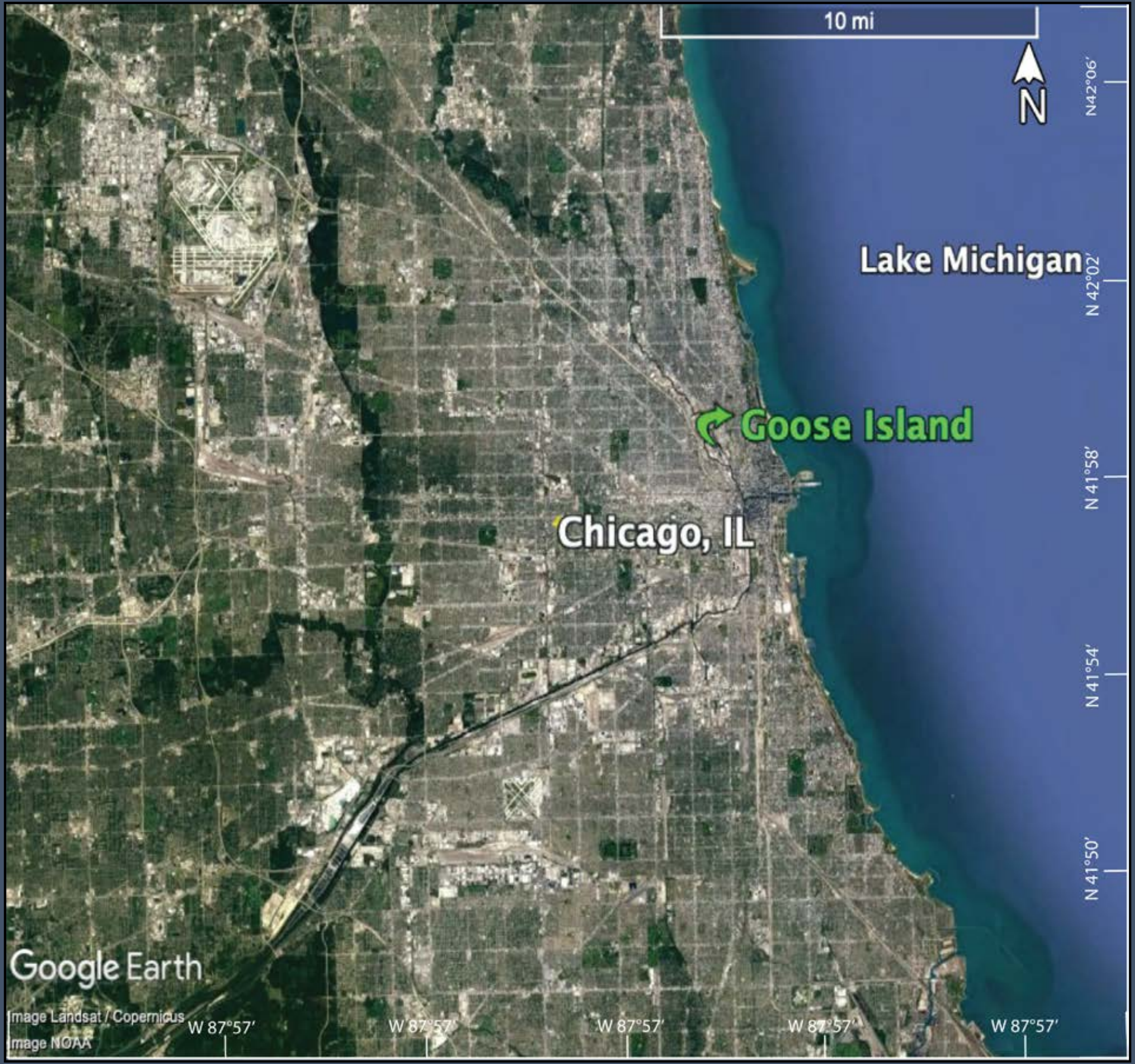
1) Heavy metal concentrations (Al, As, Be, Cd, Cr, Cu, Pb, Mn, Se, and Zn) of the waters upstream from the floating gardens will be higher than the concentrations downstream.

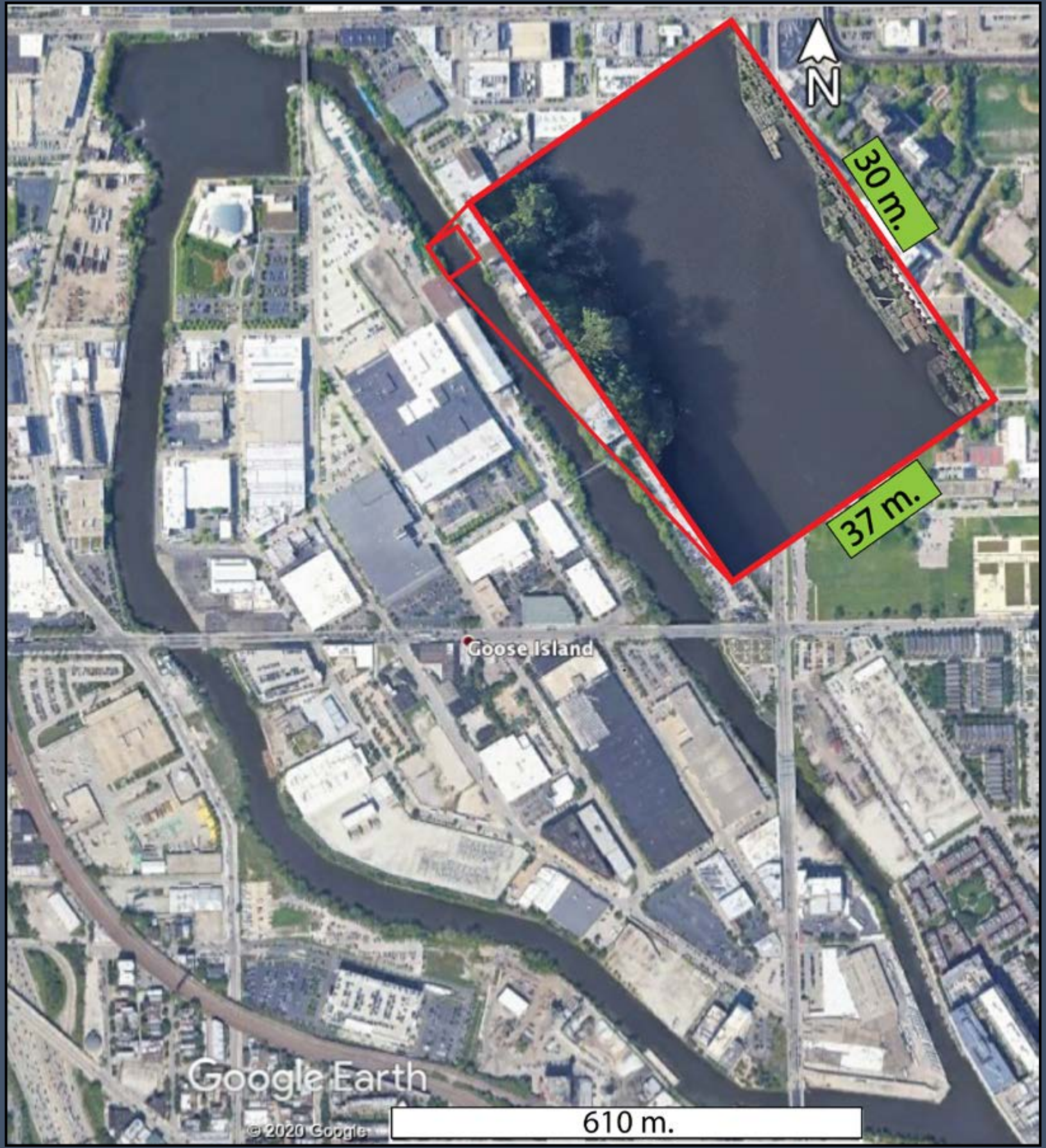
2) The floating gardens will alter the metal concentrations more during the growing season than during the dormant season.



