Long-term Trends in Dissolved Oxygen, Nutrients and Primary Production at Lake of the Woods

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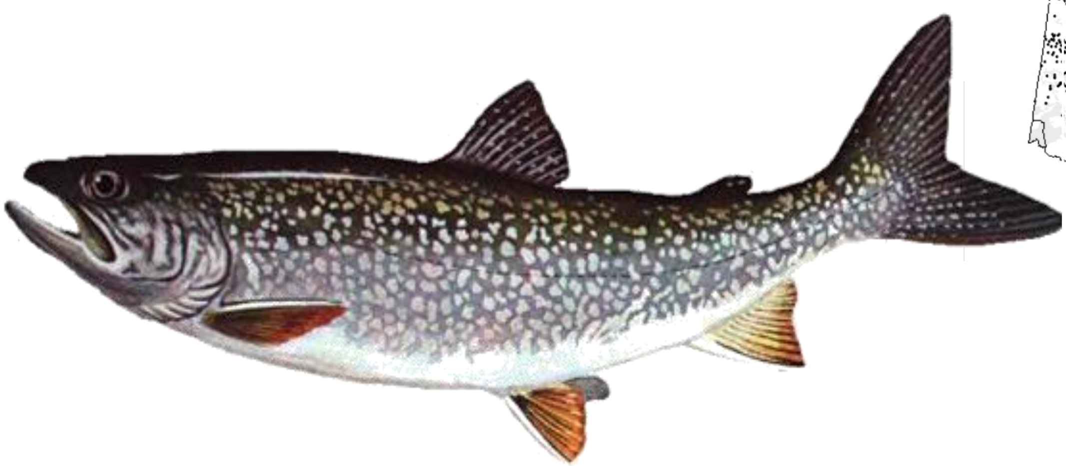
Lake Trout

Lake Trout lakes are relatively rare – only 1% of Ontario lakes

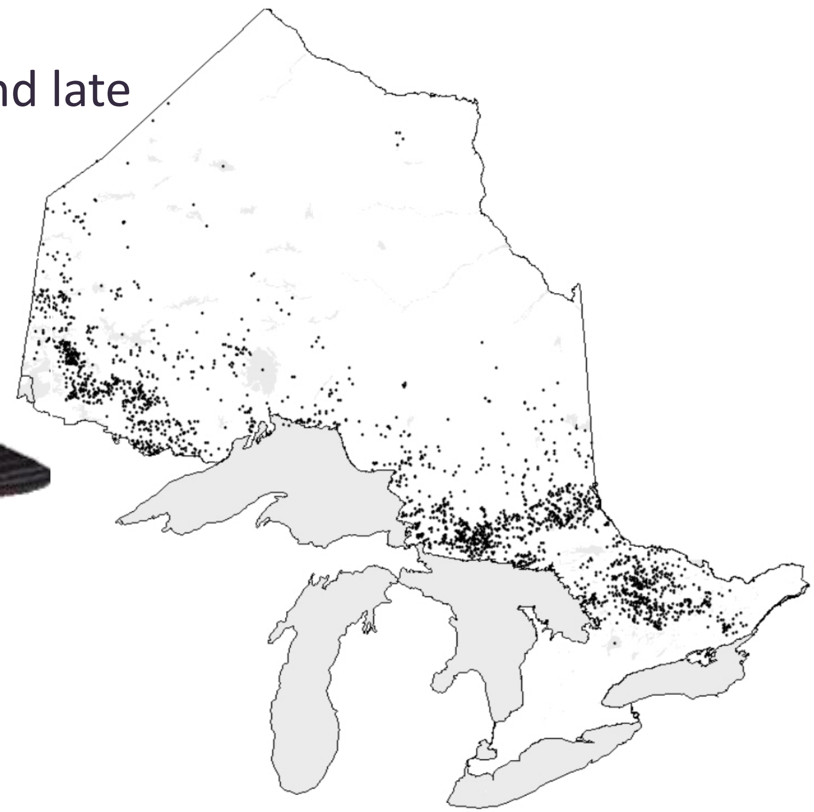
- This represents 20-25% of all Lake Trout lakes worldwide

Good ecological indicator

- Large bodied (30-80 cm in length) and late maturing (5-10 yrs)
- Specific habitat requirements for



Lake Trout *(Salvelinus namaycush)*



(OMNRF 2006)
(Photo http://www.hookhack.com/html/fom020113_laketrout.html)

Lake of the Woods

Lake Trout are present in many northern LOW bays

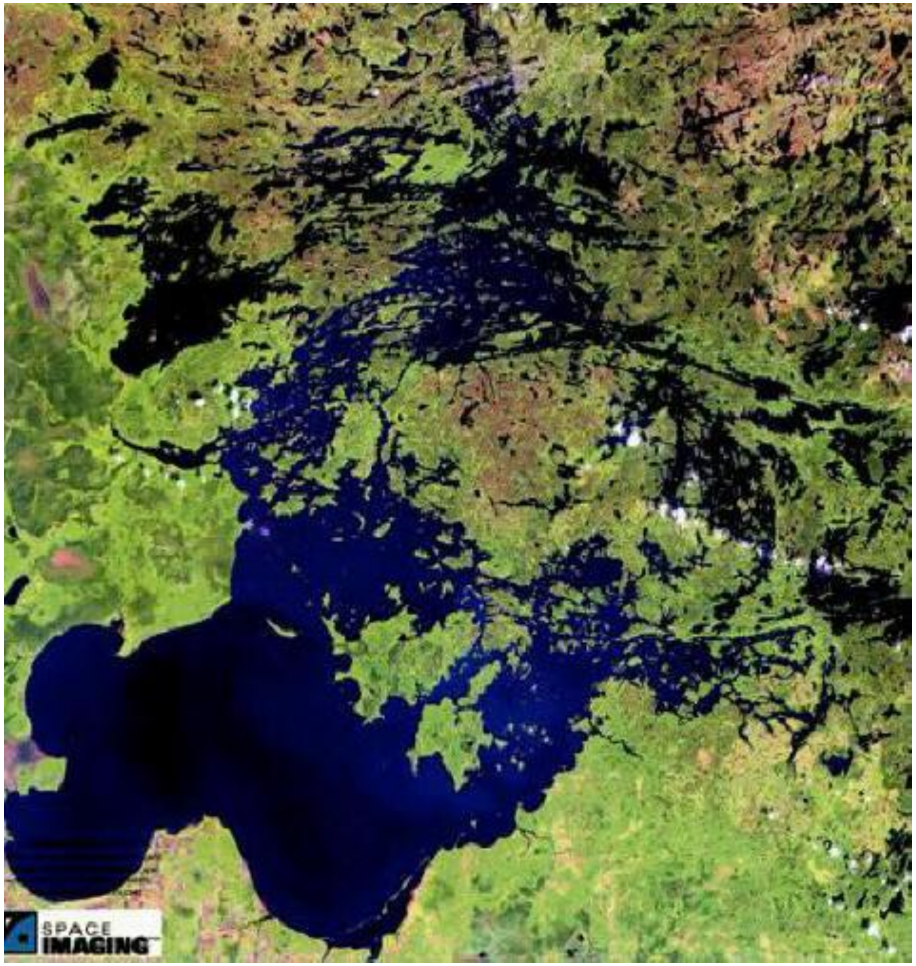
In the 1980s, populations known to be impacted by overharvesting, reduced hypolimnetic O_2, and high TP and chlorophyll-*a*

Recent improvement in the quality of the Lake Trout fishery

- Increases in population size, spawning and recruitment, and declines in fish mortality

