Some results from the Ecosystem Monitoring Program (2011-2014)

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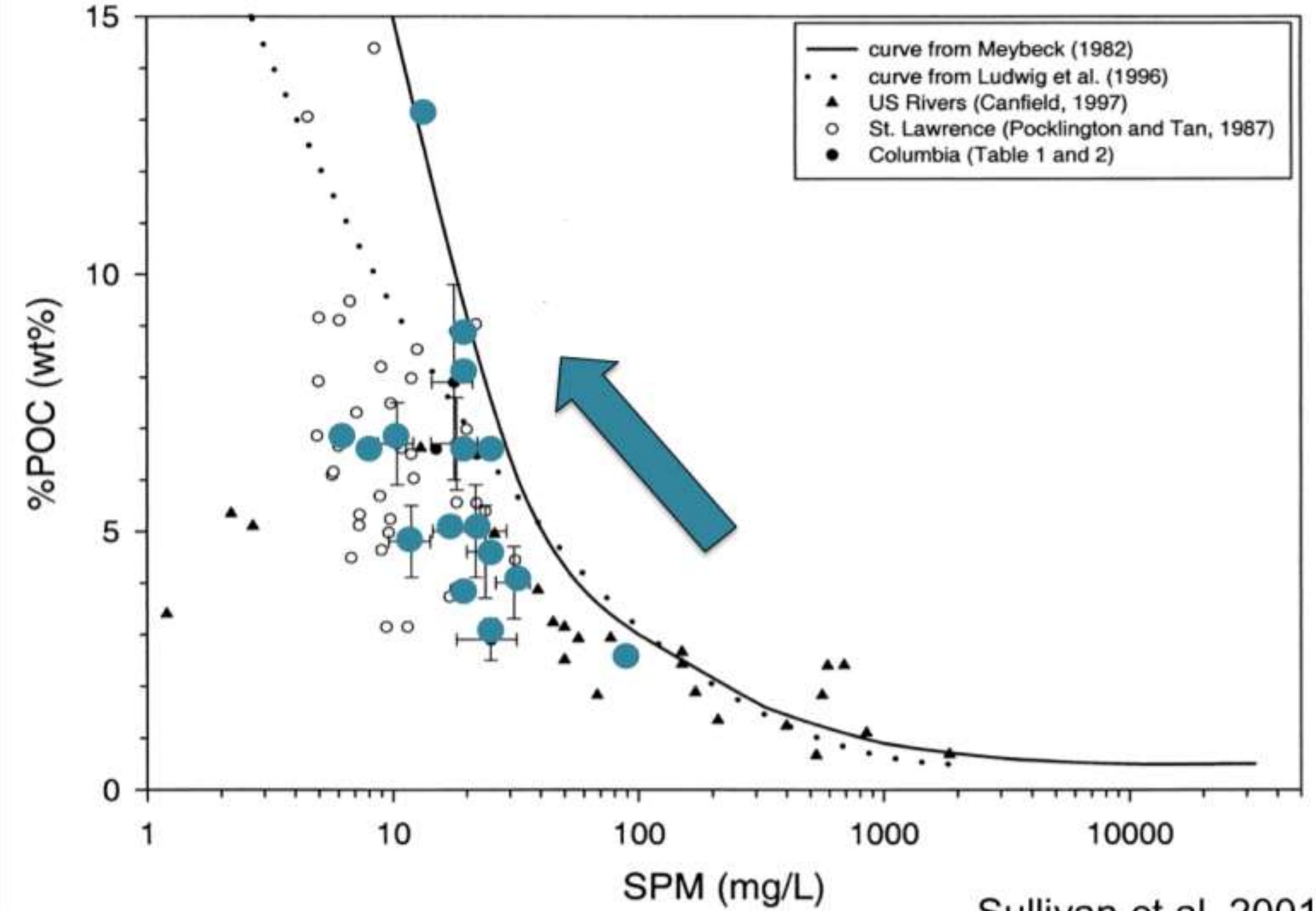
Many thanks to Whitney Temple, Sean Sol & NOAA team

The Columbia River provides critical salmon habitat

- Multiple causes for salmon decline
- Among other factors, changes in aquatic habitats and food webs have probably contributed to the decline
- How can rehabilitation efforts be guided by better knowledge of food web dynamics?

Impoundments have increased phytoplankton production in the Columbia – “greening of the river”



Sullivan et al. 2001

Overarching Q: How has the greening of the Columbia river affected salmon habitat, specifically, salmon-supporting food webs?

Specific goal:

- Identify controls on fluvial plankton dynamics

Approach:

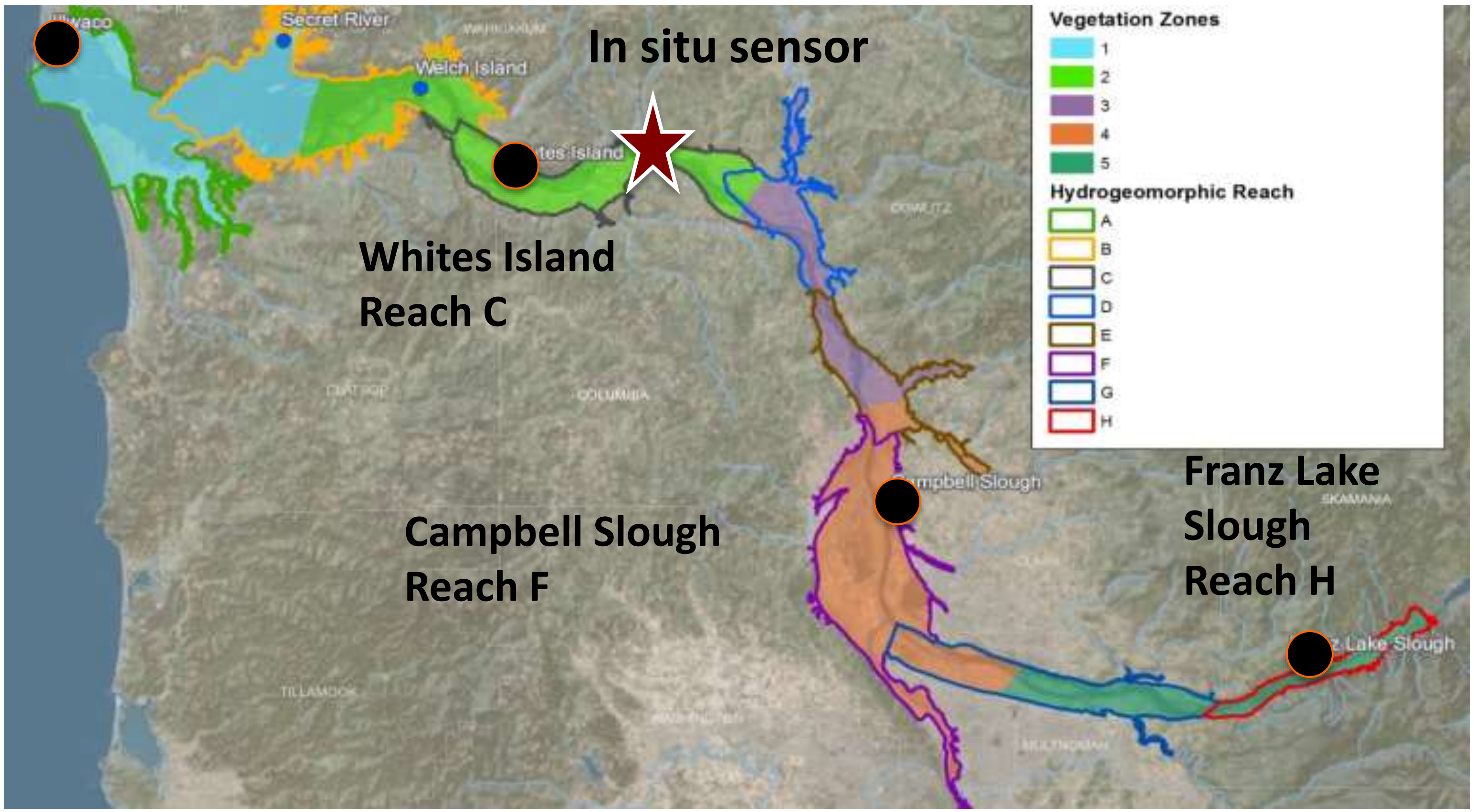
- Compare differences in plankton abundance and species composition in different years at sites with different hydrogeomorphic characteristics

Sampling

Site	2011	2012	2013	2014
Ilwaco	X	X	X	
Welch Island		X	X	X
Secret River		X	X	
Whites Island	X	X	X	X
Campbell Slough	X	X	X	X
Franz Lake Slough	X	X	X	X

Eight hydrogeomorphic reaches identified in the lower Columbia River

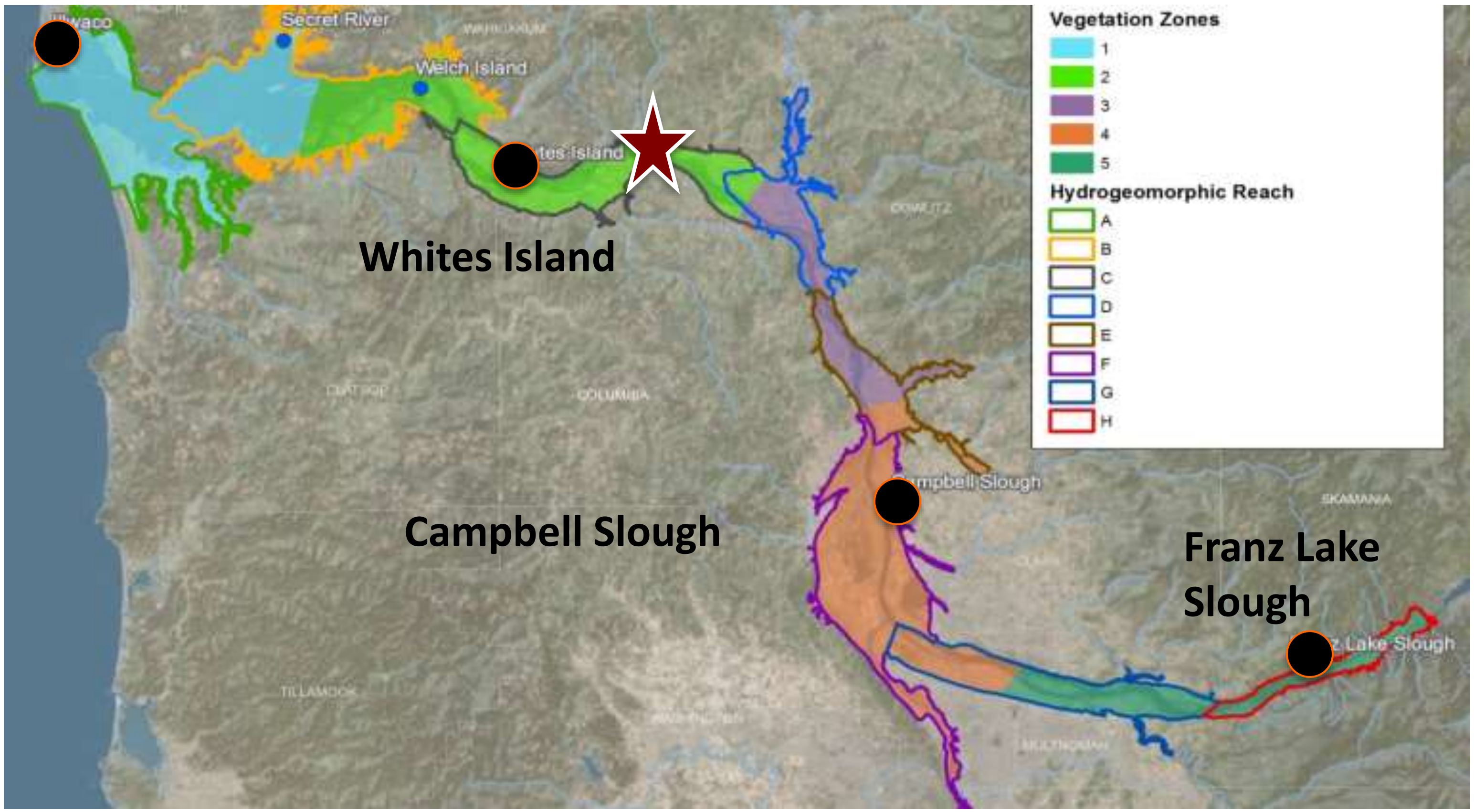
Ilwaco
Reach A



Eight hydrogeomorphic reaches identified in the lower Columbia River

Decreasing tidal flushing

Ilwaco



Study sites:
- Emergent marshes
- Shallow water habitats
- Minimally disturbed
- Connected via tidal channel to mainstem

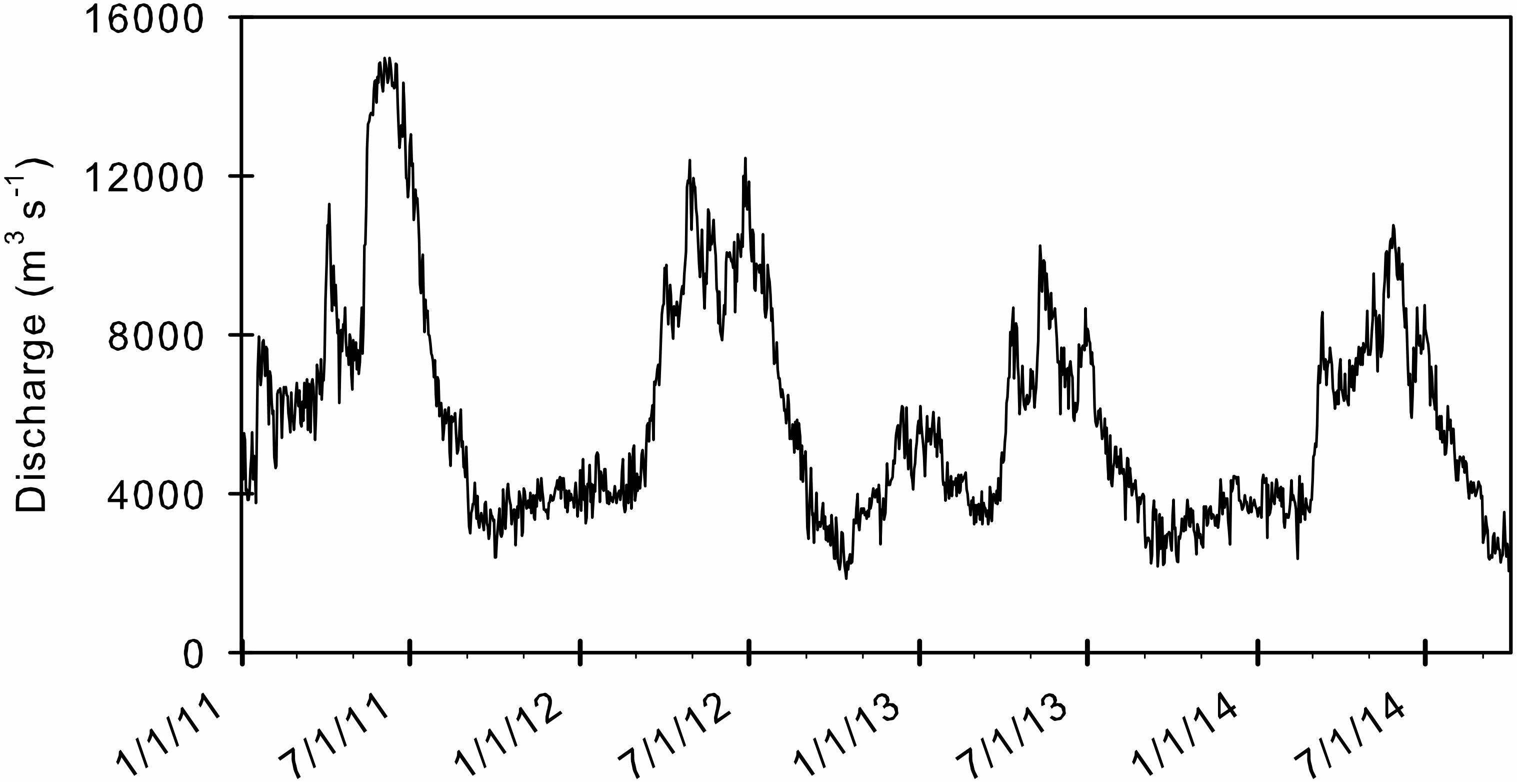
Data:
- Phytoplankton (whole water) and zooplankton (tows) abundance and species composition
- (Primary production)
- Nutrient concentrations (USGS & OHSU)
- (Continuous temperature, conductivity, pH, dissolved O_2)

Some site characteristics

Site	Distance from main channel	Time water level > thalweg	Time water level > bank	Bank elevation
Campbell Slough	2109 (4100)	93.7	27.3	1.73
Whites Island	742	80.0	35.8	1.75
Franz Lake	350 (1973)	99.0	30.0	1.91

