Fisheries and Oceans Canada

Pêches et Océans Canada

Long-term ecological change and associated environmental forcings in critical freshwater habitat for Okanagan Basin Sockeye Salmon *(O. nerka)*

A comparative paleolimnological study of Wenatchee Lake, WA, USA

& Osoyoos & Skaha lakes, BC Canada

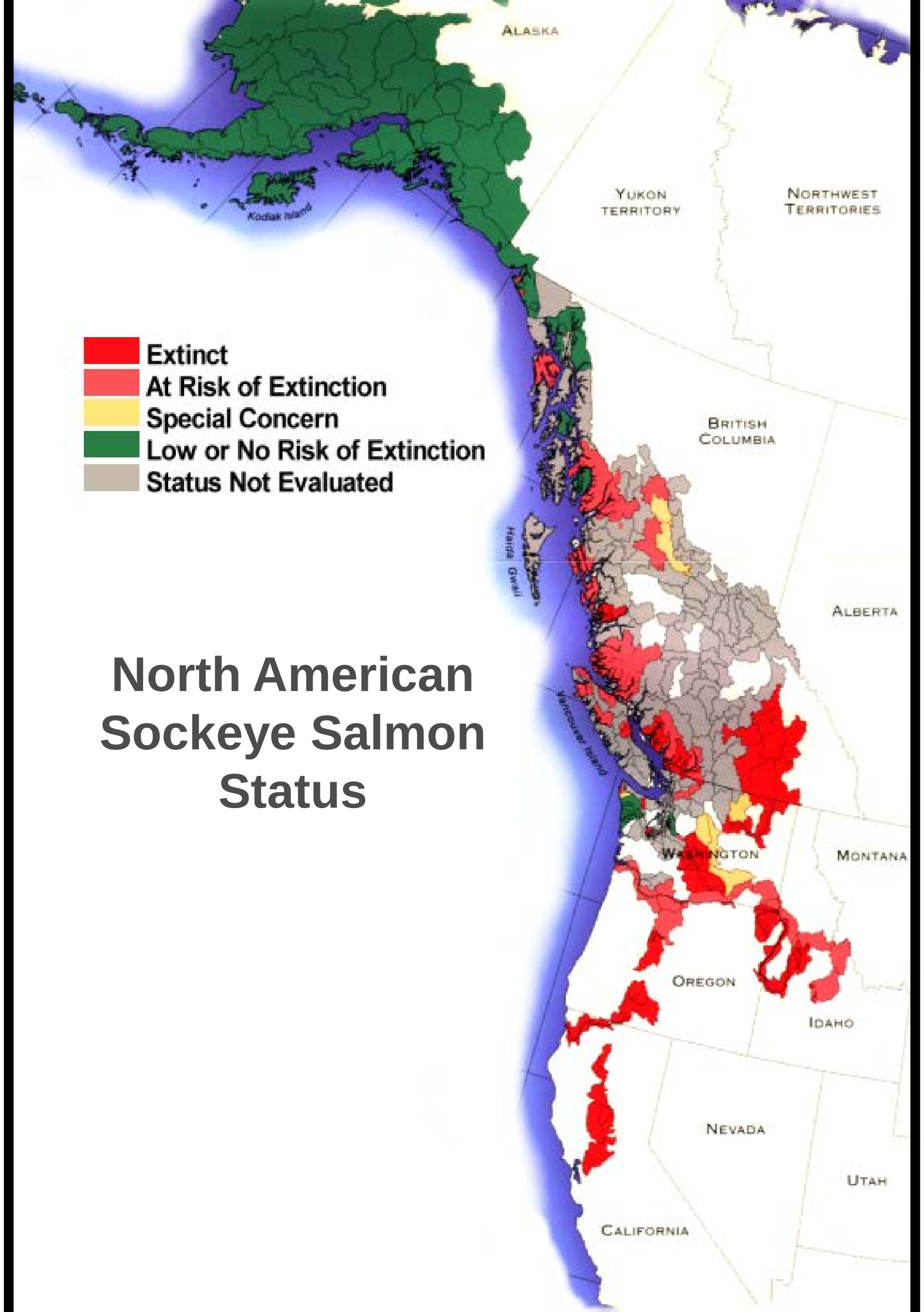
D.T. Selbie[1,2], A. Köchel[2], J. Fryer[3], K.D. Hyatt[4],

B. Simmatis[2], A. Zemanek[2], B.F. Cumming[2], and J.P. Smol[2]

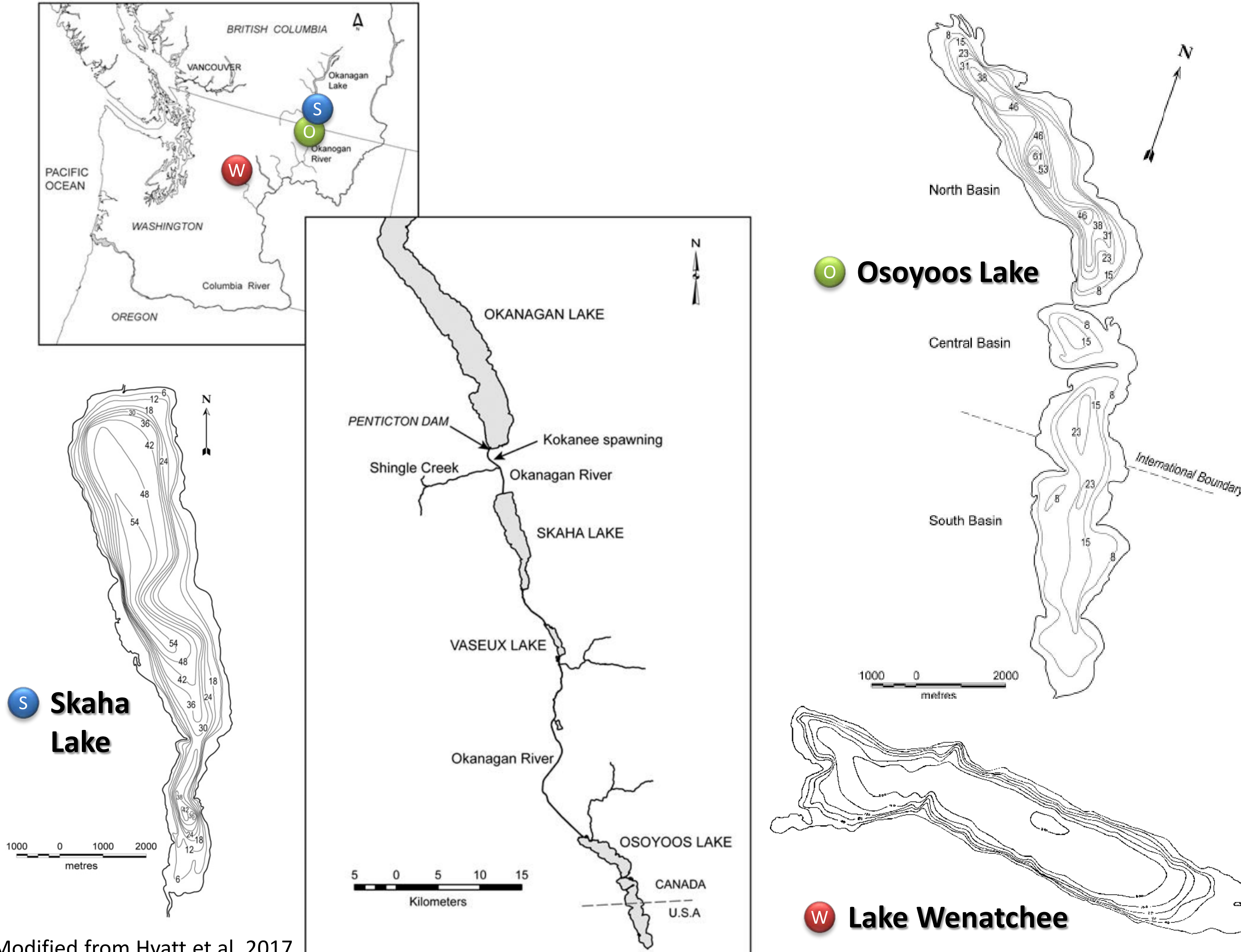
1. Science Branch, Fisheries & Oceans Canada, Cultus Lake Salmon Research Laboratory, Cultus Lake , BC, Canada
2. Department of Biology, Queen's University, Kingston, ON, Canada
3. Columbia River Inter-Tribal Fish Commission, Portland, OR, USA
4. Science Branch, Fisheries & Oceans Canada, Pacific Biological Station, Nanaimo, BC, Canada

Canada

North American Sockeye Salmon Status



Map from Wolf & Zuckerman, 1999



Modified from Hyatt et al. 2017

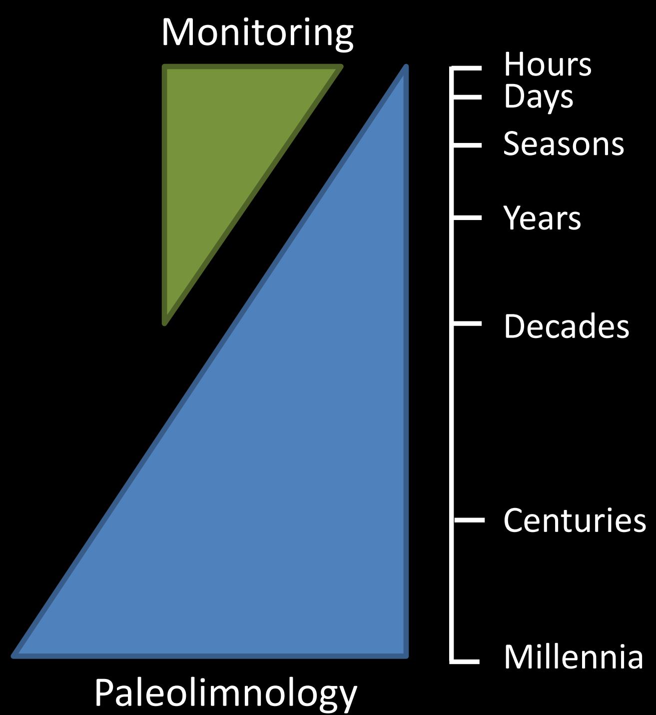
Paleolimnology:

The reconstruction of lake and river histories using the physical, chemical, and biological information stored in lake sediments

- Provides valuable information on environmental change in lakes, their watersheds, and the atmosphere
- Critical data used to address major environmental issues (i.e. acid rain, eutrophication, climate change)

Paleolimnology:

Reconstructing lake and environmental histories from sediment archives



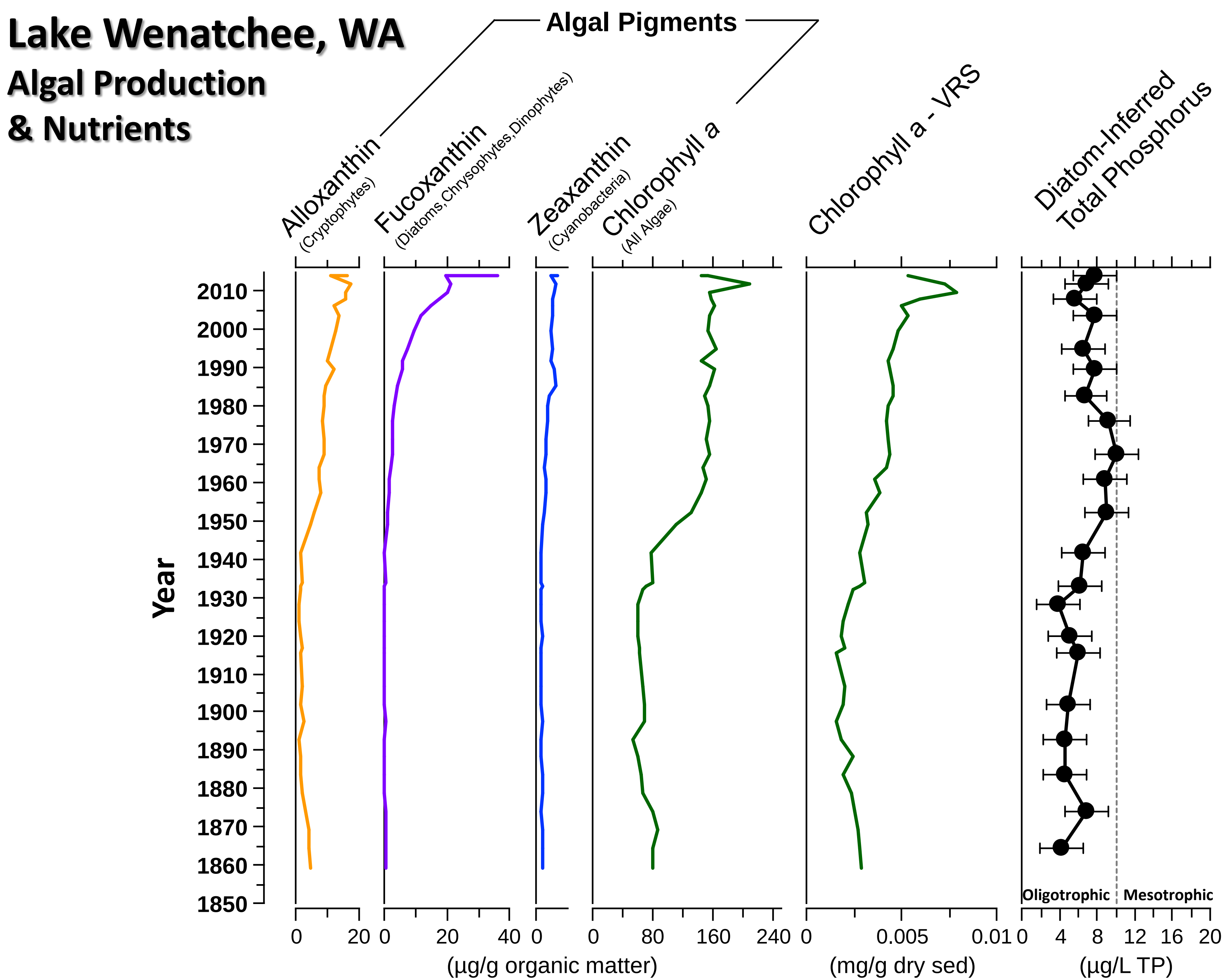
Our Objectives

- Reconstruct the trophic ecology of Okanagan and Wenatchee Sockeye nursery ecosystems over the past ~150 years
- Attempt to identify major drivers of ecological change influential to nursery lake productive capacities
- Assess relative sensitivities of nursery ecosystems to ongoing and future drivers

Our Approach

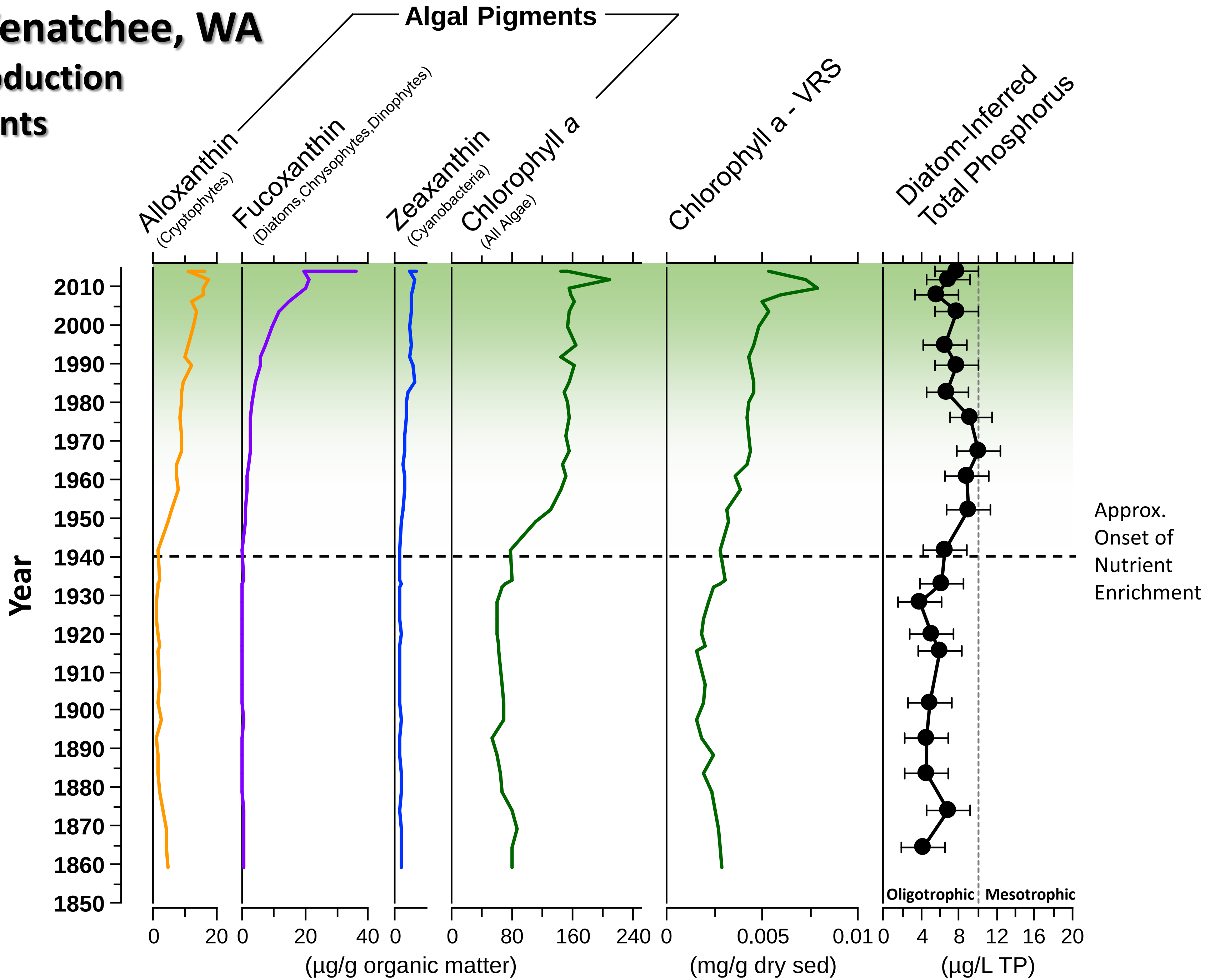
- **Radiometric Dating** (^{210}Pb, ^{137}Cs)
- **Sediment Geochemistry**
  - Sediment elemental chemistry (C/N_{molar})
  - Sediment stable isotope ratios ($\delta^{15}N$, $\delta^{13}C$)
- **Lake Trophic Reconstructions**
  - **Primary Production**
    - Fossil algal pigments
    - NIRS chlorophyll *a*
    - Diatom microfossils
  - **Secondary Production**
    - Cladoceran zooplankton sub-fossils
    - Chironomid larvae
- **Quantitative Inference of Key Limnological Parameters**
  - Total Phosphorus (diatoms)
  - Dissolved Oxygen (chironomids)