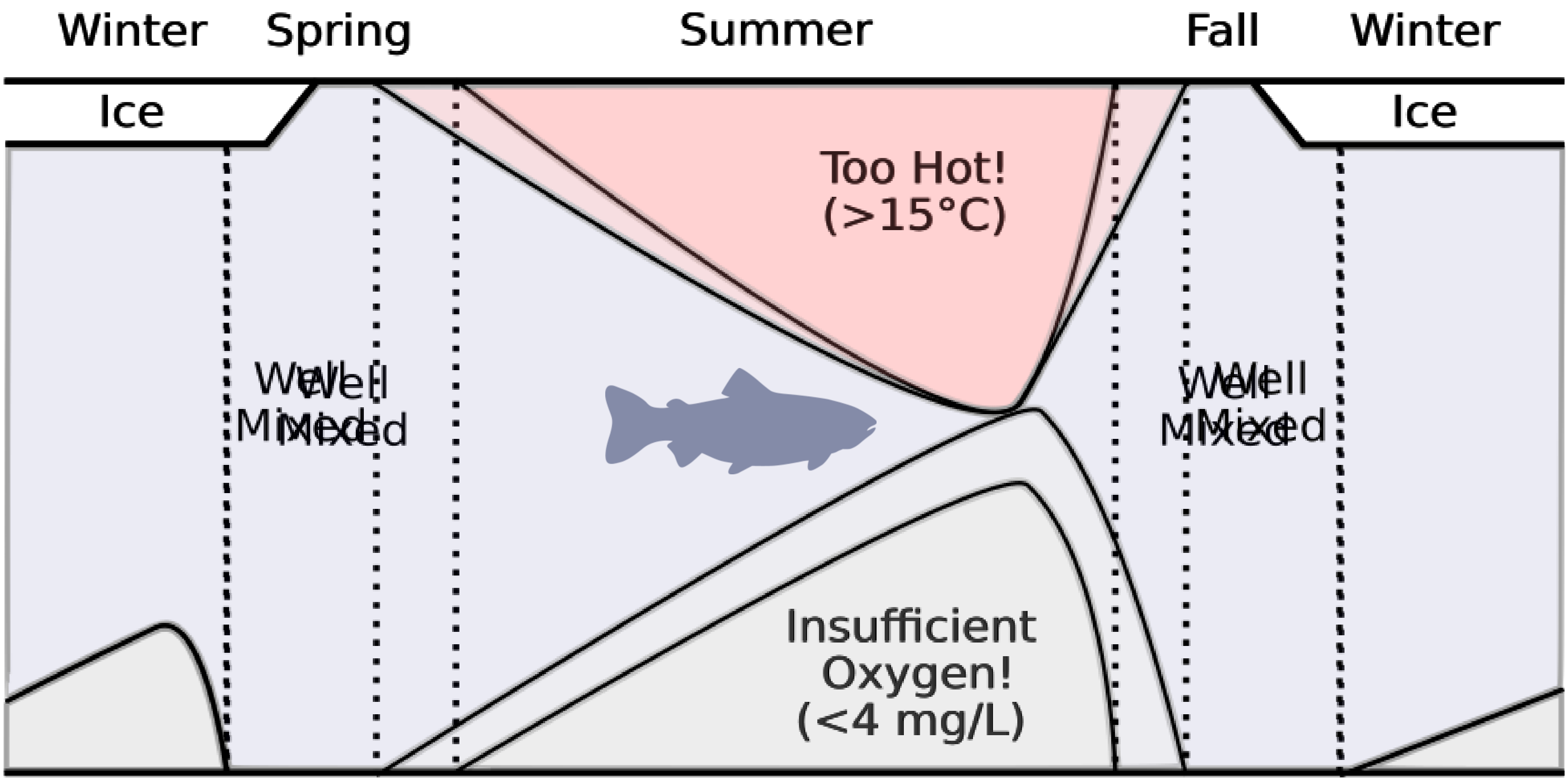
Low numbers of large-sized individuals still a concern

(Clark and Sellers 2014)



(Photo: http://www.thunderbolts.info/tpod/2008/arch08/081224lake.htm)

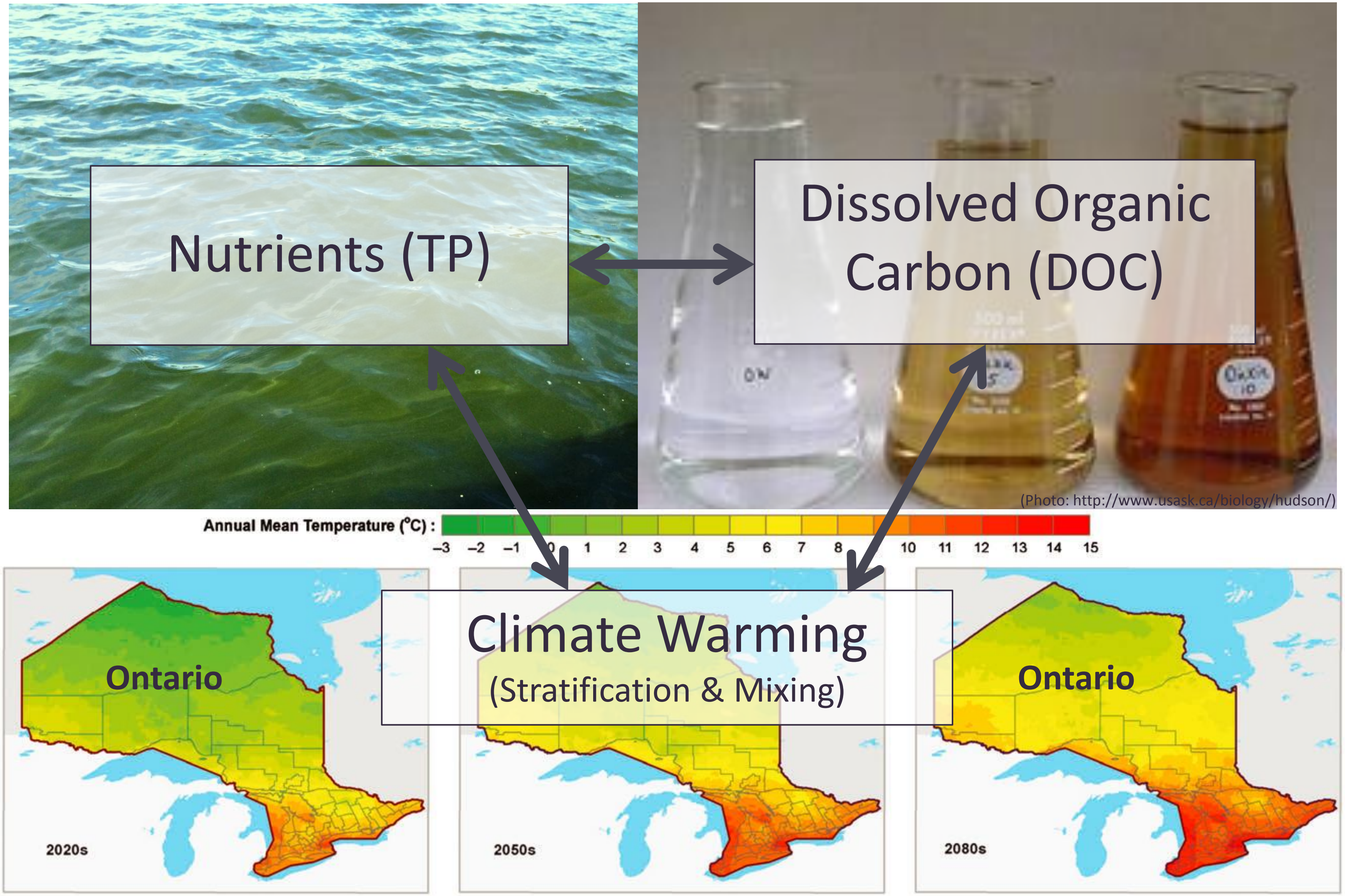
Lake Trout Habitat "Squeeze"



Provincial Standard for Volume-weighted Hypolimnetic O_2 > 7 mg/L

(Evans et al. 2007)

(Figure modified from Guzzo and Blanchfield 2016)



(Figure: Wang et al. 2014)

Study Design

Understanding the past

Modeling the present

Forecasting the future

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Develop and calibrate models on a common set of study lakes

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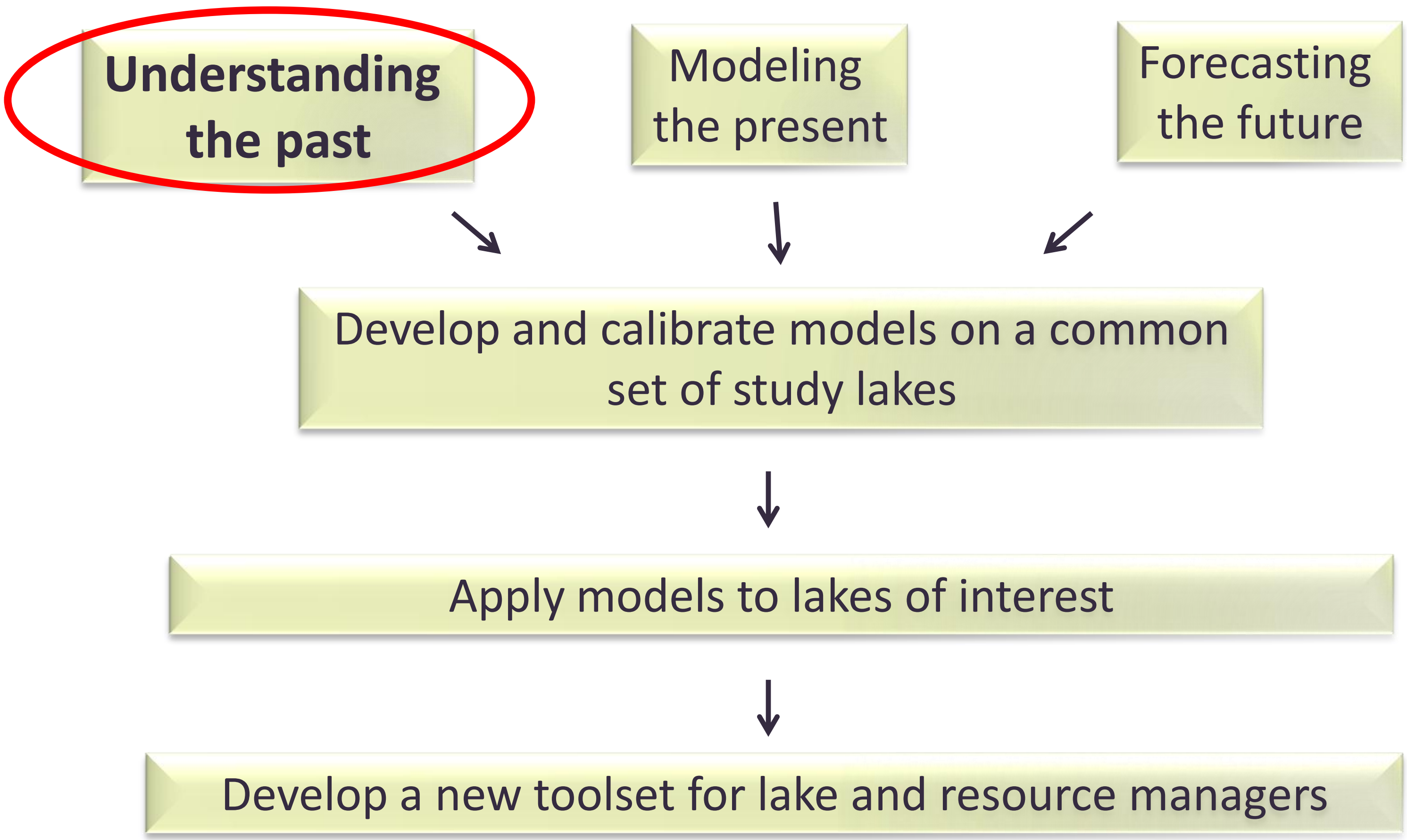
Apply models to lakes of interest

