King County

August 22, 2018

Nutrient, Phytoplankton, and Dissolved Oxygen Dynamics: What can long-term monitoring tell us?

Stephanie Jaeger, Kimberle Stark, Gabriela Hannach, and Ben Larson

King County Department of Natural Resources and Parks

King County

Goals

- Understanding algal blooms in Central Puget Sound: What do we know about spatial and temporal trends, and what are the effects on water quality?
- How can we contribute to a better understanding of potential eutrophication processes in Puget Sound and the status of the Central Basin?

What is Eutrophication?

- Process which a waterbody becomes overly enriched with nutrients that causes excessive growth of algae and aquatic plants.
- Can lead to oxygen depletion.

photo: Reuters

China

photo: www.ozcoasts.gov.au

Australia

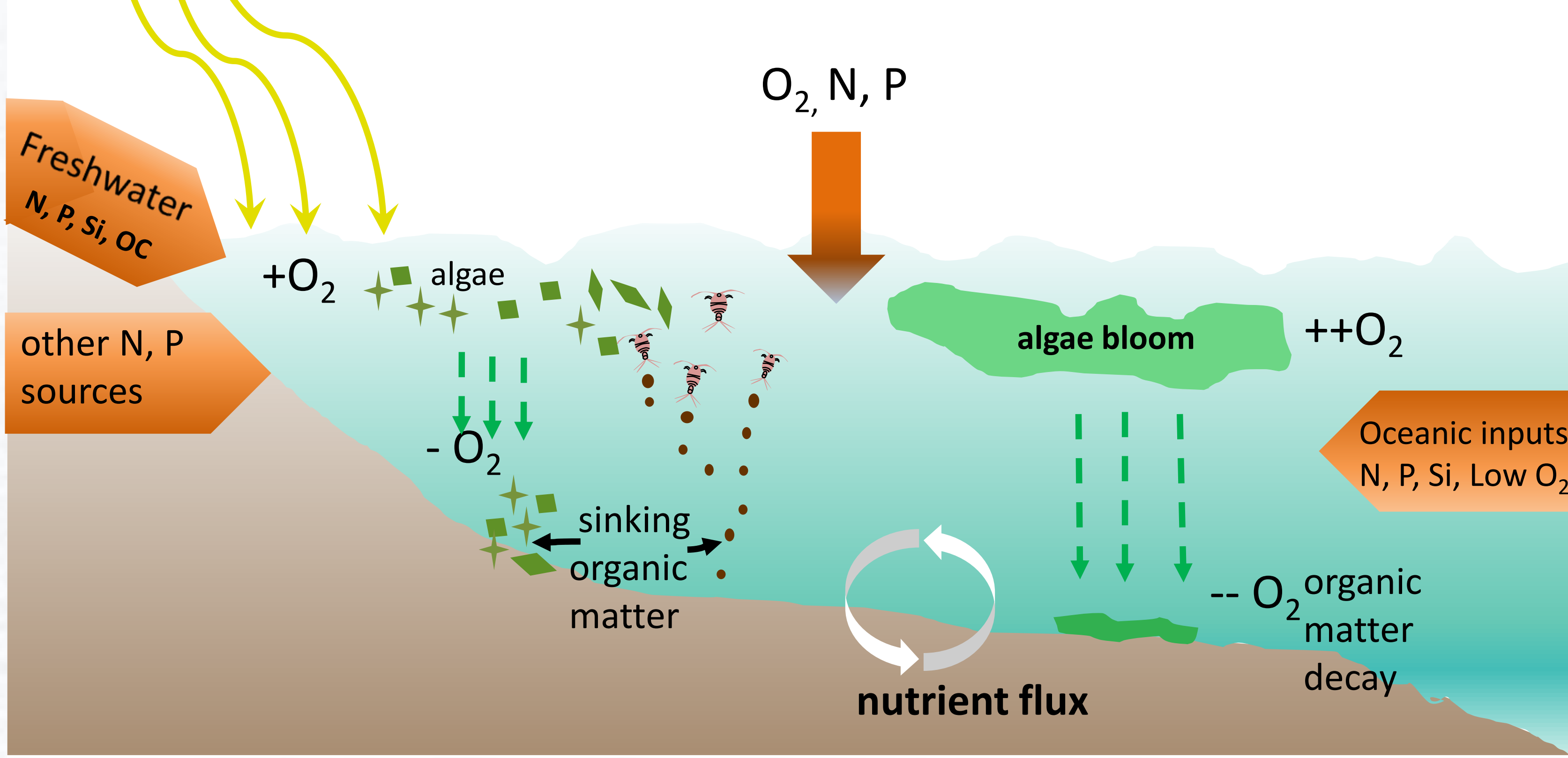