Image courtesy of N. Fobes

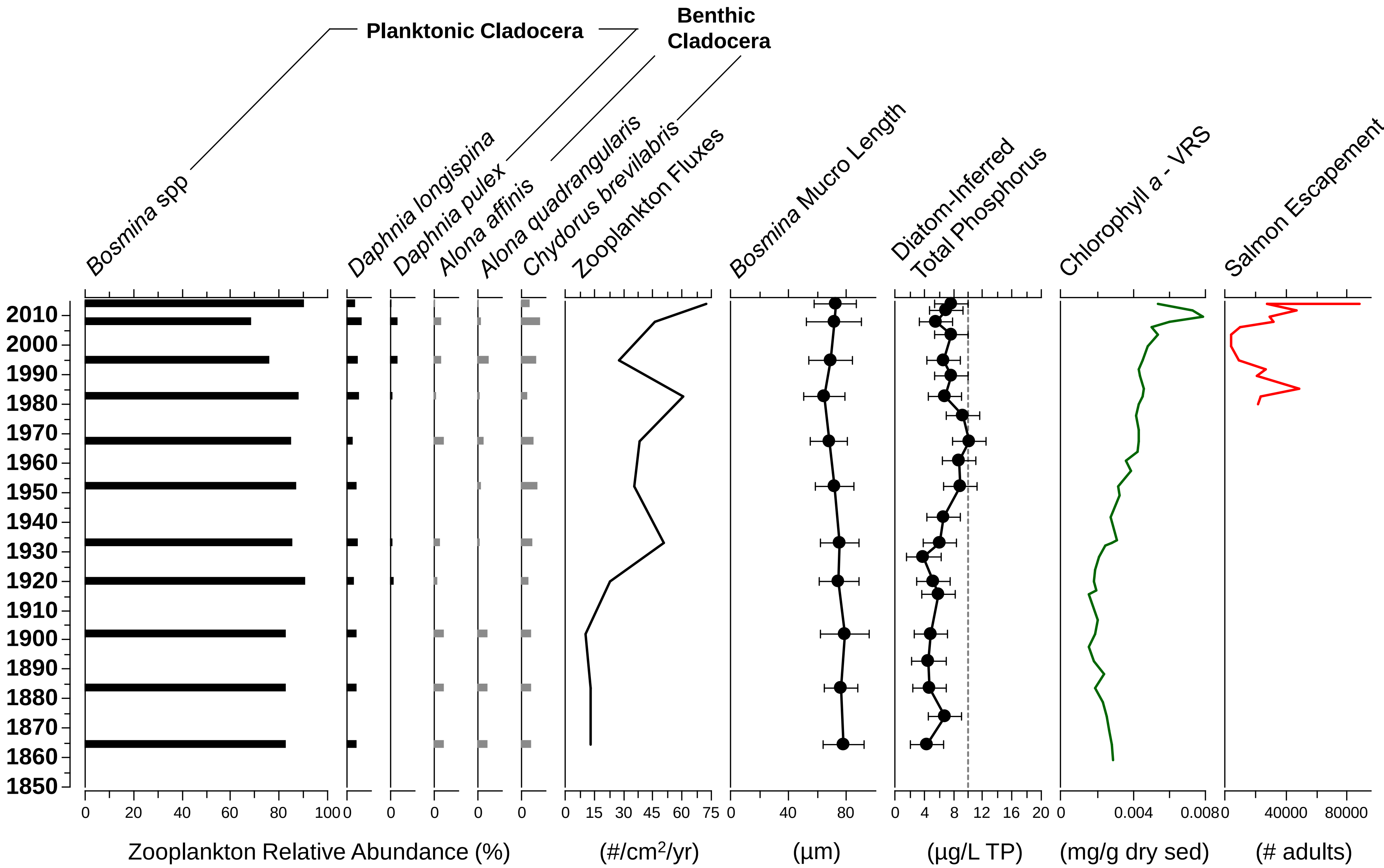


Lake Wenatchee, WA
Algal Production
& Nutrients
Algal Pigments
Alloxanthin
(Cryptophytes)
Fucoxanthin
(Diatoms,Chrysophytes,Dinophytes)
Zeaxanthin
(Cyanobacteria)
Chlorophyll a
(All Algae)
Chlorophyll a - VRS
Diatom-Inferred
Total Phosphorus
Year
2010
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1880
1870
1860
1850
0
20
0
20
40
0
0
80
160
240
0
0.005
0.01
0
4
8
12
16
20
(µg/g organic matter)
(mg/g dry sed)
(µg/L TP)
Oligotrophic
Mesotrophic

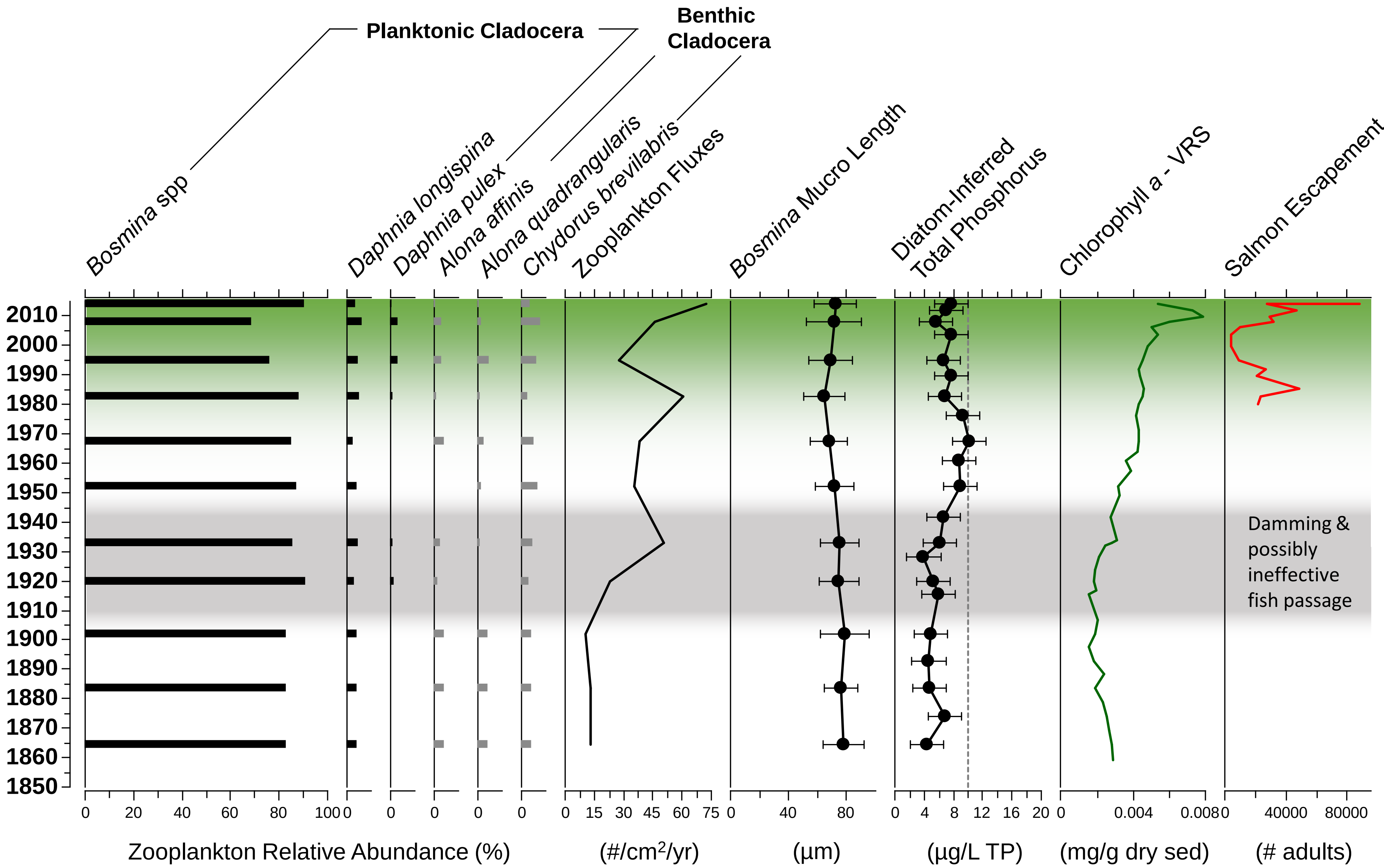
Lake Wenatchee, WA
Algal Production & Nutrients