↓

Develop a new toolset for lake and resource managers

Study Design

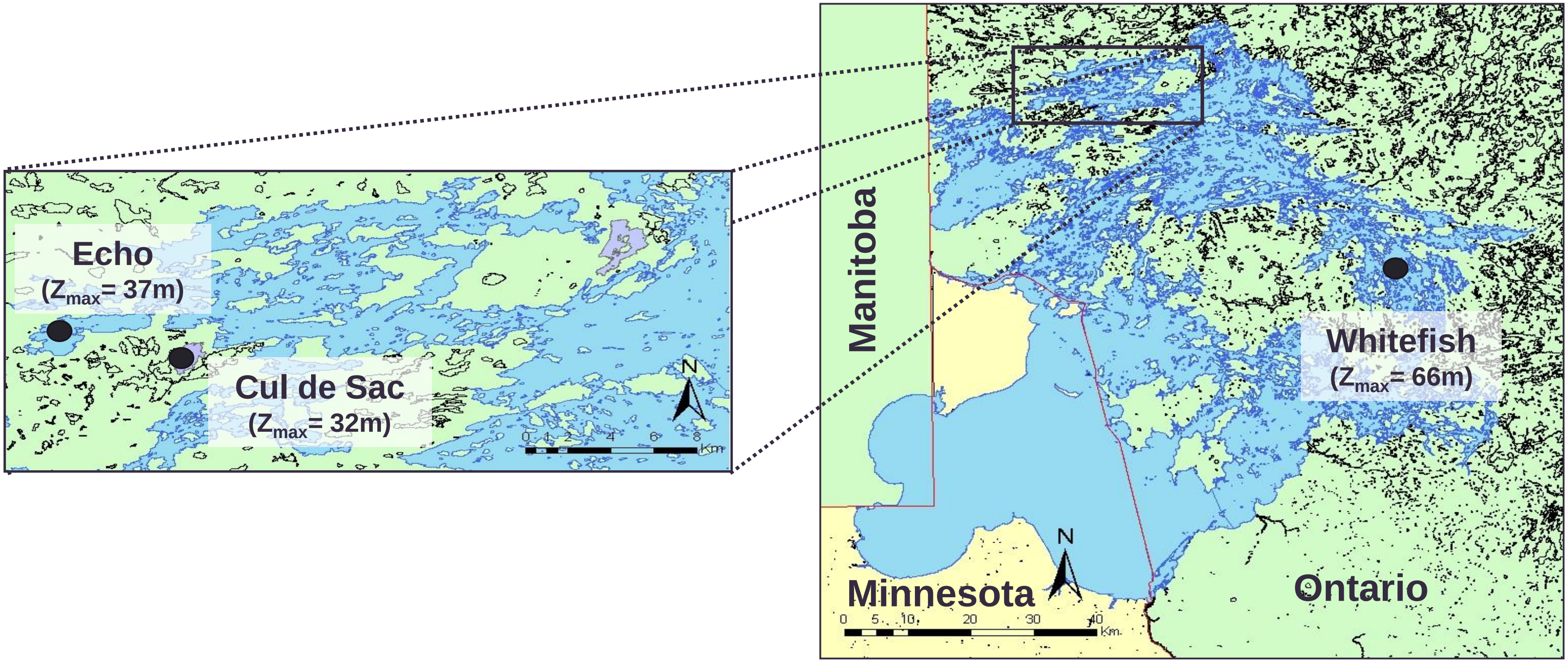


Objectives

Detailed information about past conditions is needed to understand the influence of modern stressors

Goal is to reconstruct background conditions and assess how lake water quality has changed

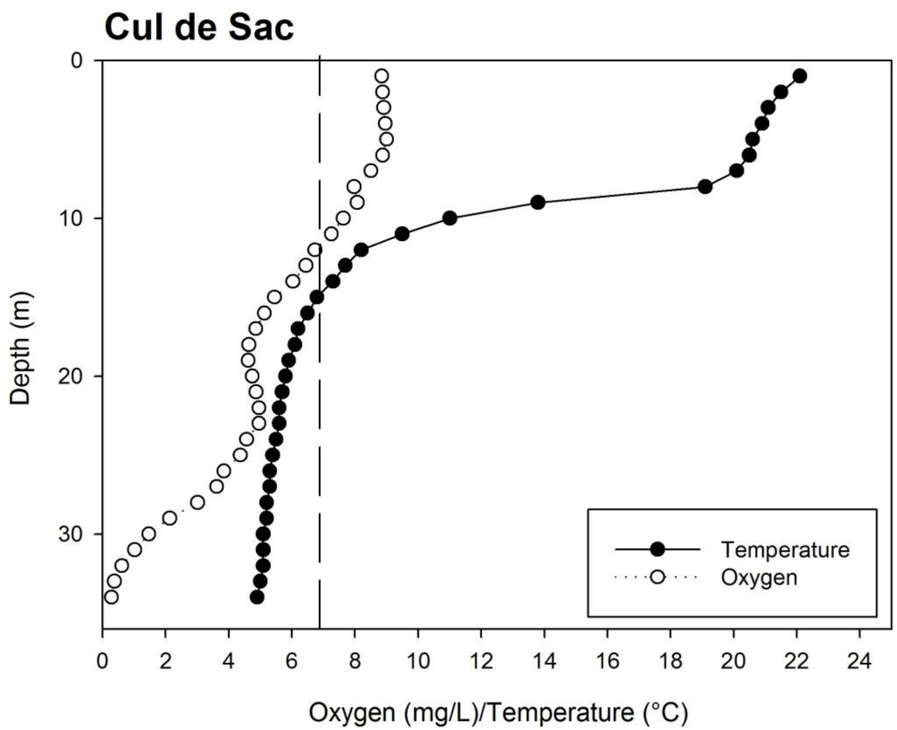
Study Sites

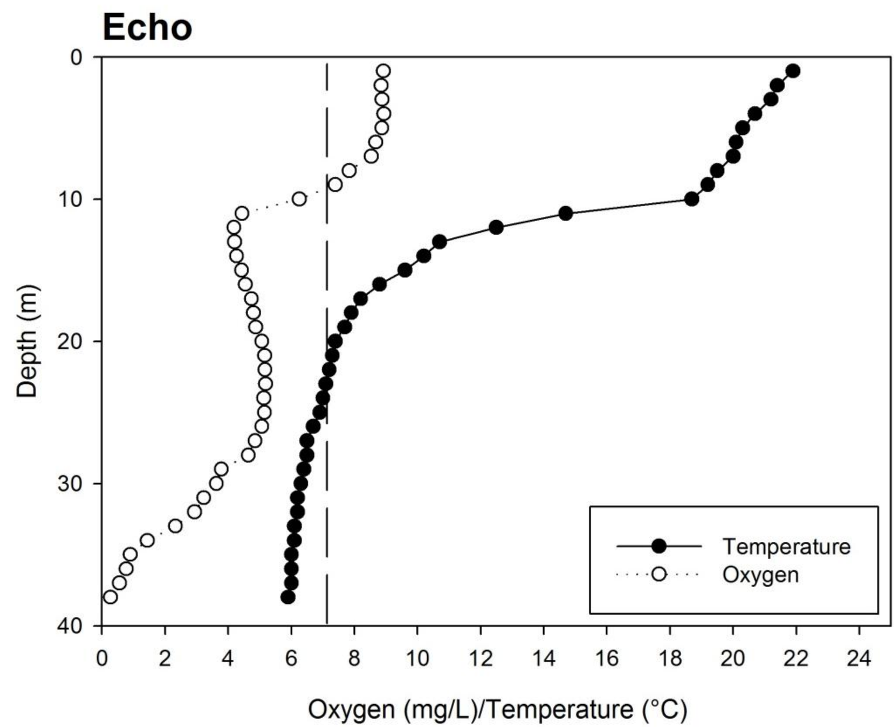


Bay	Latitude (N)	Longitude (W)	Lake area (ha)	Catchment area (ha)	% Wetland	Residencies			
						Seasonal	Perman.	Condo.	Campground
Whitefish	49'31	94'31	24,876	406,098	2	467	115	240	50
Echo	49'38'34	94'54'50	667	1,282	4	41	0	0	0
Cul De Sac	49'37'44	94'49'49	138	128	0	2	0	0	0