King County

Eutrophication

Impairment pathways:

- Over-abundance of algae
- Shifts in phytoplankton dominance & size classes
- Increased harmful algal blooms
- Low dissolved oxygen related to blooms

(Source: Sutula and Senn 2017)



King County

How Can We Monitor for Eutrophication in Marine Systems?

- **Status Indicators**

1. - ***Nutrient concentrations and trends***
   - ***Water clarity***

- **Biological Response Indicators**

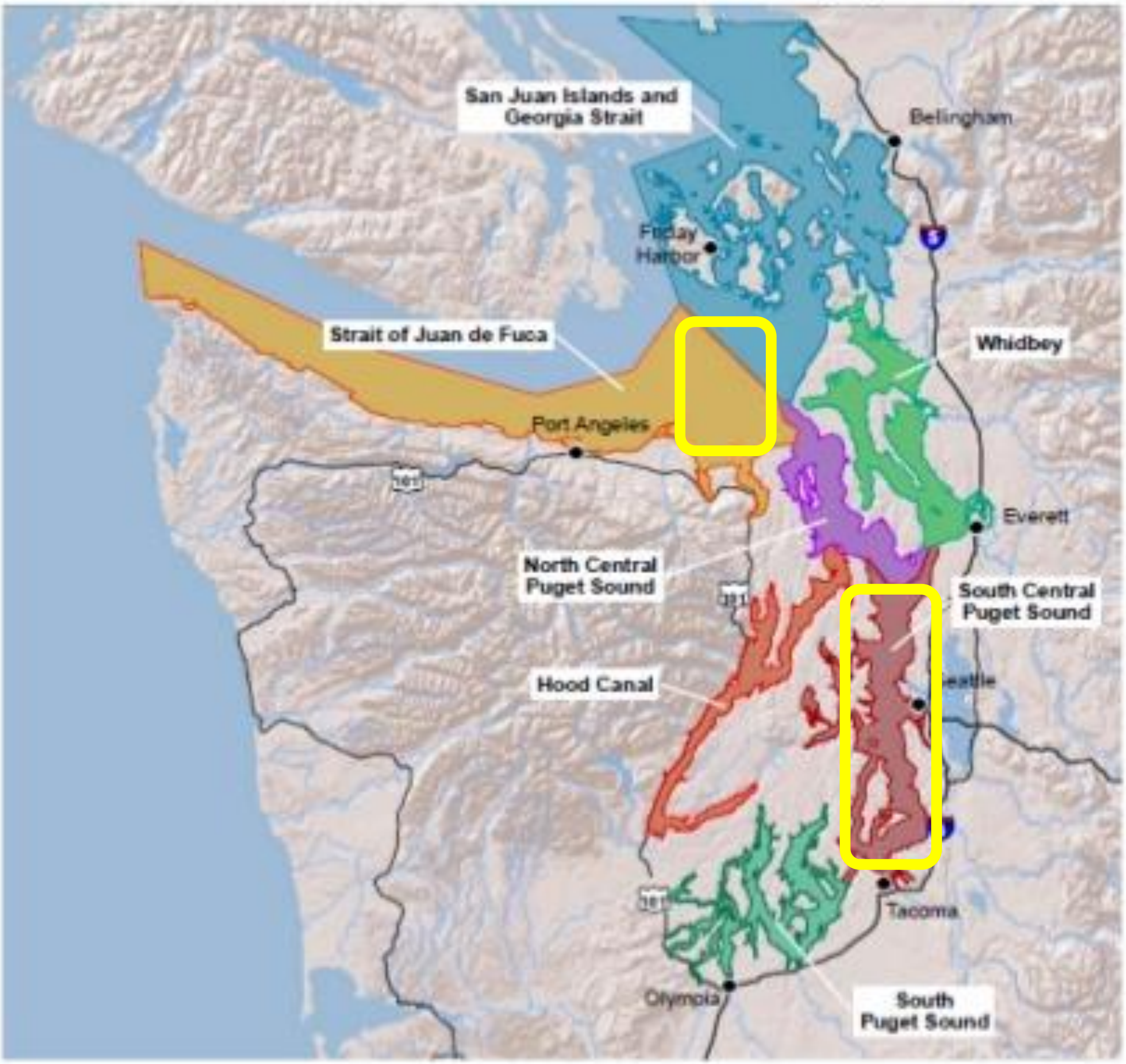
2. - ***Phytoplankton (chlorophyll-a) biomass***
   - ***Phytoplankton production rate (gross and net)***
3. - ***Phytoplankton species composition and abundance***
   - ***Zooplankton species composition and abundance***
4. - ***Dissolved oxygen levels***
   - ***Harmful algal blooms & toxin concentrations***
   - ***Macroalgae and eelgrass abundance***