Methods

Floating Gardens Study Area





Water Sampling

- Surface water grab samples were drawn from the river upstream and downstream during the growing and dormant seasons
- During each season, five sampling events took place, each consisting of four sets of 10 water samples.
- 10 samples were collected to analyze for heavy metals and 10 samples were collected to analyze for anions for each upstream and downstream event
- YSI Sonde measured in-situ temperature (°C), dissolved oxygen (mg/l), and pH.


7/6/19
7/8/19
7/30/19
8/5/19
8/13/19
10/24/19
11/5/19
11/7/19
11/16/19
11/19/19

Chemical Analysis

- Heavy metals: PerkinElmer Optima 8300 Inductively Coupled Plasma Optical Emission Spectrometer

- Anions: Dionex ICS-1100 Ion Chromatograph

Data Analysis

- The data were separated by element (As, Cd, Cl, Cr, Cu, Fe, Pb, Mn, Se, Zn) for each season
- Non-normal distribution of the heavy metal and chloride samples determined by a Shapiro-Wilks test
  - Upstream vs. downstream concentrations were tested using a non-parametric Mann Whitney Rank Sum Test with $\alpha = 0.05$ to assess any statistical differences for each pair (upstream vs. downstream)
- Paired t-tests ($\alpha = 0.05$) were used to assess any statistical differences for each pair (upstream vs. downstream) of DO, ph, and temperature

Results and Discussion

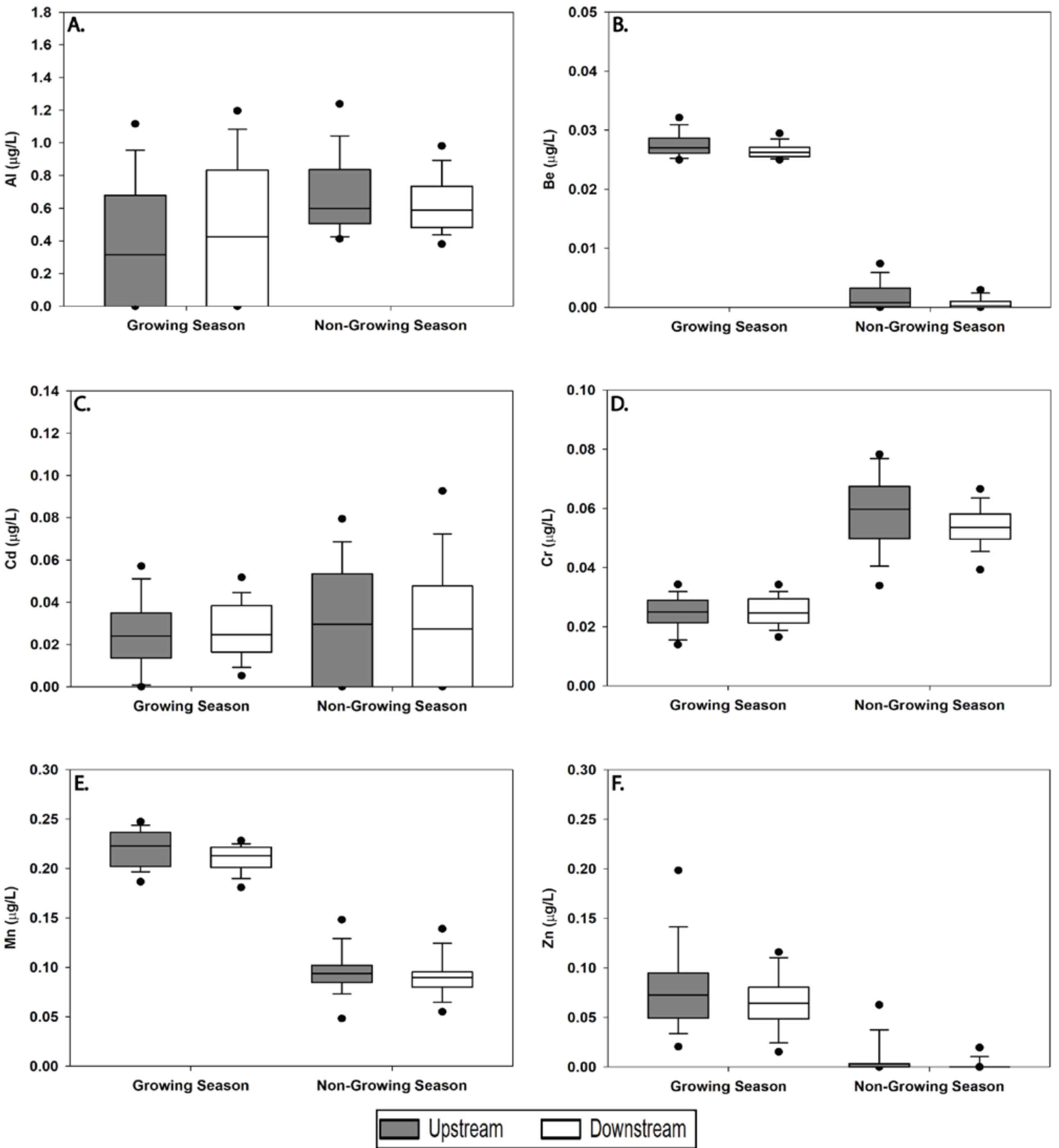
Heavy Metals: Upstream vs. Downstream

- Presence of Al, Be, Cd, Cr, Mn, and Zn
- Absence of As, Cu, Se, and Pb

Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*p*
Al	Upstream	50	0.31	0.679	50	0.60	0.368
	Downstream	50	0.42		50	0.59	
Be	Upstream	50	0.027	0.015	50	0.00077	0.017
	Downstream	50	0.026		50	0.00024	
Cd	Upstream	50	0.024	0.459	50	0.030	0.566
	Downstream	50	0.025		50	0.027	
Cr	Upstream	50	0.025	0.915	50	0.06	0.021
	Downstream	50	0.025		50	0.054	
Mn	Upstream	50	0.22	0.007	50	0.094	0.093
	Downstream	50	0.21		5	0.090	