(Hargan 2010)

Sept 2009 Temperature-Oxygen Profiles





Volume Weighted Hypolimnetic Oxygen (mg/L)		
Year	**Cul de Sac**	**Echo**
2004	5.62	Not Available
2005	5.63	5.85
2009	4.89	4.64

(Data from OMNRF and Hargan 2010)

Methods

Indicators to be analyzed:

Diatoms:

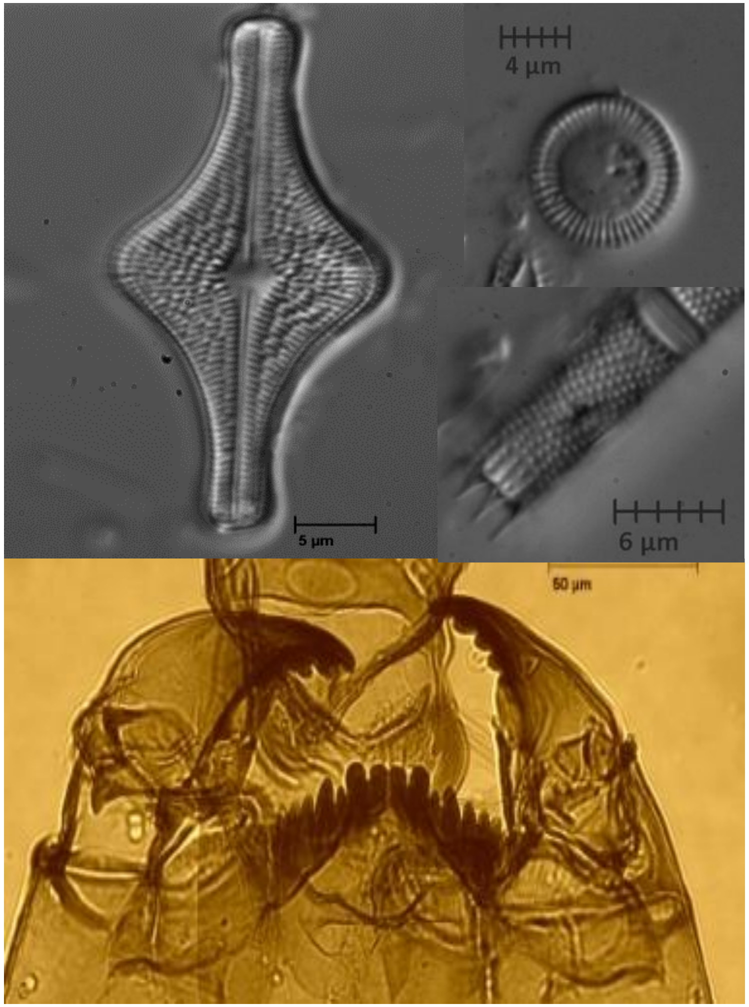
- To reconstruct past [TP]

Chironomids:

- To reconstruct end-of-summer volume-weighted hypolimnetic [O_2] (VWHO)

VRS-chlorophyll-*a*

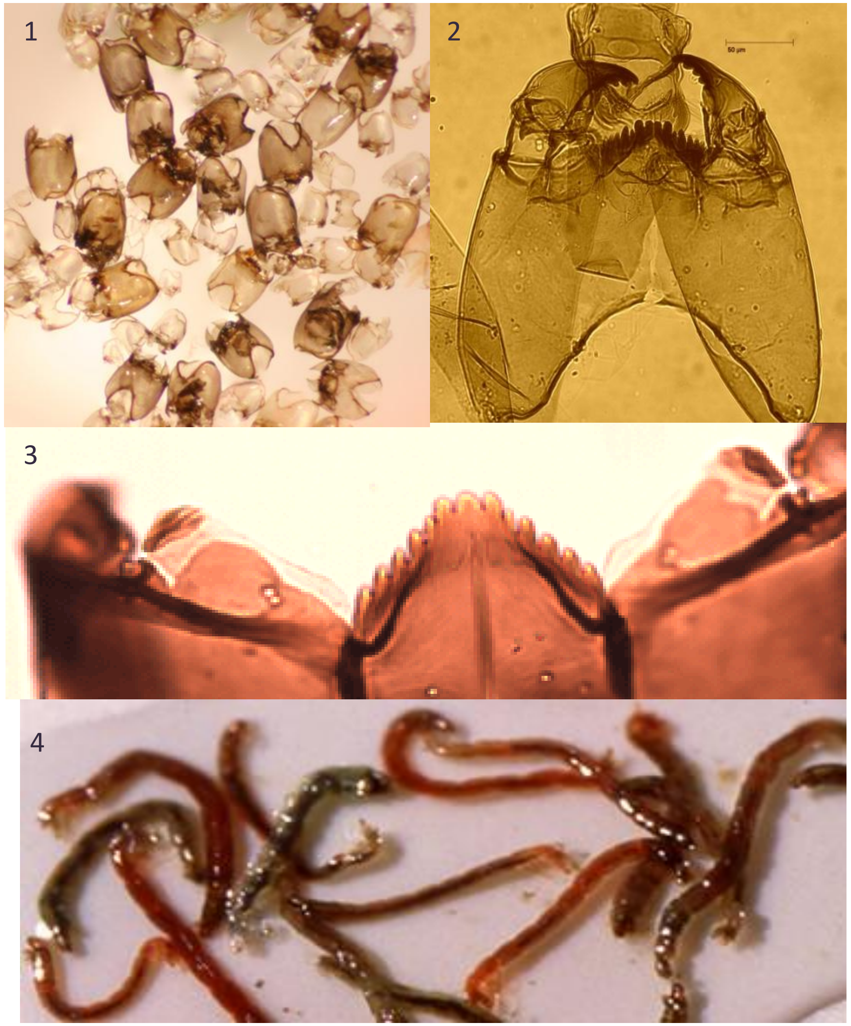
- To infer whole-lake primary production



(Photo: http://post.queensu.ca/~pearl/cf8/cf8pics.html)

Chironomids

- Non-biting midges
- Aquatic larval stage
- Head capsules preserve well in sediments
- Good indicator of lake oxygen conditions



Photos: 1) https://ecologyofthepast.info/2012/05/11/the-mighty-midge/, 2) http://www.earth.northwestern.edu/~yarrow/research.html, 3) http://post.queensu.ca/~pearl/PNAS2005.html, 4) http://www.flyfishersrepublic.com/tactics/chironomid-tactics/

Research Questions

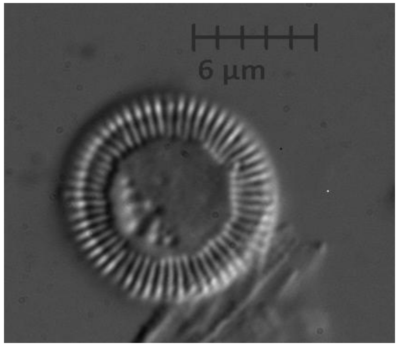
1. How have TP, whole-lake primary production and end-of-summer VWHO changed in LOW bays that support Lake Trout?
2. How have diatom and chironomid assemblages changed over the past ~150?
3. Do assemblage changes suggest the influence of a particular environmental stressor?

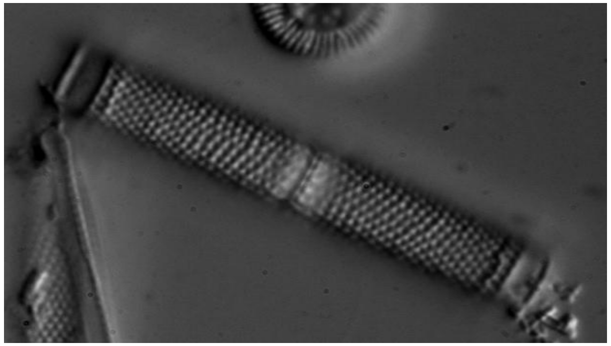
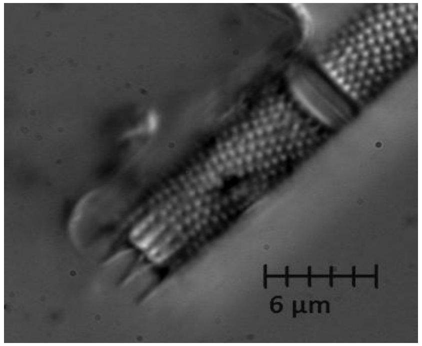
Diatom Results Summary

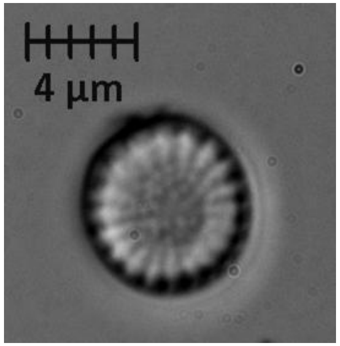
Taxon-specific shifts across all bays suggest changes in thermal stratification

- Shifts between small cyclotelloid taxa and heavily silicified *Aulacoseira* taxa
- The timing of change varies among bays (~1980s – 2000)