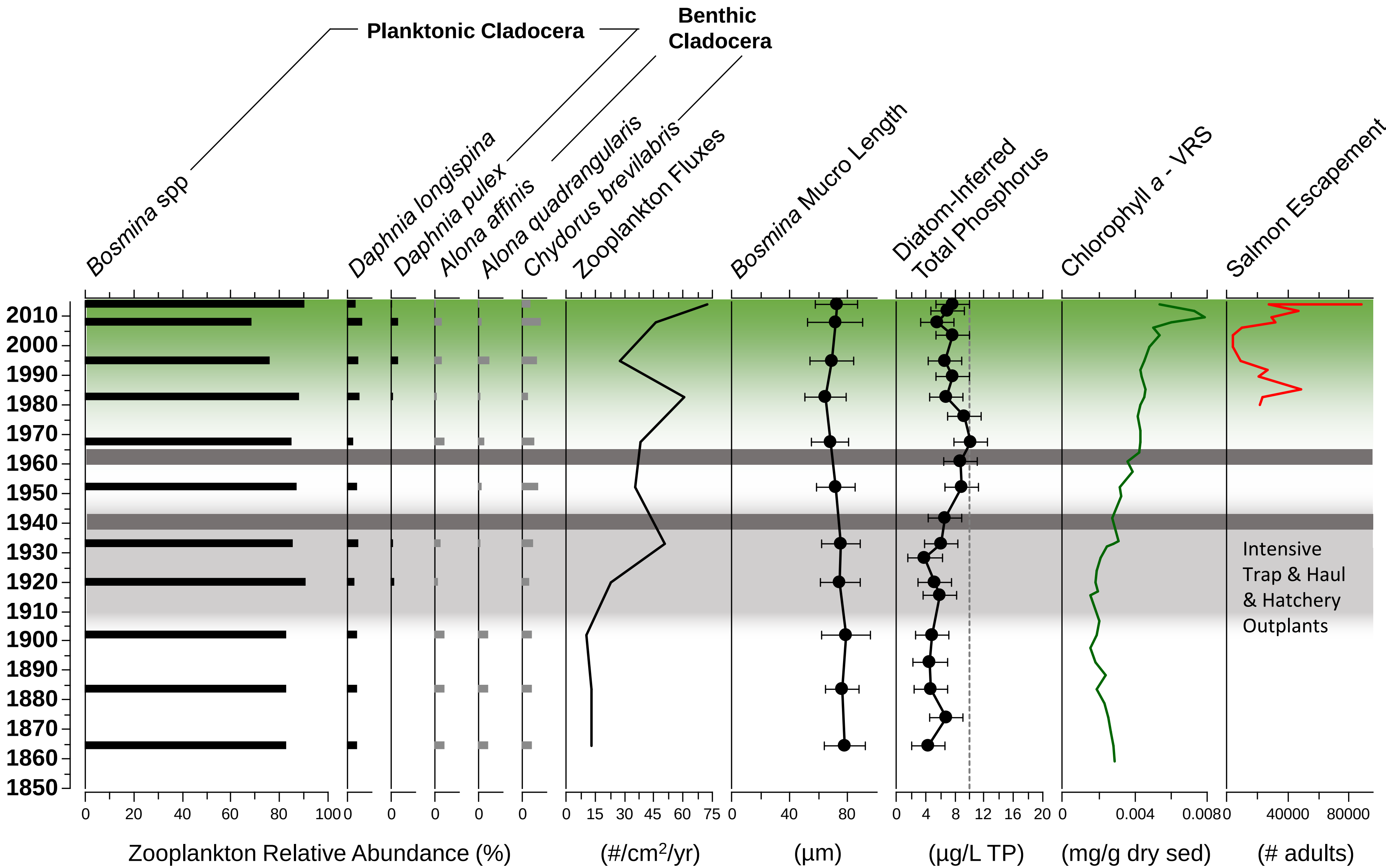
Wenatchee Lake, WA
Secondary Production



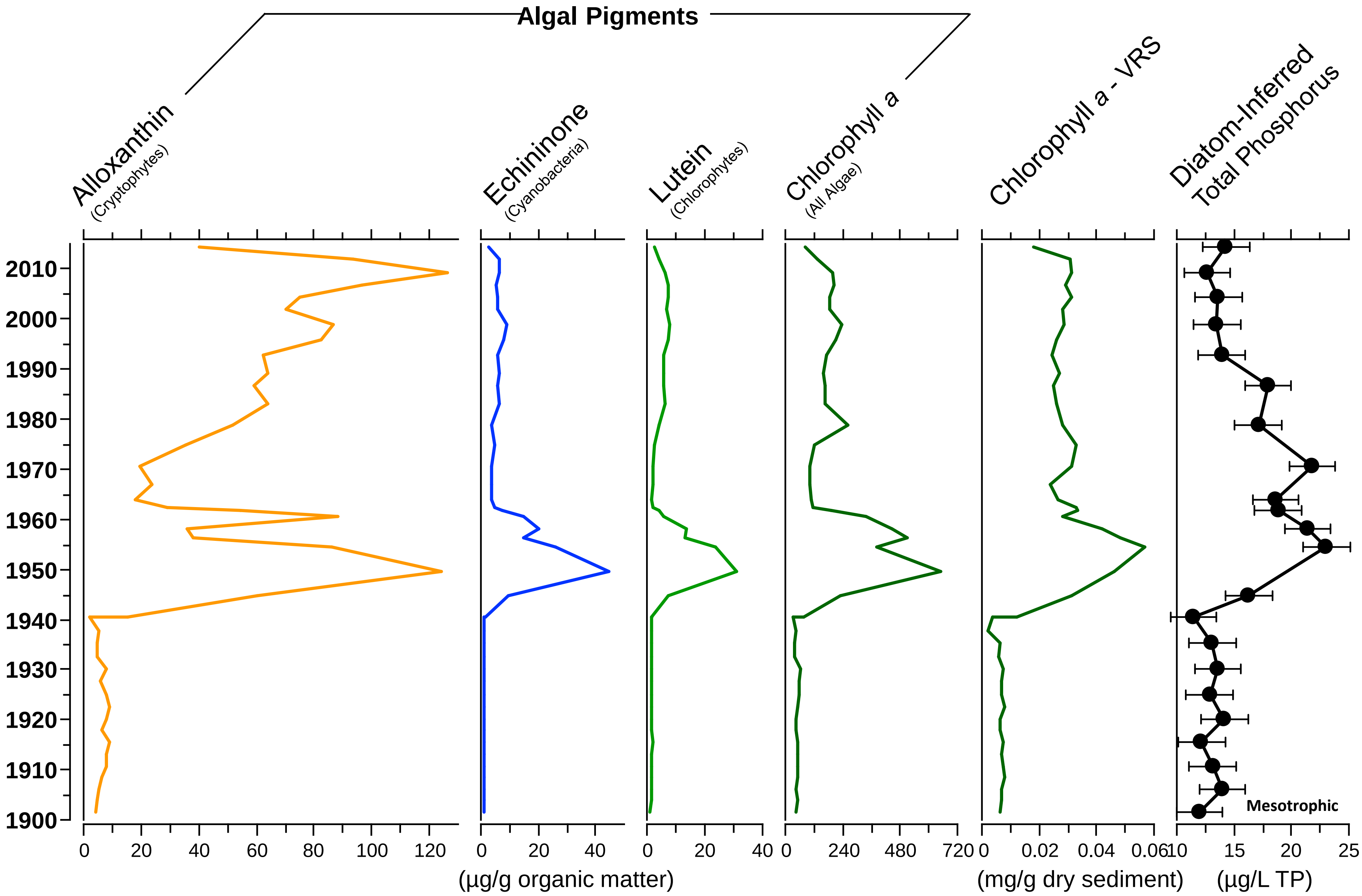
Wenatchee Lake, WA
Secondary Production



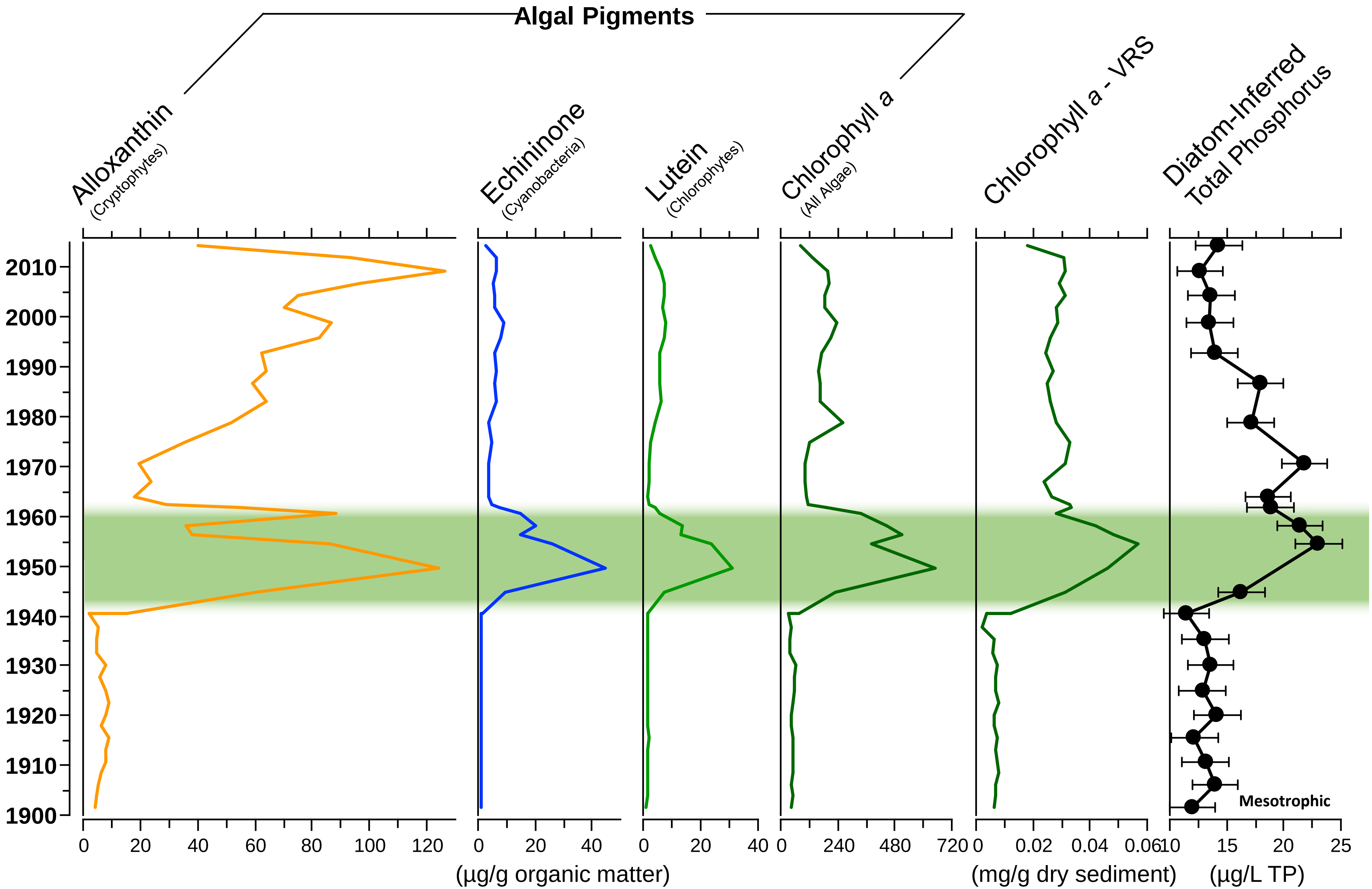
Wenatchee Lake, WA
Secondary Production



Skaha Lake, BC
Algal Production & Nutrients

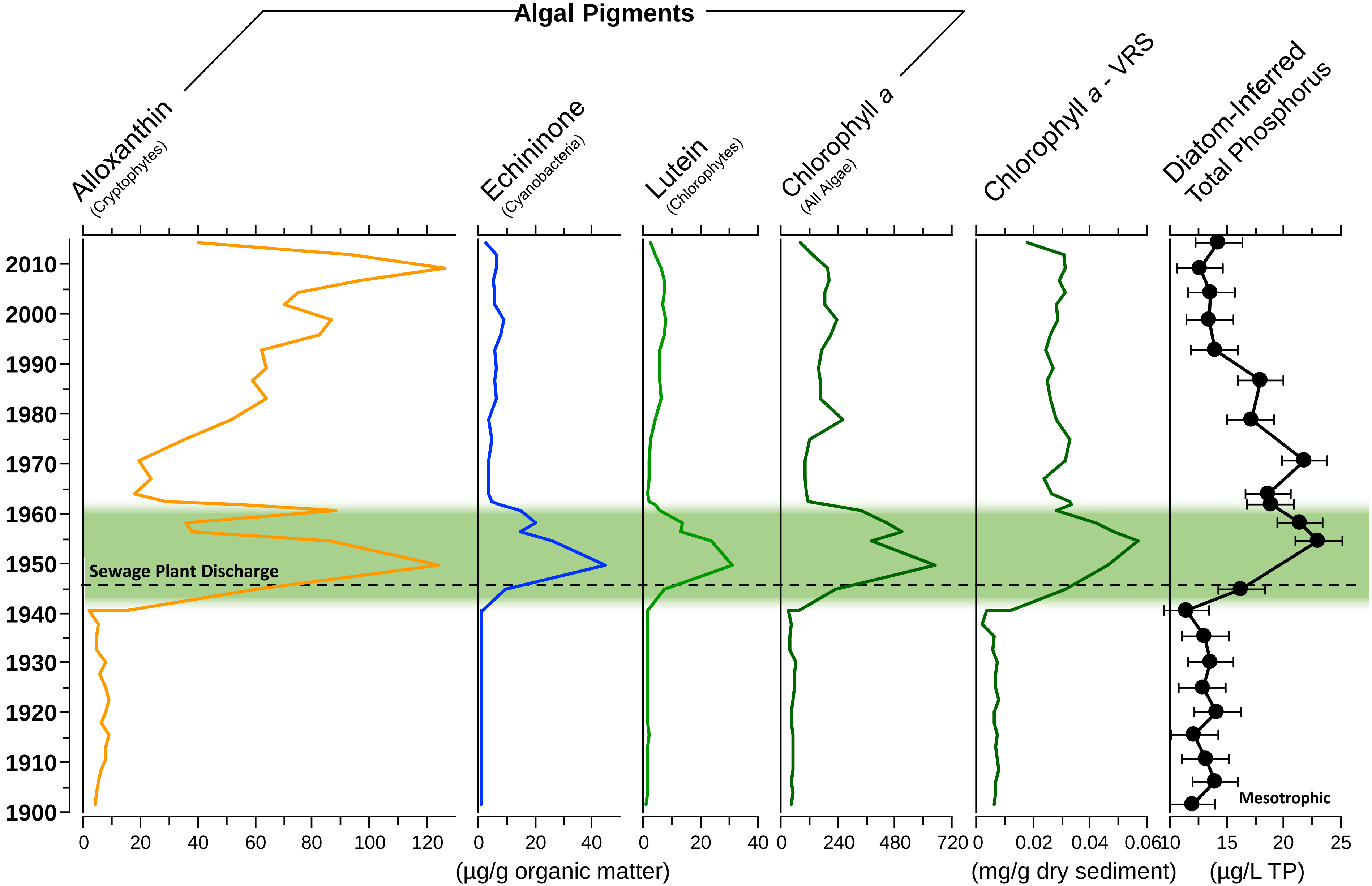


Skaha Lake, BC
Algal Production & Nutrients



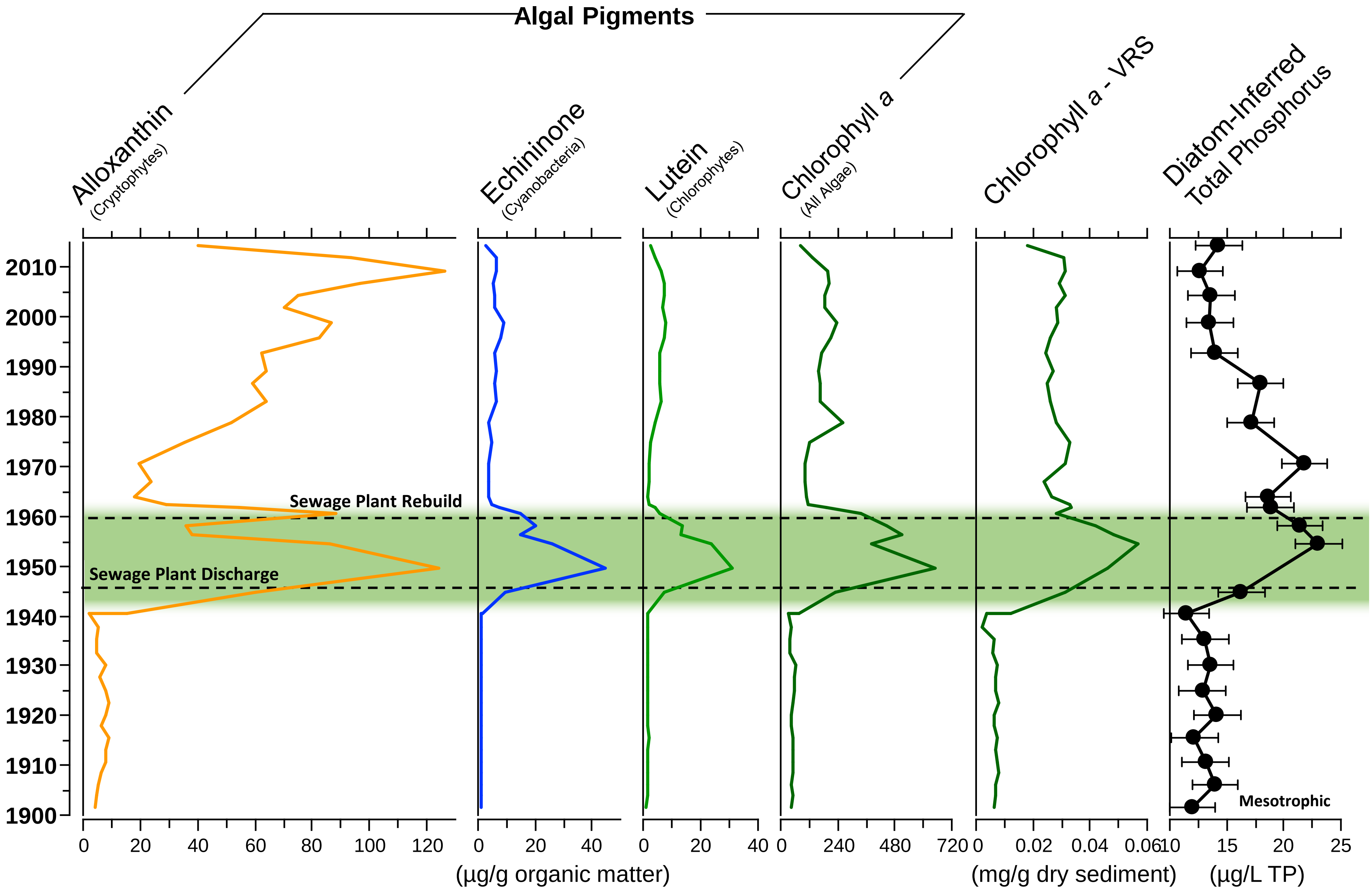
Skaha Lake, BC

Algal Production & Nutrients

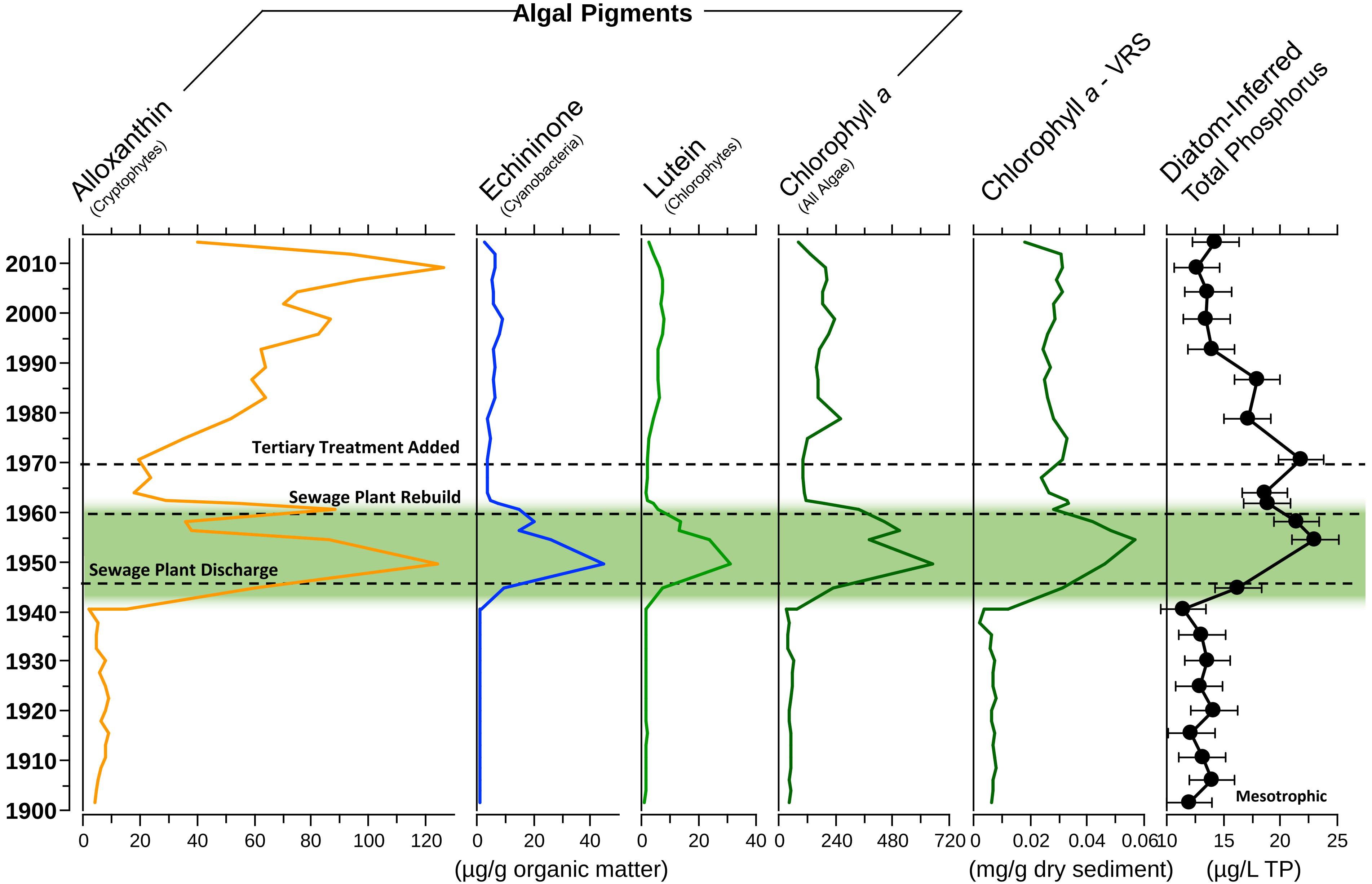


Skaha Lake, BC

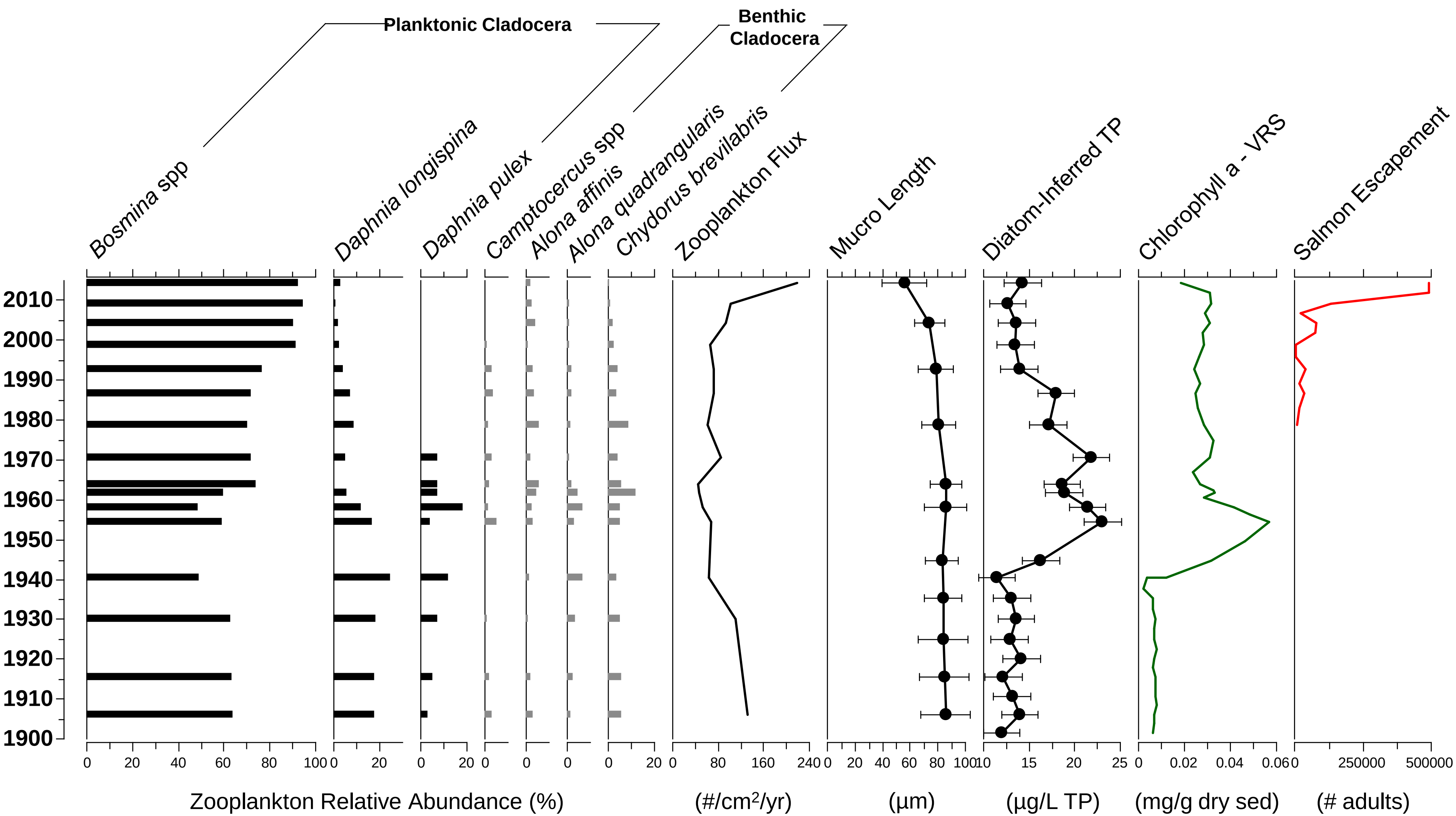
Algal Production & Nutrients



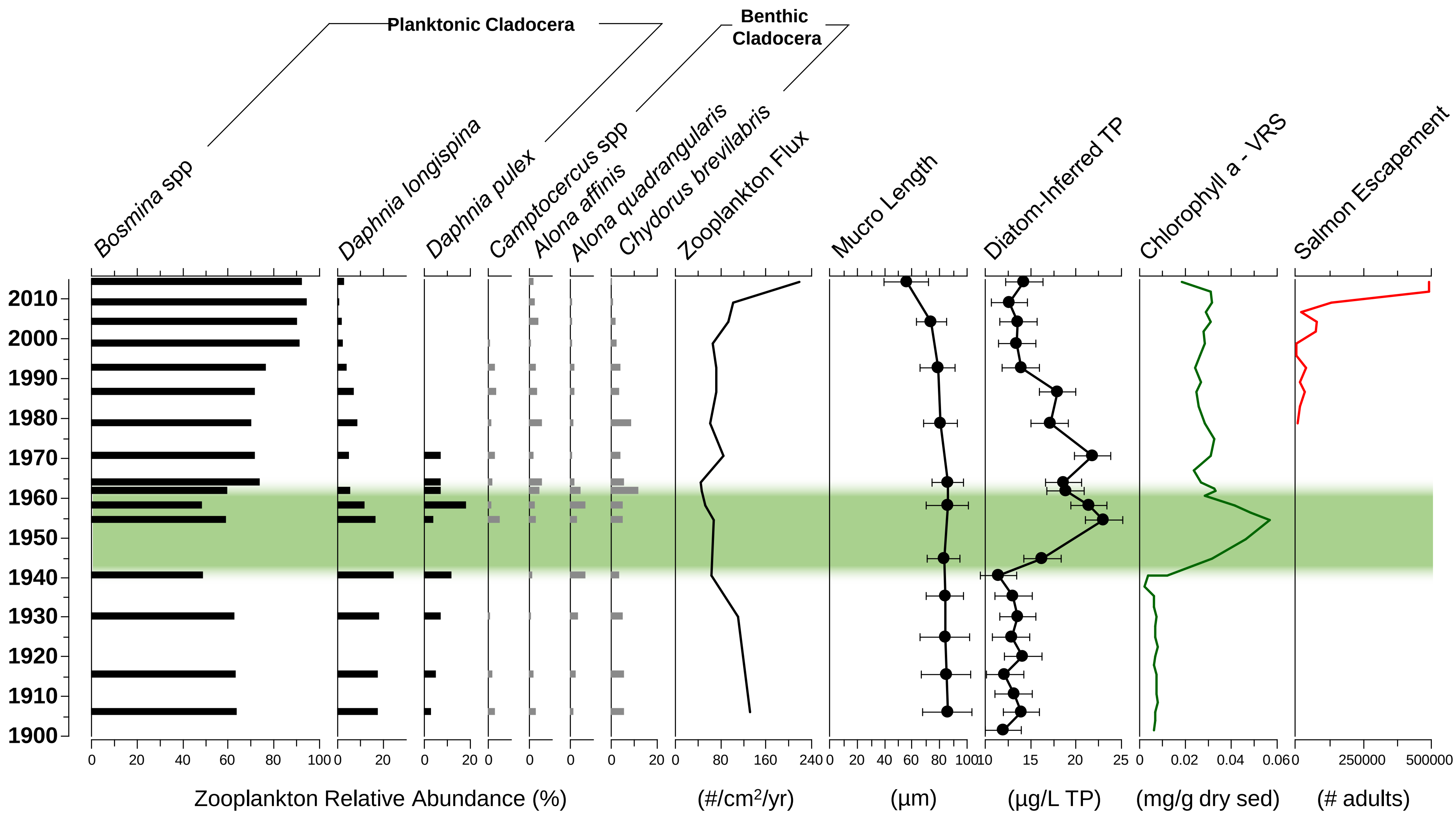
Skaha Lake, BC
Algal Production & Nutrients