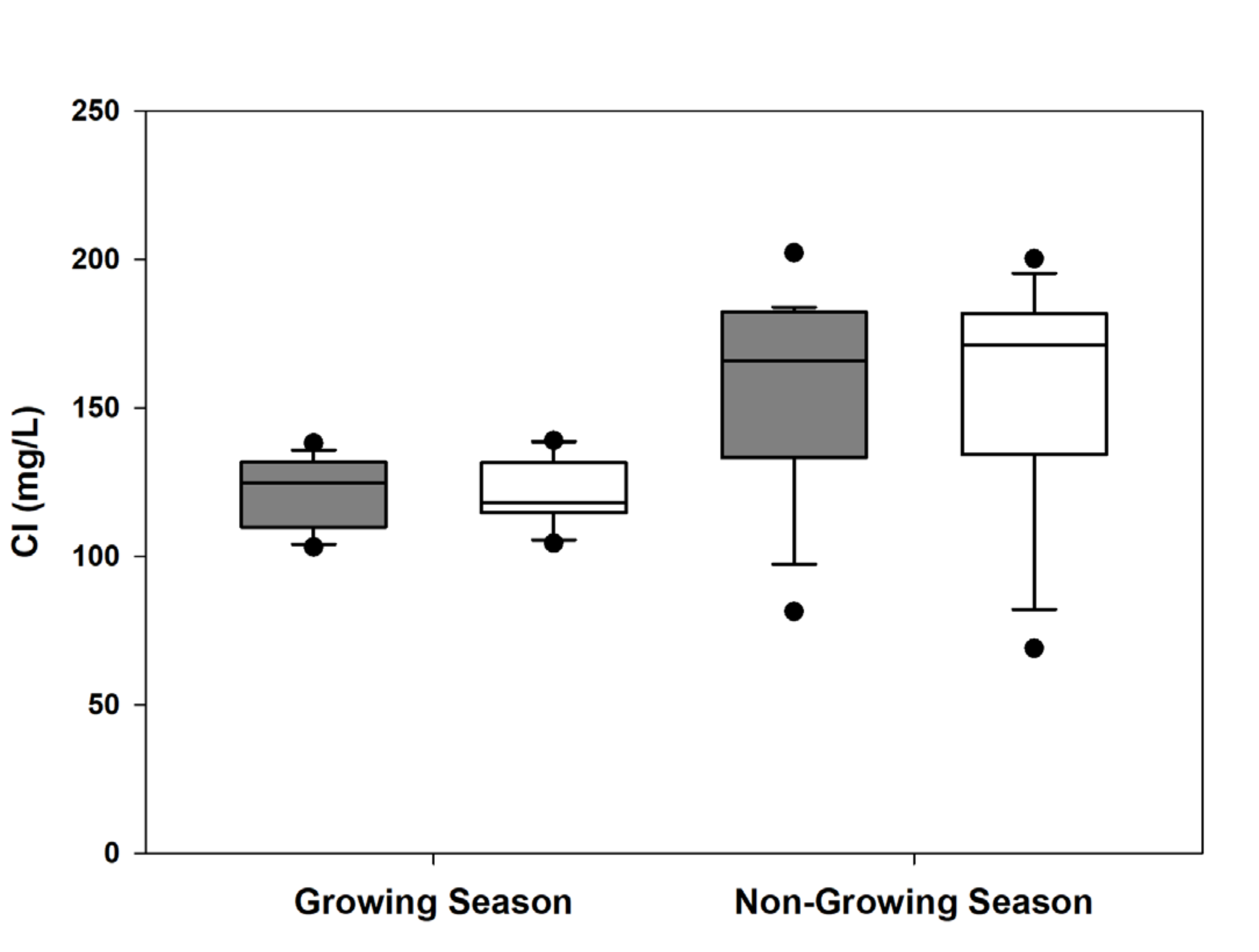
Heavy Metals

- Be and Mn displayed significant changes in the median concentrations upstream to downstream



Chloride

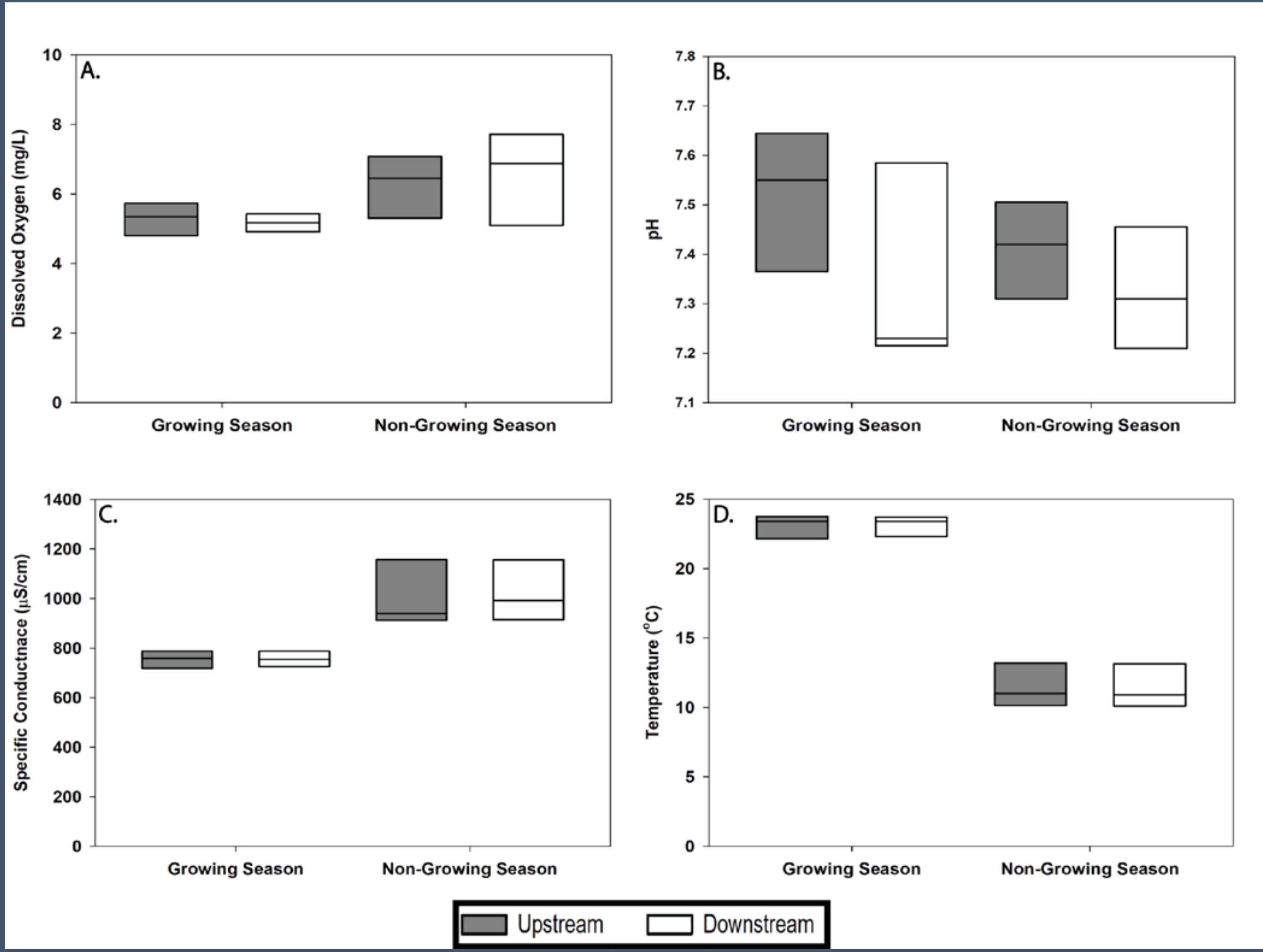
- Similar concentrations upstream vs. downstream for both seasons