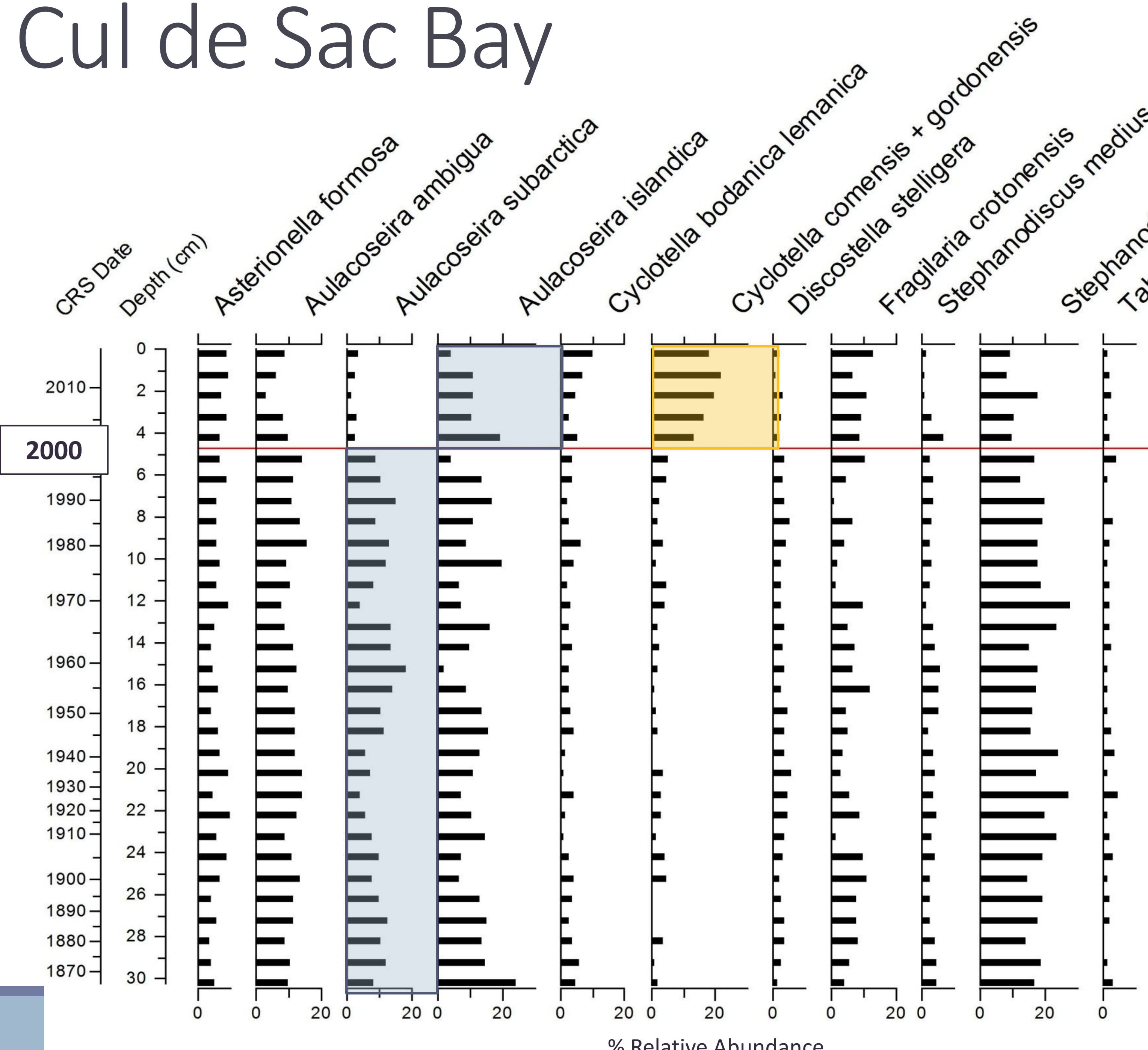
Diatom taxa with higher nutrient optima (e.g. *Stephanodiscus minutulus*) decrease slightly over the sediment record



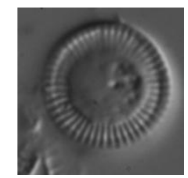





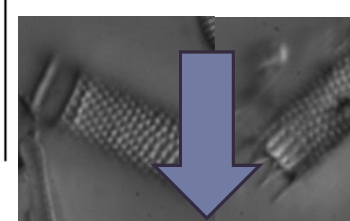
Cul de Sac Bay



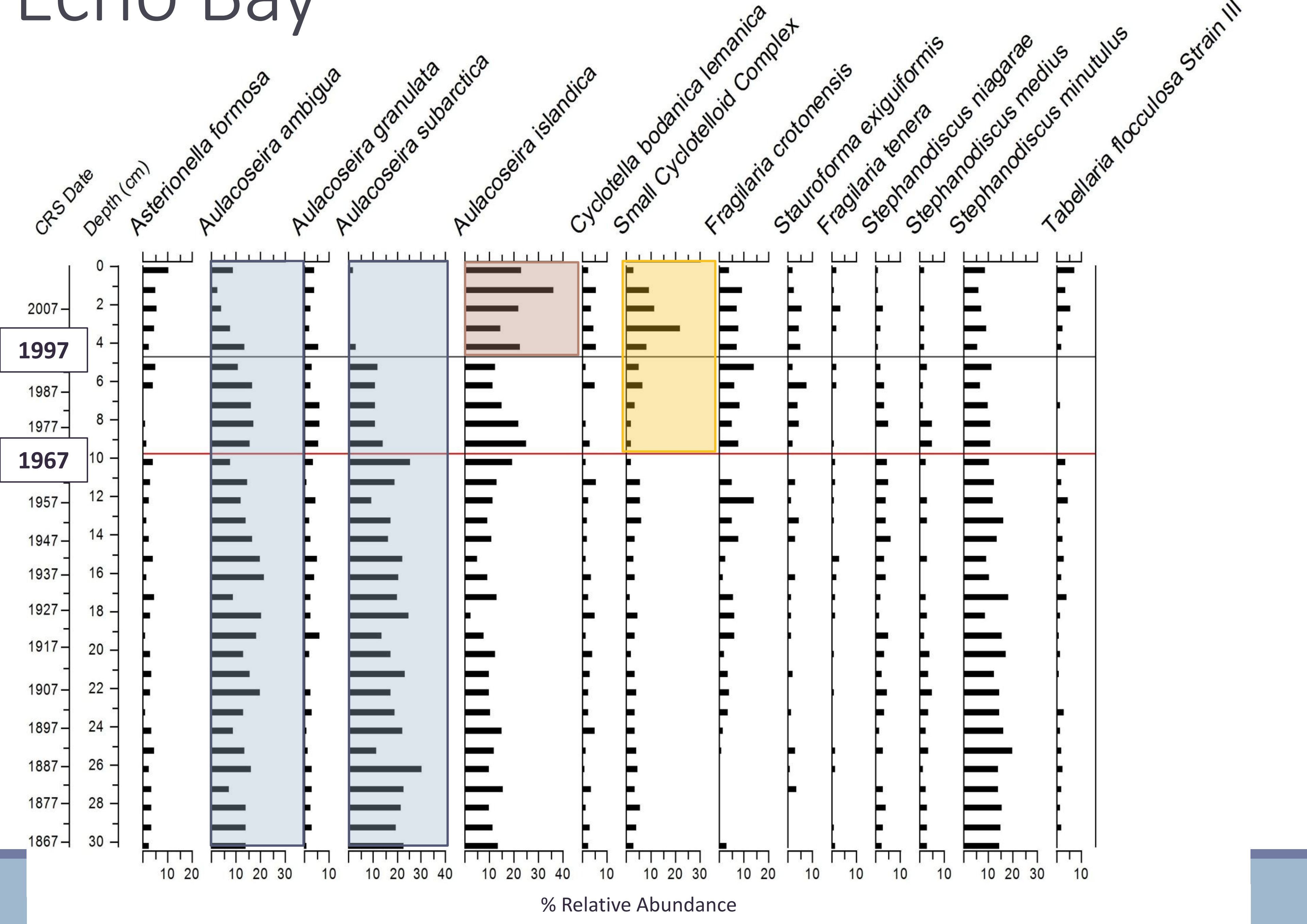
Increase in *Cyclotella comensis* and *C. gordonensis*