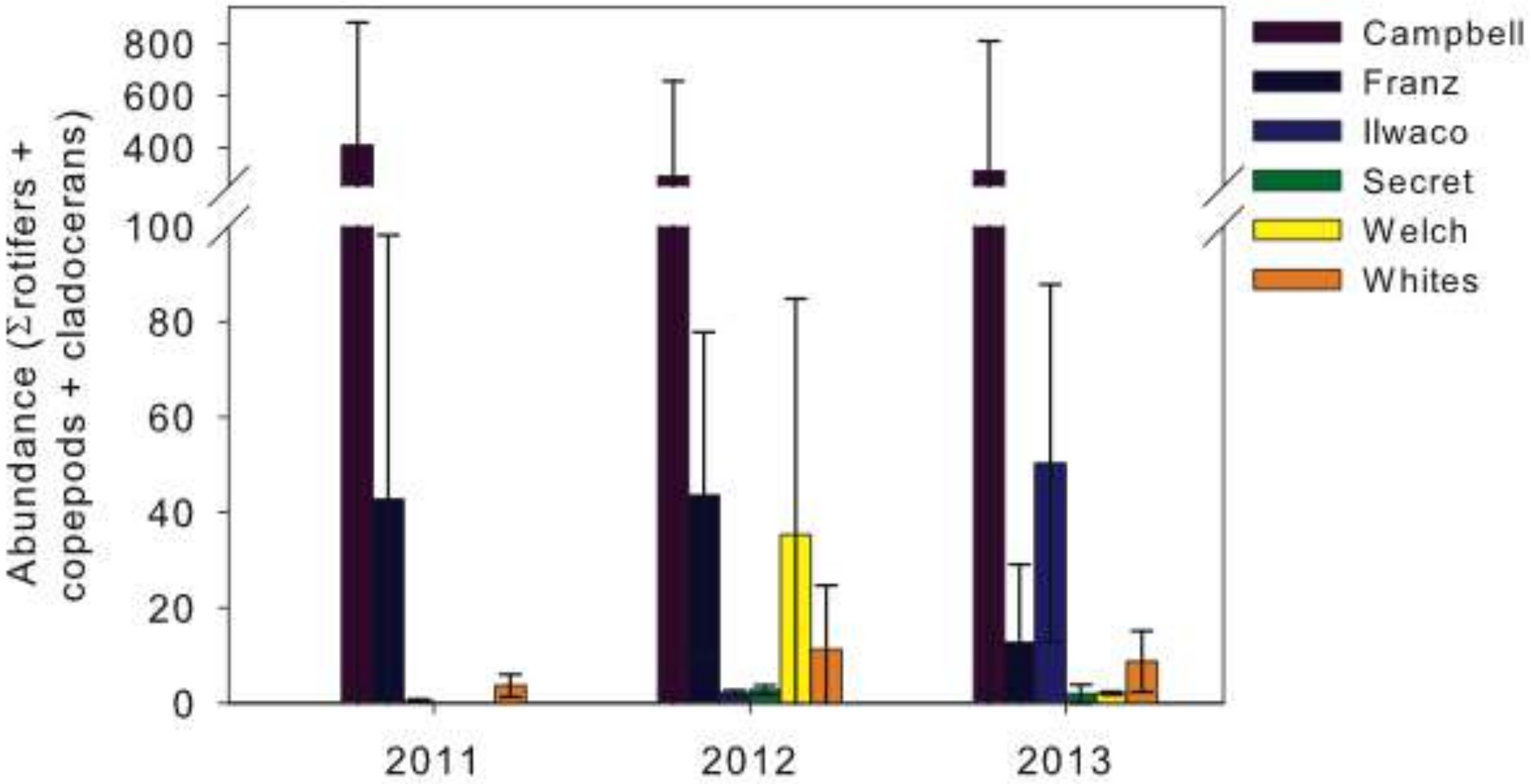
Data from Amy Borde et al., PNNL

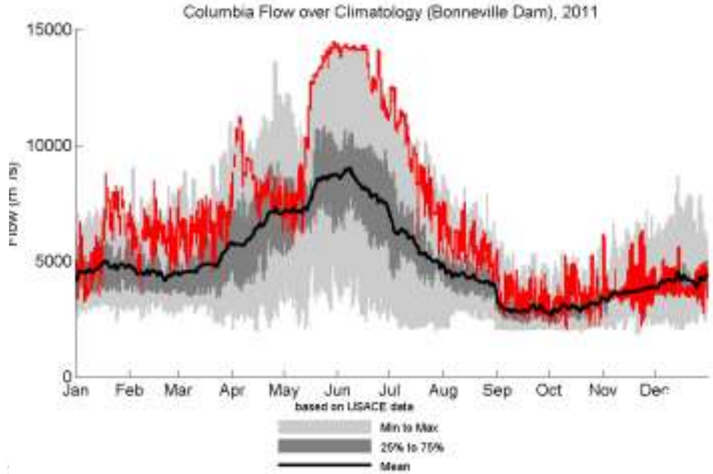
2011-14

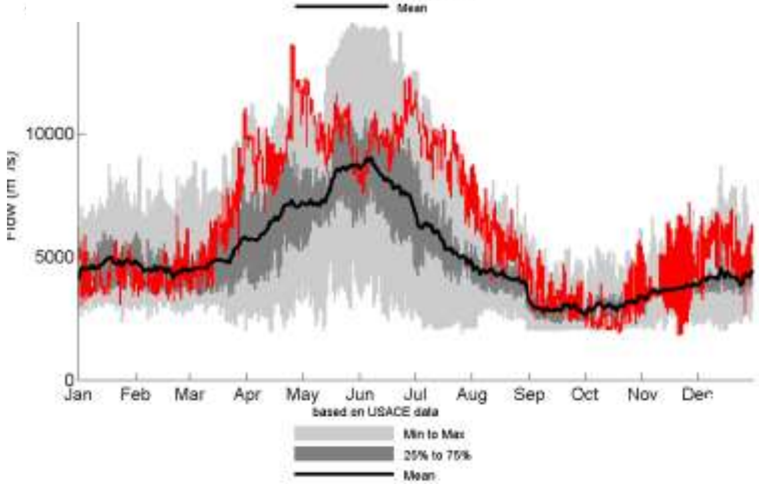


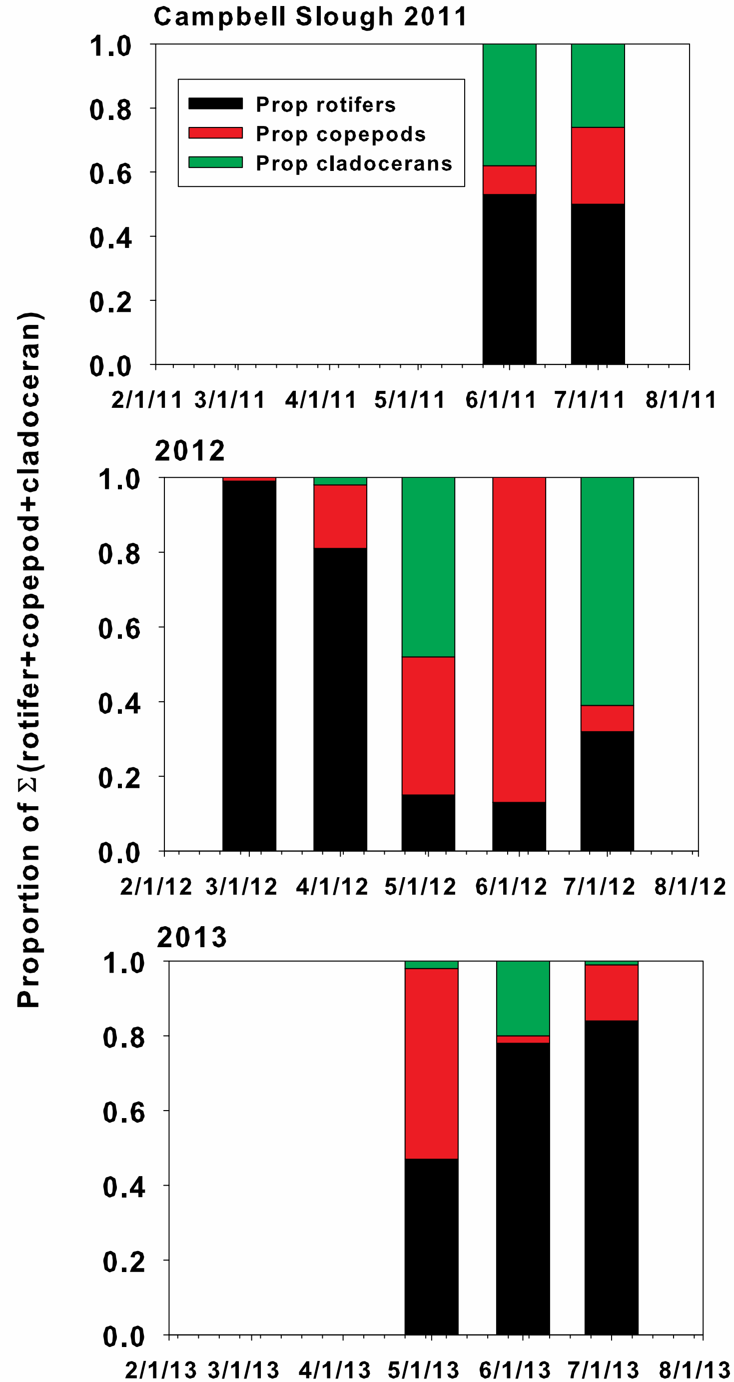
Discharge at The Dalles, OR

Yearly averaged zooplankton abundances were highest at Campbell Slough



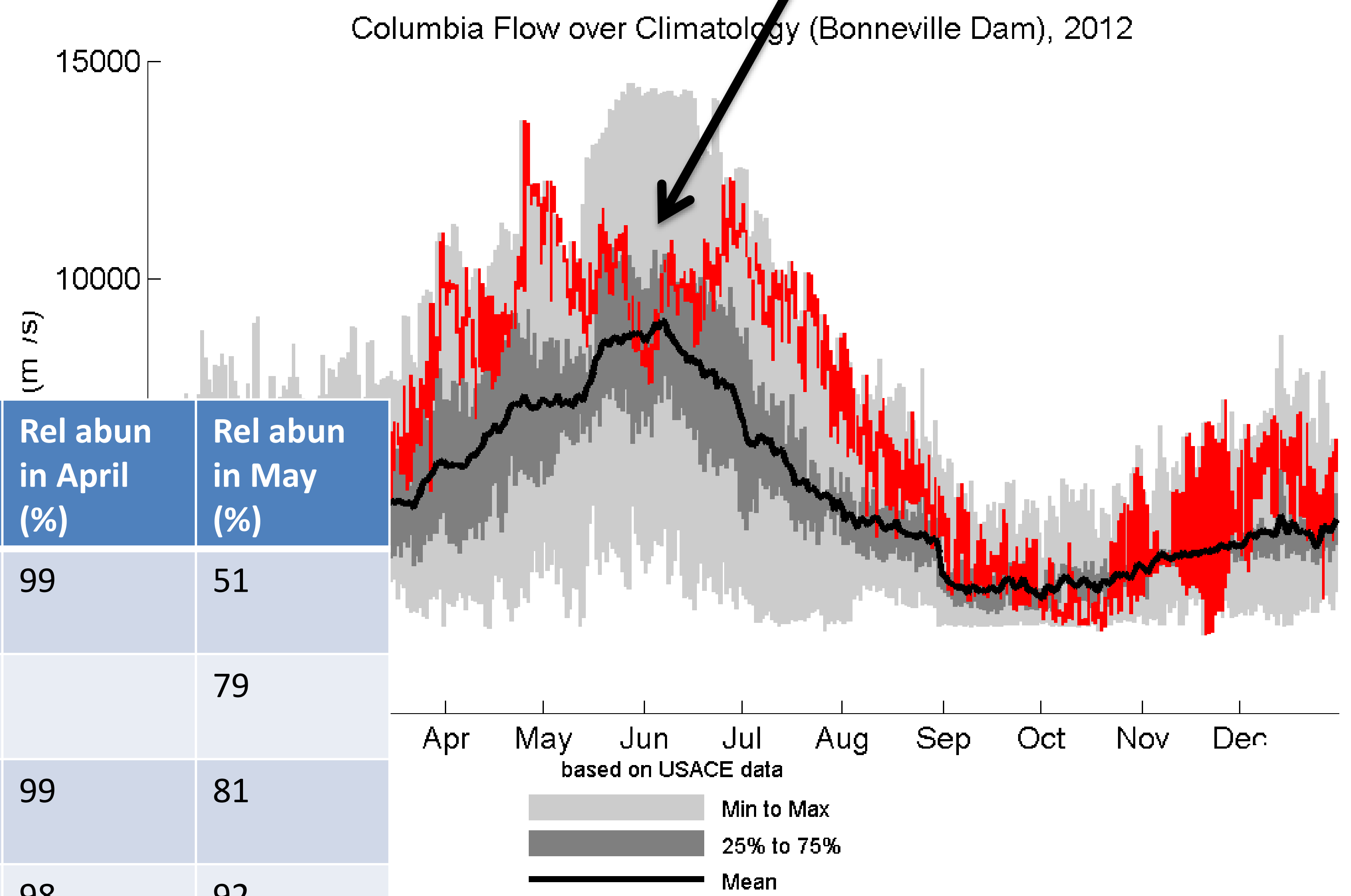






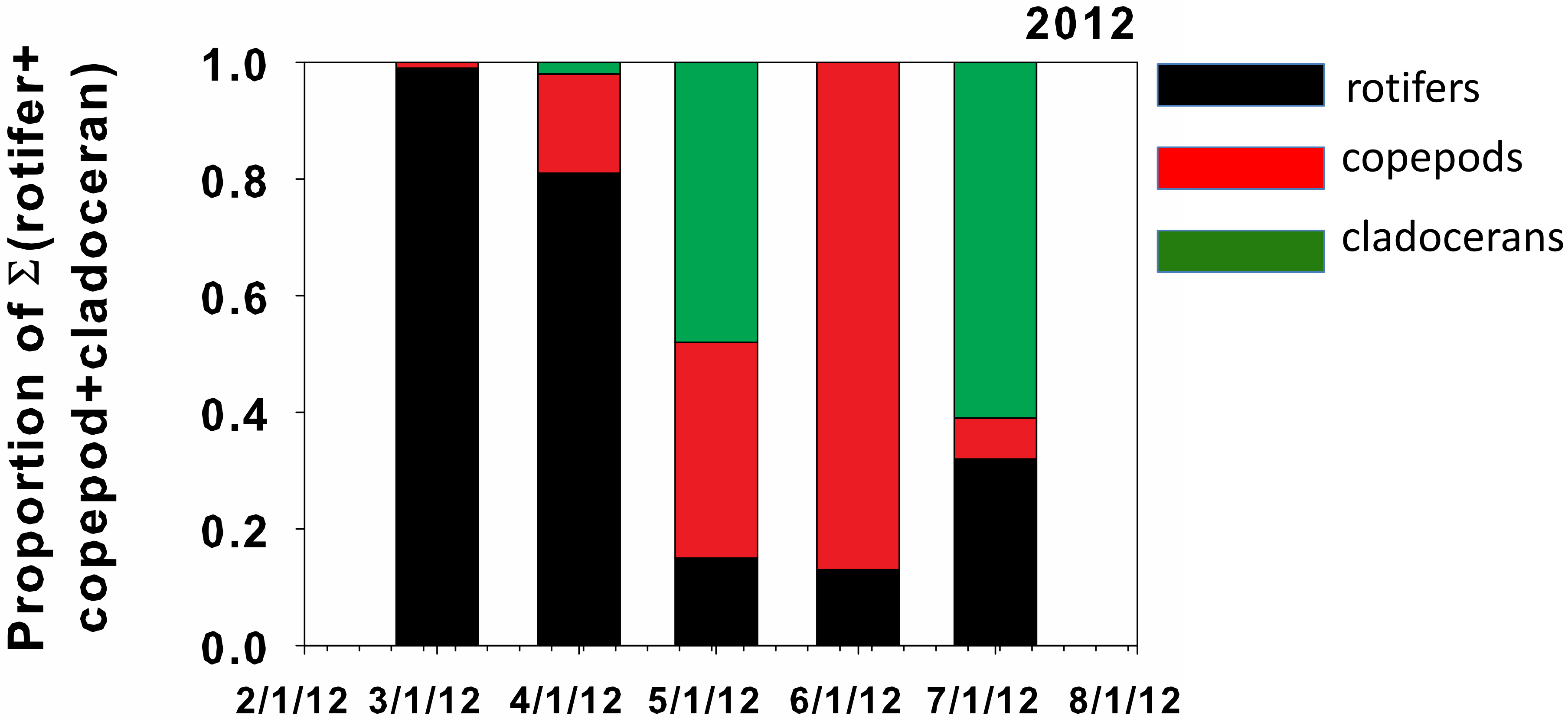
Once water levels rise, rotifer relative abundance seems to decrease; zooplankton are replaced by copepods and cladocerans