Species	Location	Growing Season			Dormant Season		
		n	Median (mg/L)	*p*	n	Median (mg/L)	*p*
Cl	Upstream	50	124.828	0.839	50	165.839	0.493
	Downstream	50	117.943		50	171.227	

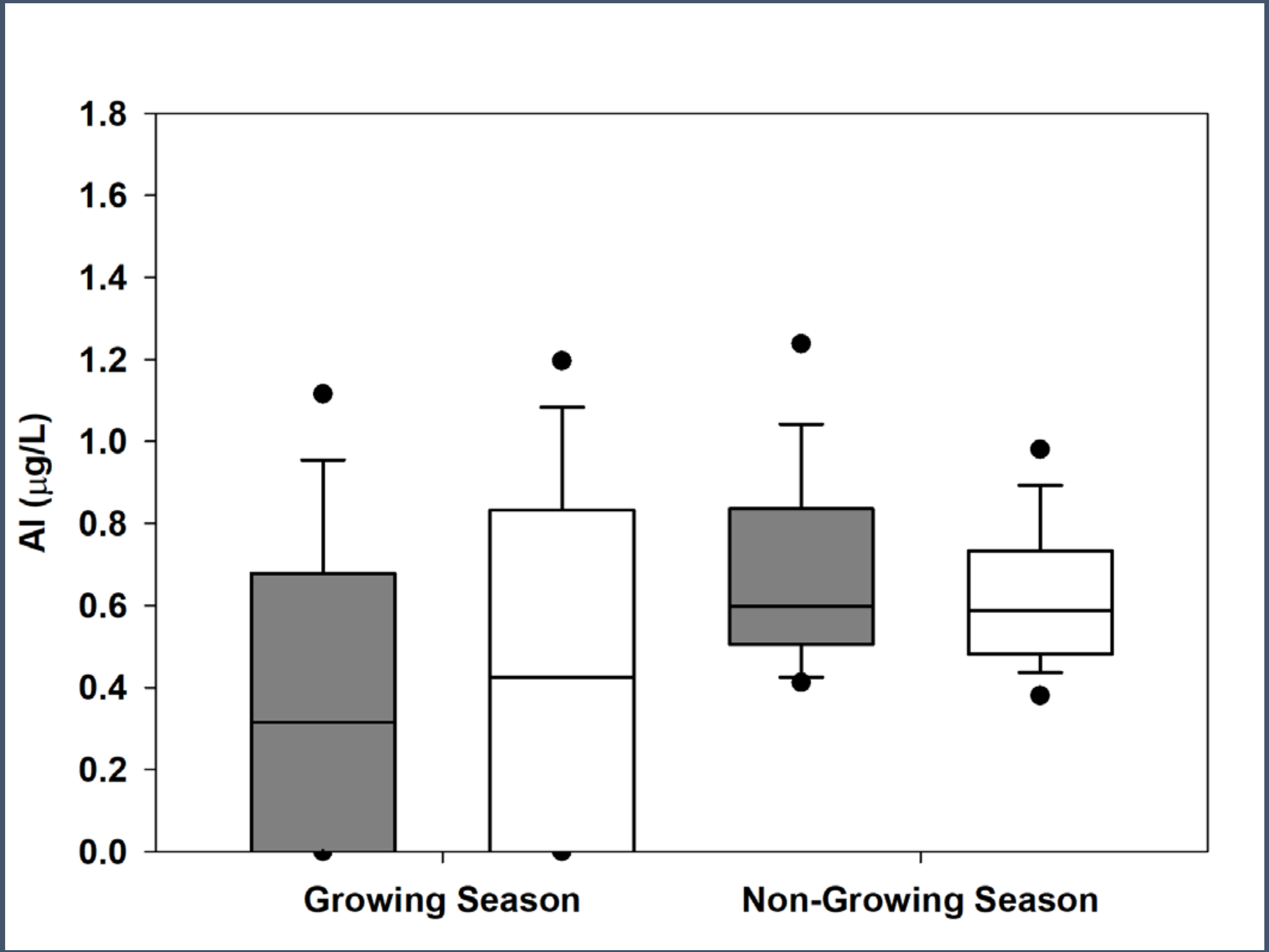
Other Parameters: Upstream vs. Downstream

Species	Location	Growing Season			Dormant Season		
		n	Mean	*p*	n	Mean	*p*
DO (mg/L)	Upstream	5	5.278	0.634	5	6.242	0.381
	Downstream	5	5.168		5	6.498	
pH	Upstream	5	7.514	0.215	5	7.14	0.41
	Downstream	5	7.366		5	7.328	
Temp. (°C)	Upstream	5	23.04	0.477	5	11	0.25
	Downstream	5	23.08		5	10.9	