King County

Themes

- Place matters
- Variability is the back drop to assessing change
- Consistent long-term monitoring is key
- Information gaps in understanding of a complex ecosystem

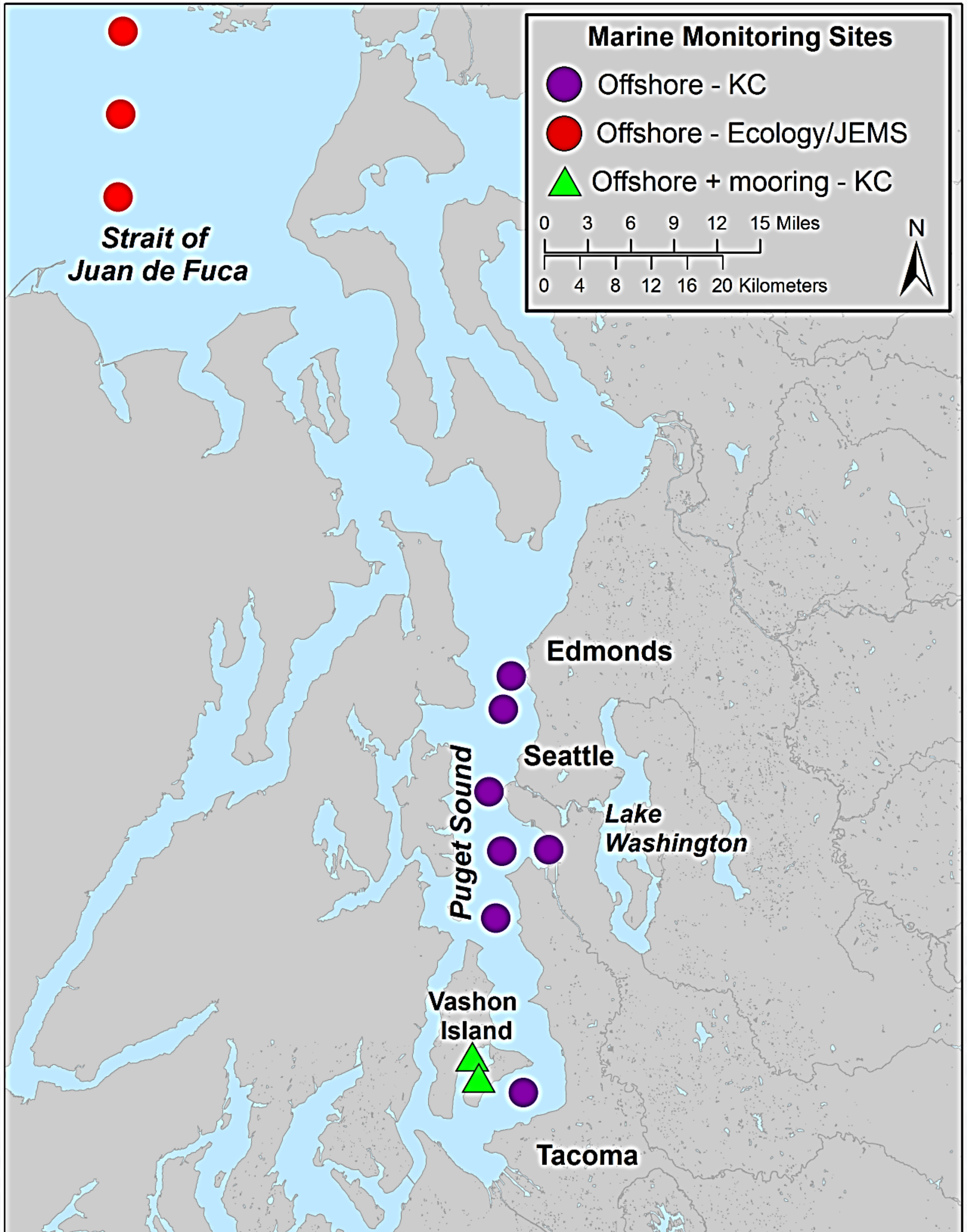
Puget Sound Basins



King County

Source: Puget Sound Partnership