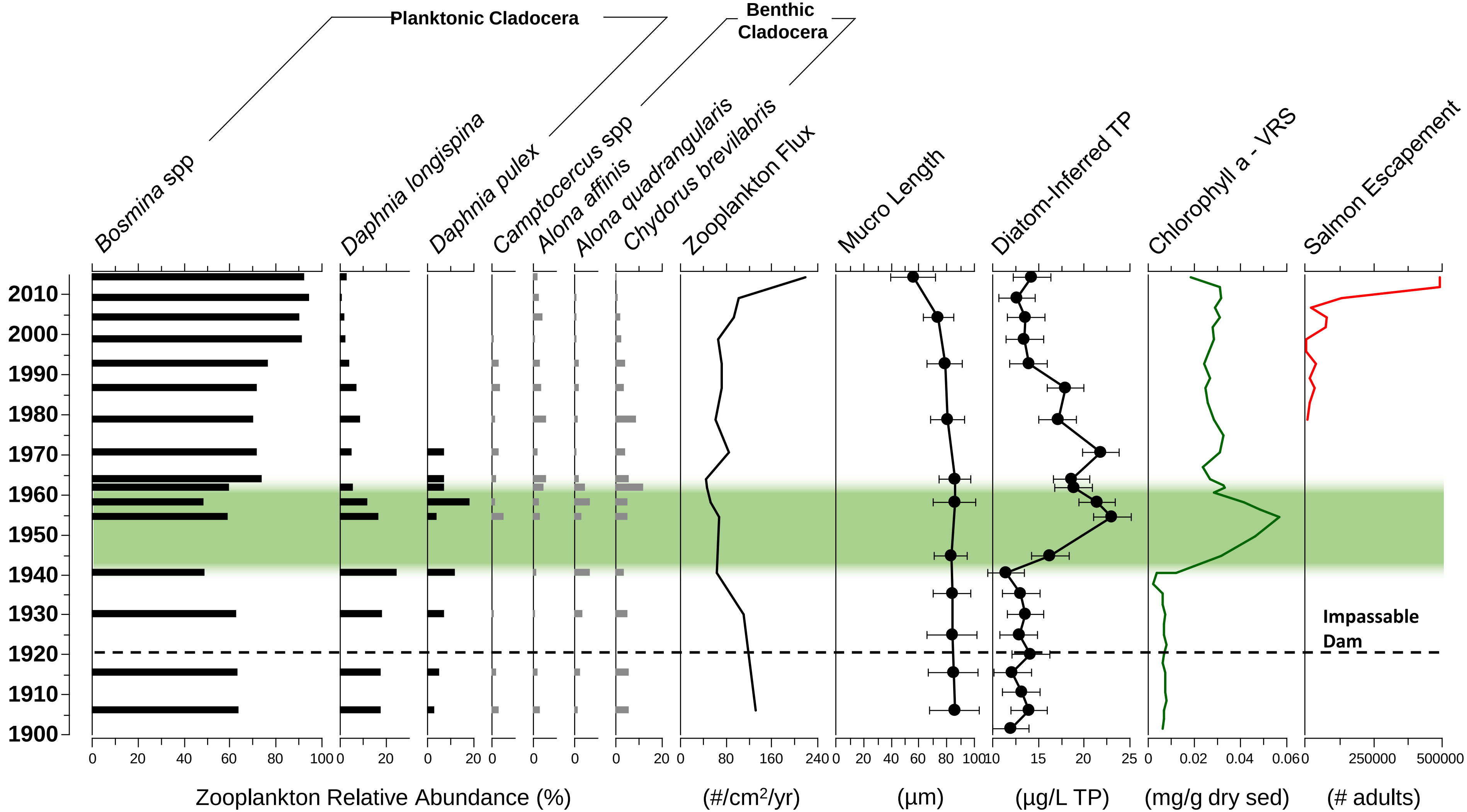
Skaha Lake, BC
Secondary Production



Skaha Lake, BC
Secondary Production

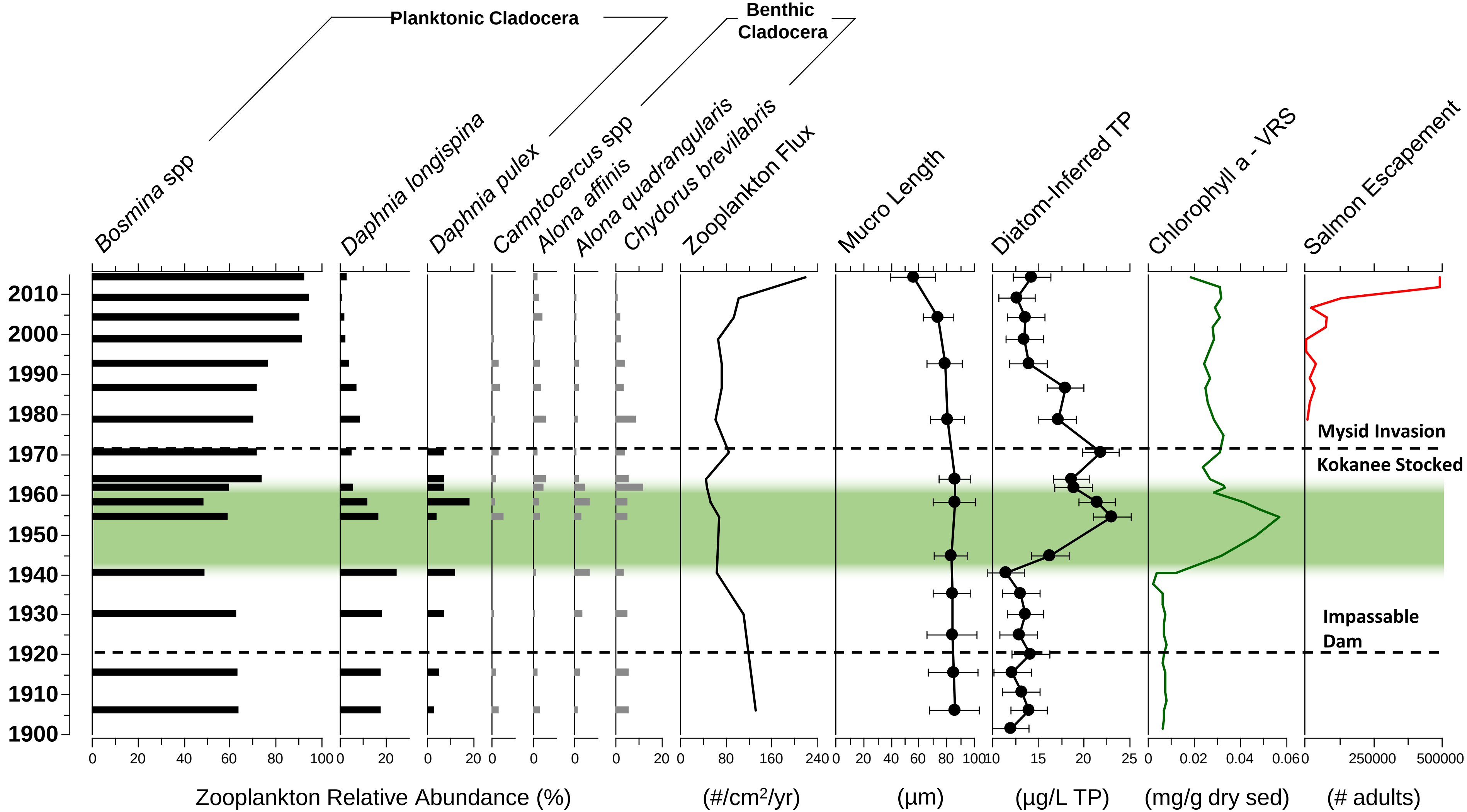


Skaha Lake, BC
Secondary Production

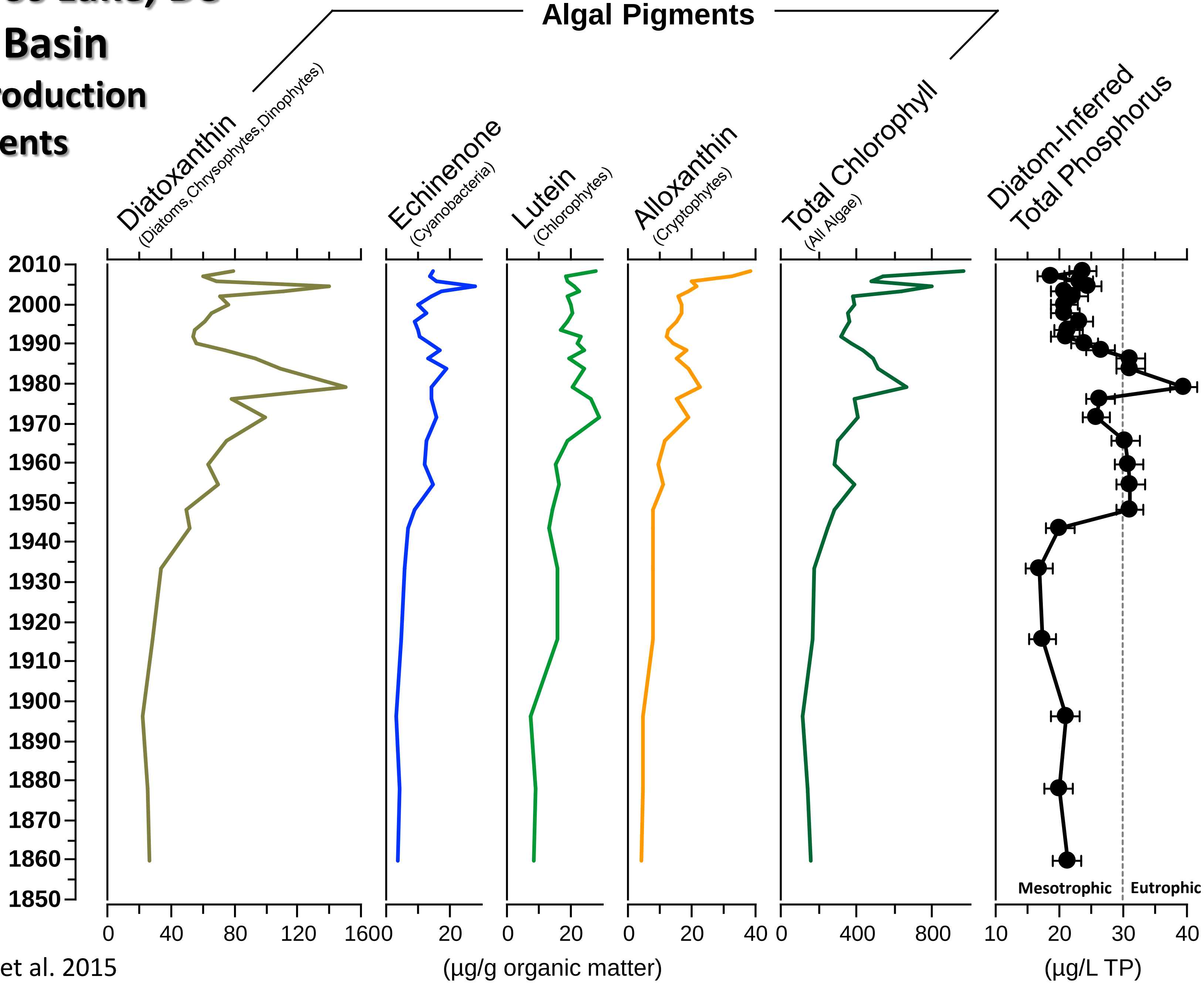


Skaha Lake, BC

Secondary Production

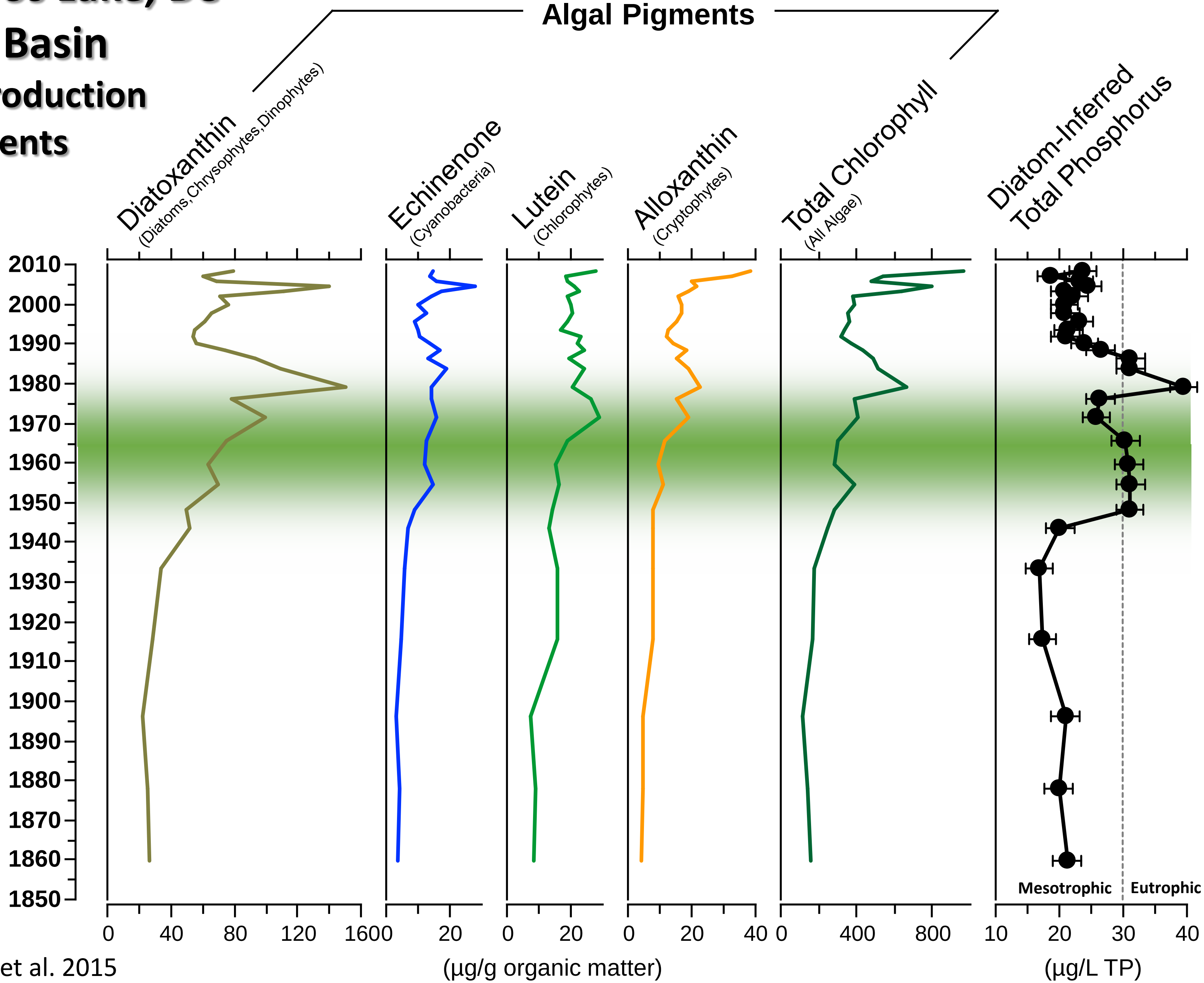


Osoyoos Lake, BC
North Basin
Algal Production & Nutrients



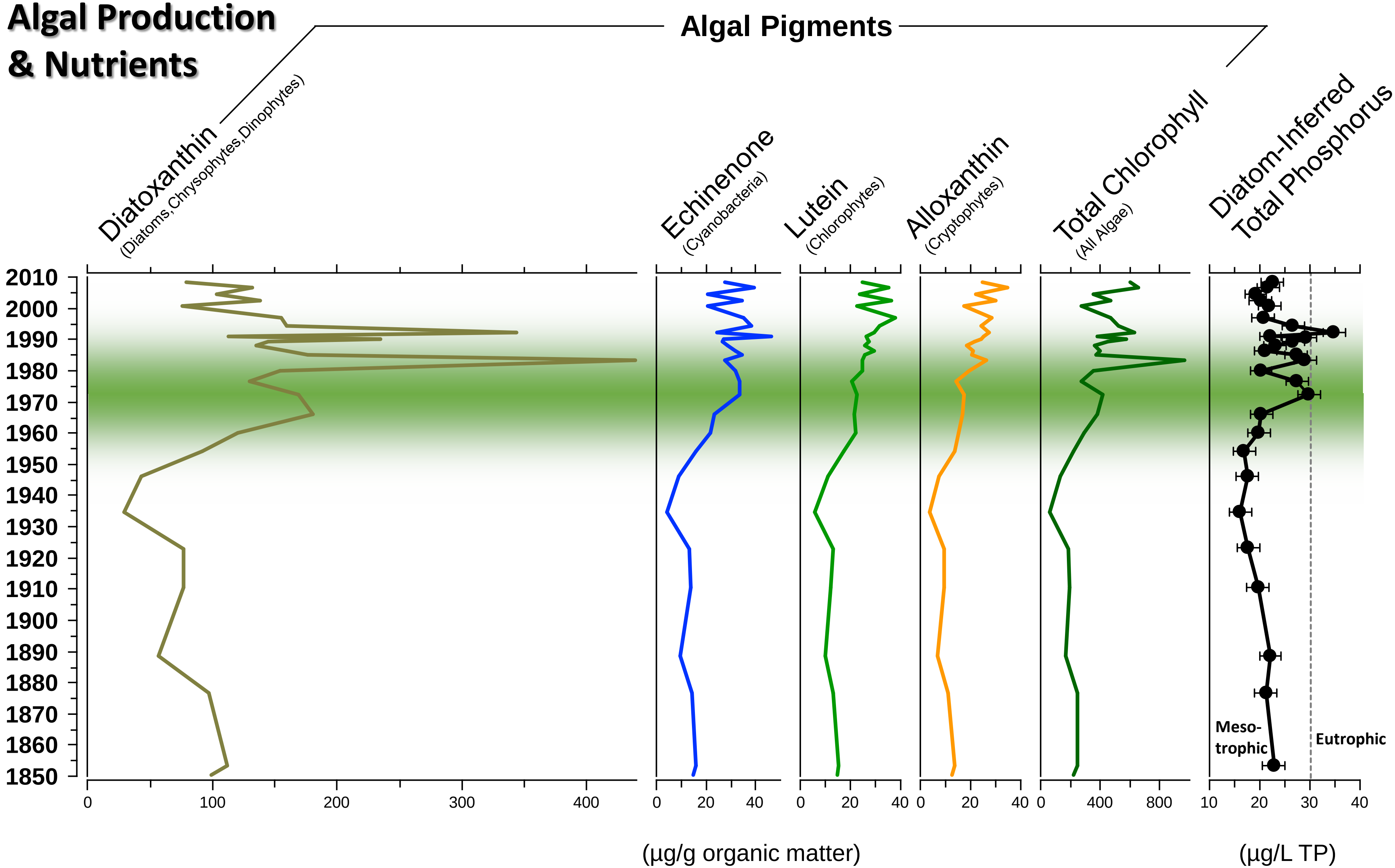
Cumming et al. 2015

Osoyoos Lake, BC
North Basin
Algal Production & Nutrients



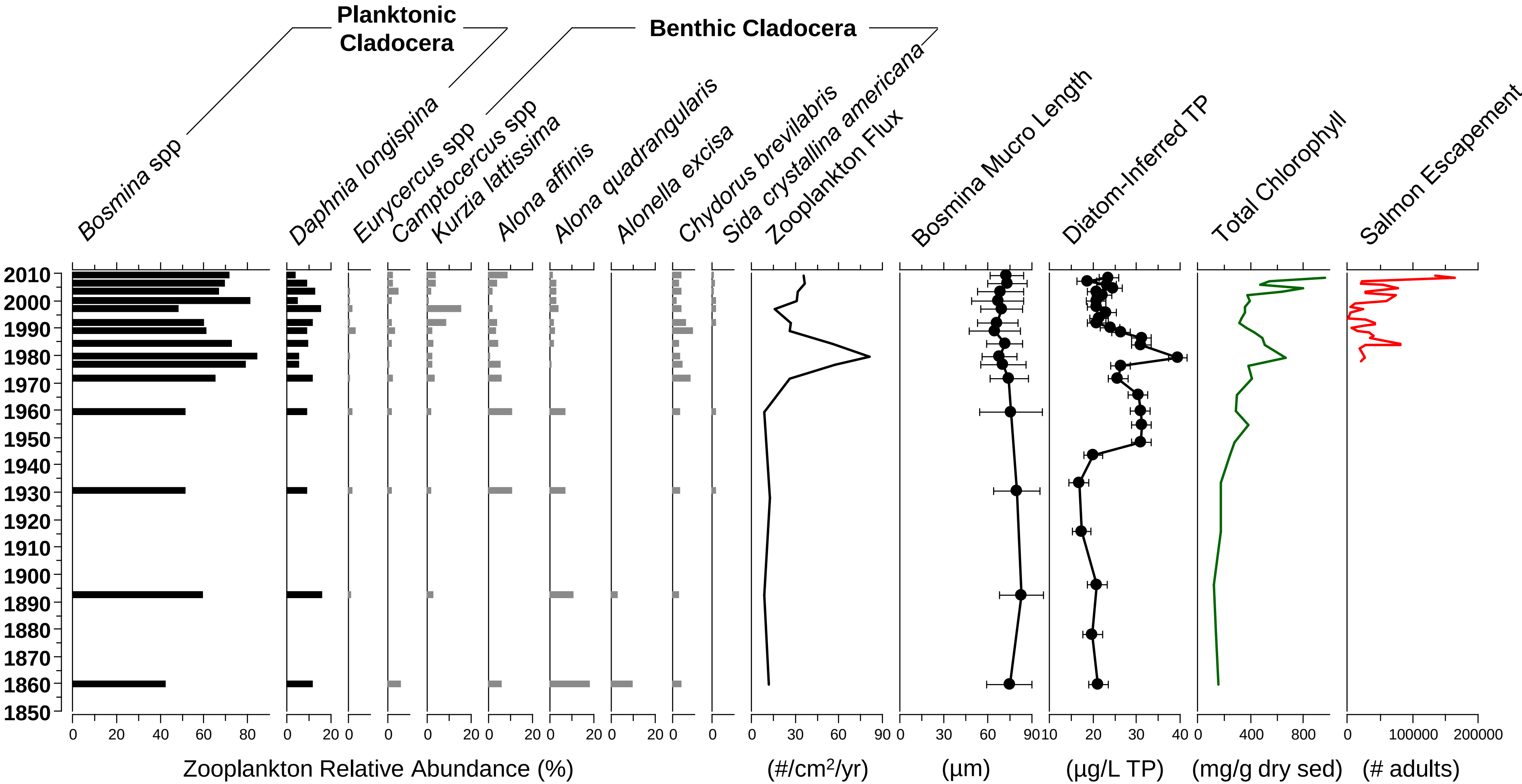
Cumming et al. 2015

Osoyoos Lake, BC