Aluminum

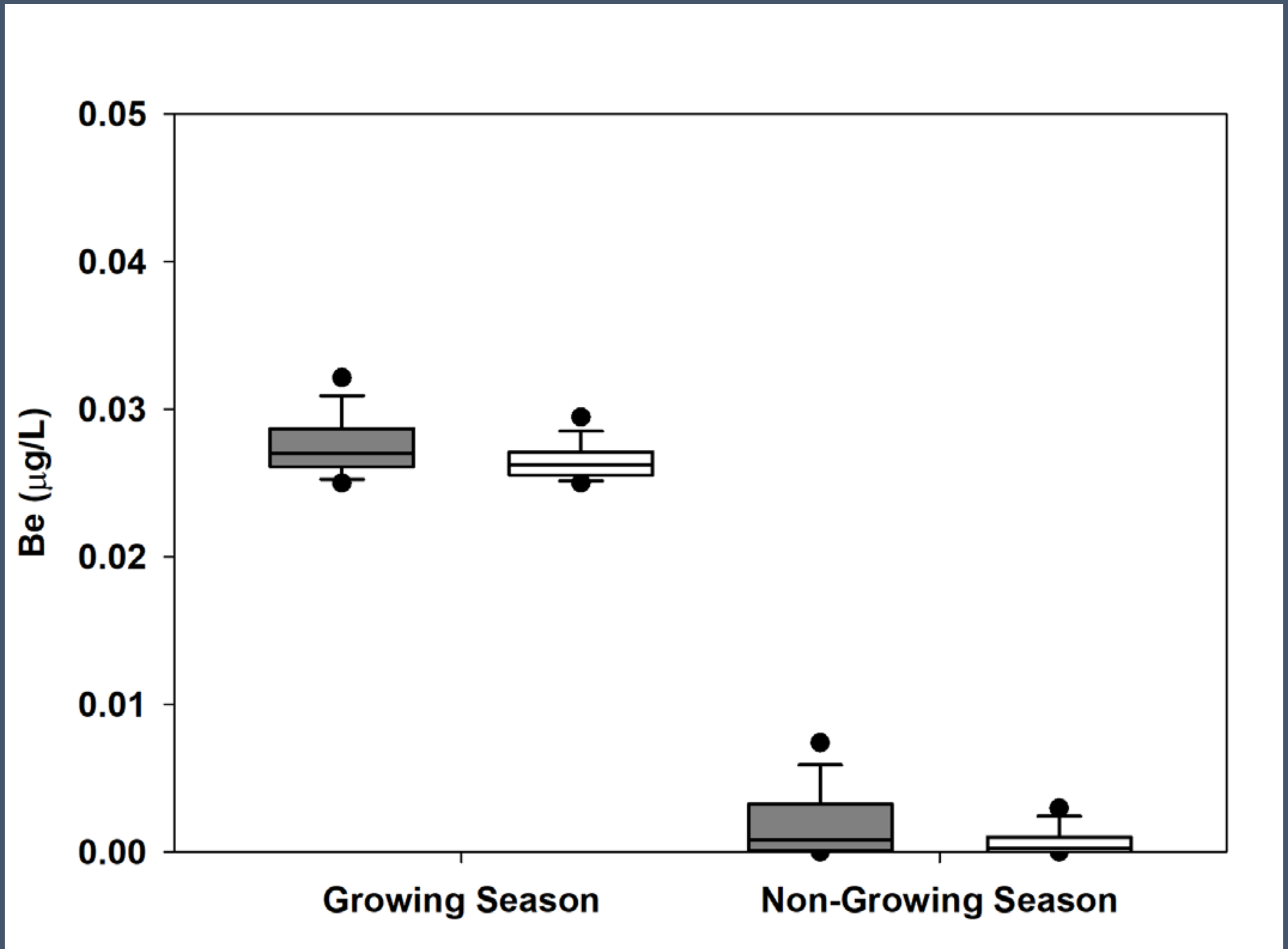
- At a near-neutral pH, dissolved Al concentrations typically range from 1 µg/L to 50 µg/L (WHO, 2010)
- At pH > 6 like that of the study site, Al solubility is low and precipitates onto sediments and substrates (Adriano, 1986)



Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*P*
Al	Upstream	50	0.31	0.679	50	0.60	0.368
	Downstream	50	0.42		50	0.59	

Beryllium

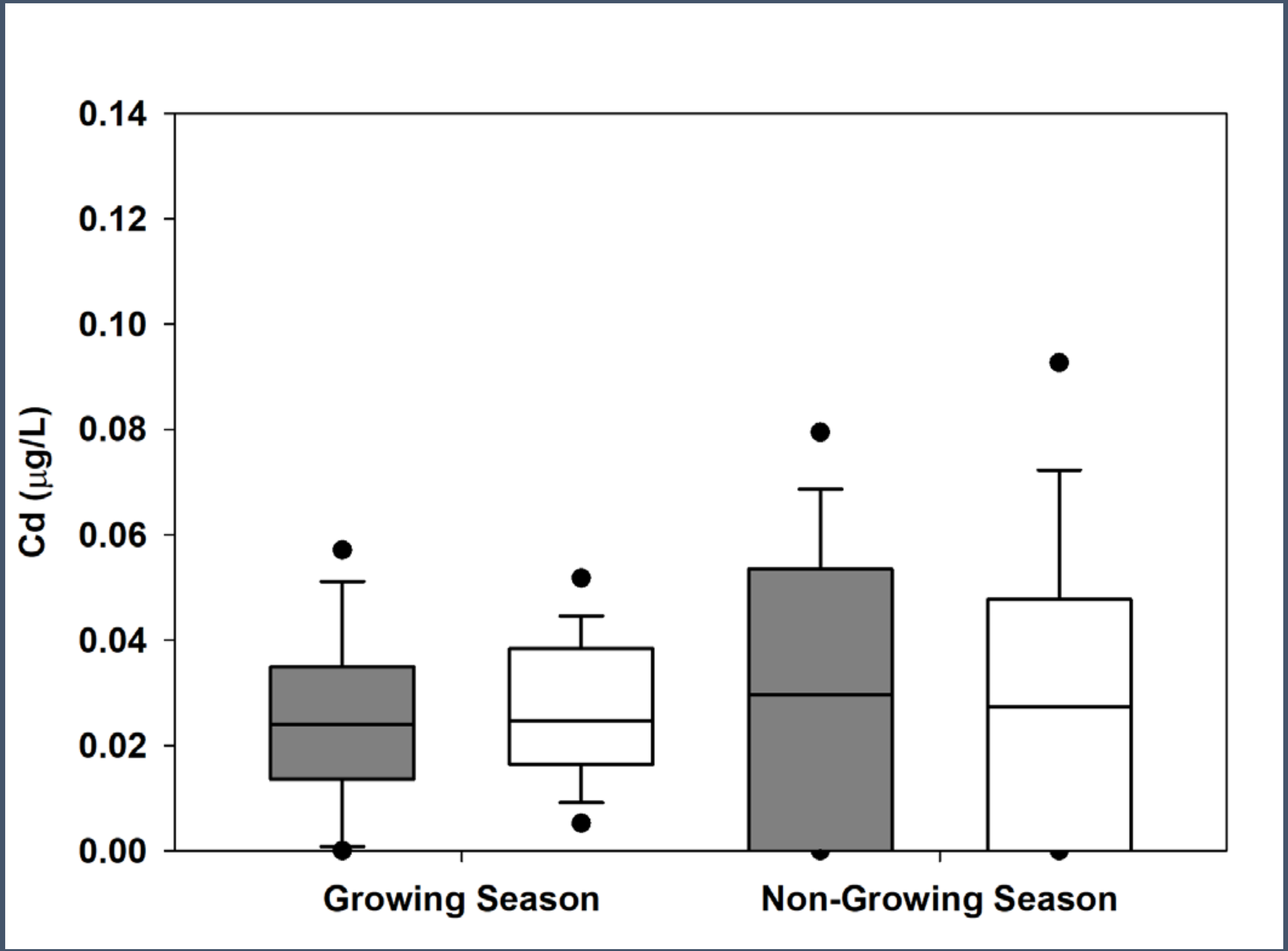
- In the surface water of the Great Lakes, concentrations ranged from less than 0.004 µg./L. to 0.12 µg/L (WHO, 2014)
- Sajwan et al. (2003) found that beryllium readily absorbs via cation exchange in the roots of hydroponic soybean plants



Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*p*
Be	Upstream	50	0.027	0.015	50	0.00077	0.017
	Downstream	50	0.026		50	0.00024	