Juan de Fuca data from Ecology & WWU



Central Basin data from King County

King County

Nutrients are one important fuel for primary production

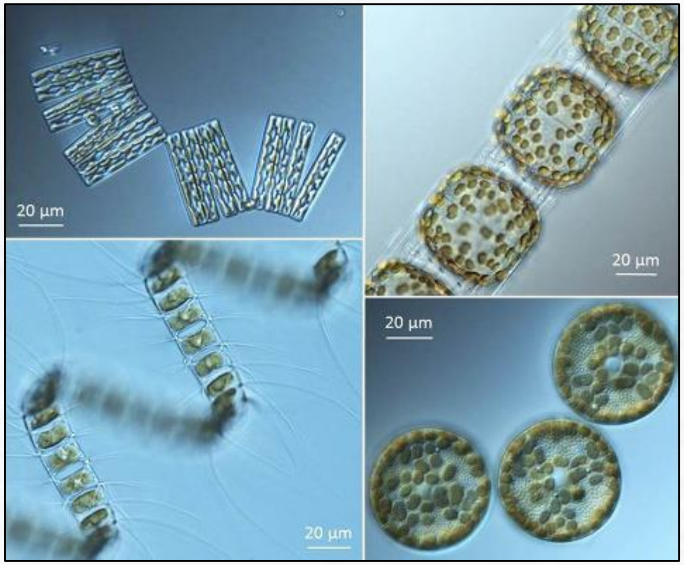
Macronutrients

Dissolved Inorganic Nitrogen (**DIN**)

- Nitrate+Nitrite
- Ammonia

Phosphate (OP)

Silica (Si)