South Basin
Algal Production & Nutrients

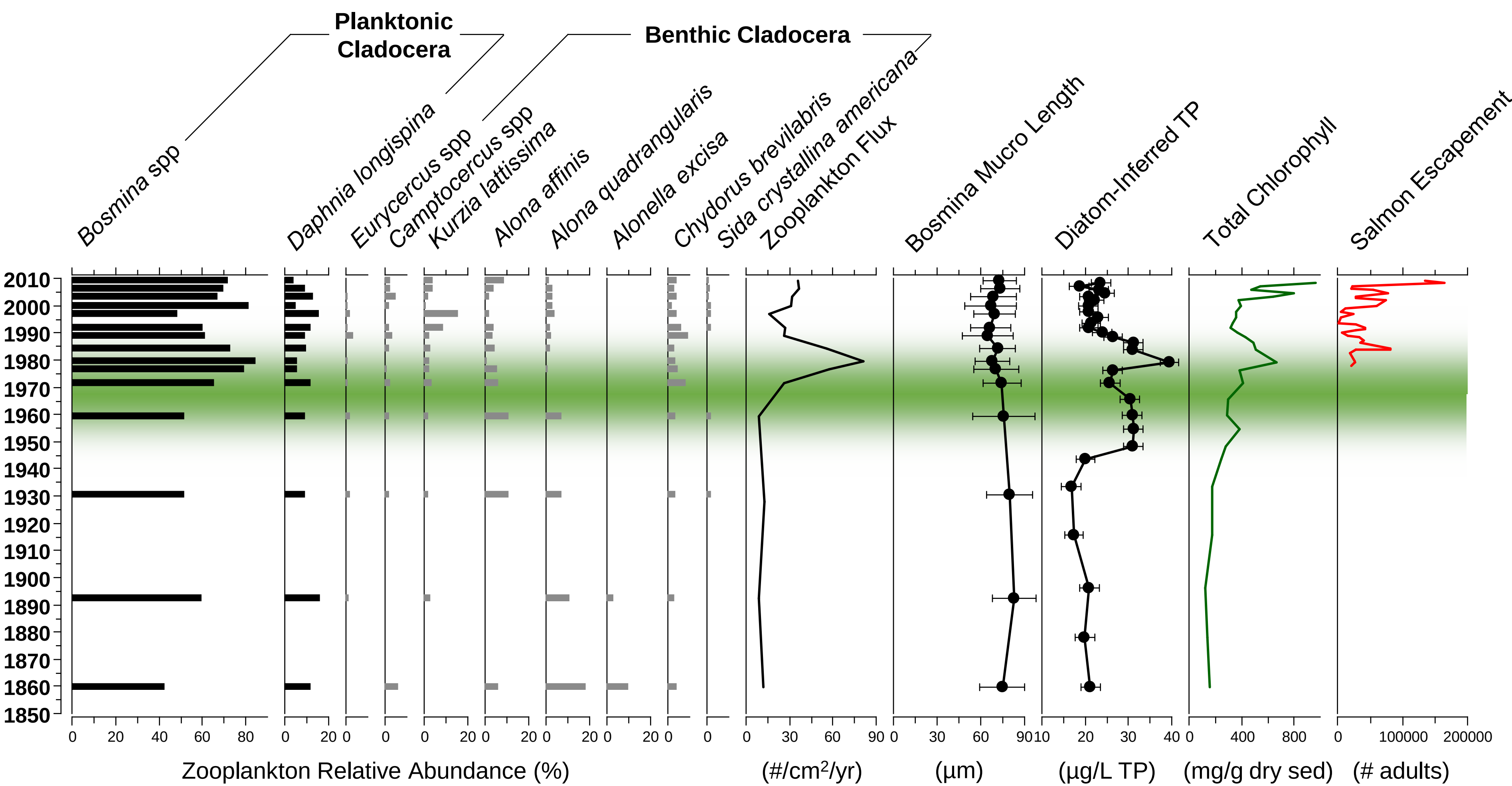


Cumming et al. 2015

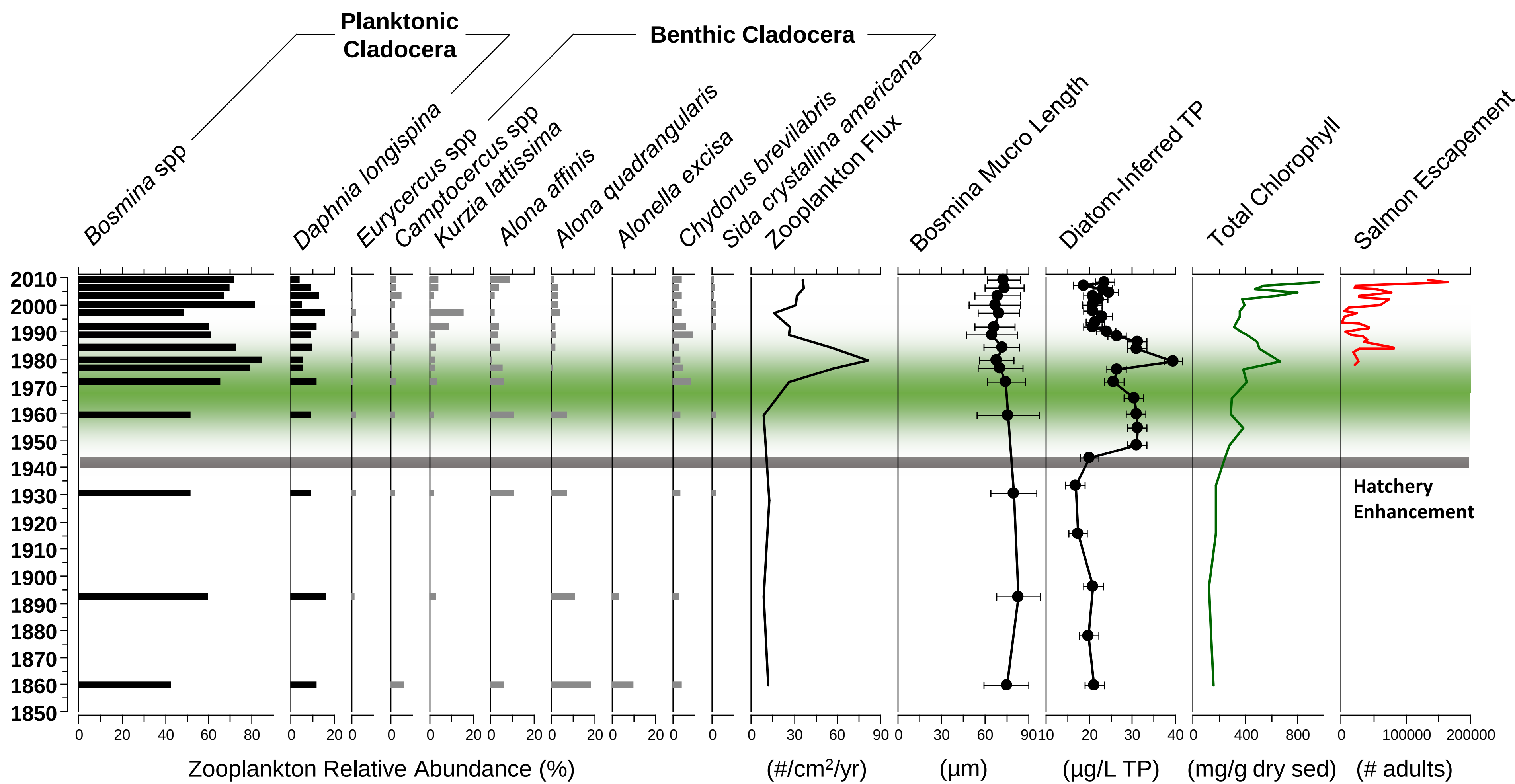
Osoyoos Lake, BC
North Basin
Secondary Production



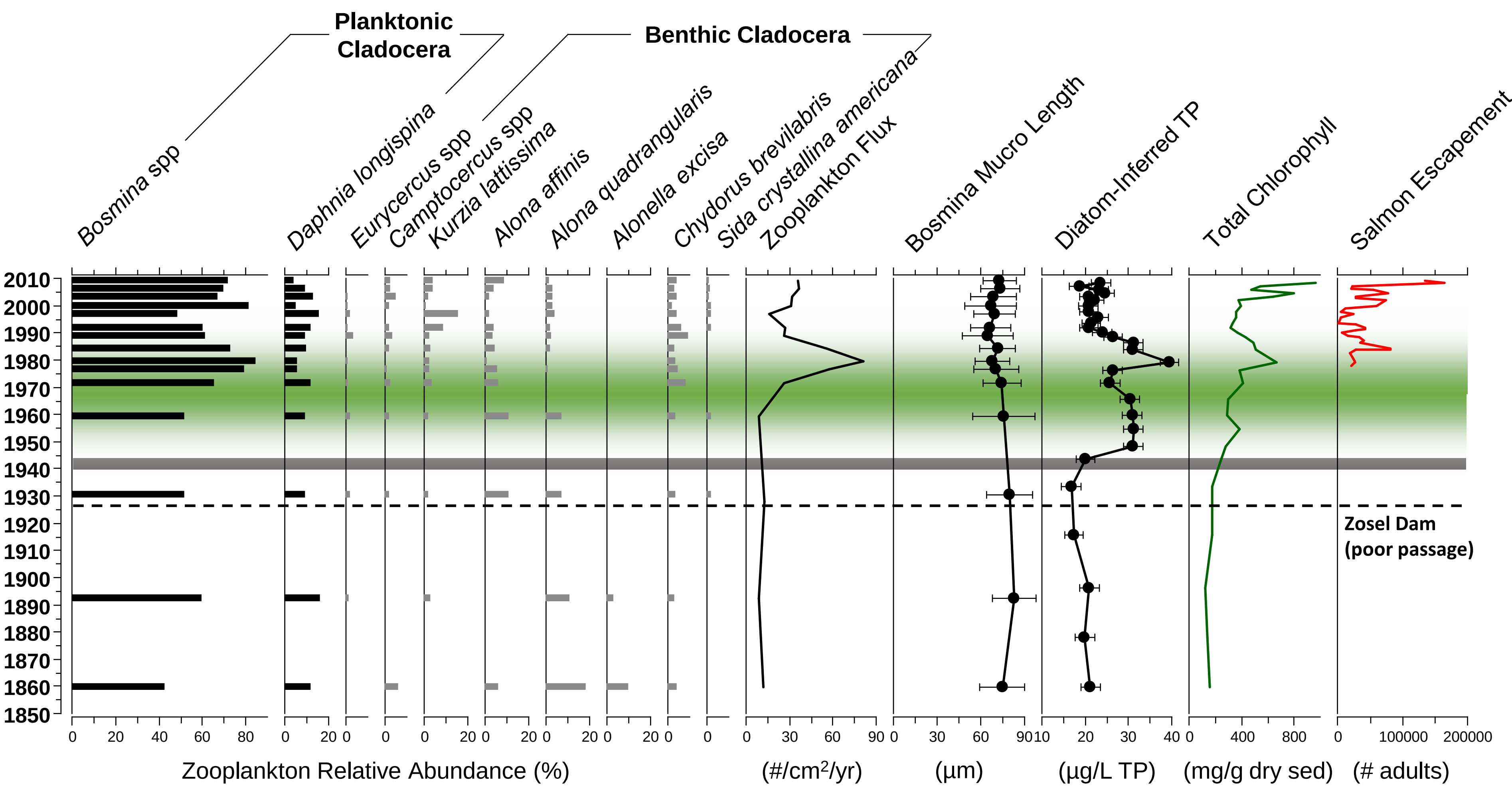
Osoyoos Lake, BC
North Basin
Secondary Production



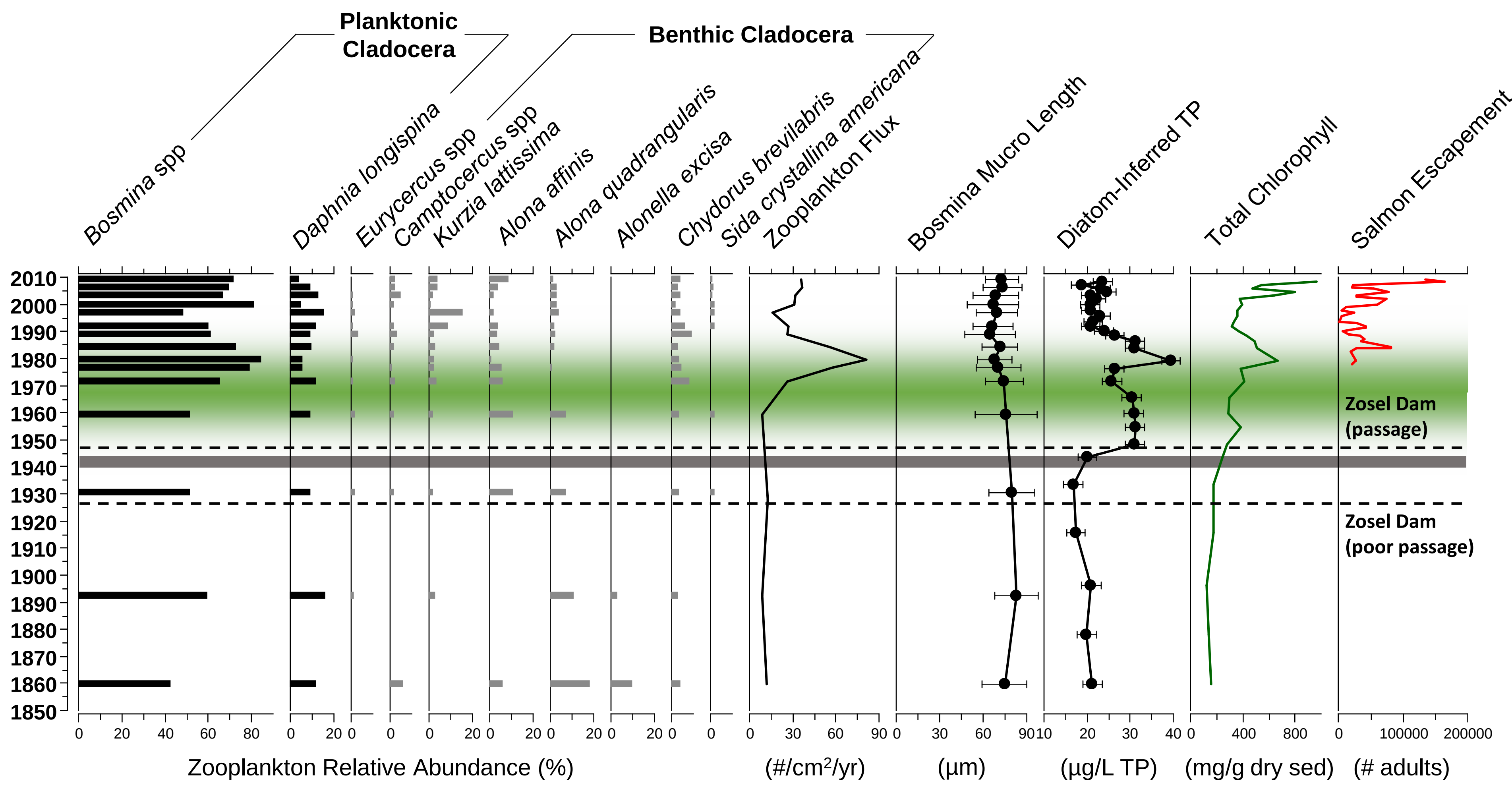
Osoyoos Lake, BC
North Basin
Secondary Production



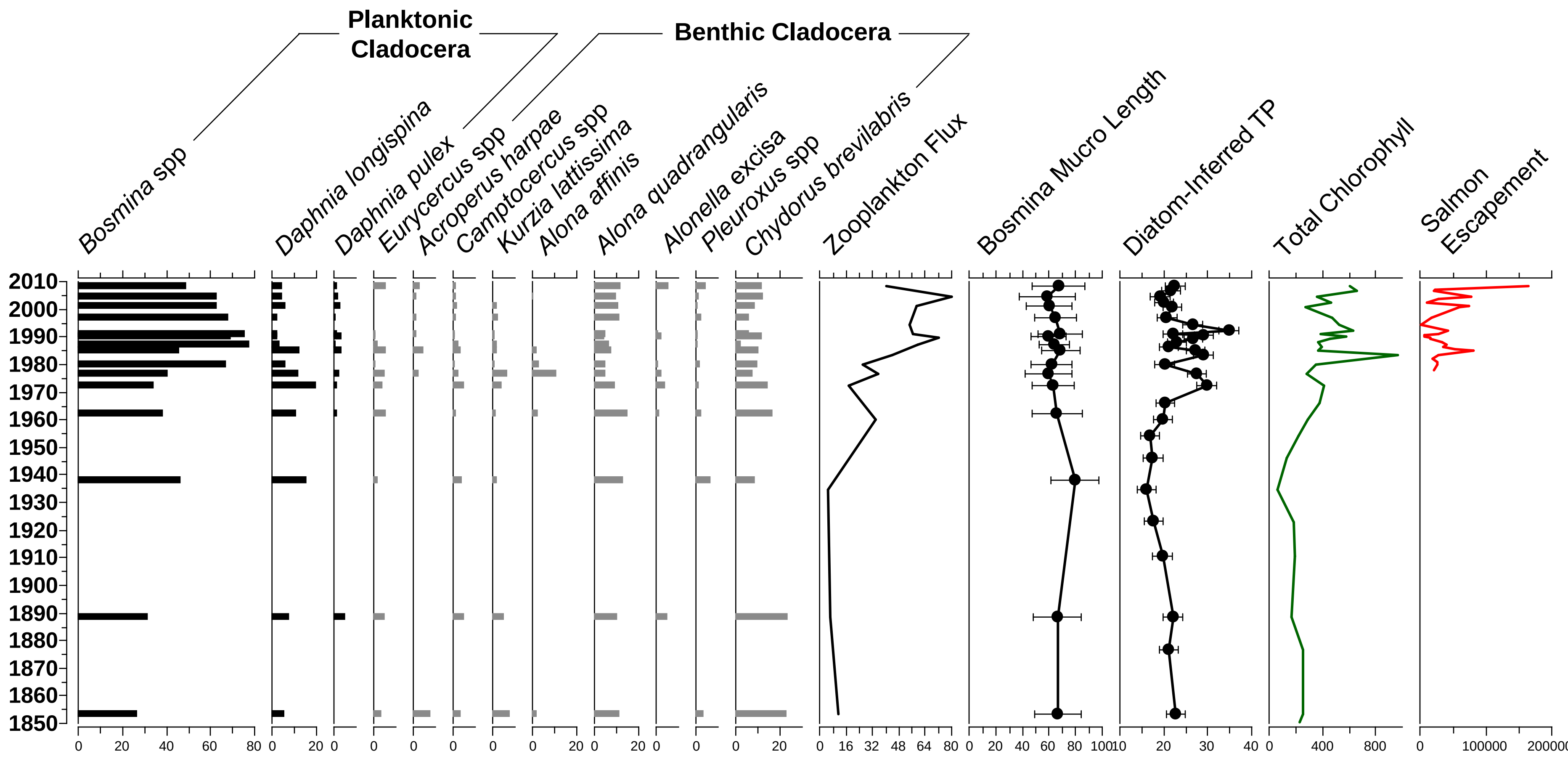
Osoyoos Lake, BC
North Basin
Secondary Production



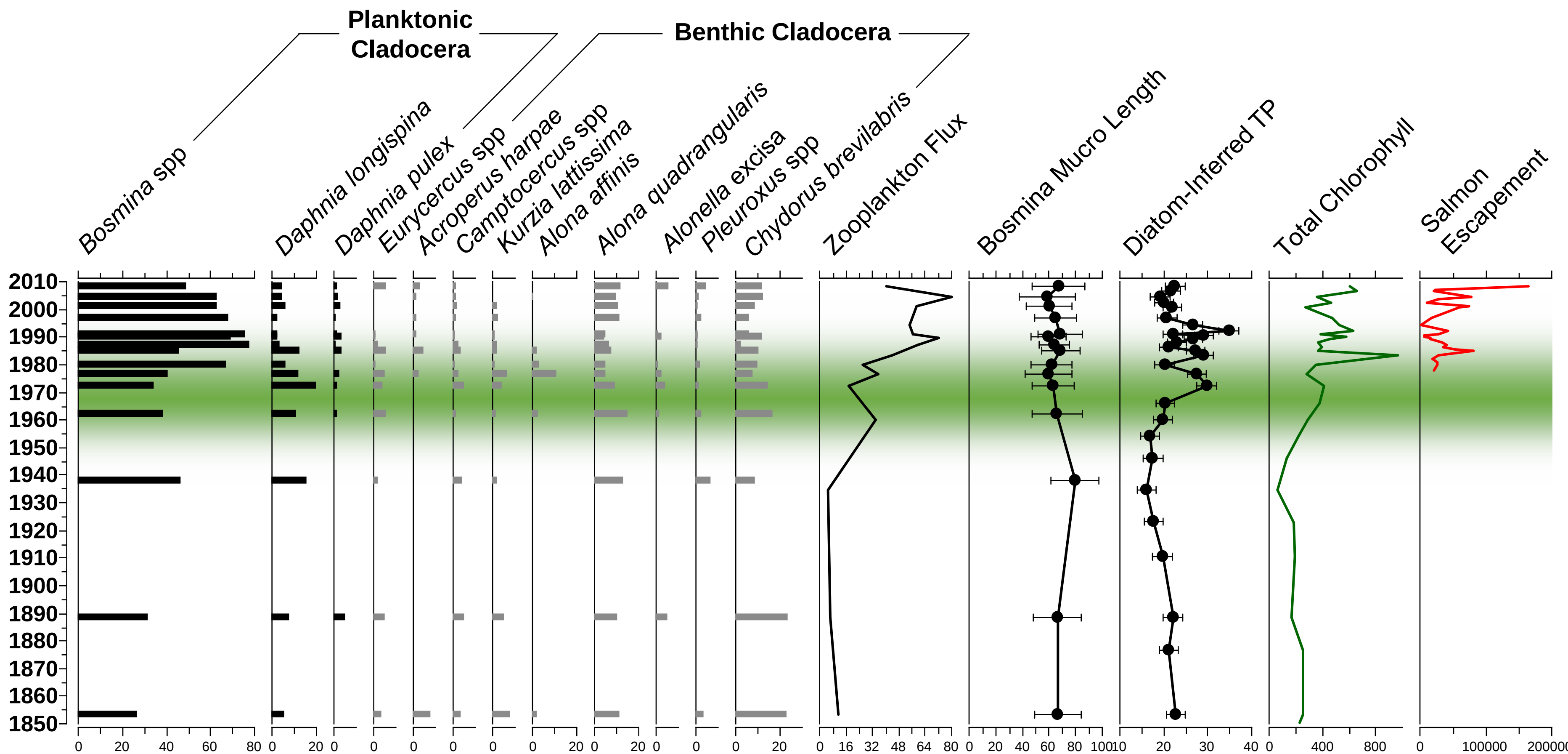
Osoyoos Lake, BC
North Basin
Secondary Production