In general, dip seen in proportional abundance of rotifers

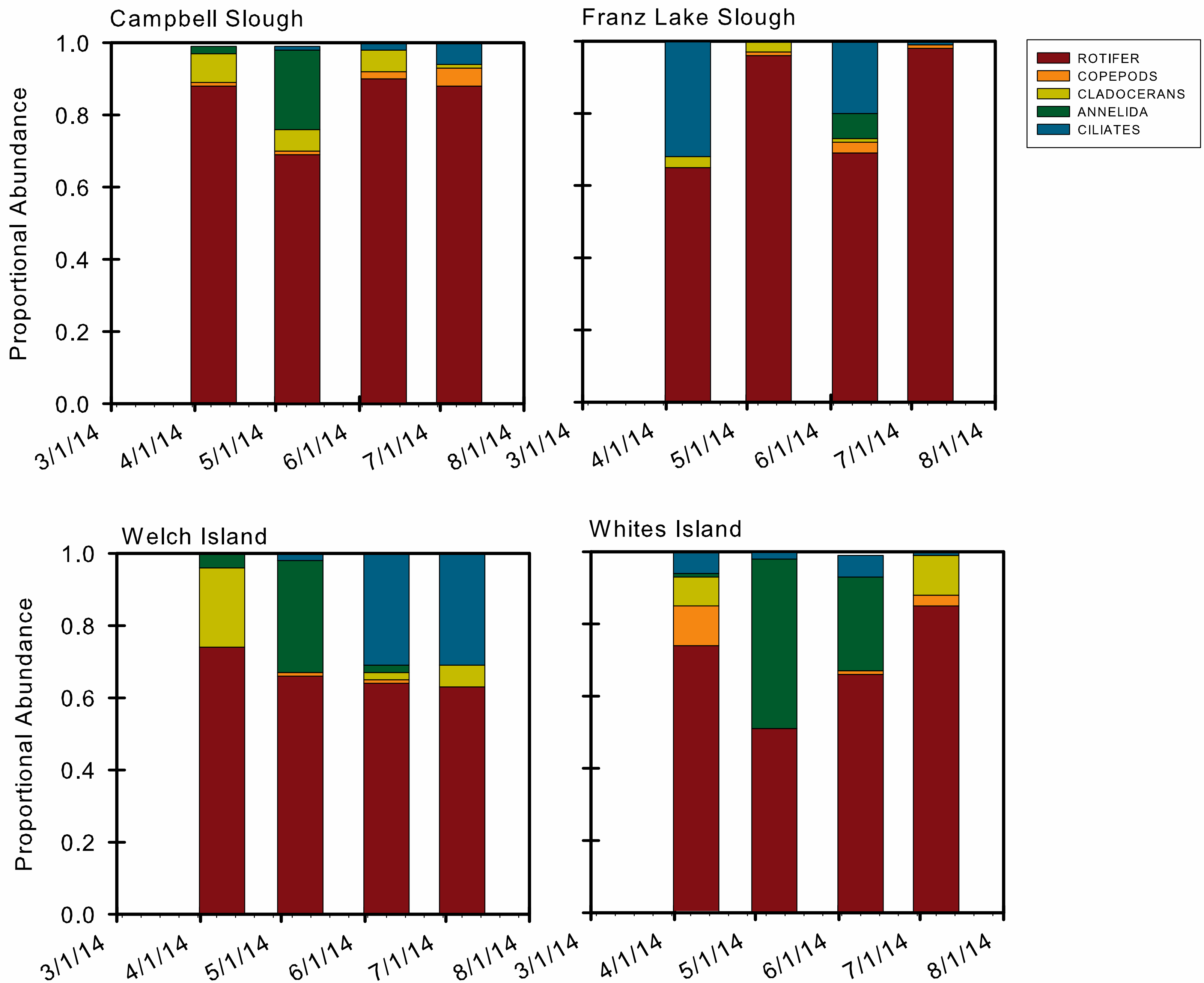


Site (2012)	Rel abun in April (%)	Rel abun in May (%)
Franz Lake (H)	99	51
Secret River (B)		79
Campbell Slough (F)	99	81
Whites Island	98	92

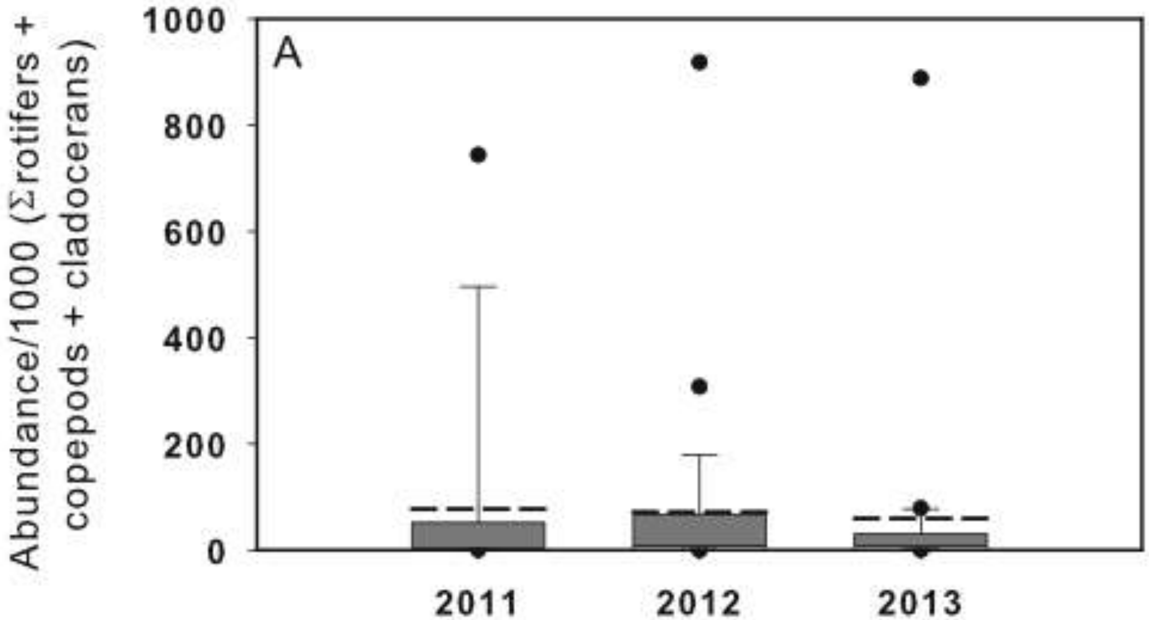
Zooplankton assemblages shifted between March and August at Campbell Slough (Reach F)



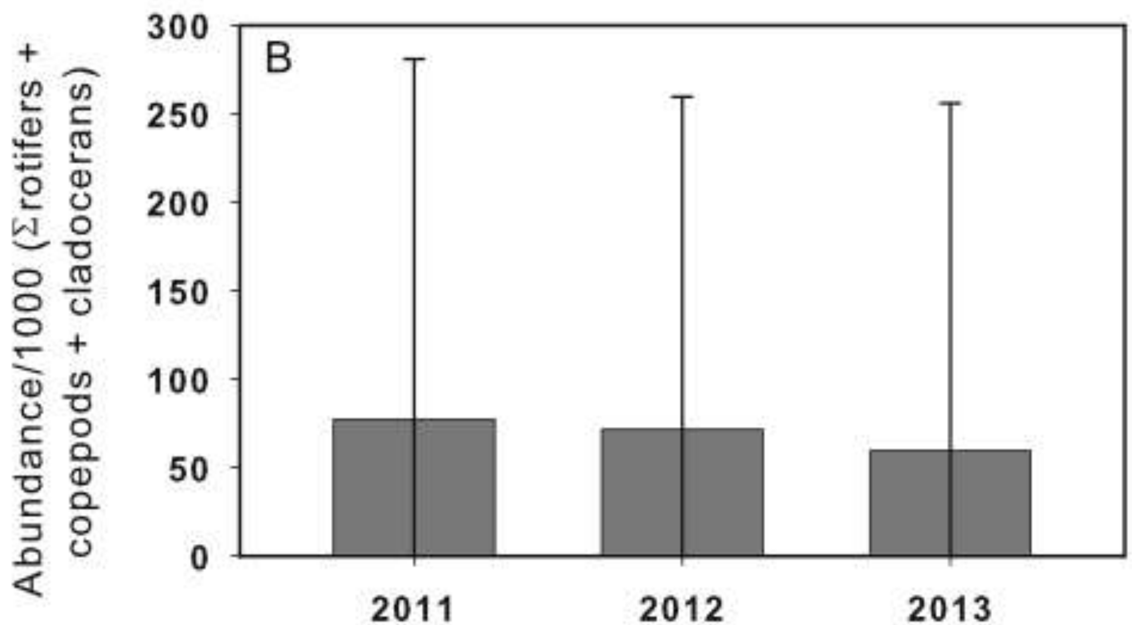
2014



Campbell Slough
Franz Lake Slough
Welch Island
Whites Island
Proportional Abundance
1.0
0.8
0.6
0.4
0.2
0.0
3/1/14
4/1/14
5/1/14
6/1/14
7/1/14
8/1/14
ROTIFER
COPEPODS
CLADOCERANS
ANNELIDA
CILIATES



Range, mean (dashes), outliers



Mean and standard deviation

2014: Preliminary look at along-river chlorophyll

Pre-freshet:

In April, similar chl concentrations at the four sites

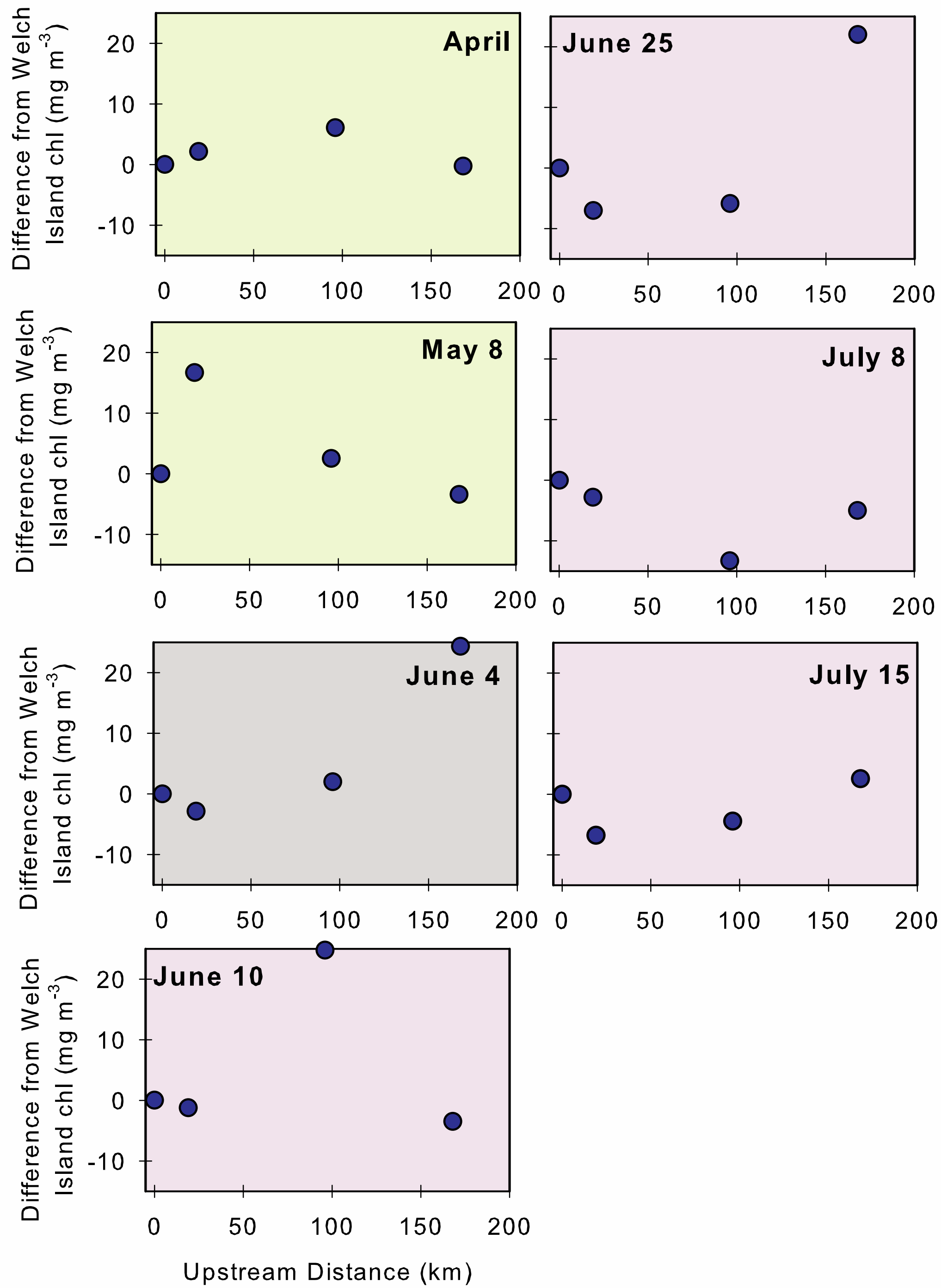
In May, Whites Island had elevated chl

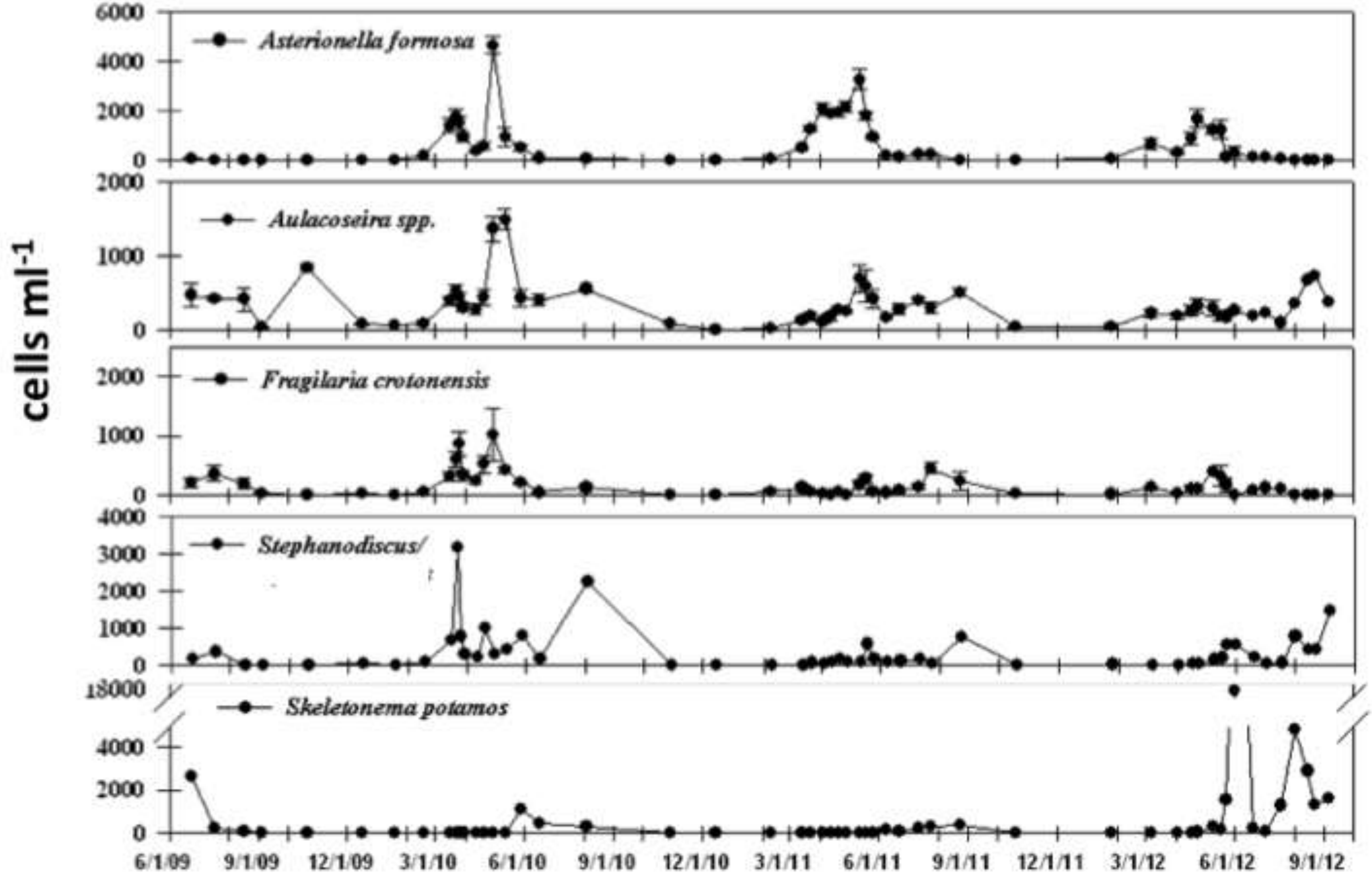
In June (freshet):