Dissolved organic matter

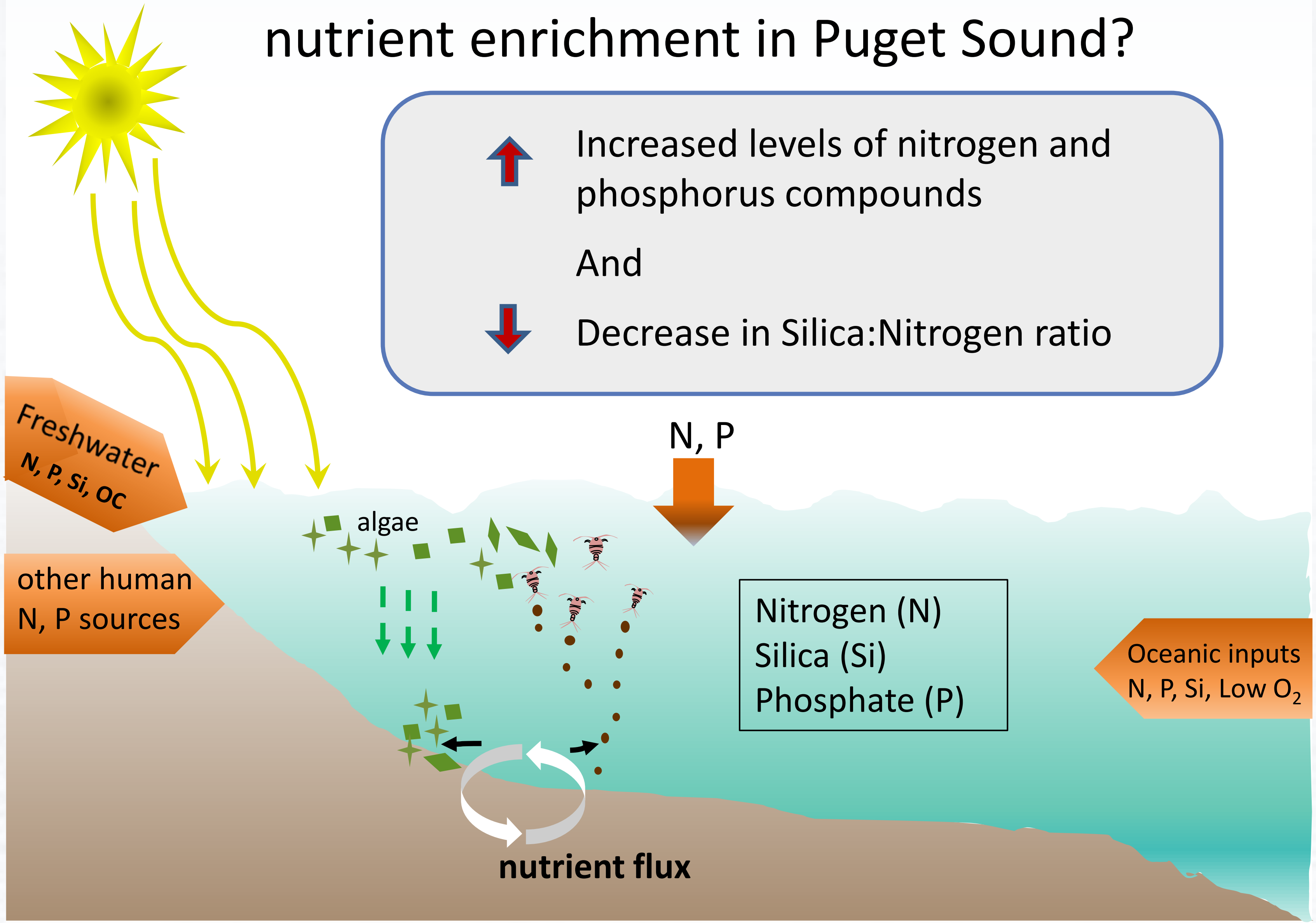
Micronutrients (such as iron, copper)

What are measurable variables of potential human nutrient enrichment in Puget Sound?