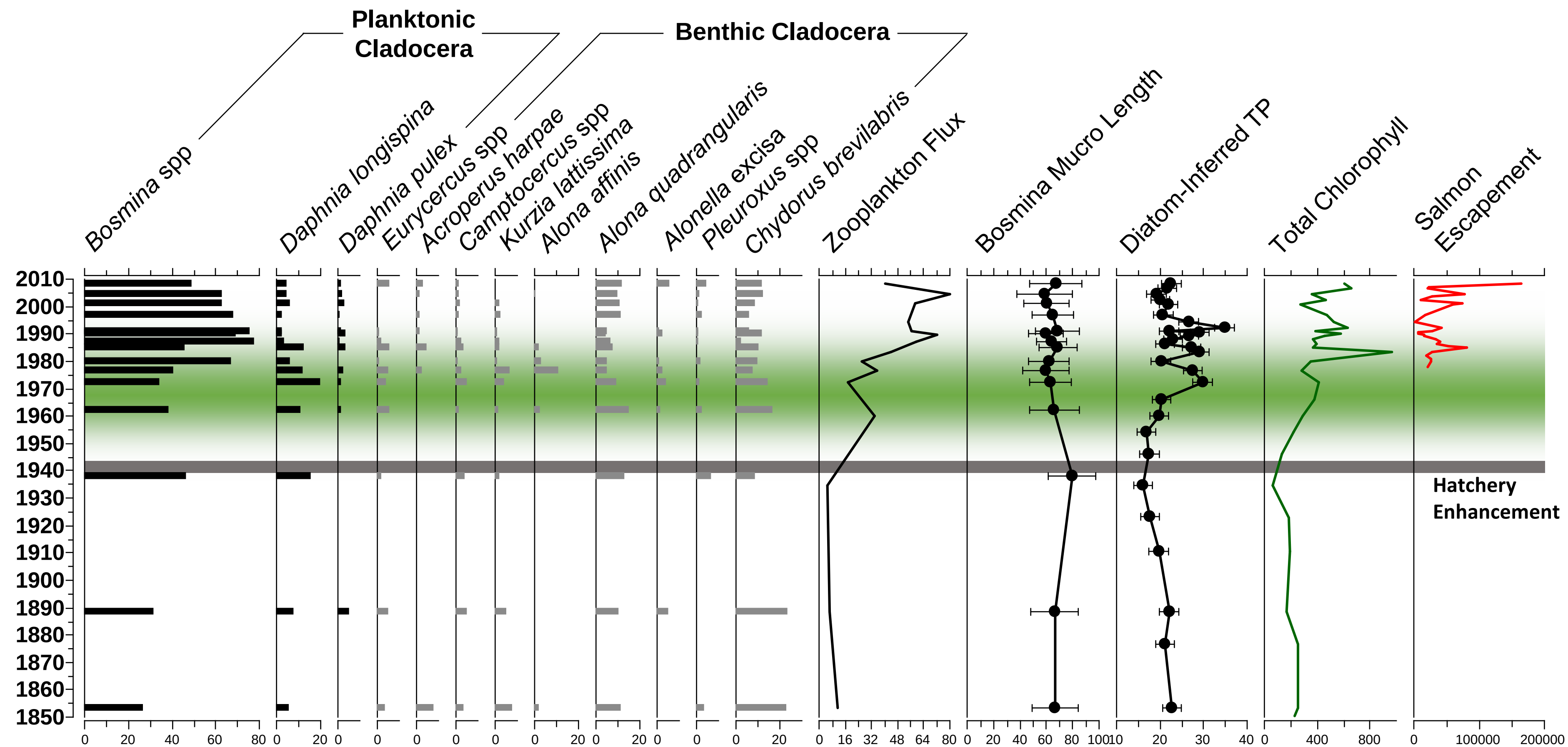
Osoyoos Lake, BC
South Basin
Secondary Production



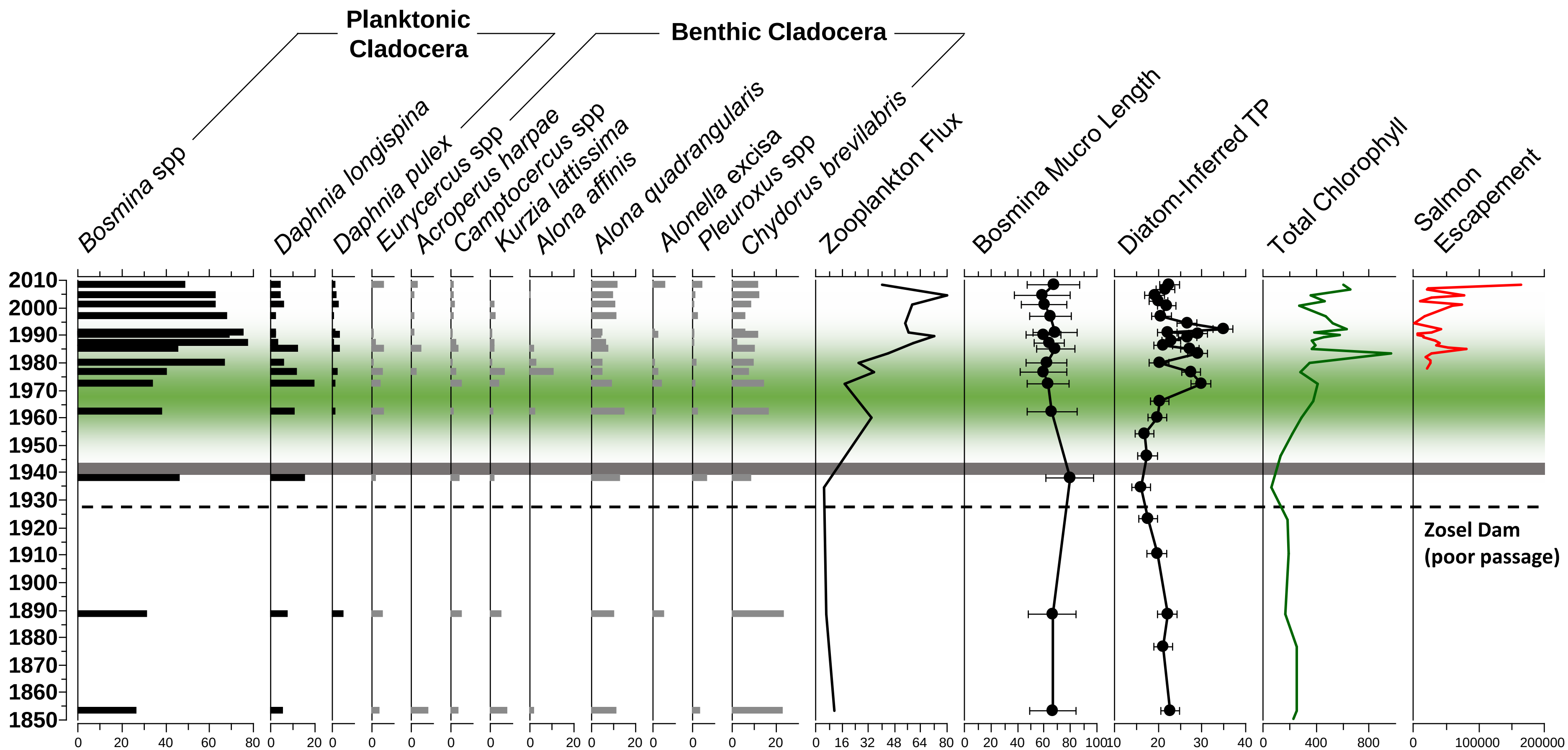
Osoyoos Lake, BC
South Basin
Secondary Production



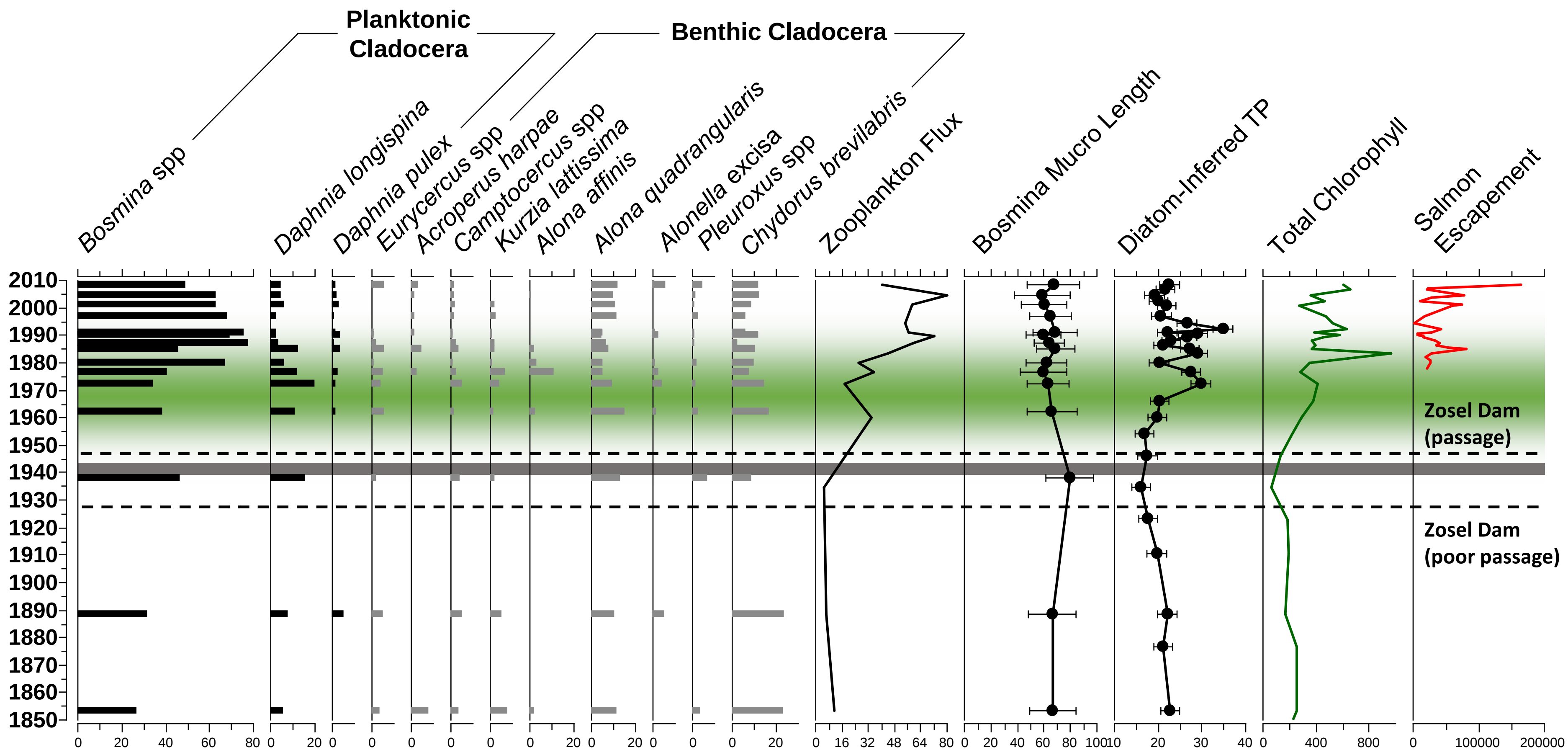
Osoyoos Lake, BC
South Basin
Secondary Production



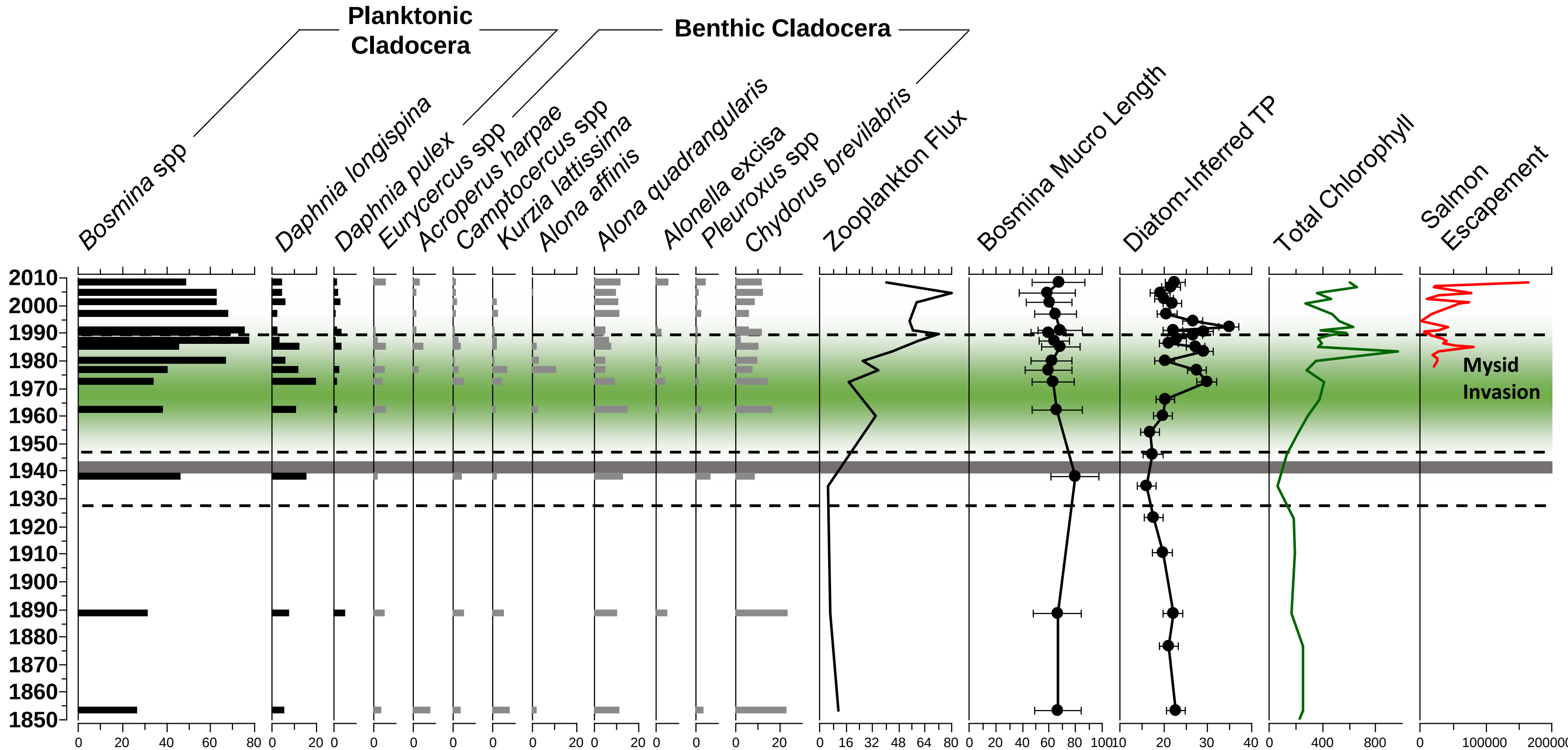
Osoyoos Lake, BC
South Basin
Secondary Production