highest chl at Franz

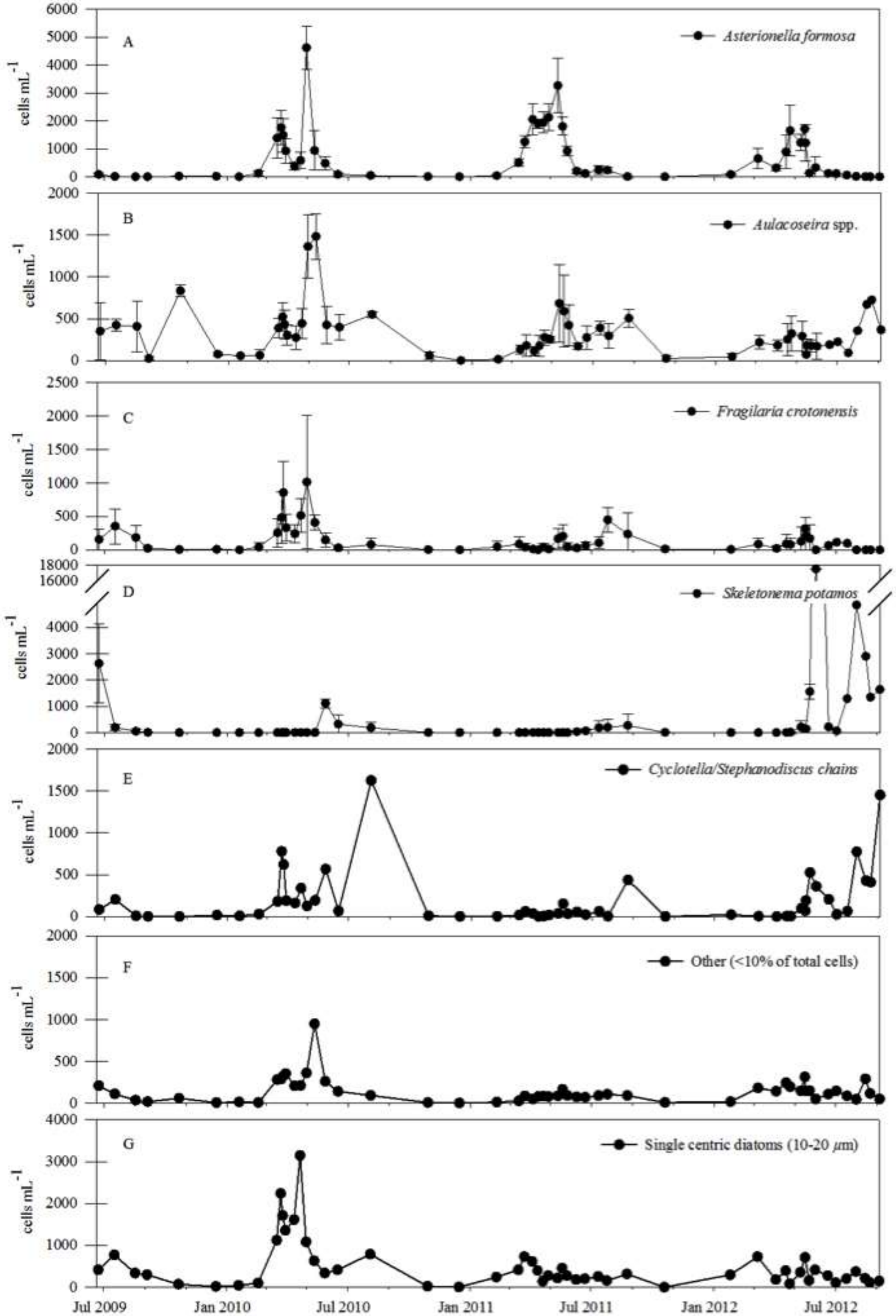
Post-freshet:

High chl at Campbell, then Franz





cells ml-1
Asterionella formosa
Aulacoseira spp.
Fragilaria crotonensis
Stephanodiscus/
Skeletonema potamos
6000
4000
2000
0
2000
1000
0
2000
1000
0
4000
3000
2000
1000
0
18000
4000
2000
0
6/1/09
9/1/09
12/1/09
3/1/10
6/1/10
9/1/10
12/1/10
3/1/11
6/1/11
9/1/11
12/1/11
3/1/12
6/1/12
9/1/12

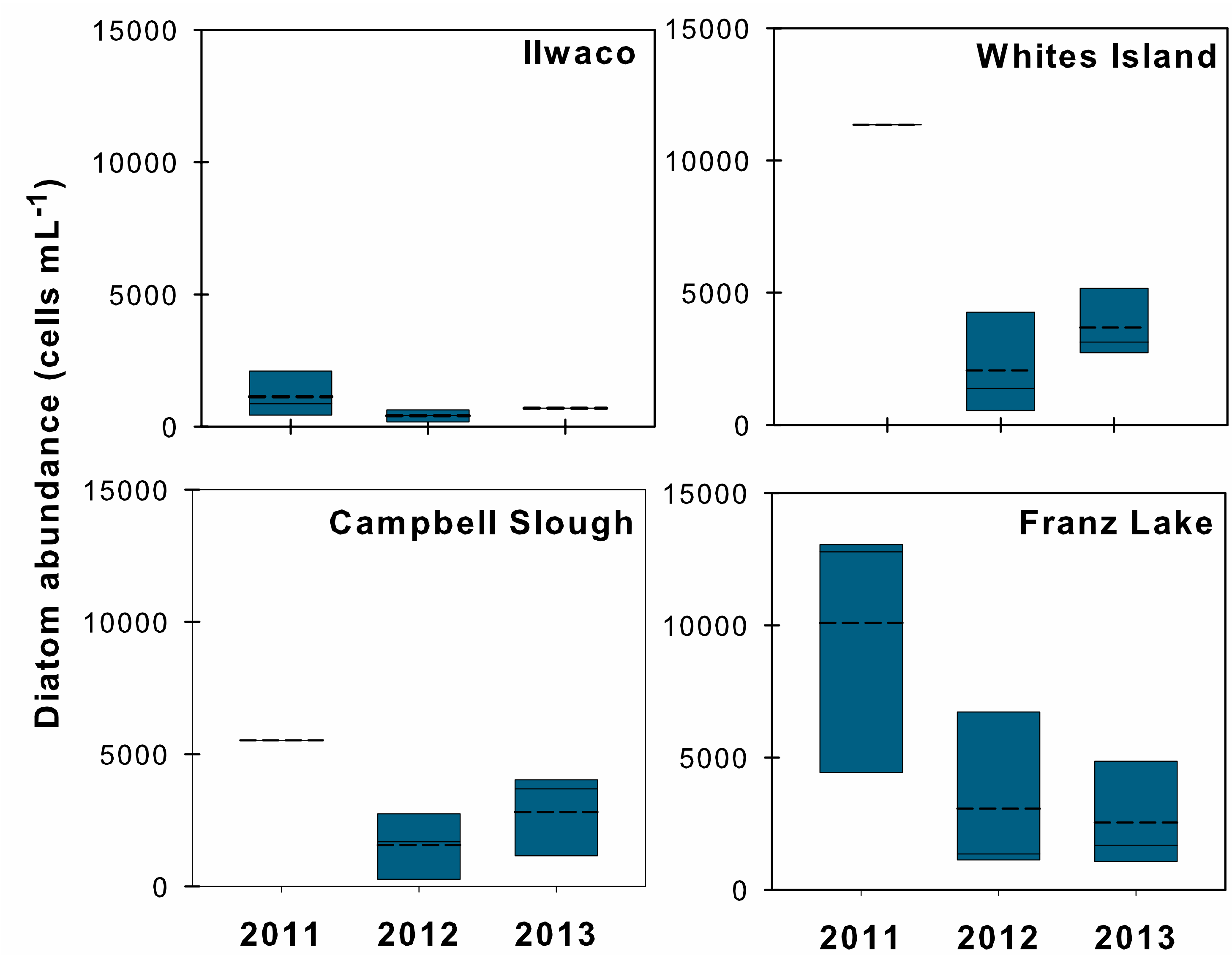

A
Asterionella formosa
B
Aulacoseira spp.
C
Fragilaria crotonensis
D
Skeletonema potamos
E
Cyclotella/Stephanodiscus chains
F
Other (<10% of total cells)
G
Single centric diatoms (10-20 μm)
cells mL-1
Jul 2009
Jan 2010
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012

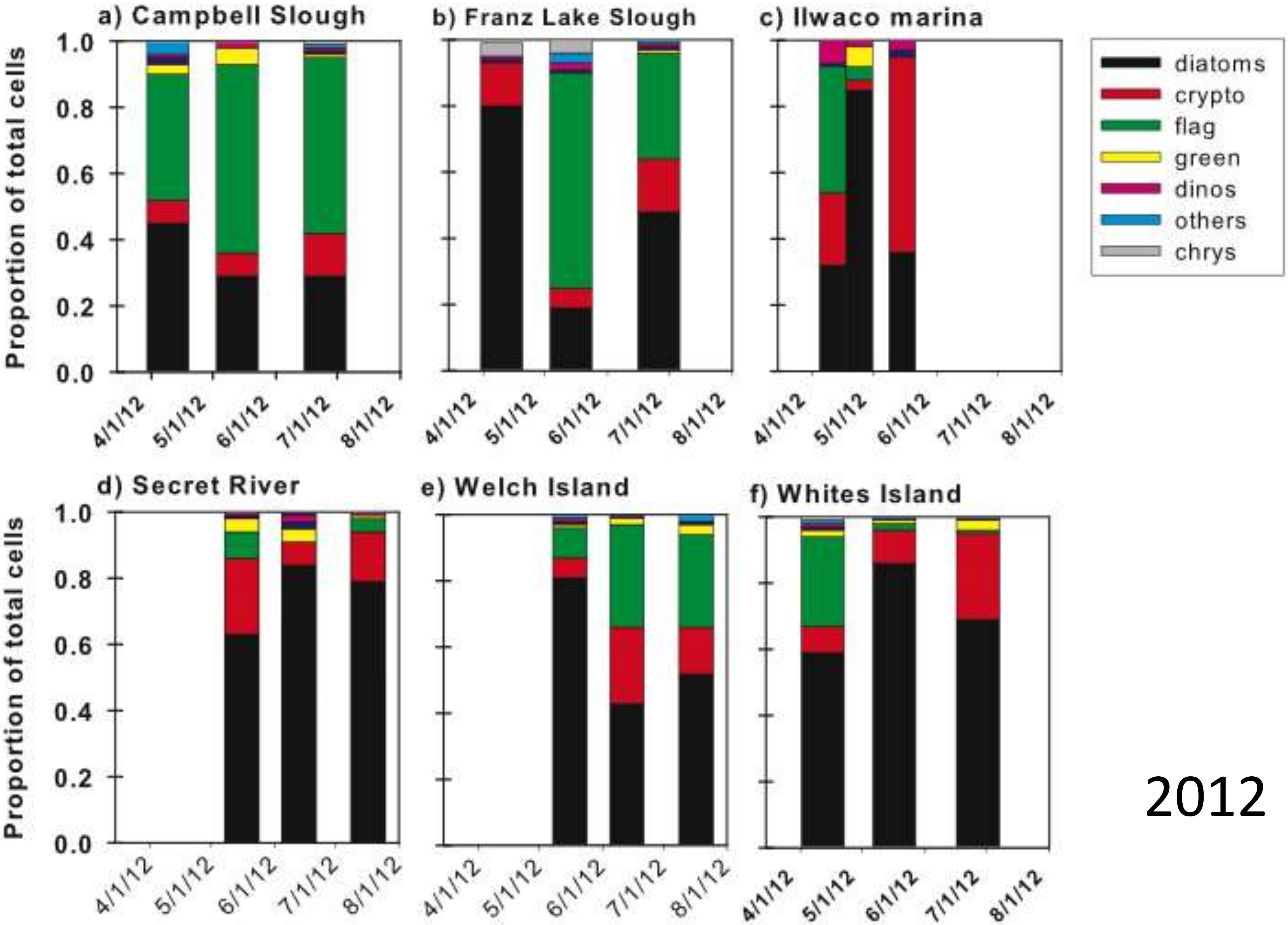
Spearman rank order correlations between phytoplankton species and environmental variables from discrete samples from 23 June 2009–4 December 2012 (n = 54). *A. form* = *Asterionella formosa*, *Aulac* = *Aulacoseira* spp., *Syned* = *Synedra* spp., *F. croto* = *Fragilaria crotonensis*, Lg *Steph* = large *Stephanodiscus* spp., *Steph/Cyclo* = *Stephanodiscus/Cyclotella* chains, *S. potam* = *Skeletonema potamos*, PENN = pennate diatoms, Σ Lg DIATOM = large (> 20 μm) diatoms. Shaded areas indicate significant correlations.

Env variable	*A. form*	*Aulac*	*Syned*	*F. croto*	Lg *Steph*	*Steph/Cyclo*	*S. potam*	PENN	Σ Lg DIATOM
Chl	0.53**	0.54**	0.55**	0.55**	0.02	0.57**	0.05	0.03	0.72**
$H_2PO_4^{3-}$	-0.15	-0.57**	-0.34*	-0.53**	-0.10	-0.51**	-0.22	-0.10	-0.51**
$H_3Si(OH)_4$	0.54**	-0.35*	0.10	-0.13	-0.18	-0.38*	-0.55**	0.35*	-0.11
NO_3^-	0.27	-0.41*	0.01	-0.16	-0.35*	-0.46**	-0.81**	0.11	-0.32*
Temp	-0.47**	0.43*	-0.10	0.04	0.43*	0.42*	0.80**	-0.09	0.23
Turbidity	0.46**	-0.35*	0.08	-0.08	-0.11	-0.38*	-0.52**	0.33*	-0.22
Discharge	0.44*	-0.22	0.09	-0.10	0.16	-0.18	0.00	0.29*	-0.02
Solar rad	0.00	0.34*	0.08	0.23	0.29*	0.45**	0.46**	0.03	0.38*
Seasonal association	Winter/ spring	Spring/ summer		Late spring	Summer	Summer	Summer	Winter/ spring	