Decrease in *Aulacoseira ambigua* and *A. subarctica*

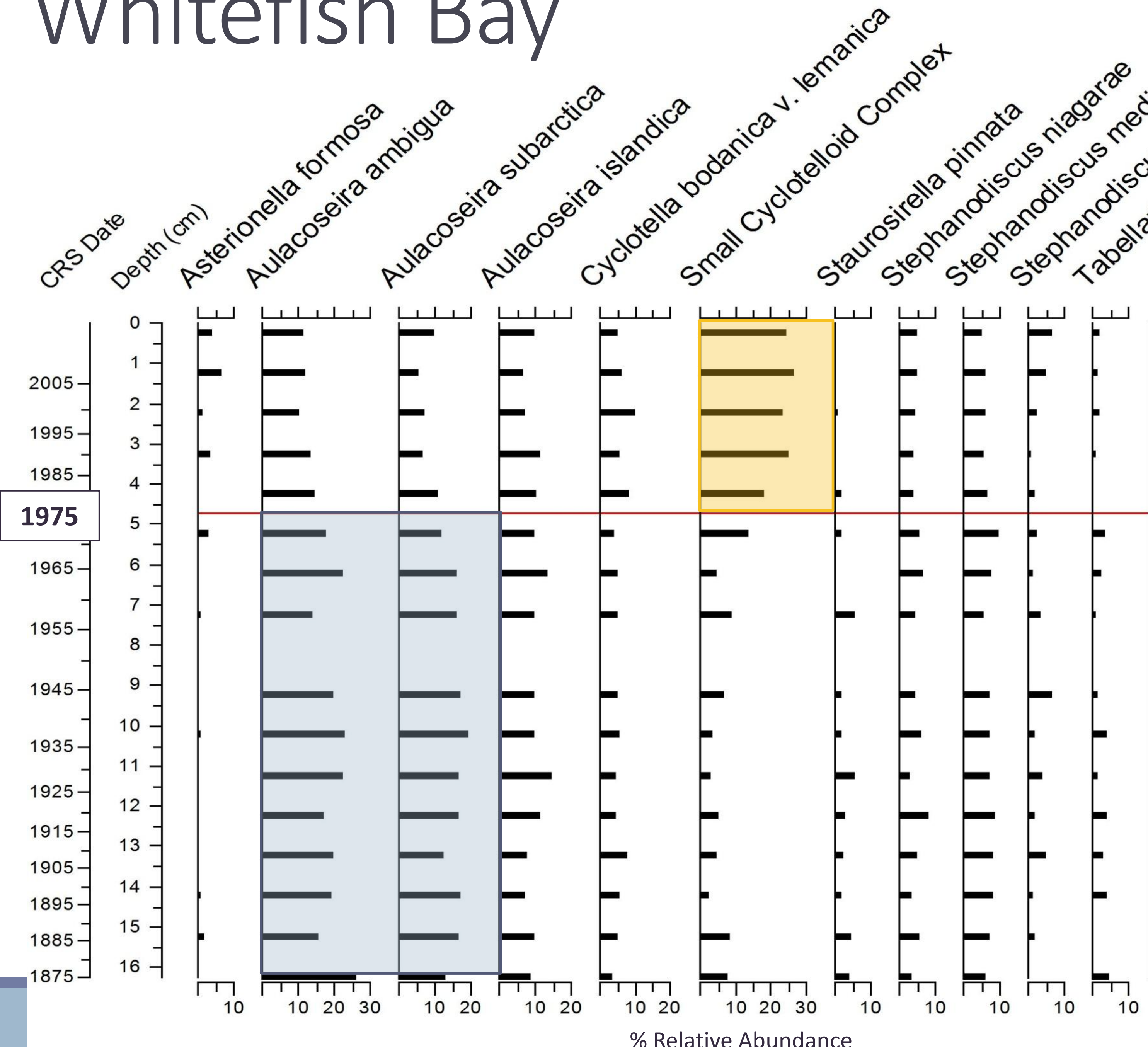


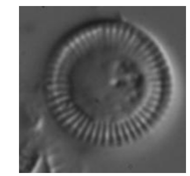
Echo Bay

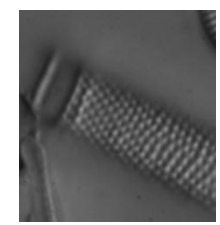


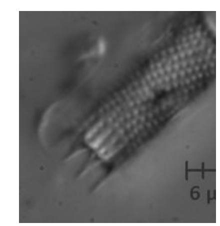
CRS Date
Depth (cm)
Asterionella formosa
Aulacoseira ambigua
Aulacoseira granulata
Aulacoseira subarctica
Aulacoseira islandica
Cyclotella bodanica lemanica
Small Cyclotelloid Complex
Fragilaria crotonensis
Stauroforma exiguiformis
Fragilaria tenera
Stephanodiscus niagarae
Stephanodiscus medius
Stephanodiscus minutulus
Tabellaria flocculosa Strain III
1997
1967
2007
1987
1977
1957
1947
1937
1927
1917
1907
1897
1887
1877
1867
% Relative Abundance

Whitefish Bay



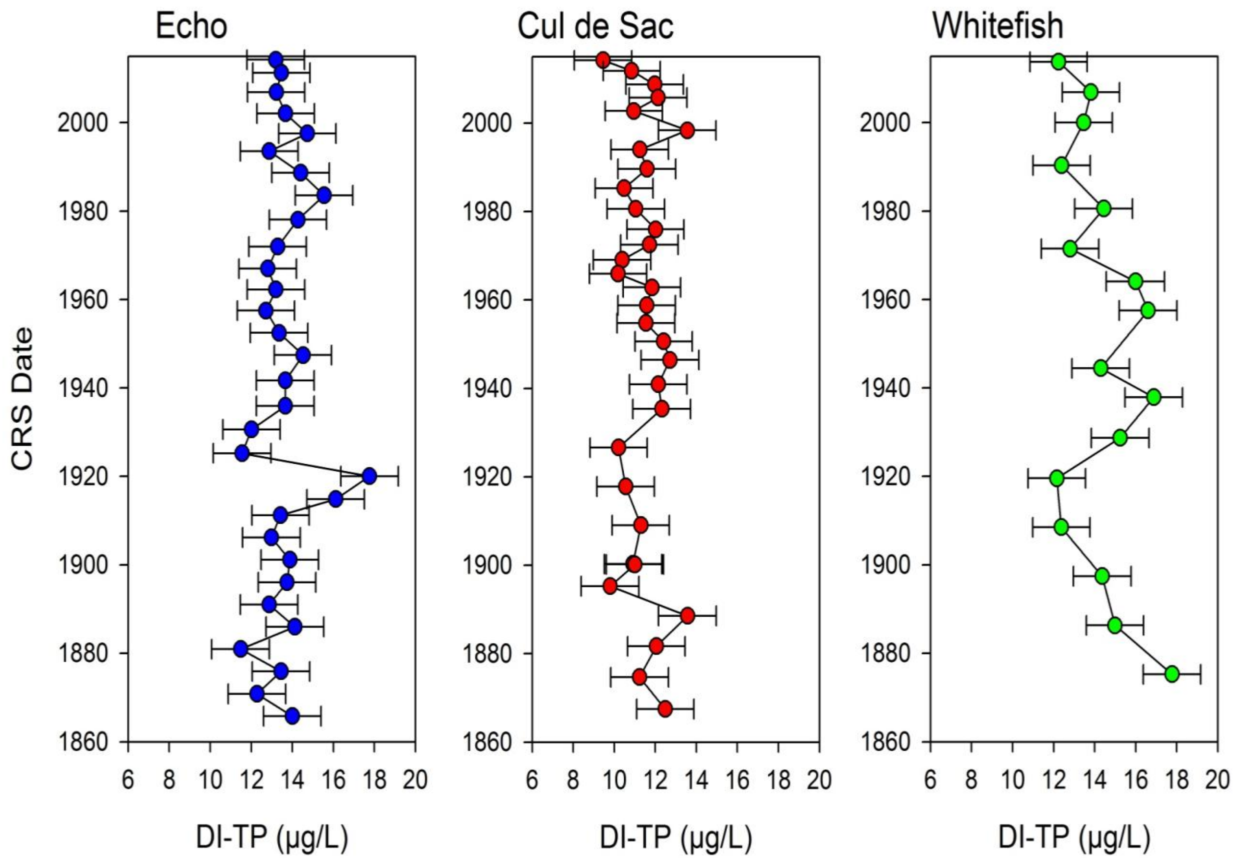






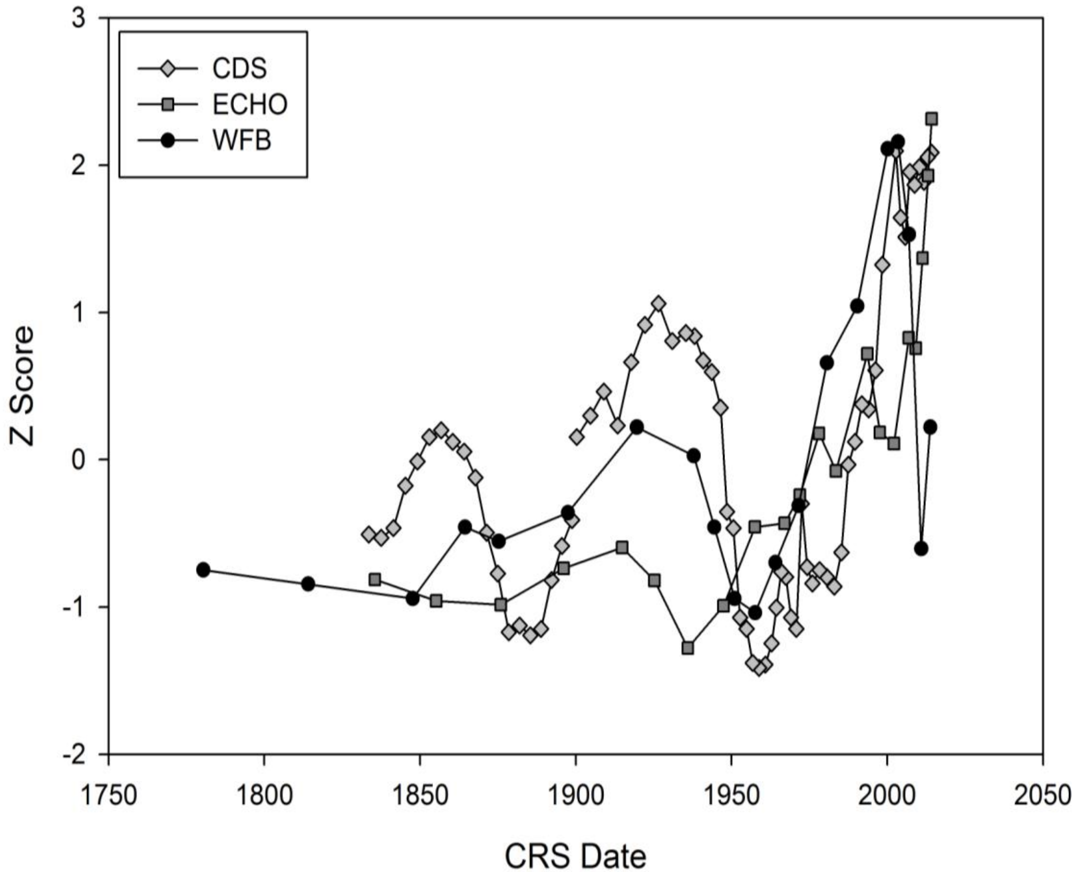
Diatom-inferred TP

Applied the Hyatt et al. (2011) TP model (R^2_{boot}=0.58, RMSEP=0.15)