Increased levels of nitrogen and phosphorus compounds

And

Decrease in Silica:Nitrogen ratio

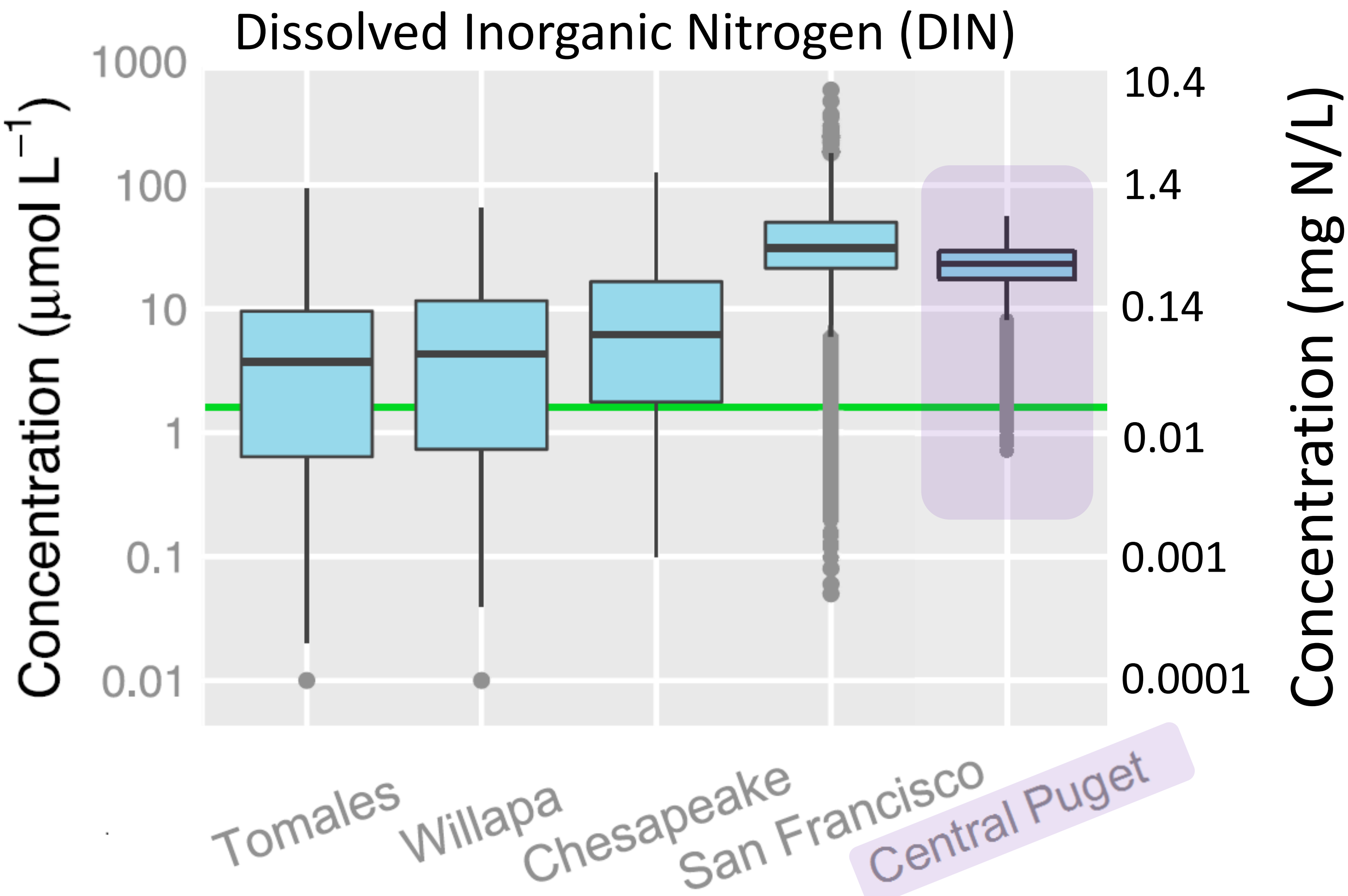


King County

What do we observe in nutrients?

- Strong seasonal variability
- Differences in nutrient trends between basins over the last 2 decades and…
- Same trends across macronutrients in a particular basin
- Increase in both DIN and silica (Si) in the Central Basin in the winter and increasing Si:DIN ratio
- Similar ranges of nutrients compared to last century
- Suggests that hydrological cycle and circulation are important contributors

How does Puget Sound compare to other estuaries?