*$p < 0.05$, ** $p < 0.001$

Average diatom abundances vary by year

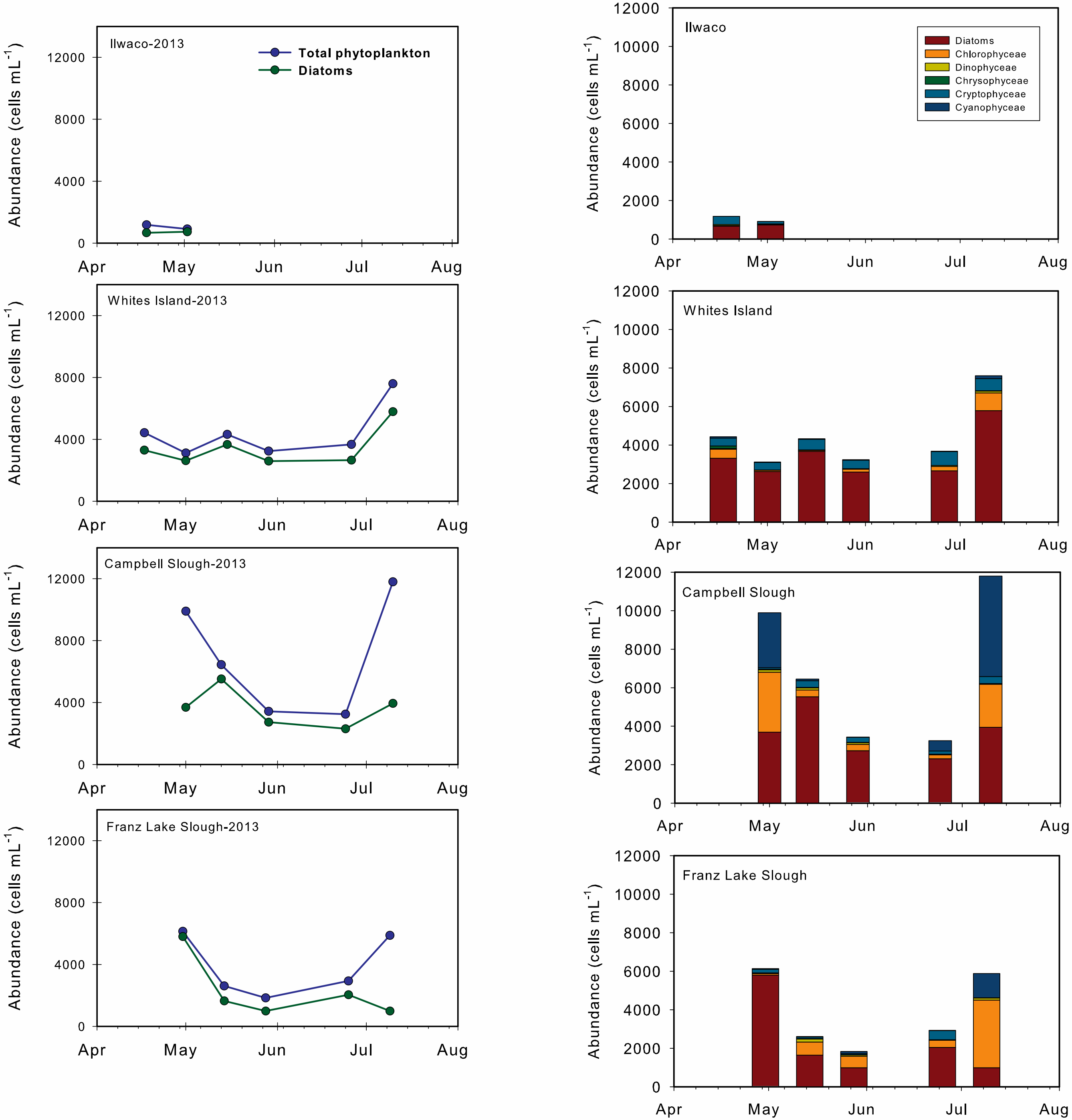




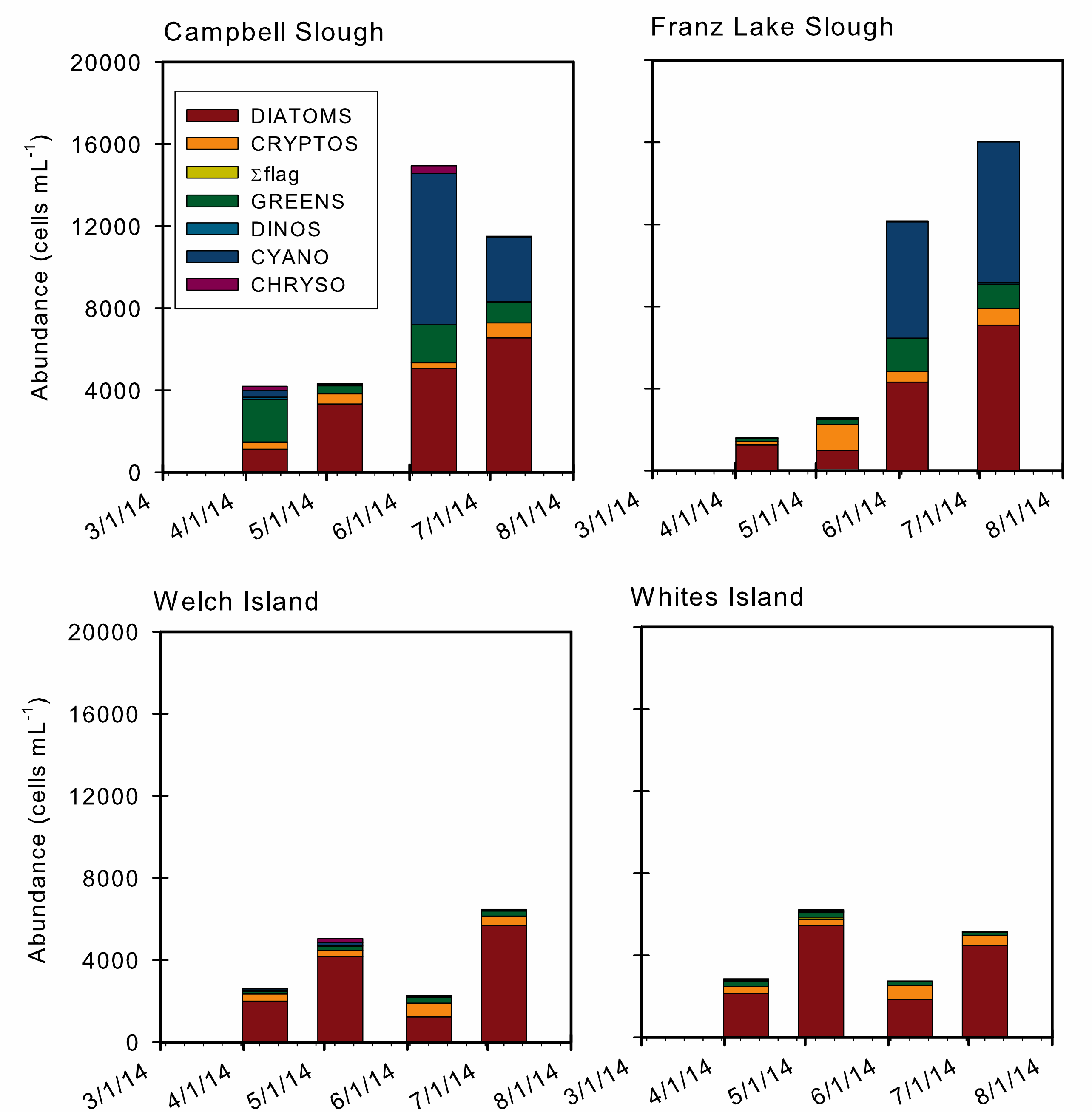
a) Campbell Slough
b) Franz Lake Slough
c) Ilwaco marina
d) Secret River
e) Welch Island
f) Whites Island
Proportion of total cells
1.0
0.8
0.6
0.4
0.2
0.0
4/1/12
5/1/12
6/1/12
7/1/12
8/1/12
diatoms
crypto
flag
green
dinos
others
chrys

2012

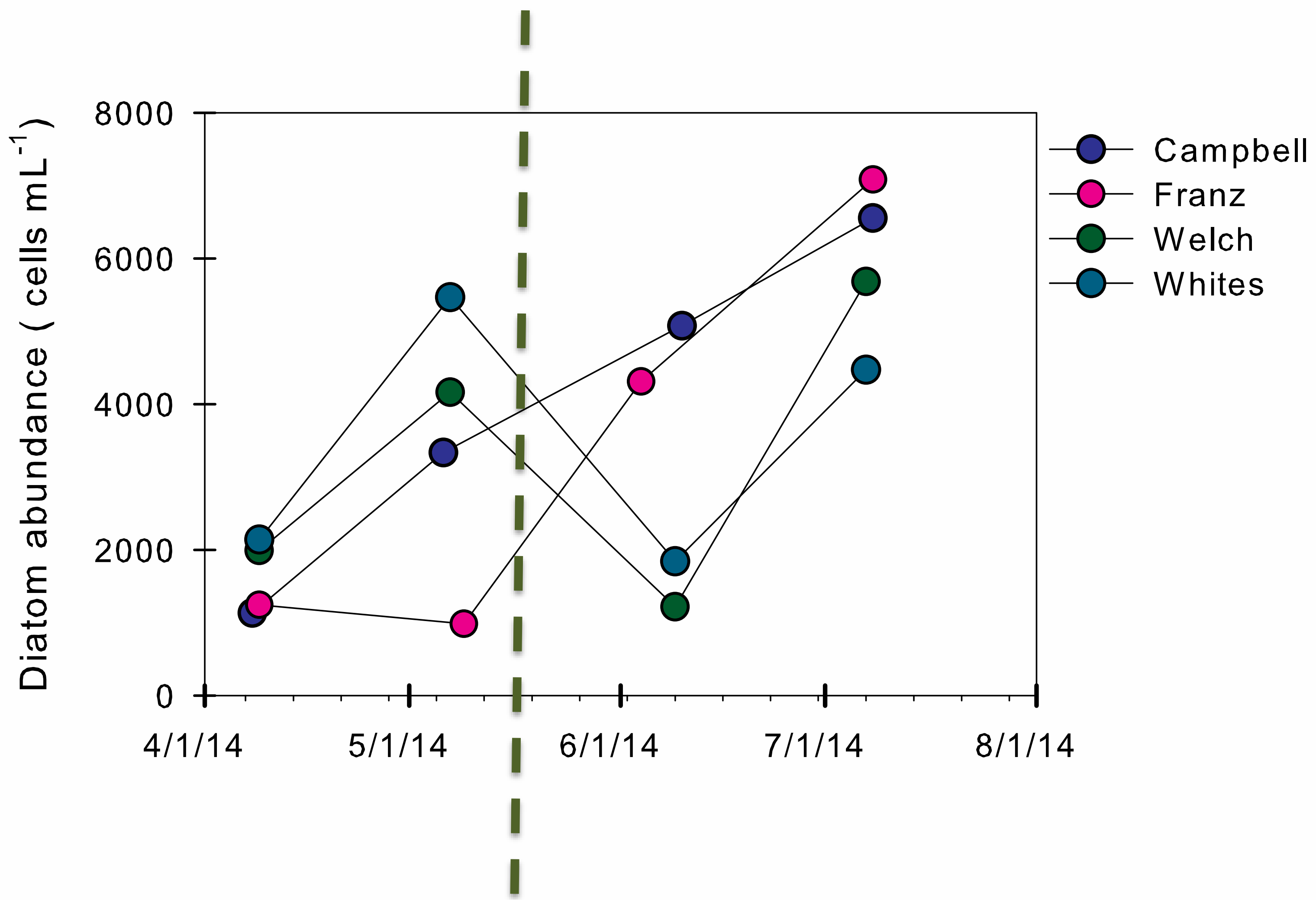
2013



Ilwaco-2013
Total phytoplankton
Diatoms
Whites Island-2013
Campbell Slough-2013
Franz Lake Slough-2013
Abundance (cells mL^{-1})
0
4000
8000
12000
Apr
May
Jun
Jul
Aug
Ilwaco
Diatoms
Chlorophyceae
Dinophyceae
Chrysophyceae
Cryptophyceae
Cyanophyceae
Whites Island
Campbell Slough
Franz Lake Slough
0
2000
4000
6000
8000
10000
12000

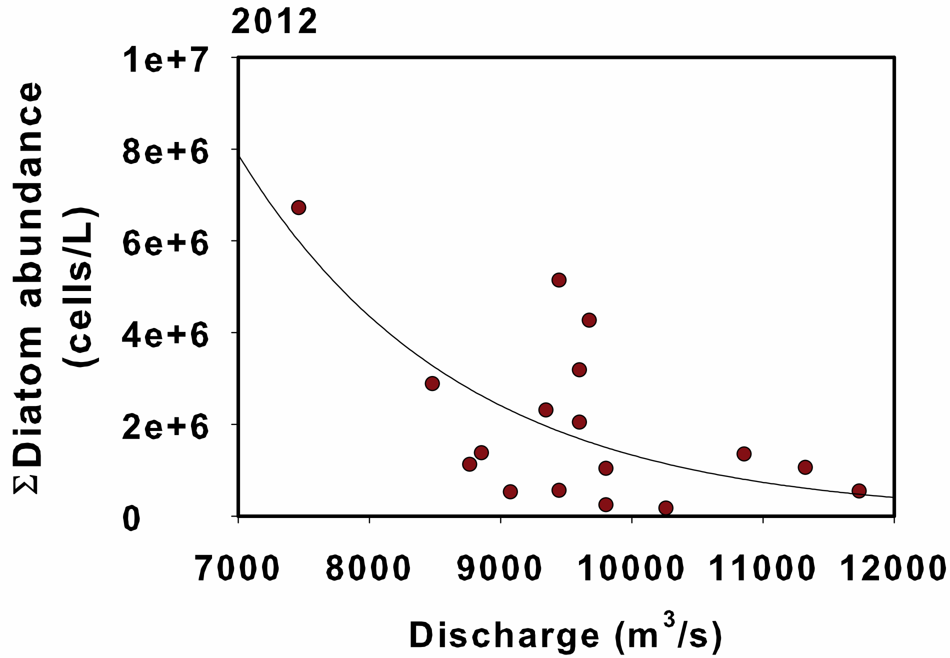

Campbell Slough
Franz Lake Slough
Welch Island
Whites Island
DIATOMS
CRYPTOS
Σflag
GREENS
DINOS
CYANO
CHRYSO
Abundance (cells mL-1)
0
4000
8000
12000
16000
20000
3/1/14
4/1/14
5/1/14
6/1/14
7/1/14
8/1/14

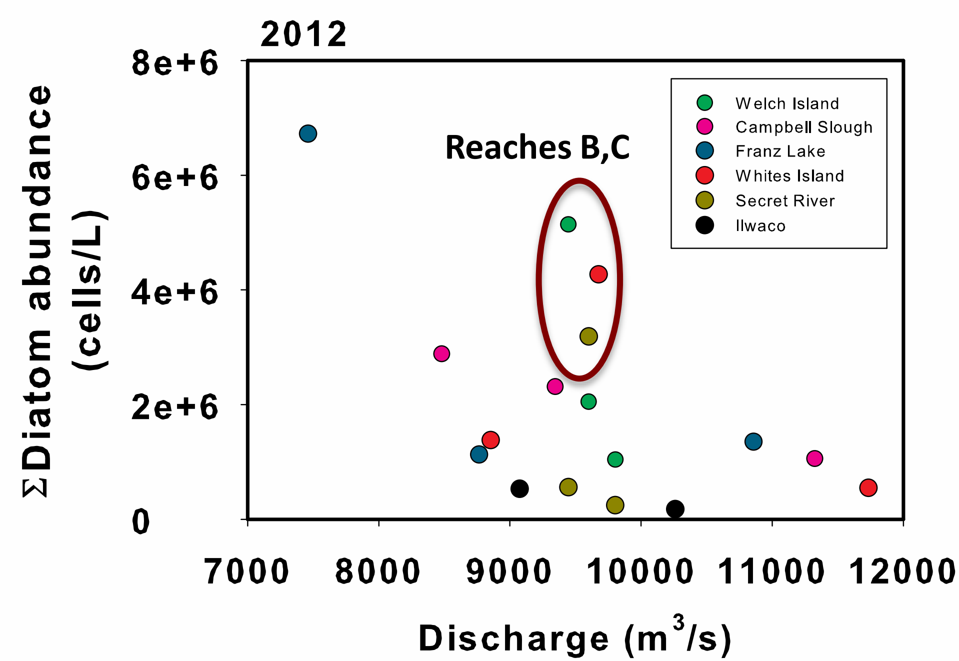
2014

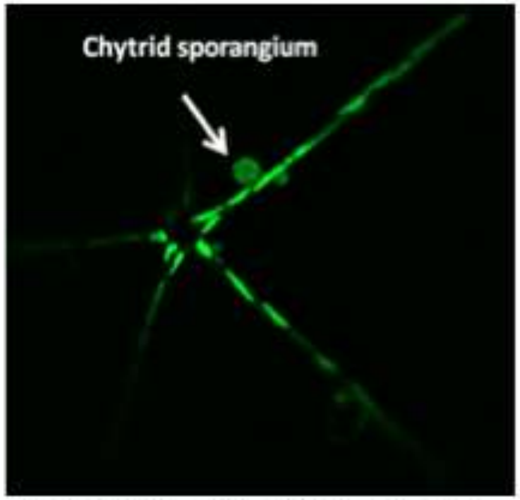


Diatom abundance (cells mL^{-1})
8000
6000
4000
2000
0
4/1/14
5/1/14
6/1/14
7/1/14
8/1/14
Campbell
Franz
Welch
Whites

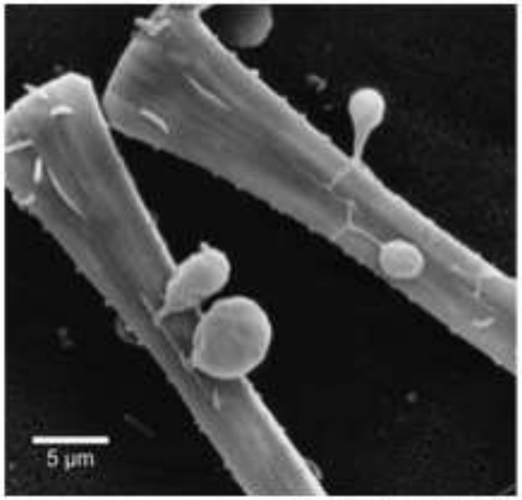
- Sites in Reaches B and C had higher abundance than other sites at moderately high discharge