Cadmium

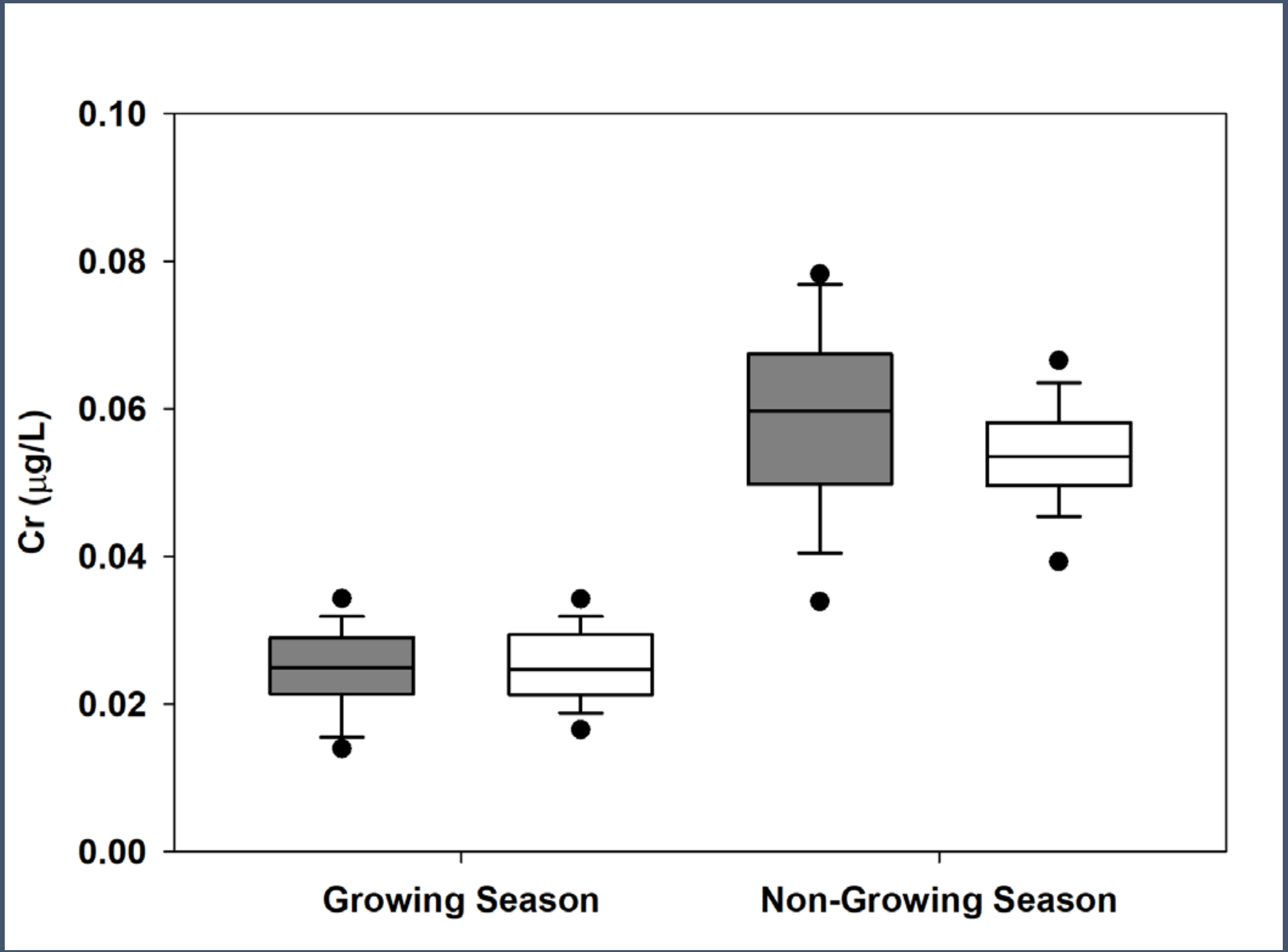
- Cd concentrations are commonly below 1 µg/L and median concentrations of 110 stations detected < 1 µg/L of Cd in waters (WHO, 2011)
- Under field conditions, plants take up only small amounts of Cd. Adriano (1986) found that the uptake of Cd by plants on soils treated with sewage sludge was less than 1%



Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*p*
Cd	Upstream	50	0.024	0.459	50	0.030	0.566
	Downstream	50	0.025		50	0.027	

Chromium

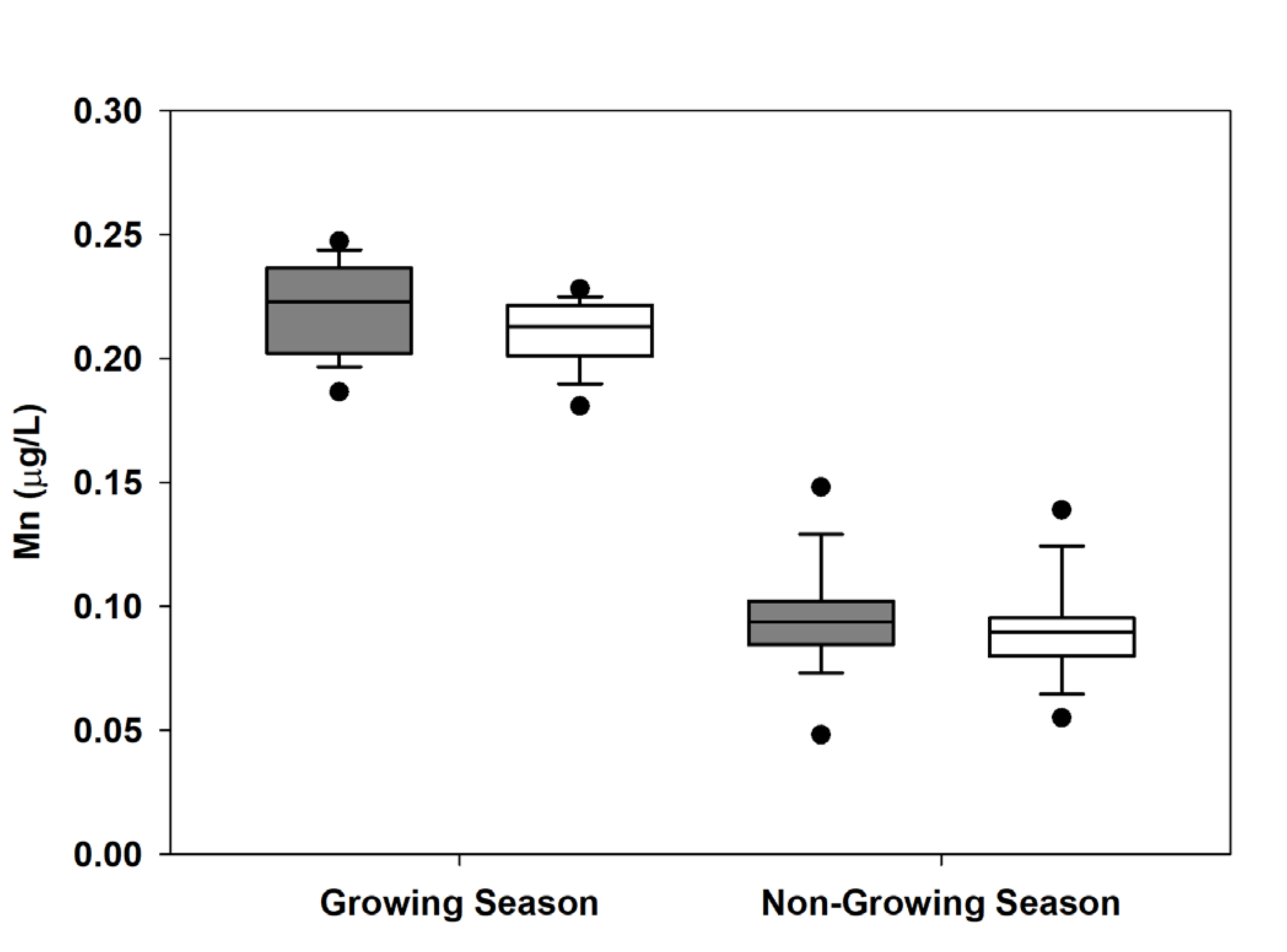
- The average Cr in surface waters is 0.5 µg/L to 2 µg/L with dissolved Cr concentrations ranging from 0.02 µg/L to 0.3 µg/L(WHO, 2011)
- Field conditions do not indicate high levels of Cr uptake (Adriano, 1986)



Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*p*
Cr	Upstream	50	0.025	0.915	50	0.06	0.021
	Downstream	50	0.025		50	0.054	

Manganese

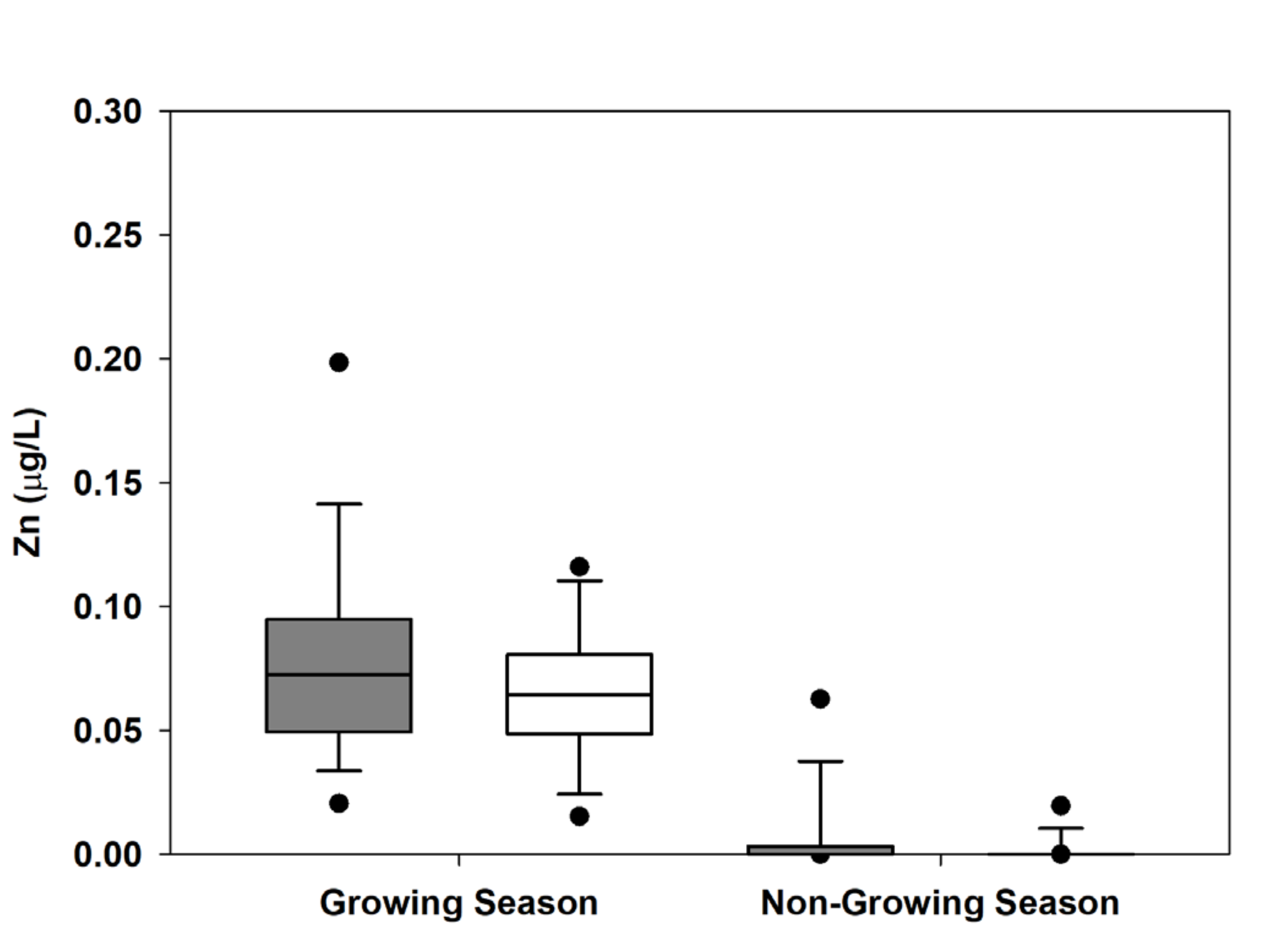
- In river water, levels of Mn typically range from 1 µg/L to 2 mg/L with median concentrations of around 16 µg/L (WHO, 2011)
- In the summer and winter months, monoculture wetland systems may have 99% removal of Mn (Marchand et al., 2010)



Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*p*
Mn	Upstream	50	0.22	< 0.01	50	0.094	0.093
	Downstream	50	0.21		50	0.090	

Zinc

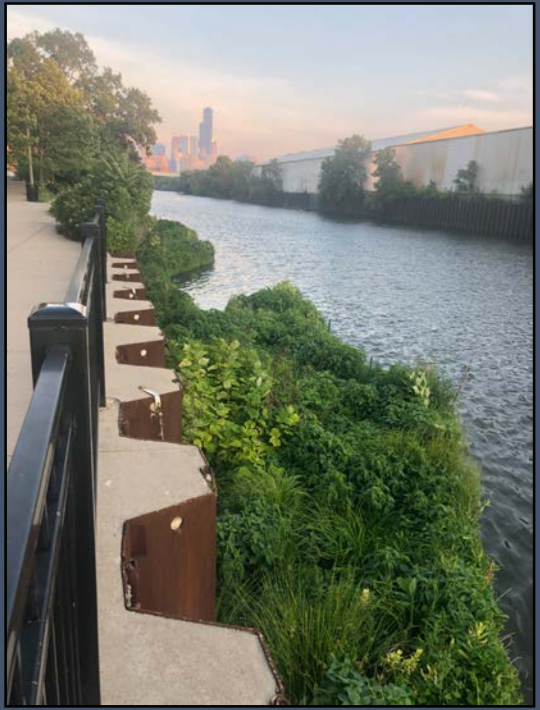
- Zn concentrations are typically below 10 µg/L with some concentrations reaching up to 1.0 mg/L (WHO, 2003)
- Monoculture wetland systems can have removal rates of 34% to 100% for Zn (Marchand et al., 2010).