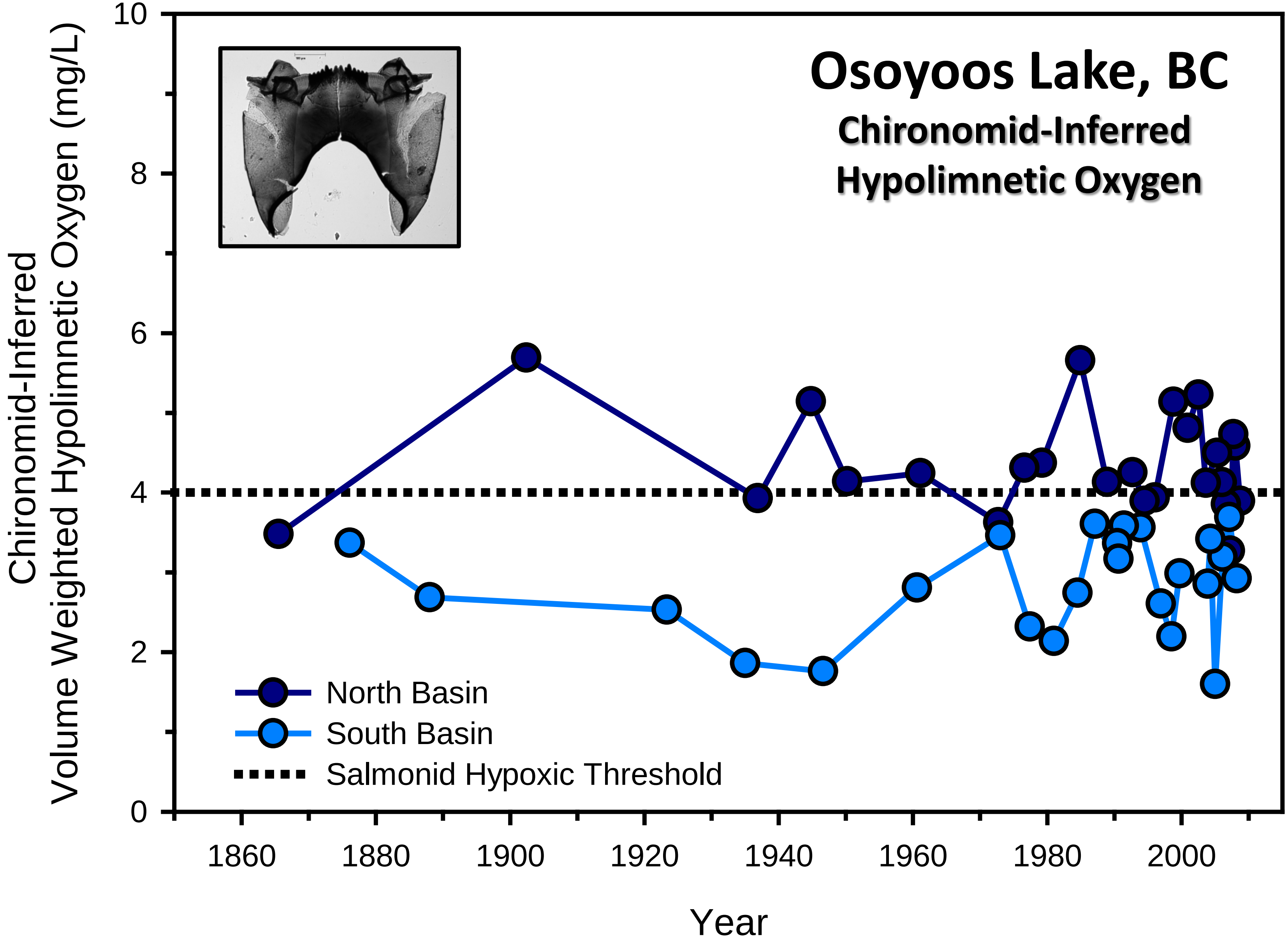


Osoyoos Lake, BC
South Basin
Secondary Production

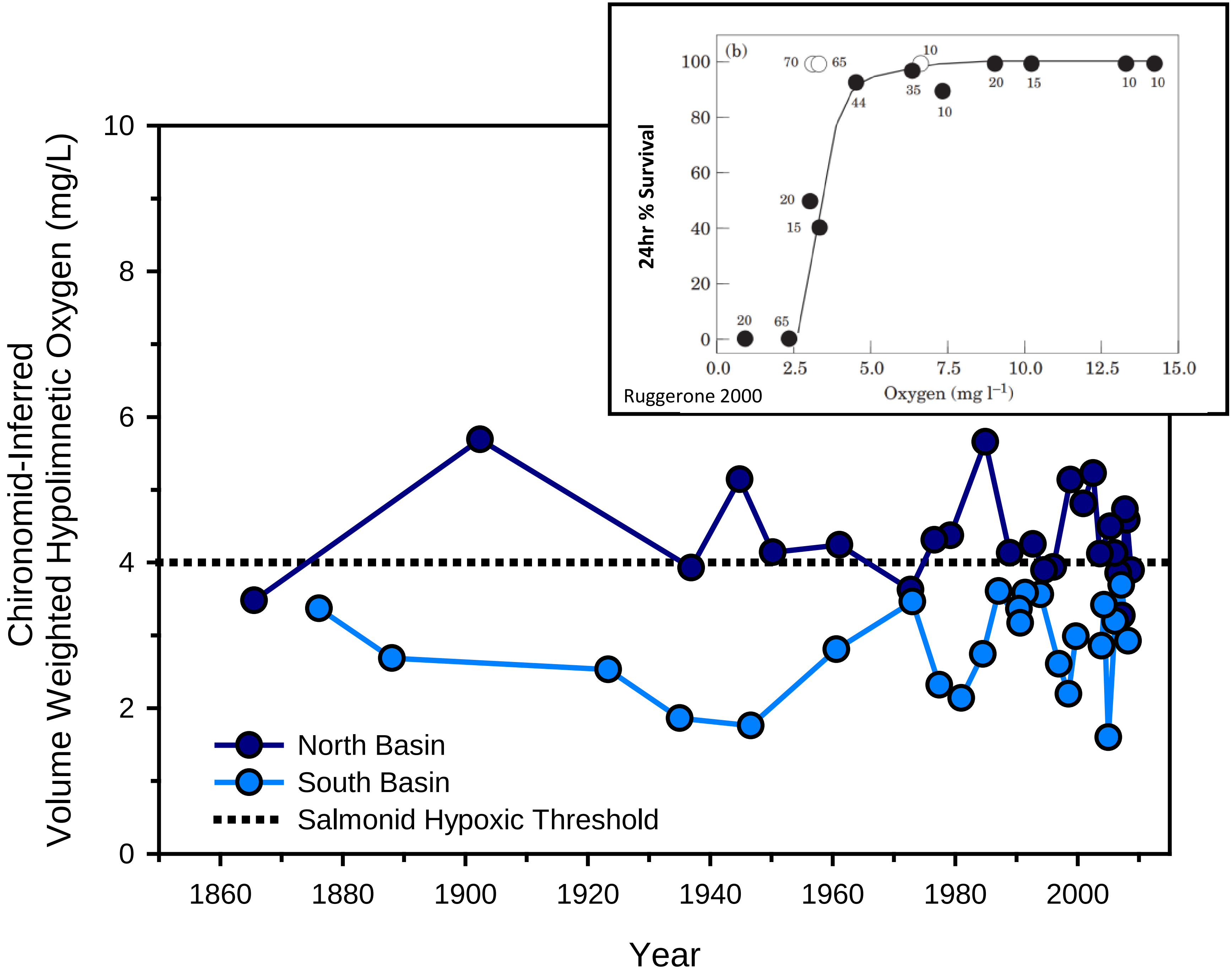


Osoyoos Lake, BC
South Basin
Secondary Production



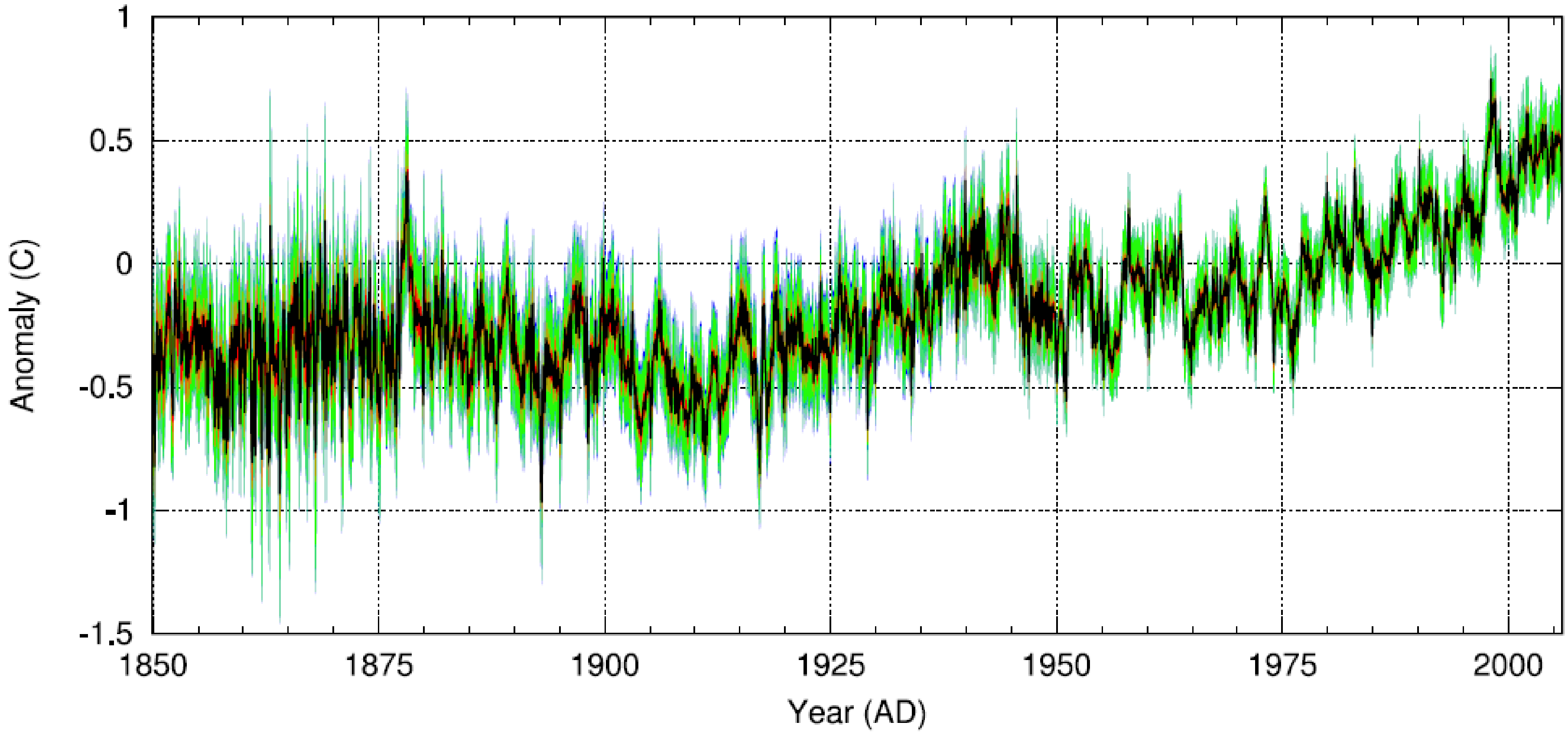


Simmatis et al. *in review*



Simmatis et al. *in review*

“The Game Changer”
Climate Change



Mean monthly global temperature anomalies relative to the 1961-1990 period

Brohan et al. 2006; J. Geophys. Res. 111: D12106

Climate Forcing of Lake Ecology

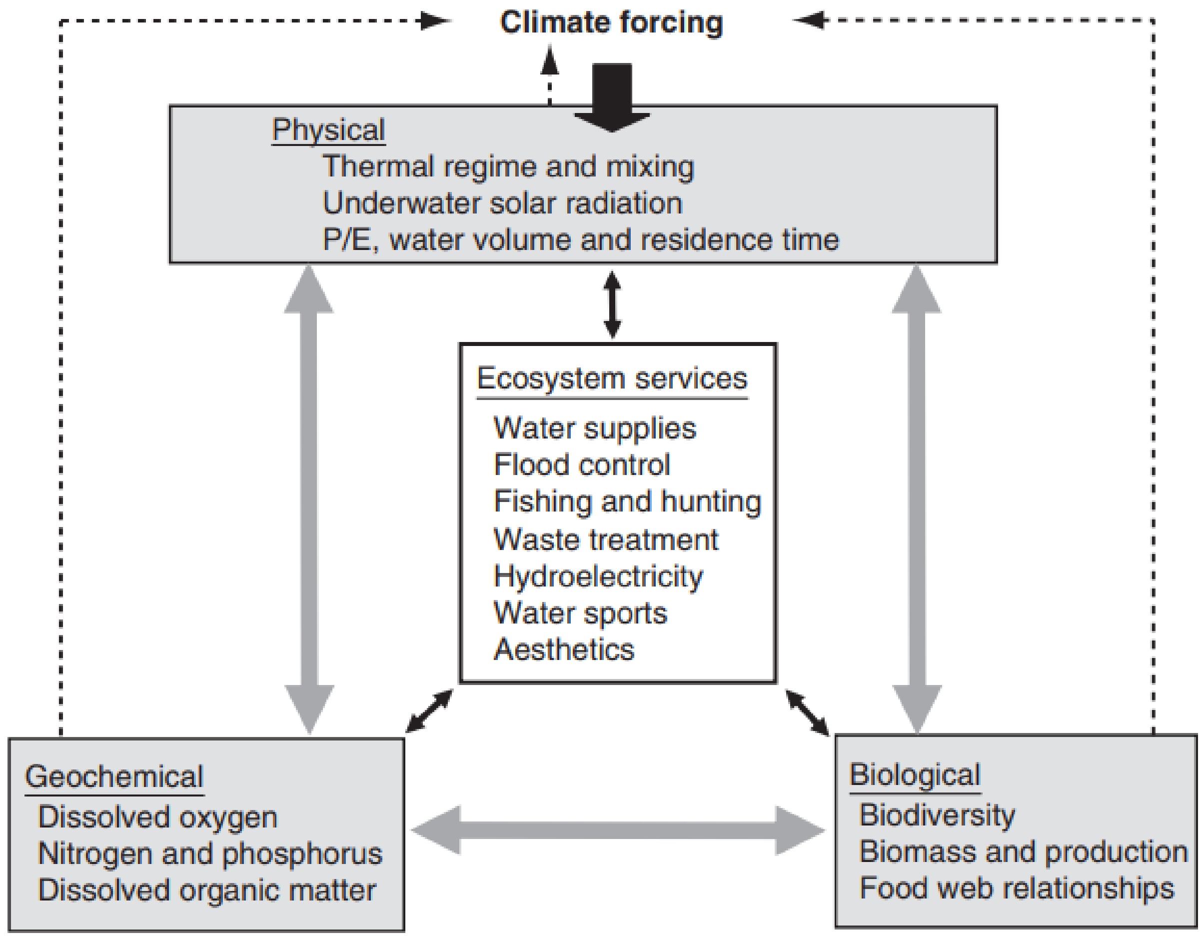
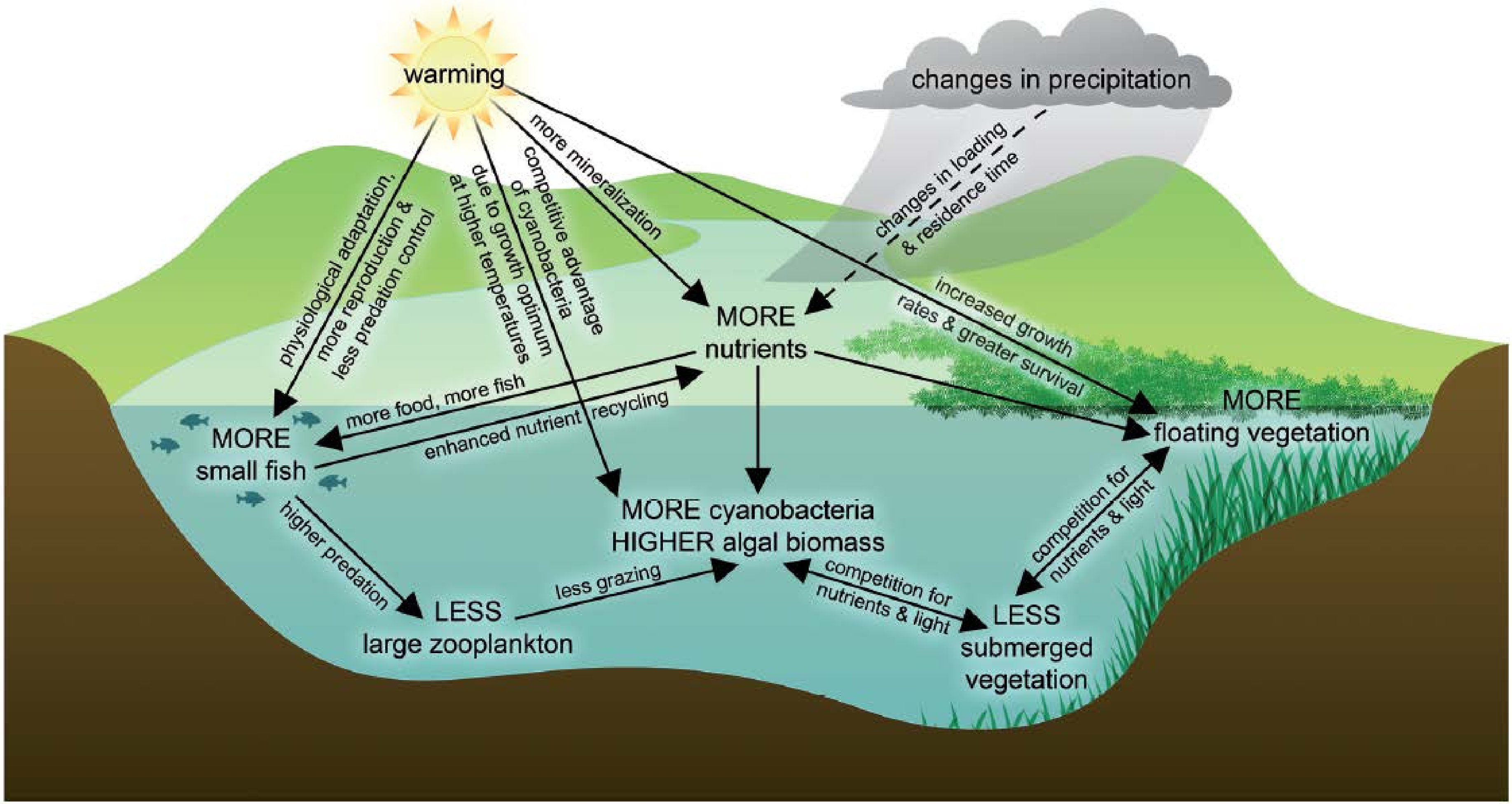


Figure 1 Changes in climate forcing affect the physical environment of lake ecosystems and thereby alter their chemical and biological properties. These changes affect the capacity of lakes to provide ecosystem services. P/E, precipitation to evaporation ratio. Dotted lines indicate positive feedback effects, e.g., via decreased ice cover or the release of greenhouse gases from lakes into the atmosphere.

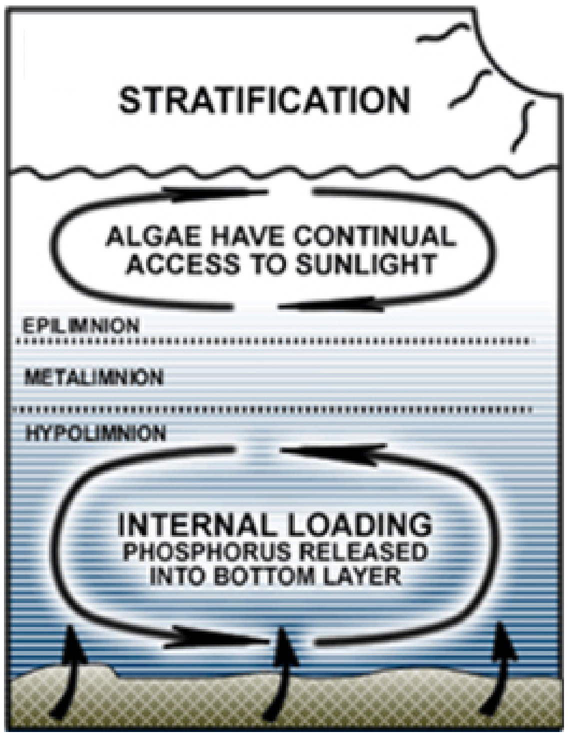
Modified from Vincent 2009

Climate Change & Eutrophication
Interactive Lake Forcings



Modified from Moss et al. 2011

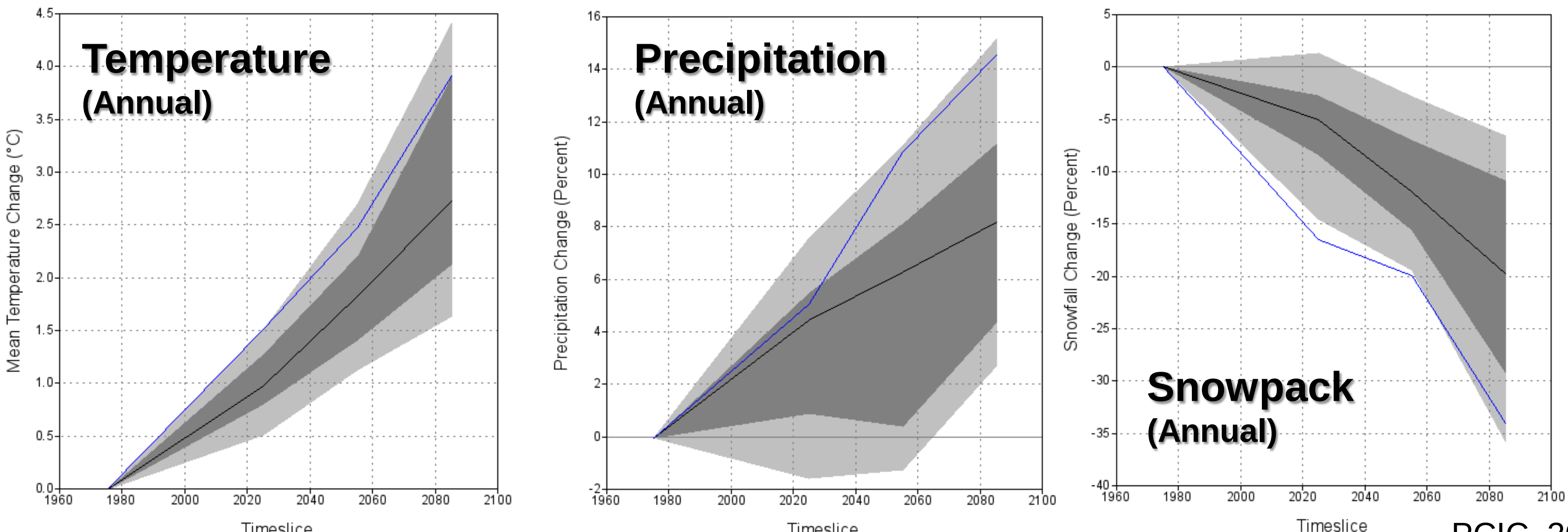
Internal Nutrient Loading



- **Internal Loading**
  - Release of limiting nutrients from sediment stores (phosphorus (P), ammonia (N))
- **Causes**
  - Oxygen loss at the sediment-water interface
  - Aerobic microbial decomposition of organic matter (e.g. dead algae, plants, animals)
- **Implications**
  - Release of “stored” nutrients from sediments
  - Increased algal and plant growth (first modest, then rapid)
  - Potential for positive feedback/runaway eutrophication
  - Changes to lake ecosystem structure & functioning

Summary of Climate Change for Thompson / Okanagan in the 2080s

Climate Variable	Season	Projected Change from 1961-1990 Baseline	
		Ensemble Median	Range (10th to 90th percentile)
Mean Temperature (°C)	Annual	+2.7 °C	+1.6 °C to +4.4 °C
Precipitation (%)	Annual	+8%	+3% to +15%
	Summer	-10%	-28% to +1%
	Winter	+11%	+3% to +26%
Snowfall* (%)	Winter	-16%	-38% to -5%
	Spring	-74%	-89% to -14%
Growing Degree Days* (degree days)	Annual	+511 degree days	+280 to +878 degree days
Heating Degree Days* (degree days)	Annual	-975 degree days	-1541 to -581 degree days
Frost-Free Days* (days)	Annual	+36 days	+19 to +60 days



PCIC, 2018

SUMMARY

- Okanagan & Wenatchee Basins
  - Broad-scale & diverse FW habitat changes
- Wenatchee Lake
  - Minor lake enrichment
  - Remains oligotrophic
- Osoyoos & Skaha Lakes
  - Cultural eutrophication history
  - New lake “state” induced by eutrophication
  - Likely magnification of eutrophication symptoms by climate change
- Climate Change Futures
  - Winners and losers
  - Osoyoos - Internal loading, hypolimnetic oxygen, surface temps.