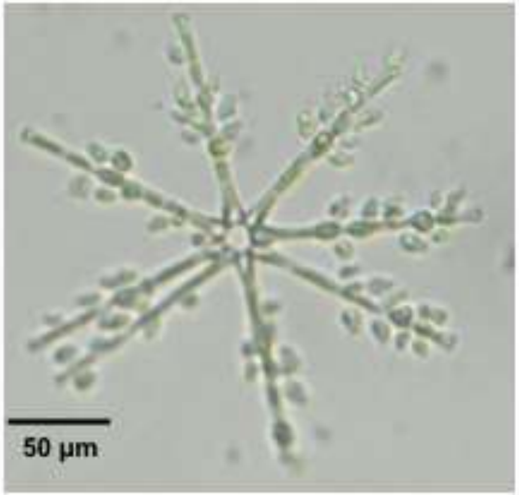




Columbia River *A. formosa*

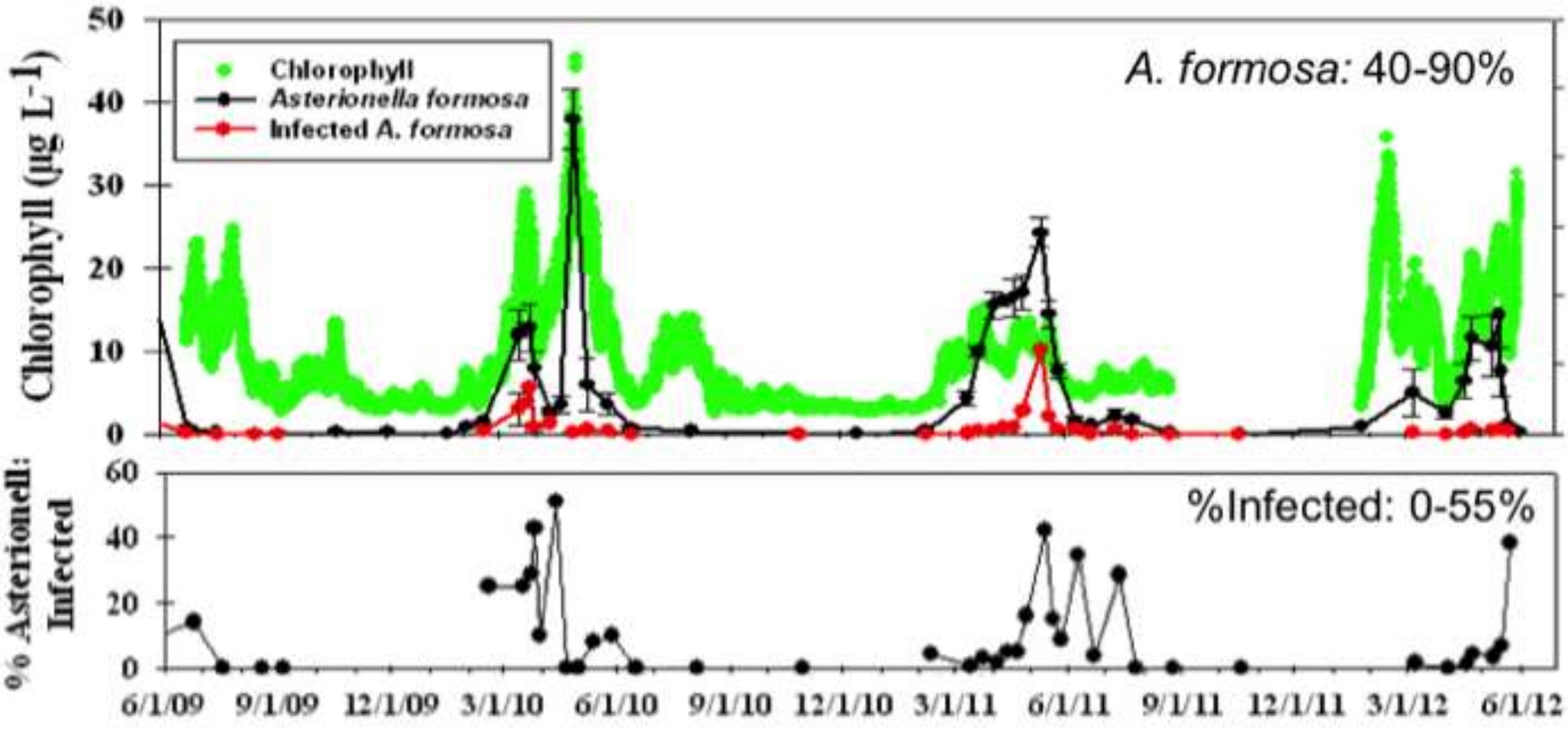


Van Donk, 1983

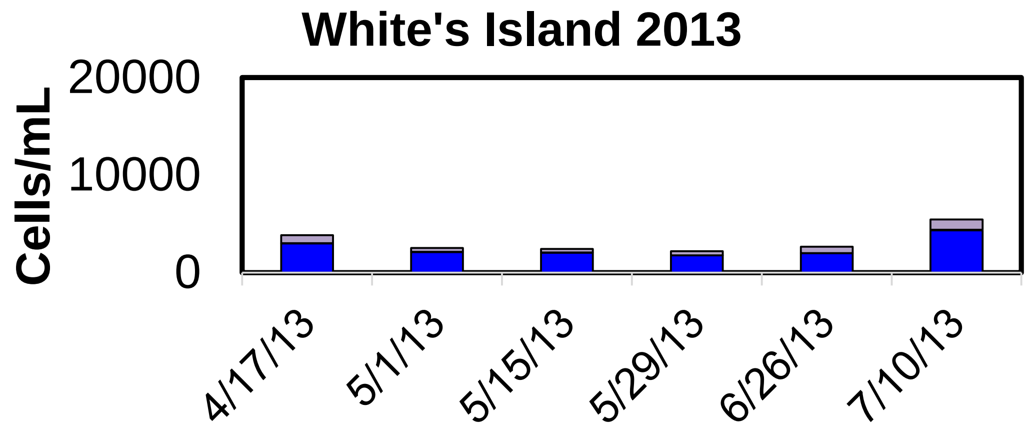


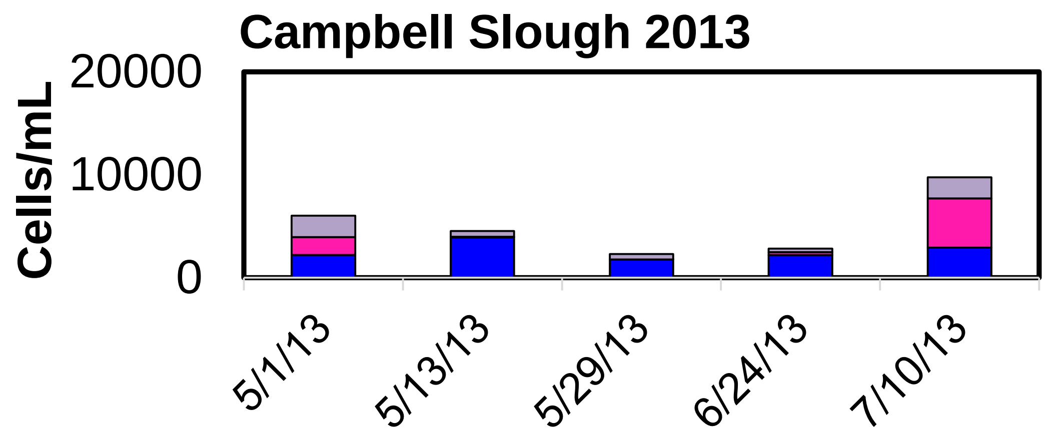
Columbia River *A. formosa*

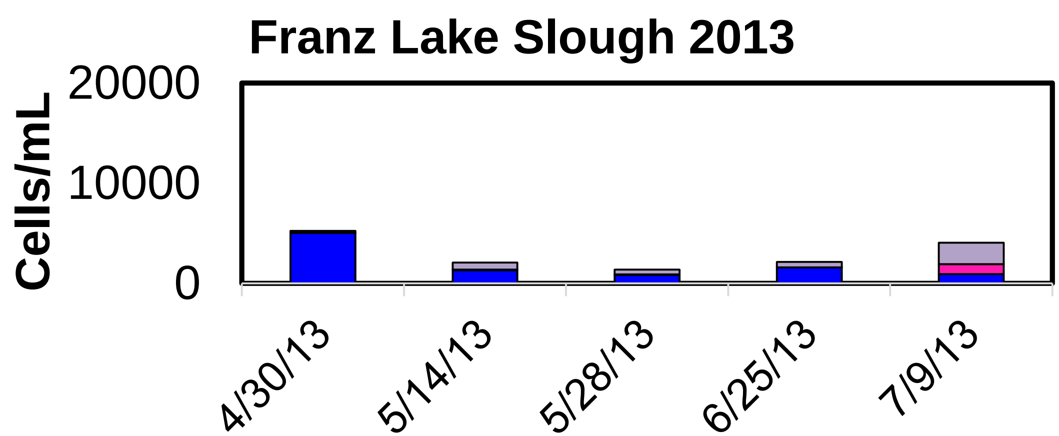
Zygorhyzidium planktonicum identified using 18S rRNA gene sequences, ITS sequences


Chlorophyll
Asterionella formosa
Infected A. formosa
A. formosa: 40-90%
Chlorophyll (µg L-1)
Cells ml-1
%Infected: 0-55%
% Asterionella Infected
50
40
30
20
10
0
6000
5000
4000
3000
2000
1000
0
60
40
20
0
6/1/09
9/1/09
12/1/09
3/1/10
6/1/10
9/1/10
12/1/10
3/1/11
6/1/11
9/1/11
12/1/11
3/1/12
6/1/12

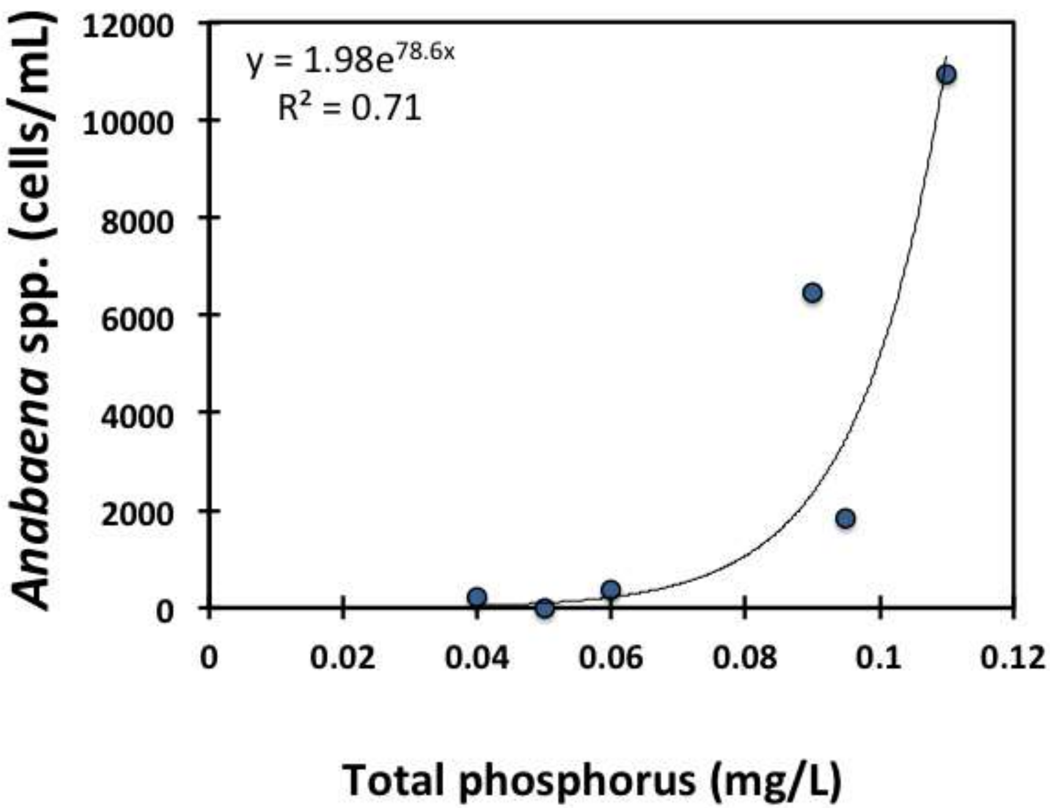
Cyanobacteria abundances higher at Campbell Slough compared to other sites



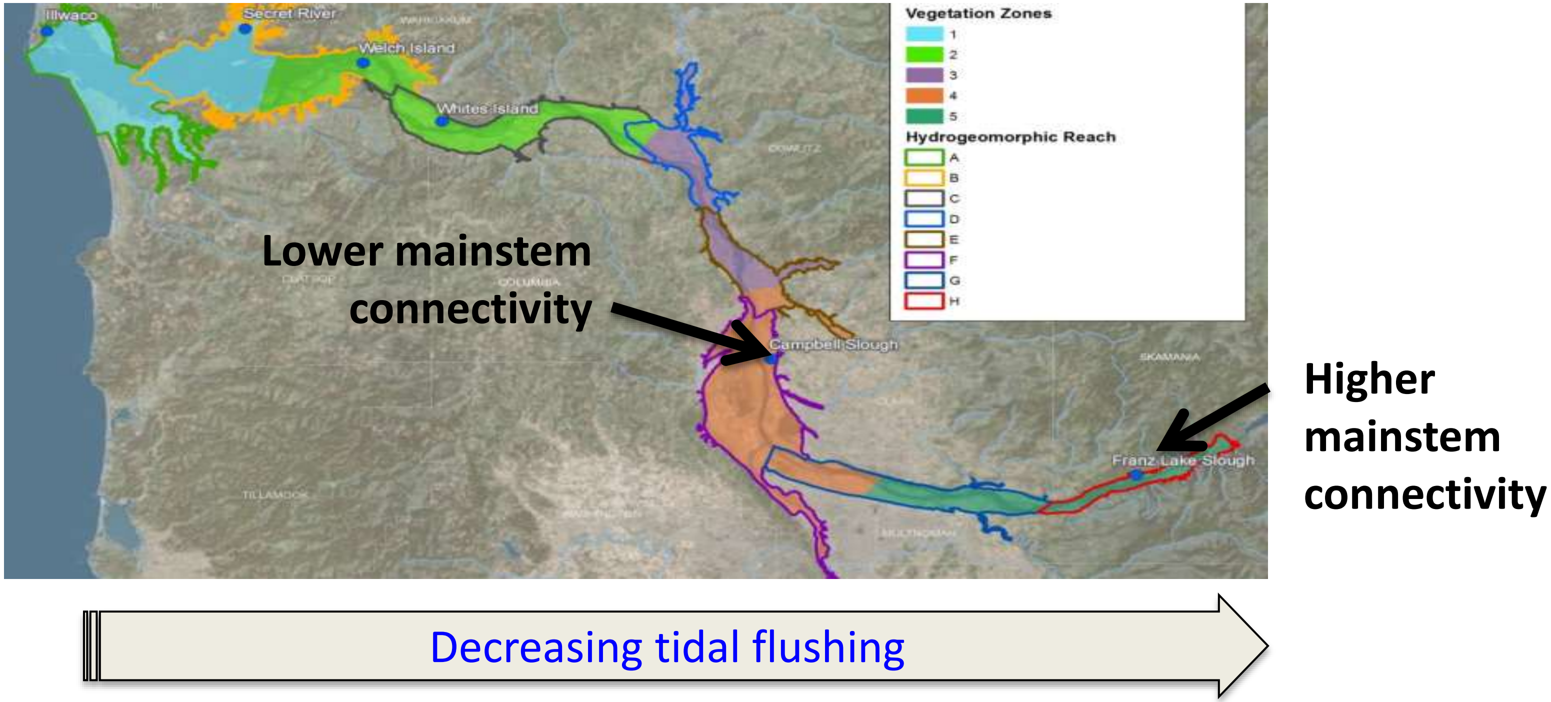




Cyanobacteria abundance related to nutrient levels



Cyanobacteria prevalent at Campbell Slough and Franz Lake in summer



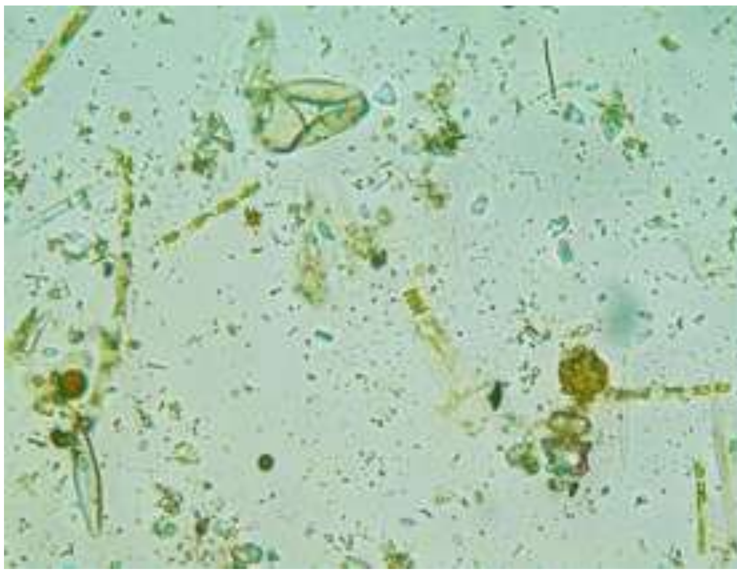
- Campbell slough: higher zooplankton abundances; poor water quality in summer (Whitney's data); high cyanobacteria abundance
- Franz Lake: higher connectivity to mainstem at sampling site, but significant lake input, not well-flushed
- Whites Island: higher connectivity to mainstem; high tidal flushing

Potential consequences for salmon habitat?