There is no trend in DI-TP in Echo and Cul de Sac bays, and a slight decreasing trend in Whitefish Bay after ~1940

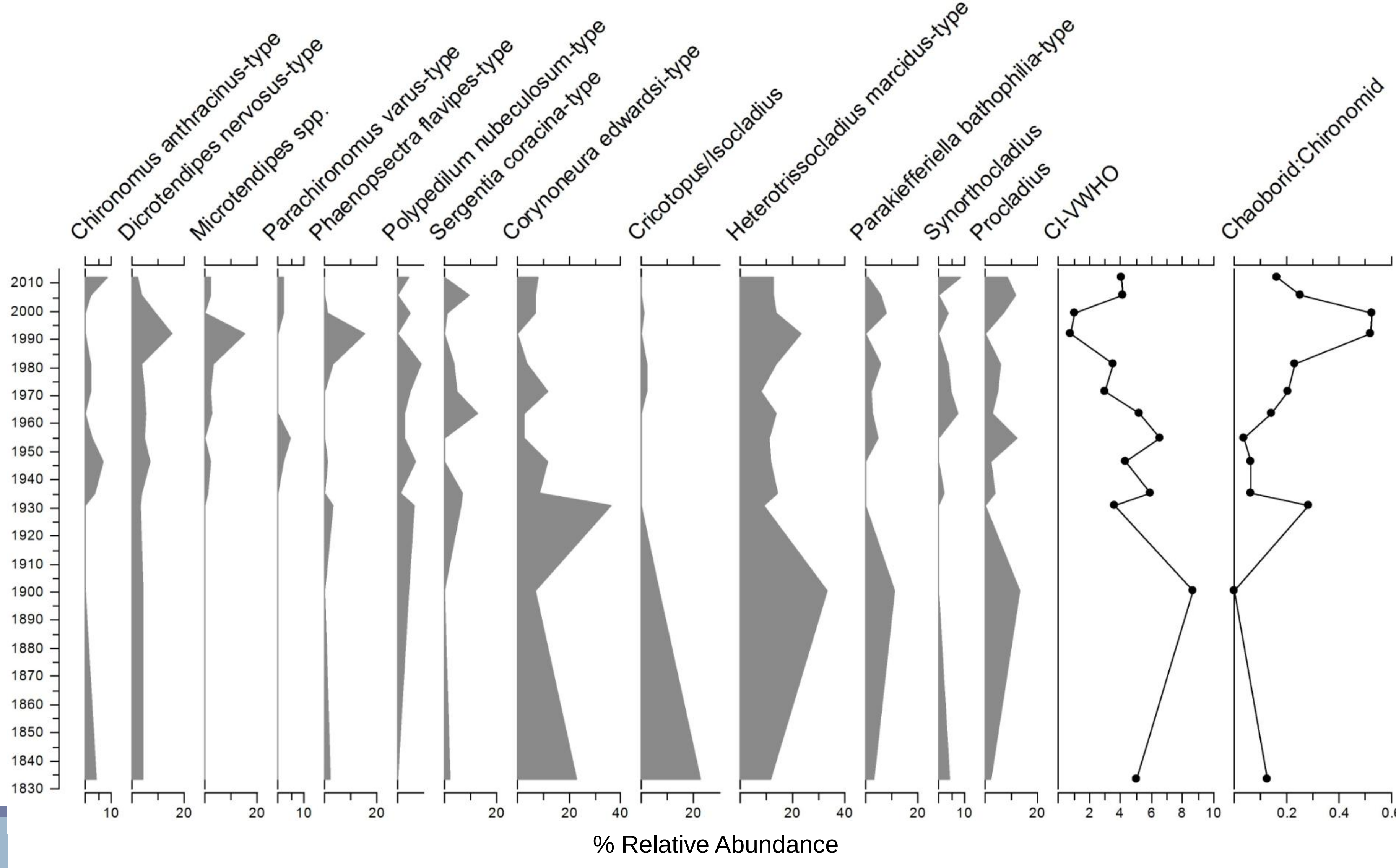
VRS-chlorophyll-*a*



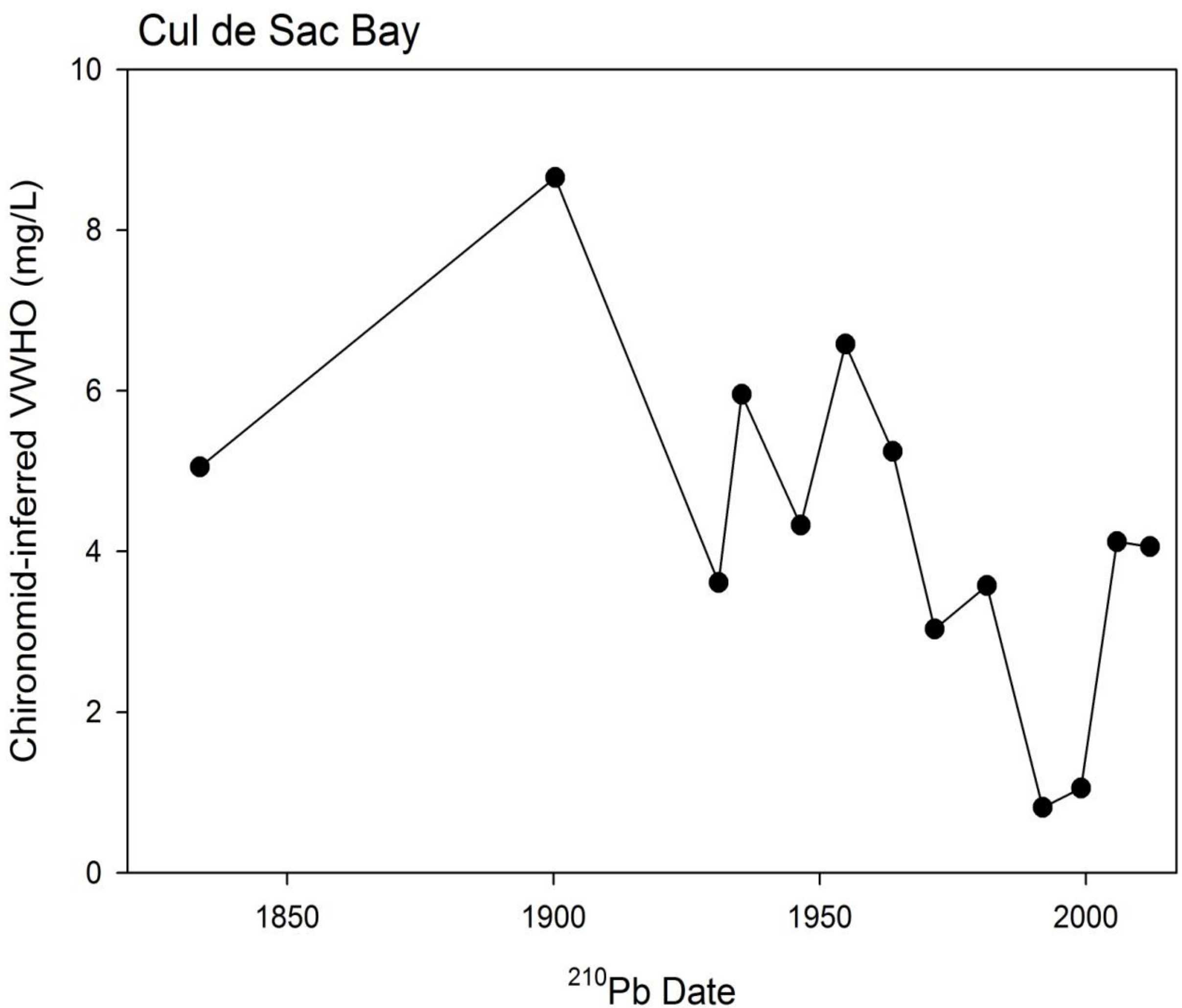
Increases in VRS-chl*a* may be associated with a longer growing season and/or internal phosphorus loading (Paterson et al. 2017)

Whitefish bay has undergone unique hydrological management which may account for the decrease in present-day VRS-chl*a*

Cul de Sac Chironomids



Chironomid-inferred VWHO



Quinlan and Smol (2001) model was used to reconstruct end-of-summer VWHO

Chironomid-inferred VWHO decreases to near anoxic conditions during the 1990s

Increase in CI-VWHO in most recent sediment intervals is observed along side enhanced stratification and primary production

What is going on?