Acknowledgements

Photo courtesy of N. Fobes

Bonneville Power Administration

Grant County Public Utility District

Chelan County Public District

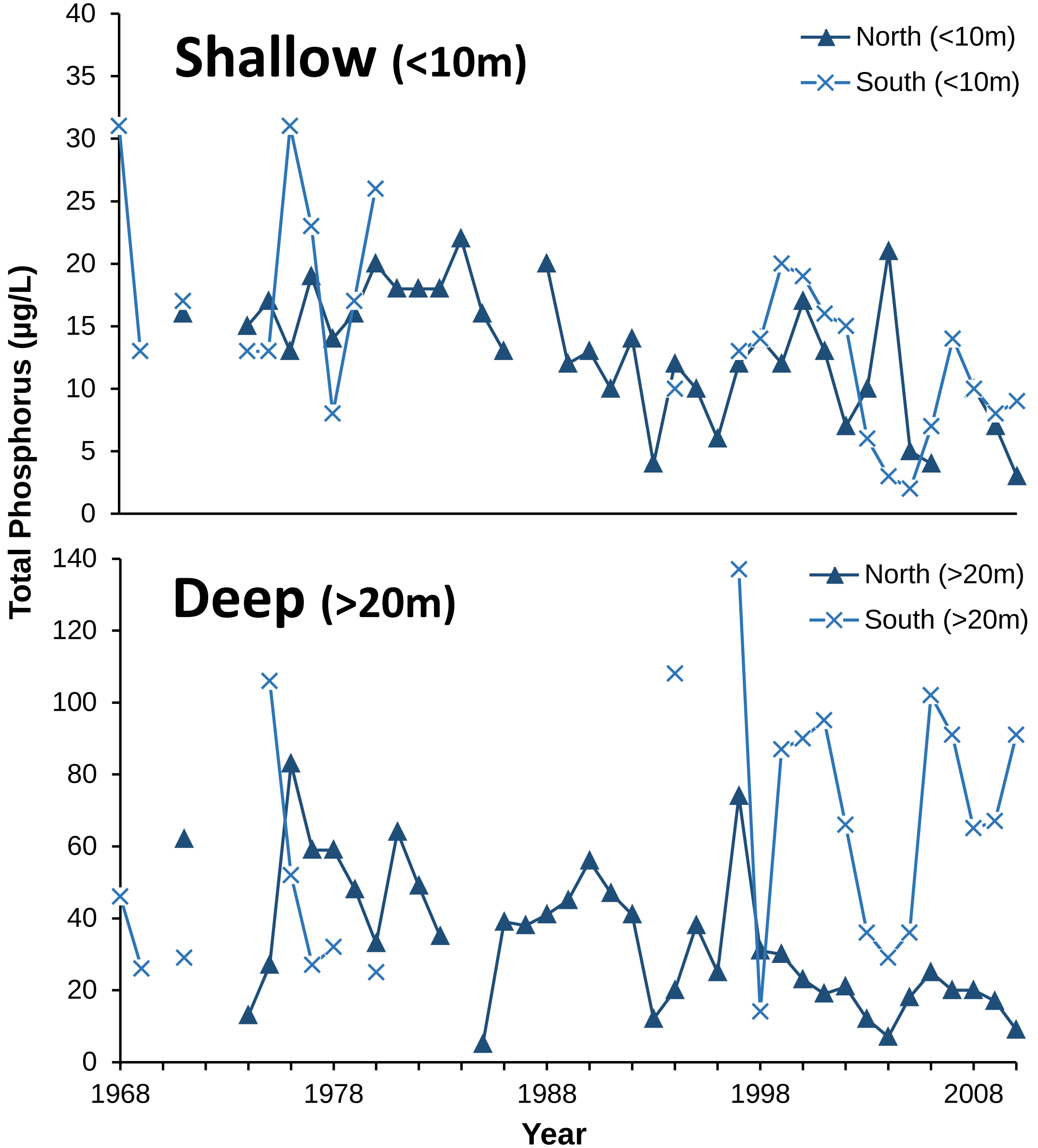
Natural Sciences & Engineering Research Council

Okanagan Nation Alliance

Columbia River Intertribal Fish Commission

Fisheries and Oceans Canada

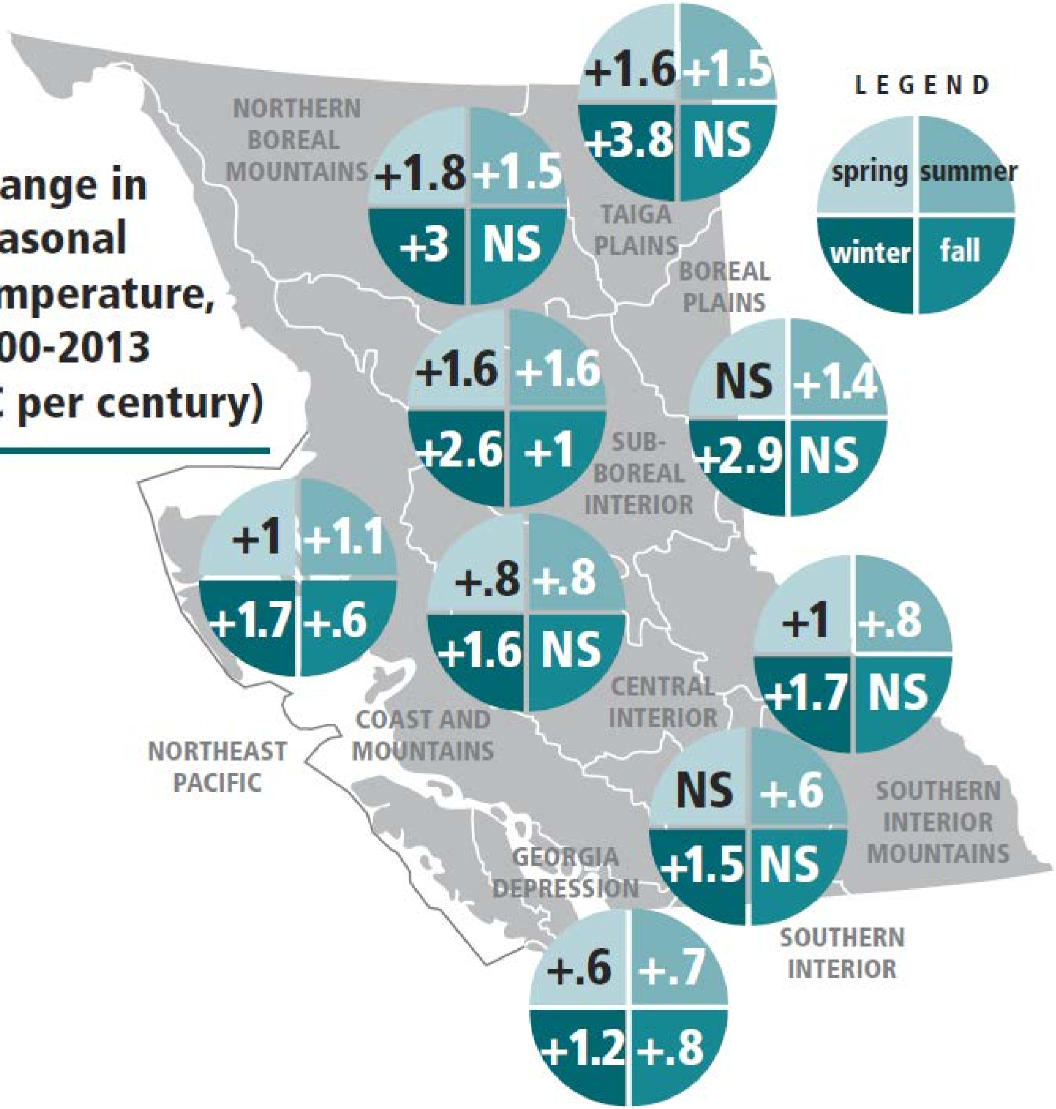
Extra Slides



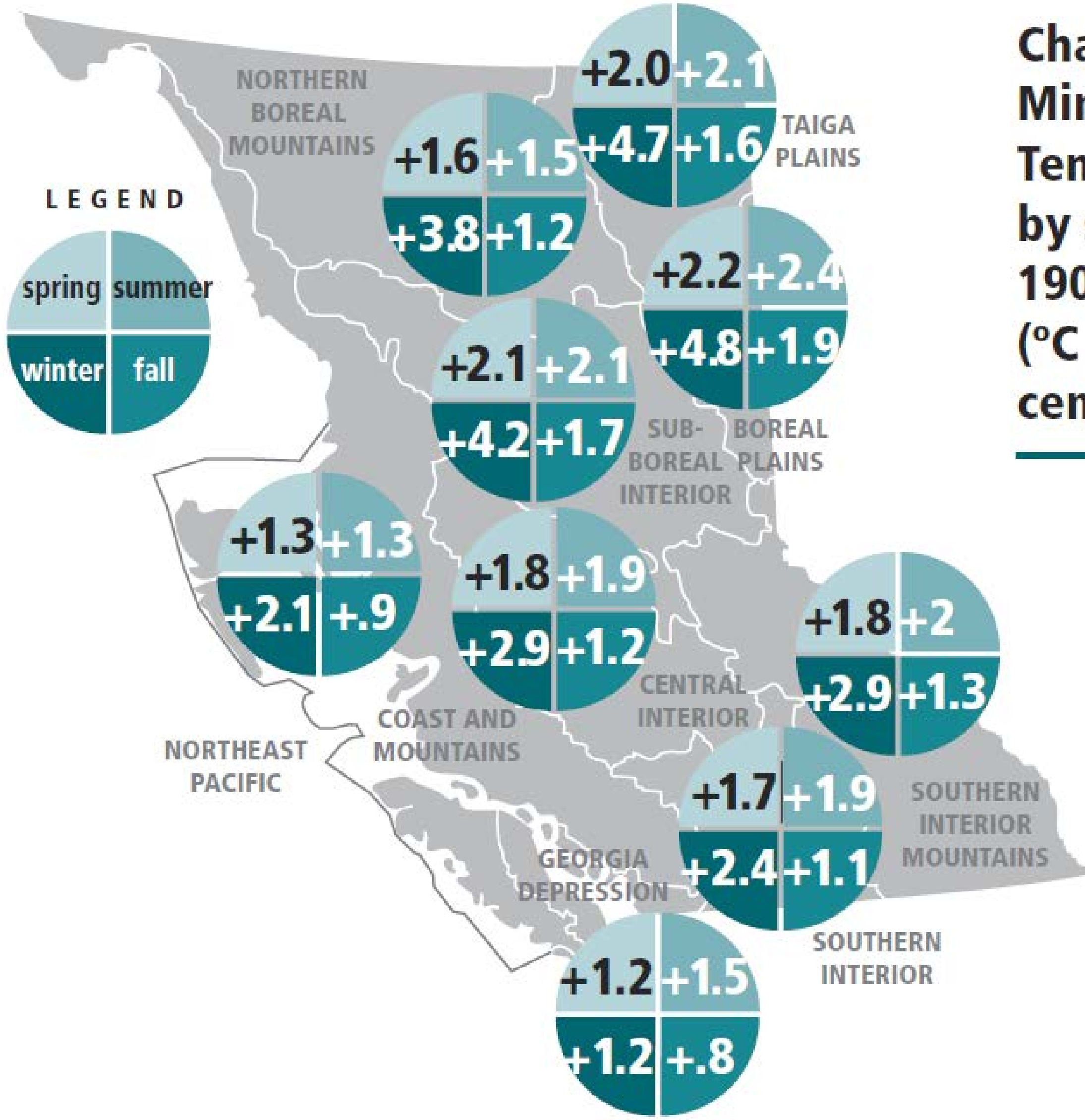
Jensen et al. 2012; Simmatis et al. *in review*

Pigment	Source[1]	Stability	Affinity
β, β-carotene	P,L,t	1	*Plantae, Algae*, some phototrophic bacteria
β, α-carotene	P,l	2	*Cryptophyta, Chrysophyta, Dinophyta*, some *Chlorophyta*
β-isorenieratene[2]	P	1	*Chlorobiaceae* (green sulphur bacteria)
isorenieratene[2]	P	1	*Chlorobiaceae* (brown varieties)
alloxanthin	P	1	*Cryptophyta*
fucoxanthin	P,L	2	*Dinophyta*[3], *Bacillariophyta, Chrysophyta*
diatoxanthin	P,L,s[4]	2	*Bacillariophyta, Dinophyta, Chrysophyta*
diadinoxanthin	P,L,s[4]	3	*Dinophyta, Bacillariophyta, Chrysophyta, Cryptophyta*
dinoxanthin	P	-	*Dinophyta*
peridinin	P	4	*Dinophyta*
echinenone	P,l	1	*Cyanobacteria*
zeaxanthin	P,l	1	*Cyanobacteria*
canthaxanthin	P,l	1	colonial *Cyanobacteria*, herbivore tissues
myxoxanthophyll	P,l	2	colonial *Cyanobacteria*
scytonemin[5]	p,L	-	colonial *Cyanobacteria*
oscillaxanthin	P,l	2	*Cyanobacteria (Oscillatoriaceae)*
aphanizophyll[6]	P,l	2	N_2-fixing *Cyanobacteria* (Nostocales)
lutein	P,L,t	1	*Chlorophyta, Euglenophyta, Plantae*
neoxanthin	l	4	*Chlorophyta, Euglenophyta, Plantae*
violaxanthin	l	4	*Chlorophyta, Euglenophyta, Plantae*
okenone[2]	P	1	purple sulphur bacteria
astaxanthin	P,l	4	invertebrates, N-limited *Chlorophyta*
chlorophyll *a*	P,L	3	*Plantae, Algae*
chlorophyll *b*	P,L	2	*Plantae, Chlorophyta, Euglenophyta*
pheophytin *a*	P,L,t,s	1	Chl *a* derivative (general)
pheophytin *b*	P,L,t,s	2	Chl *b* derivative (general)
pheophorbide *a*	P,l,s	3	Chl *a* derivative (grazing, senescent diatoms)
pyro-pheo(pigments)	L, S**	2	derivatives of *a* and *b*-phorbins
Chl *c*	P,l	4	*Dinophyta, Bacillariophyta, Chrysophyta*

Change in Seasonal Temperature, 1900-2013 (°C per century)



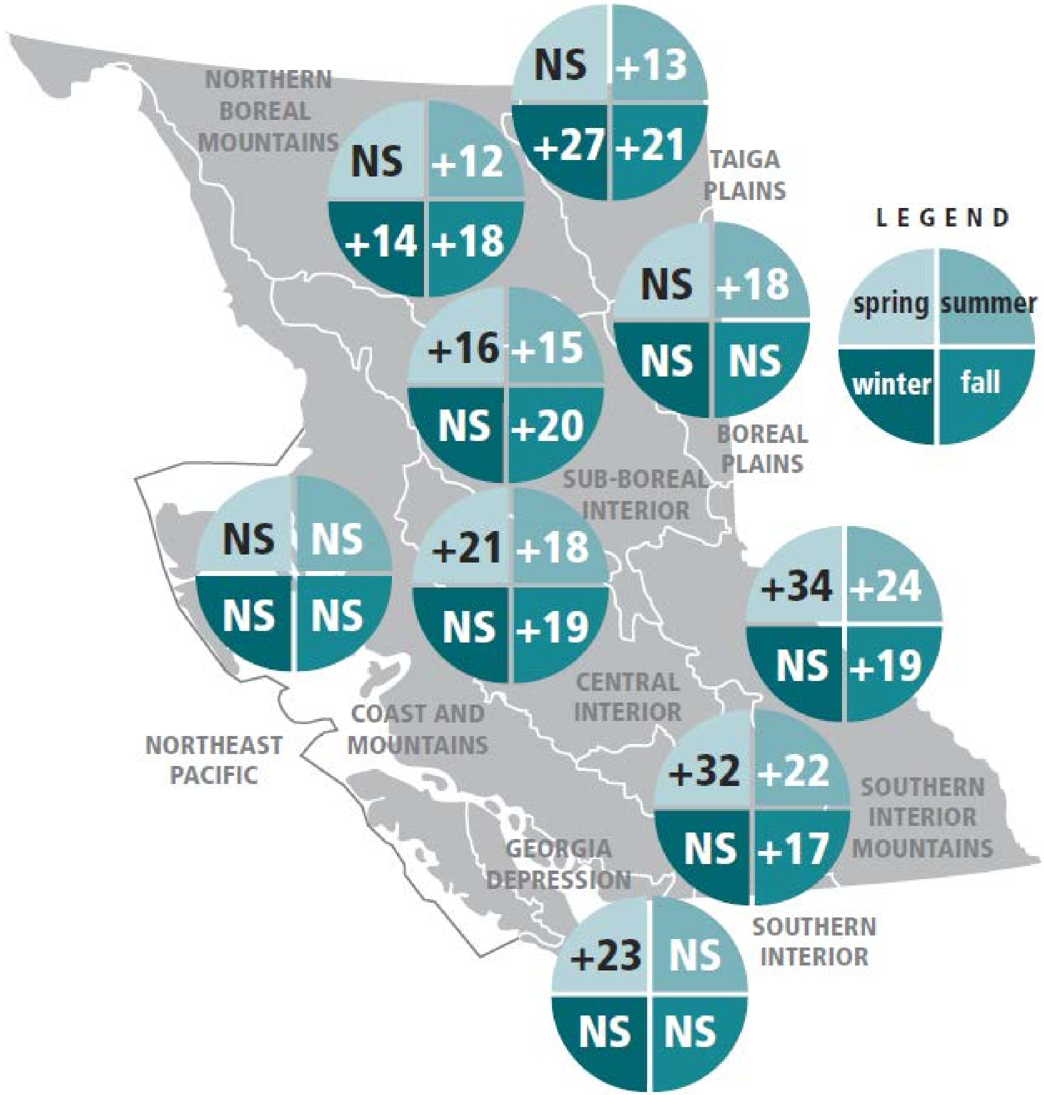
BC Ministry of Environment 2016



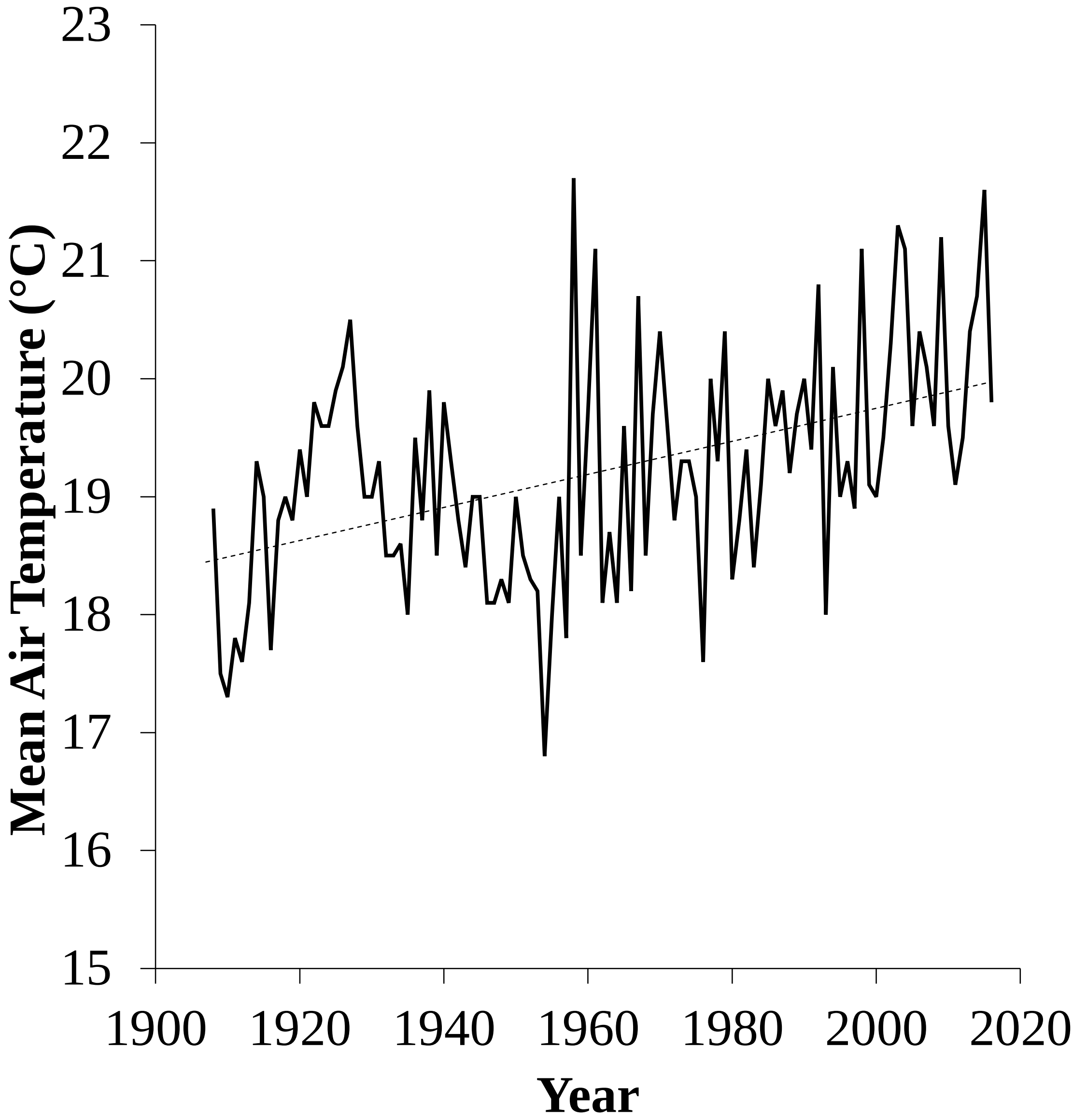
Change in Minimum Temperature by season, 1900-2013 (°C per century)

BC Ministry of Environment 2016

Change in Seasonal Precipitation, 1900-2013 (% per century)



BC Ministry of Environment 2016



Mean Air Temperature (°C)
23
22
21
20
19
18
17
16
15
1900
1920
1940
1960
1980
2000
2020
Year