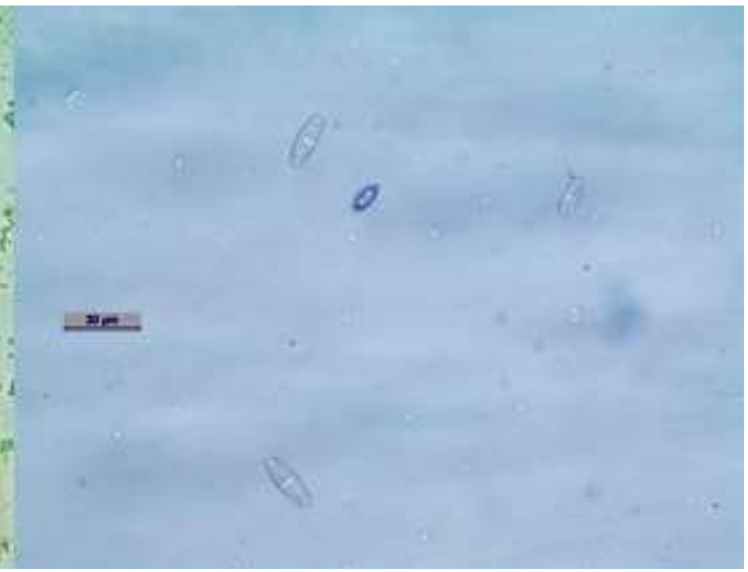
- Diatoms dominated phytoplankton assemblage throughout the year where flushing and mainstem connections highest;
- High zooplankton abundances could provide food for juvenile salmon, or competition for salmon prey in slower-flushed areas;
- High primary production (plus organic matter and nutrients) related to wide fluctuations in dissolved oxygen and pH at slower-flushed sites;
- There is an unknown threat from high cyanobacteria levels in summer.

What role do plankton play in salmon food webs?

- Phytoplankton (fluvial component) fuel zooplankton production;
- Phytoplankton abundances consistently highest in early spring (Mar-May);
- Stable isotope data suggest they are important in the food web mainly during the spring period (Maier & Simenstad, 2009);
- Outstanding questions (phytoplankton):
  - what proportion of the phytoplankton population is available to fuel invertebrate prey of salmon?
  - Does the size class structure of the phytoplankton matter for larval insect prey?
  - Do differences in phytoplankton taxa influence invertebrate nutrition? Does benthic secondary production differ with respect to organic matter source? What role do microbial decomposers play in the nutritional quality of macrodetritus?

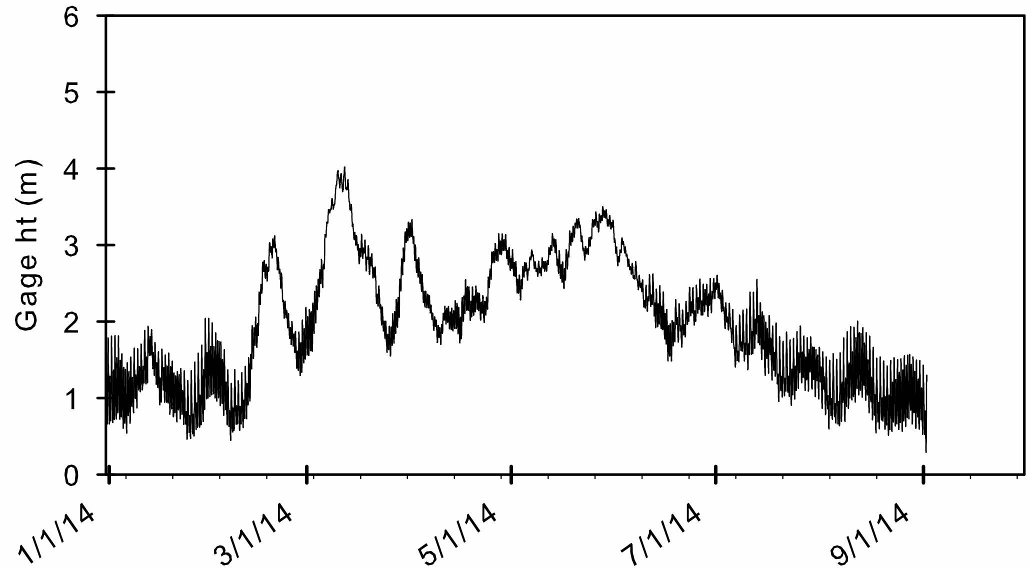


Whole water sample

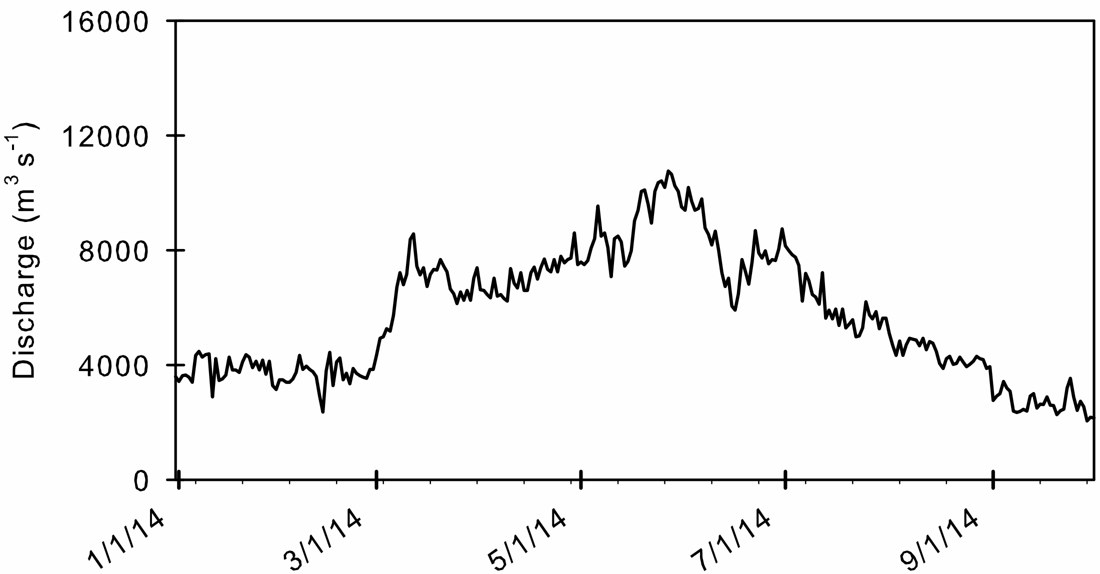


Chironomid gut contents

2014



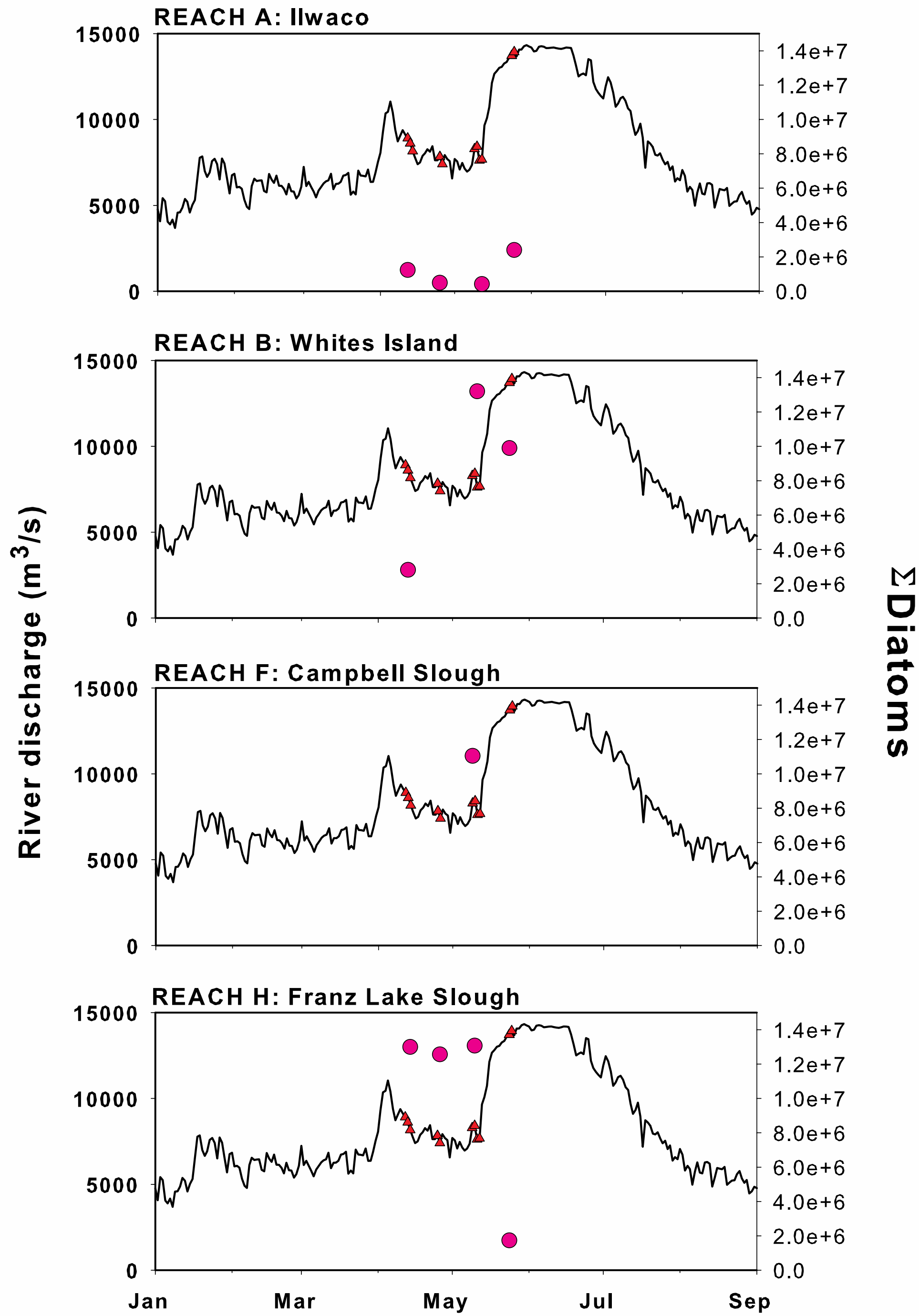
6
5
4
3
2
1
0
Gage ht (m)
1/1/14
3/1/14
5/1/14
7/1/14
9/1/14



16000
12000
8000
4000
0
Discharge (m3 s-1)
1/1/14
3/1/14
5/1/14
7/1/14
9/1/14

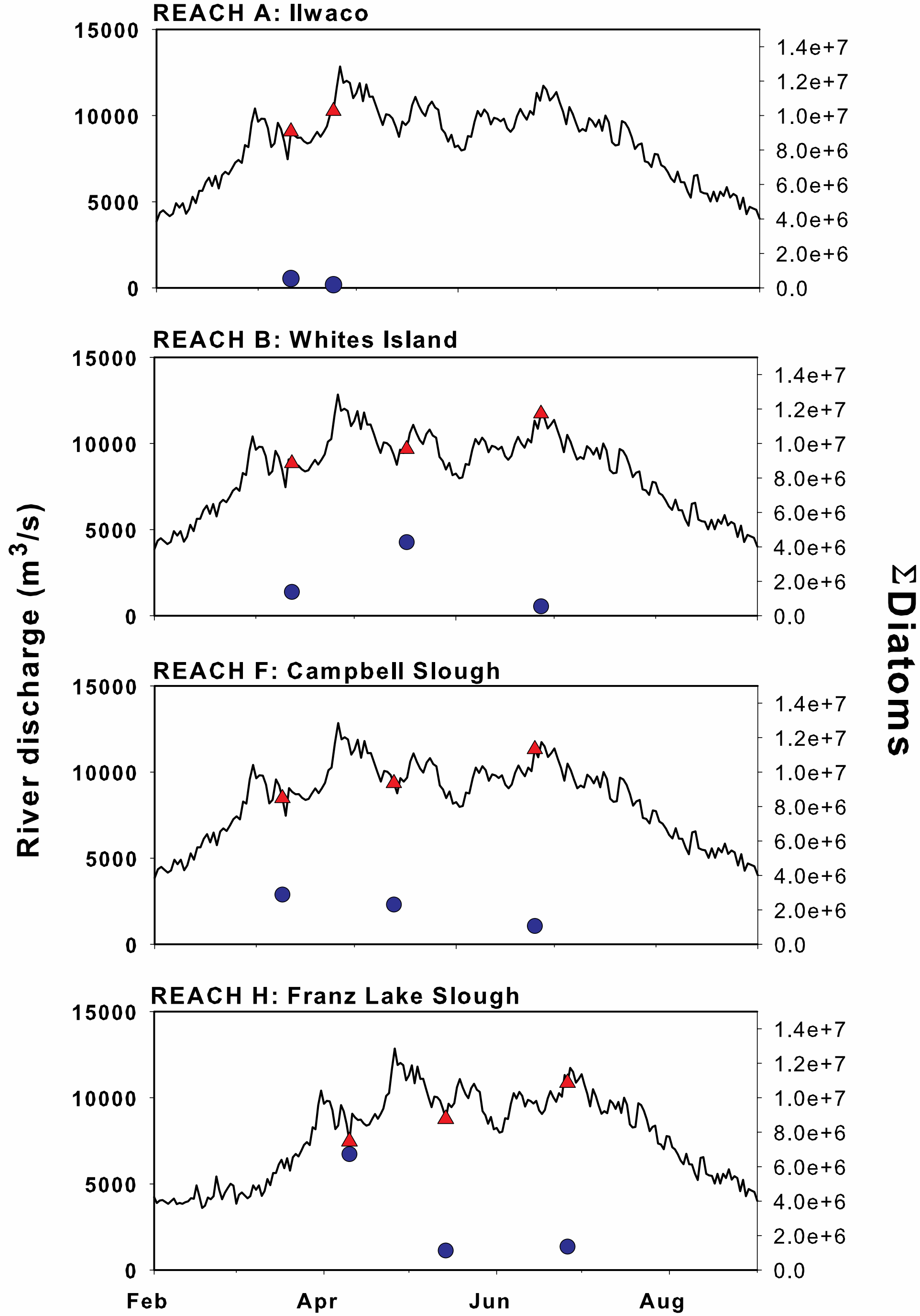
2011

- dominant phytoplankton are diatoms (Class Bacillariophyceae) throughout system;
- Abundances are lowest in Reach A (Ilwaco);
- Limited data could indicate that high water at Franz Lake Slough flushes out/dilutes phytoplankton during freshet



2012

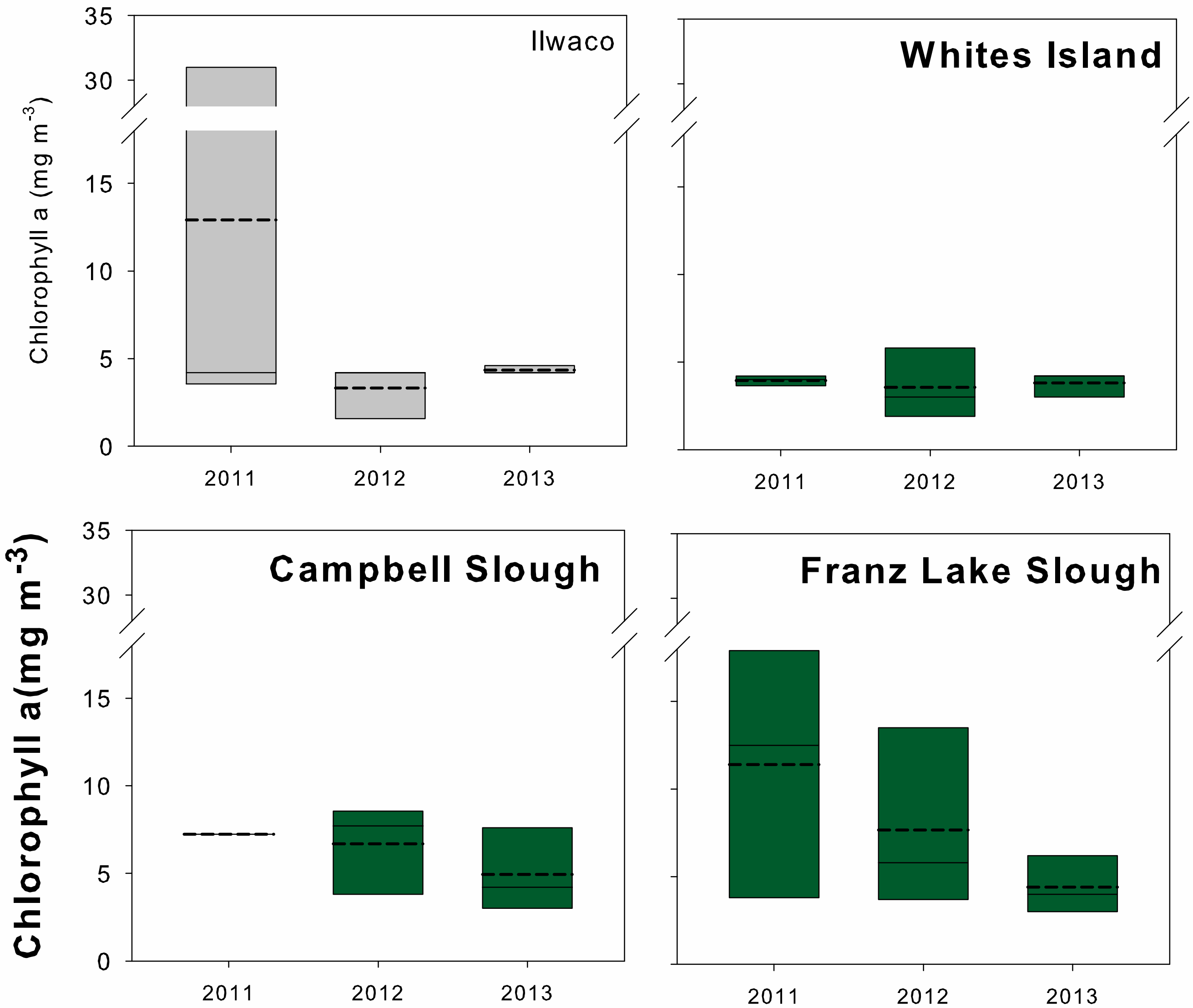
- dominant phytoplankton are diatoms (Class Bacillariophyceae) throughout system;
- Abundances are lowest in Reach A (Ilwaco);
- Abundances were less variable compared to 2011 (likely reflects smaller range in river discharge over time of sampling)
- What's happening at Franz Lake?
  - In April, ortho-phosphate low (NO_3^-:PO_4^{3-}=33.8)→incr. in May, June (ie, phytos not nutrient limited)
  - Phyto abundance may have been HIGHER before onset of freshet