13 Year Water Chemistry Trends

Bay	Secchi	Ca	Chl a	Col	Cond	DOC	Fe	K	Mg	NH_3/NH_4	NO_2/NO_3	TKN	TN	pH	TP	SiO_2	SO_4
Clearwater	↓	–	↑	↑	–	–	–	–	–	–	–	–	–	–	–	↑	↓
Cul de Sac	-	–	–	↑	–	–	–	↓	↑	–	↓	–	–	–	↑	↑	–
Deception	↓	–	↑	↑	–	–	–	↓	–	–	–	–	–	–	–	↑	↓
Echo	↓	–	–	↑	–	–	–	↓	–	–	–	–	–	–	–	↑	↓
White Partridge	↓	–	↑	↑	↑	–	–	–	–	–	–	–	–	–	–	↑	↓

(Yoshida, unpublished data)

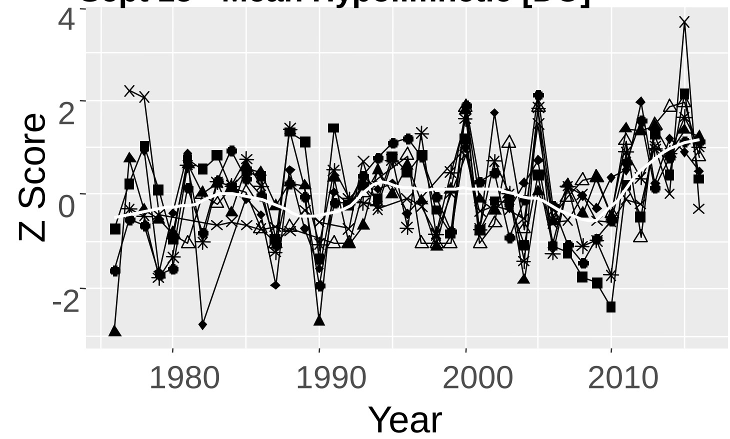
VWHO may be increasing due to an increase in hypolimnion size opening up more cold-water oxygenated habitat

South-central Ontario VWHO Trends

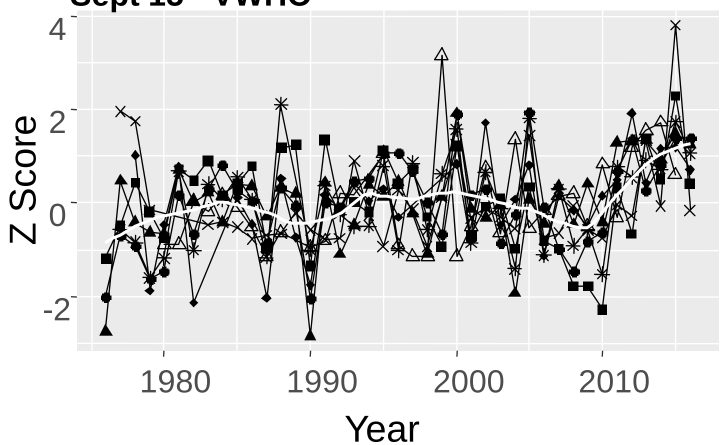
Similar trends are observed in south-central Ontario monitoring data from 1976-2016

Recent increase in both mean hypolimnetic oxygen concentration and hypolimnetic volume

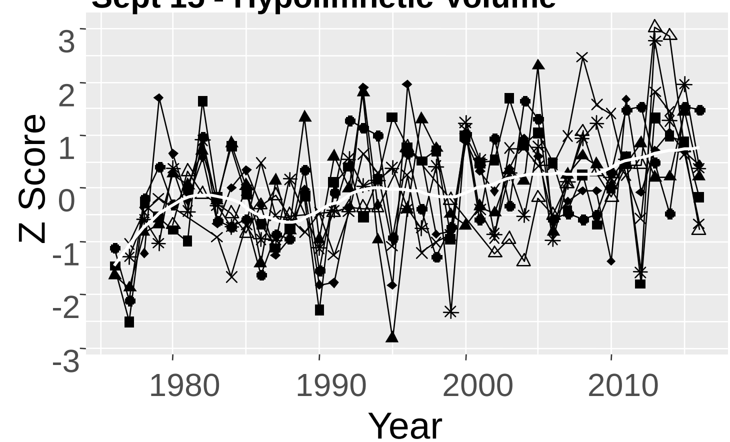
Sept 15 - Mean Hypolimnetic [DO]



Sept 15 - VWHO



Sept 15 - Hypolimnetic Volume



■ BC ● CB ▲ CR ◆ HP △ PL × RCE ✳ RCM

Conclusions

We observe consistent diatom assemblage changes across all bays characteristic of enhanced thermal stratification

Diatom-inferred TP is stable (or slightly decreasing) in all bay

Although there is no change in nutrients, we observe an increase in VRS-chl*a* in Echo and Cul de Sac that is likely associated when longer growing season

We observe increases in chironomid-inferred VWHO post-1990 suggesting that there may be more oxygenated habitat for Lake Trout in Cul de Sac Bay in recent years despite enhanced stratification and increased whole-lake primary production

VWHO trends may be associated with increased lake water colour and changes in the size of the hypolimnion

Thank you, Questions?

Key Literature

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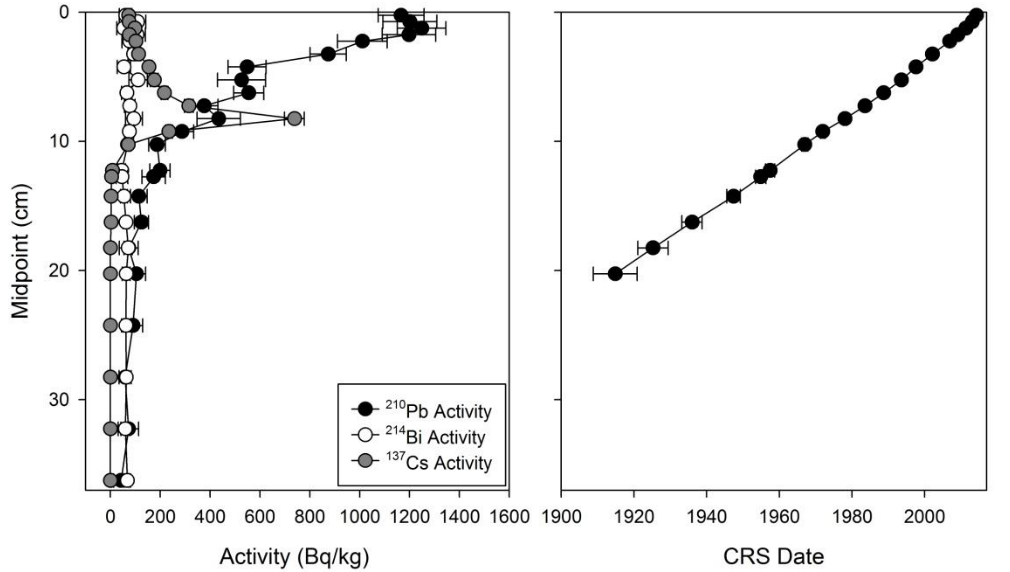
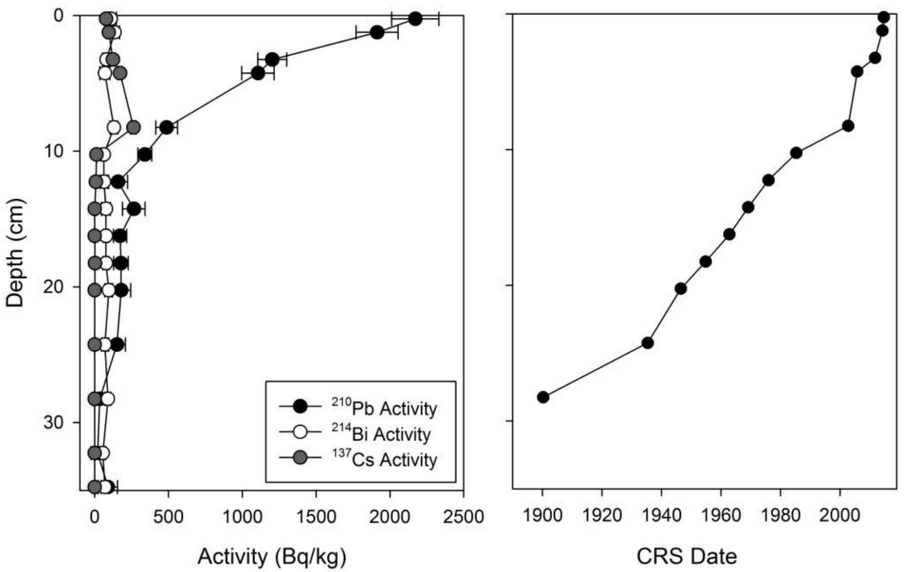
Radioisotope Profiles & Constant Rate of Supply Dating Models

Echo



Cul de Sac



Whitefish