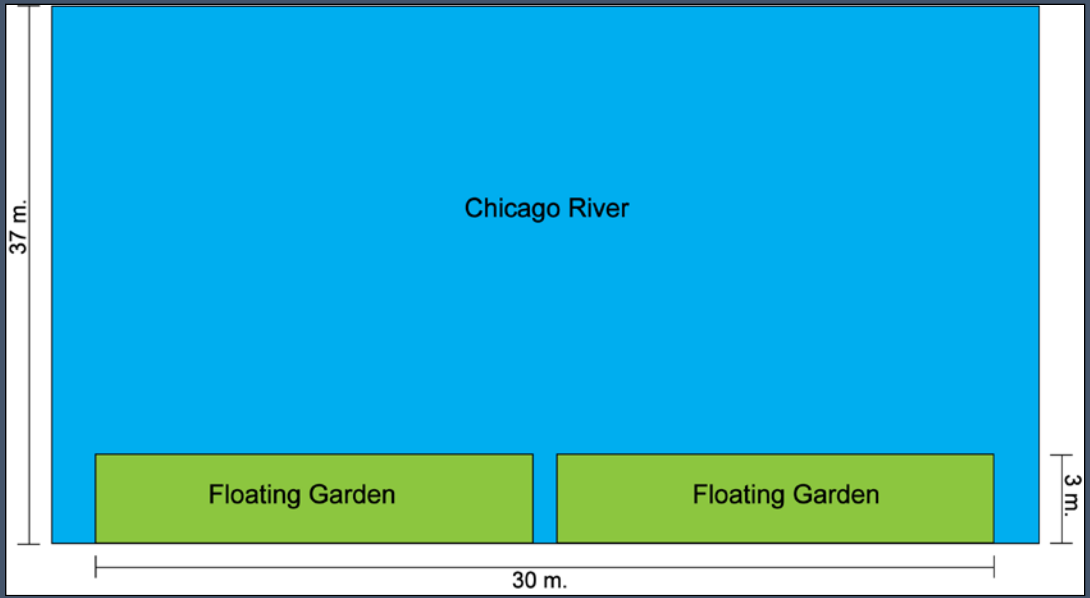


Species	Location	Growing Season			Dormant Season		
		n	Median (µg/L)	*p*	n	Median (µg/L)	*p*
Zn	Upstream	50	0.073	0.165	50	0	0.016
	Downstream	50	0.064		50	0	

Study Limitations

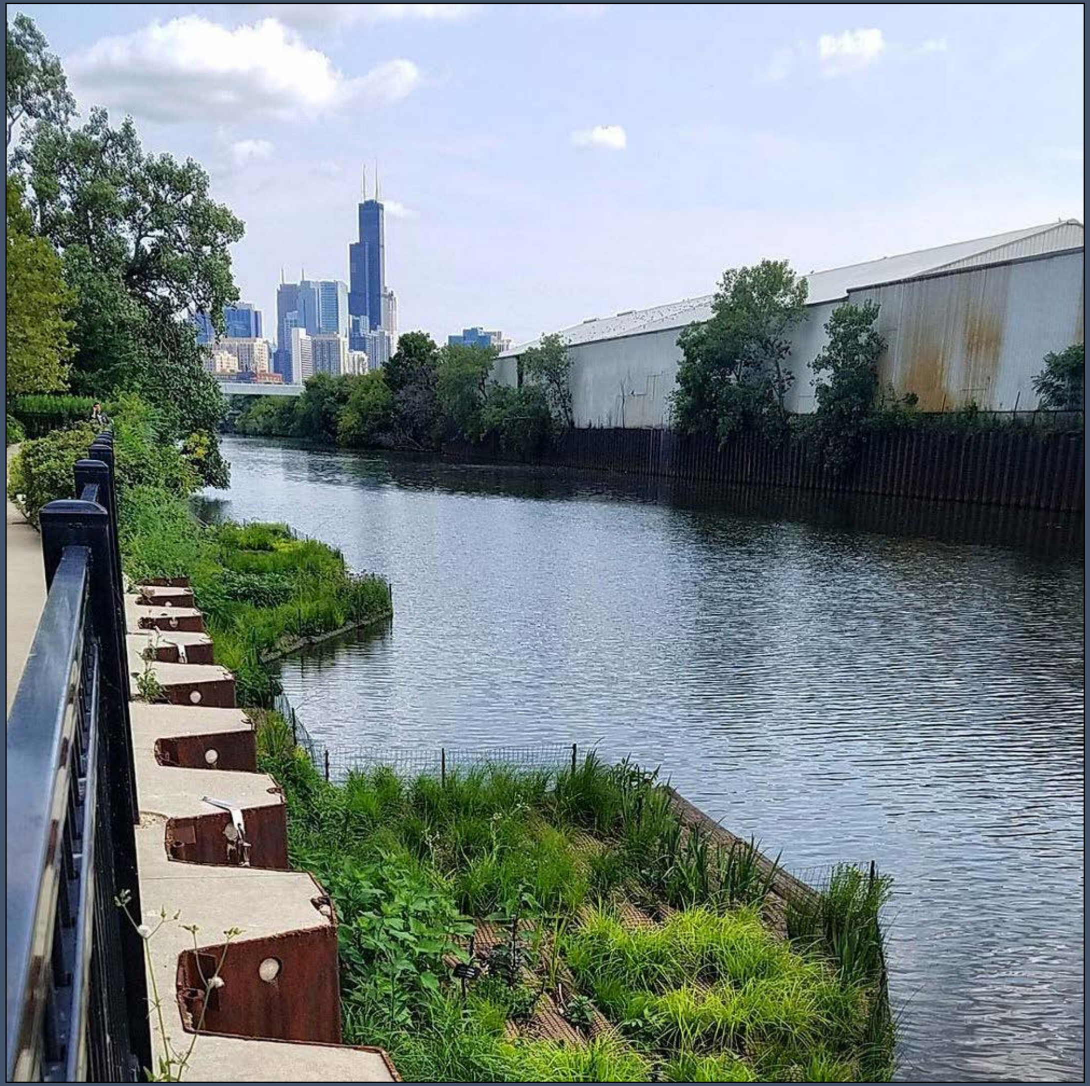
- Size of the gardens compared to the size of the Chicago River
- By only collecting surface water samples and not collecting plant samples it is likely that additional processes were not detected
- Lack of a controlled environment





Conclusions

- Be reduction during the growing and dormant season
- Mn reduction during only the growing season
- Gardens were not effective in reducing the concentrations of Al, Cd, Cr, Se, or Zn.
- The removal rates of Be and Mn are on the nanogram scale, leading to a statistically significant but not necessarily environmentally significant differences.
- Growing season: greater concentrations of metals were detected in the water column for Be, Mn, and Zn
- Dormant season: greater concentrations were detected for Al, Cd, and Cr.



Climate Culture- https://www.climateculture.co/2018/08/river-innovation/

Thank you to:

- Dr. Peterson, Dr. Perry, Dr. O'Reilly, Dr. Hamaker, and Dr. Thayn at Illinois State University
- Jack Wang and Tony Ludwig for all the help in chemical analysis
- Phil Nicodemus of Urban Rivers for allowing us to access the field site and for providing additional insight into the gardens
- Payton Shlemon for her help in field work and sample collection

Questions?

References

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