Some early conclusions: phytoplankton

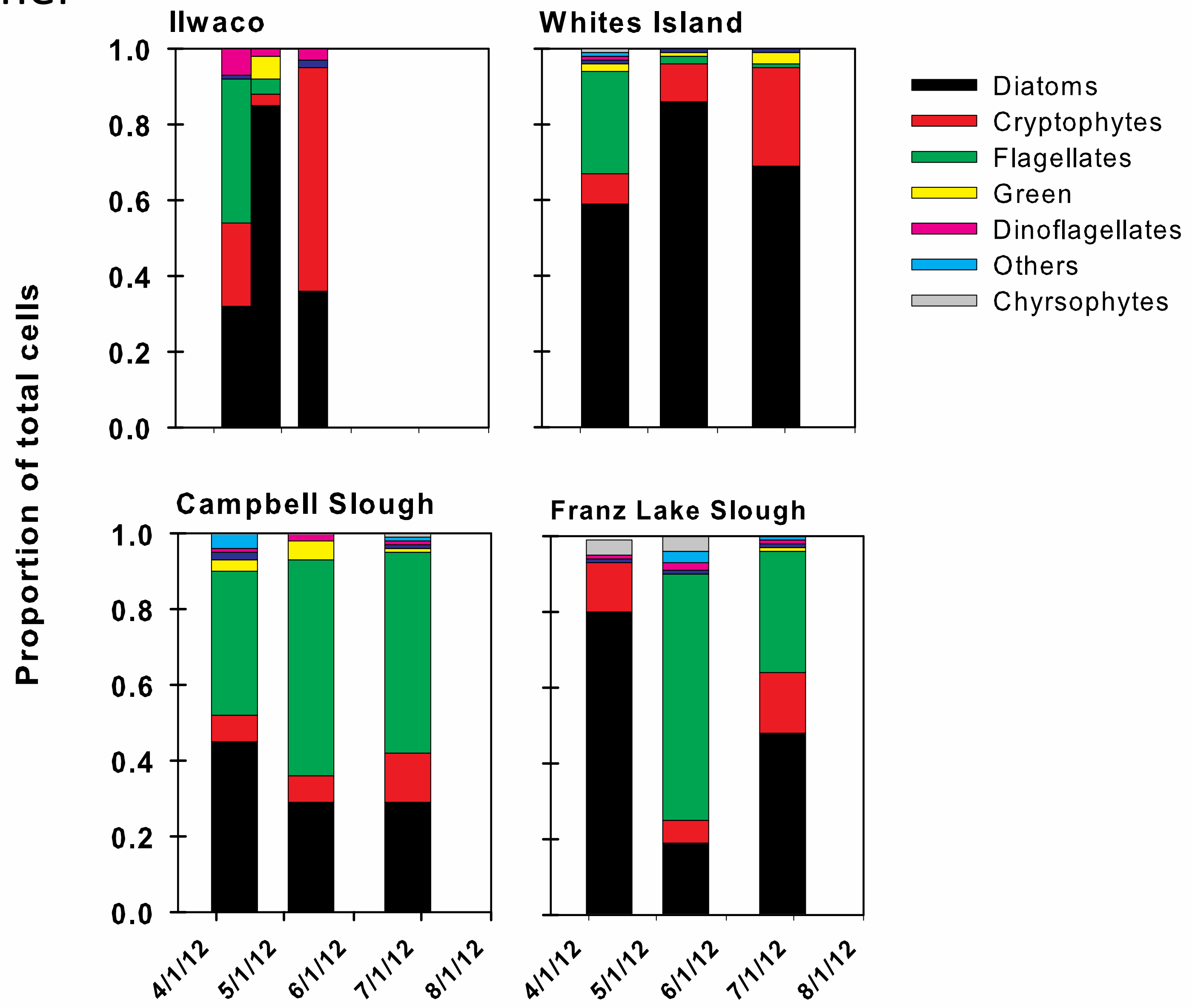
- Repeatable spring bloom with minor blooms, dominated by similar species (*Asterionella formosa*, *Aulacoseira granulata*, *Skeletonema potamos*, etc.);
- Inverse spatial relationship between phytoplankton vs. periphyton primary production (C-uptake rates);
- Phytoplankton seem to contribute to salmon diet in early spring (based on stable isotope of organic matter)
- Phytoplankton biomass/abundance/species composition strongly influenced by river flow

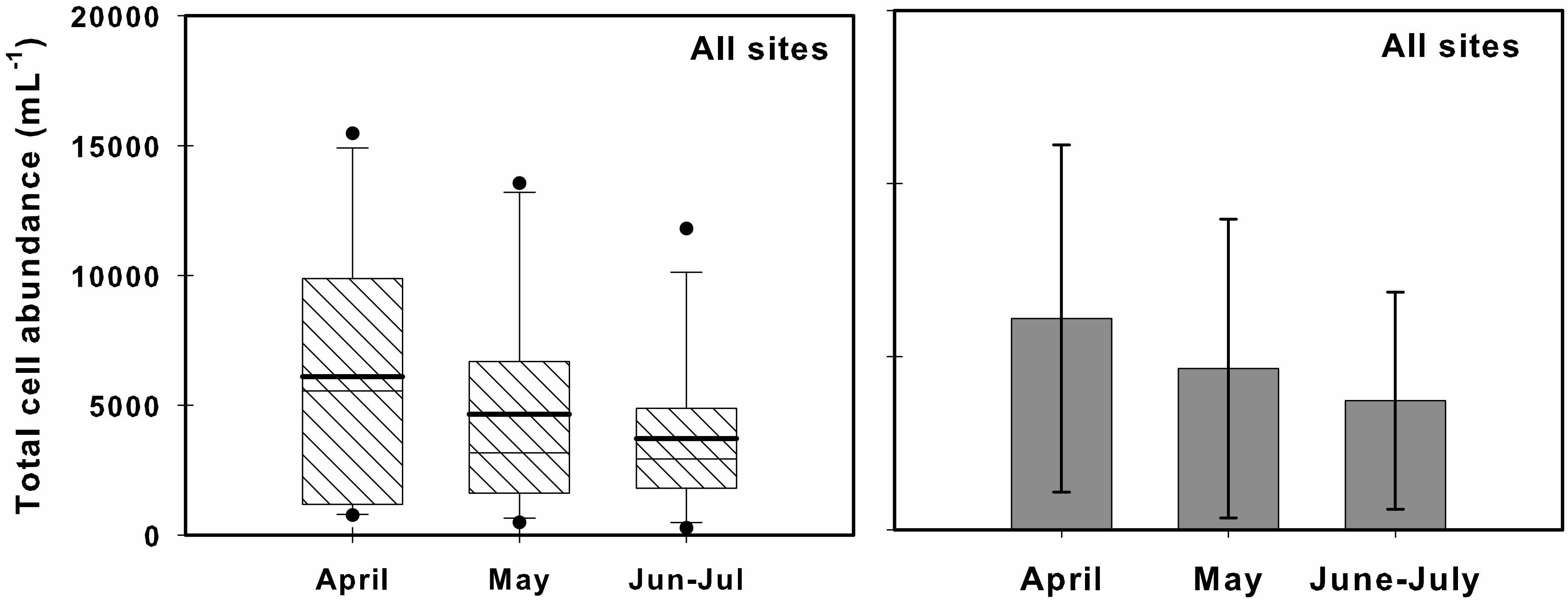
Chlorophyll levels varied by year



*Differences largely driven by diatom abundances

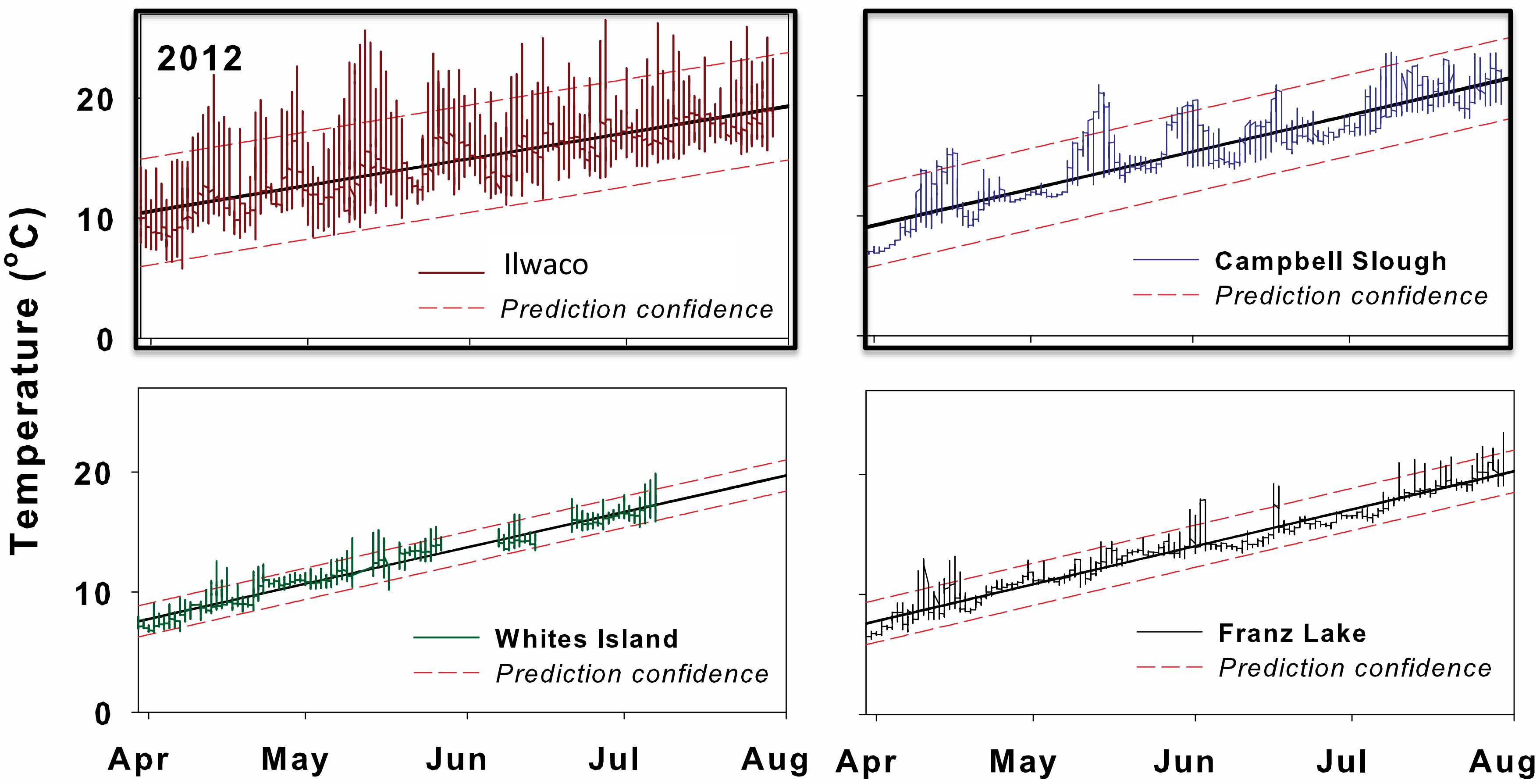
Dominant phytoplankton taxa differ among sites, especially in summer



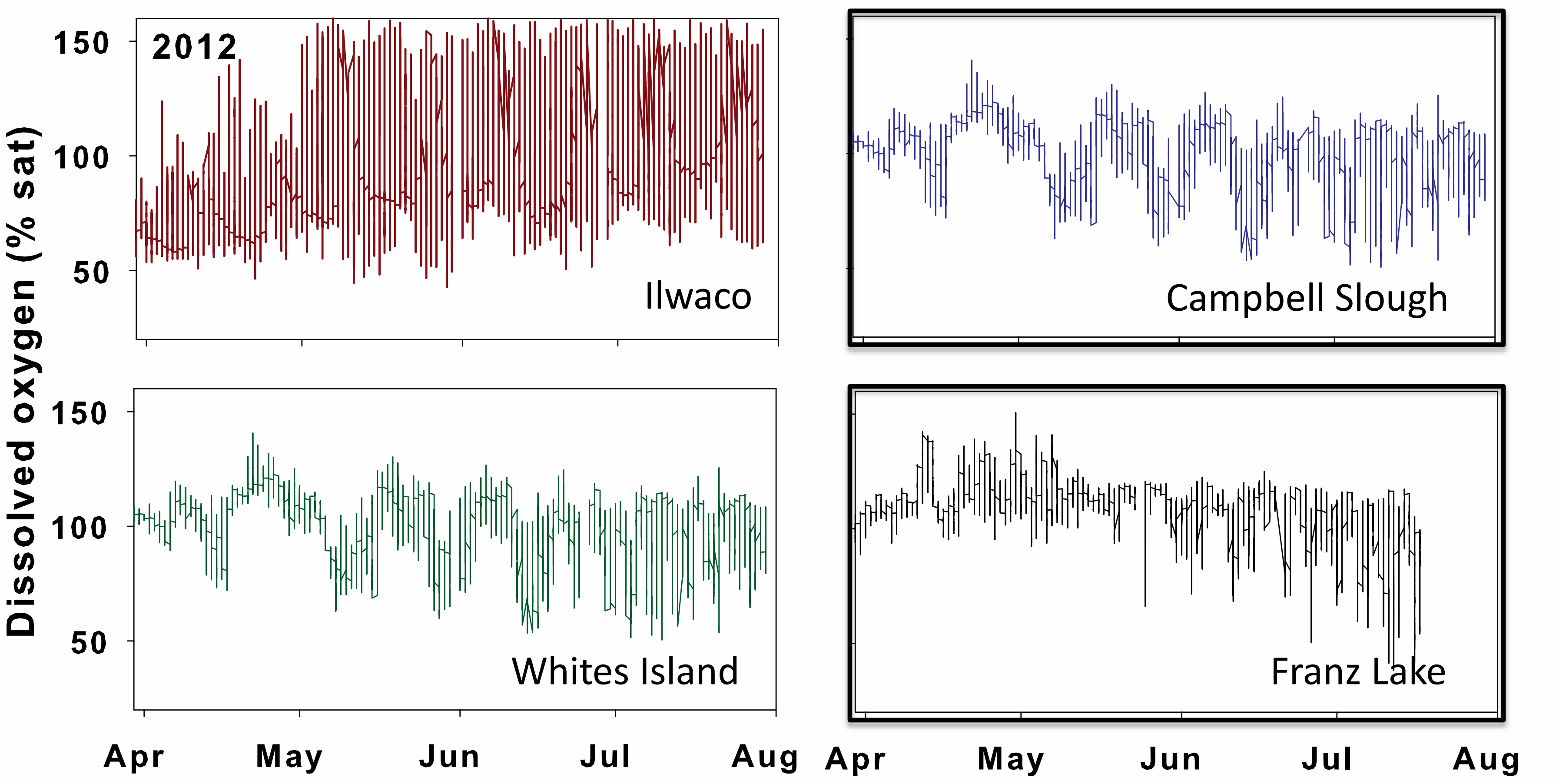


20000
15000
10000
5000
0
Total cell abundance (mL-1)
All sites
April
May
Jun-Jul
All sites
April
May
June-July

Temperature fluctuations related to high (Ilwaco) or low (Campbell Slough) tidal flushing



Low DO (%saturation) observed at Campbell Slough and Franz Lake Slough in summer



Juvenile salmon prey consume fluvial phytoplankton in early-mid spring

	Month	Vascular plants	Aquatic plants	Benthic diatoms	Fluvial phytoplankton
Chironomidae spp.	April	7	14	7	**60**
	May	14	66	5	12
	June	60	11	6	19
	July	20	0	83	0
Corophium salmonis	April	60	3	4	**31**
	May	65	0	0	**39**
	June	83	6	4	5
	July	41	37	6	2