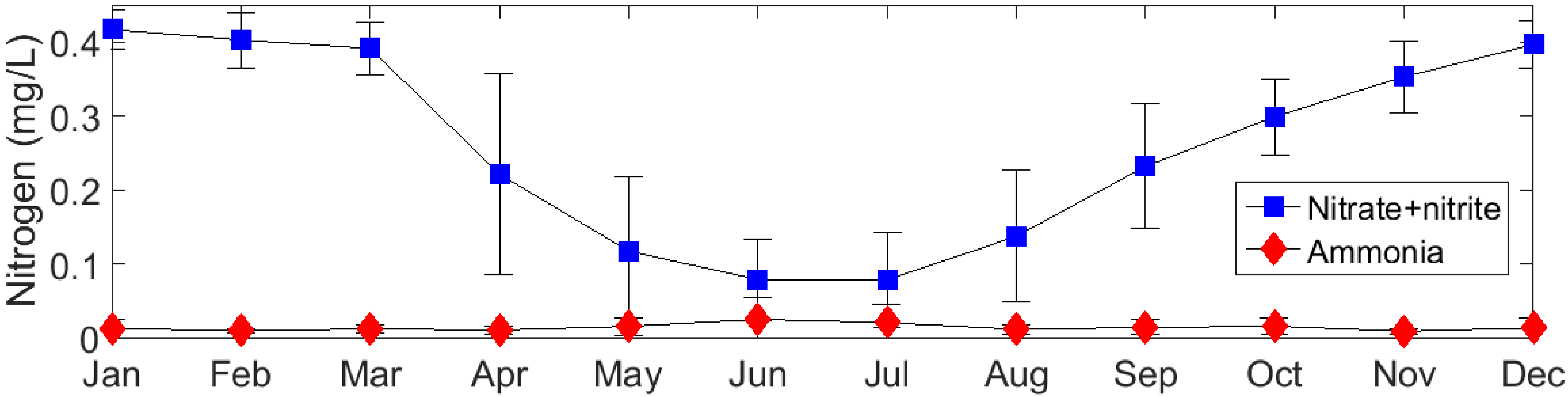
Line in the box is median, boxes are 1st – 3rd quartiles, lines show all points within 1.5 interquartile distance (box height), points are outliers.*

King County

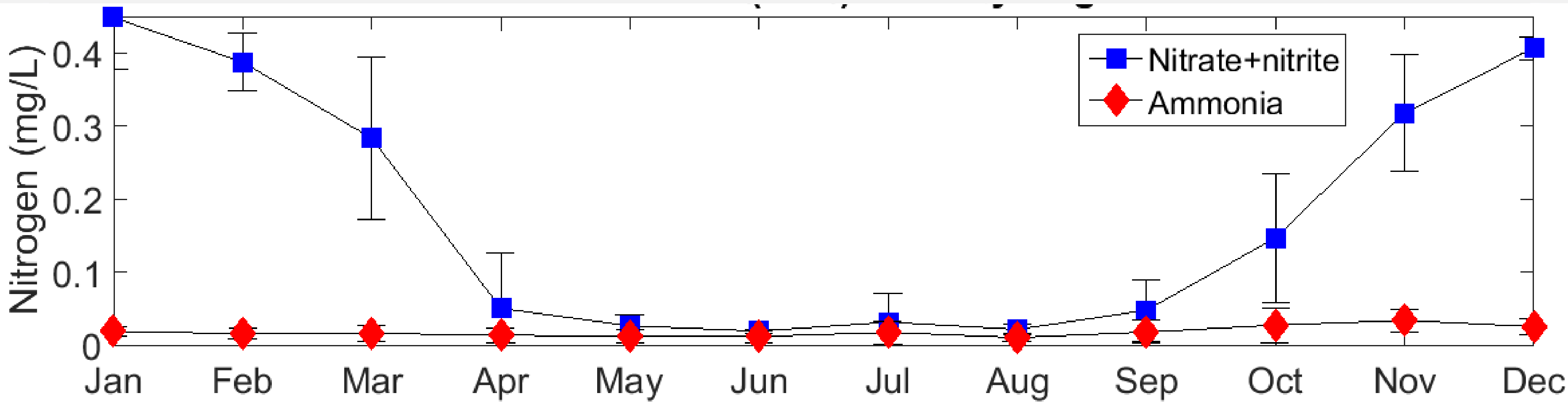
Source: Cloern & Jassby 2012, modified by B. Larson

Seasonal Patterns Vary by Month & Location

Pt. Jefferson: Near-Surface (<2-m) Monthly Average (1994 – 2017)



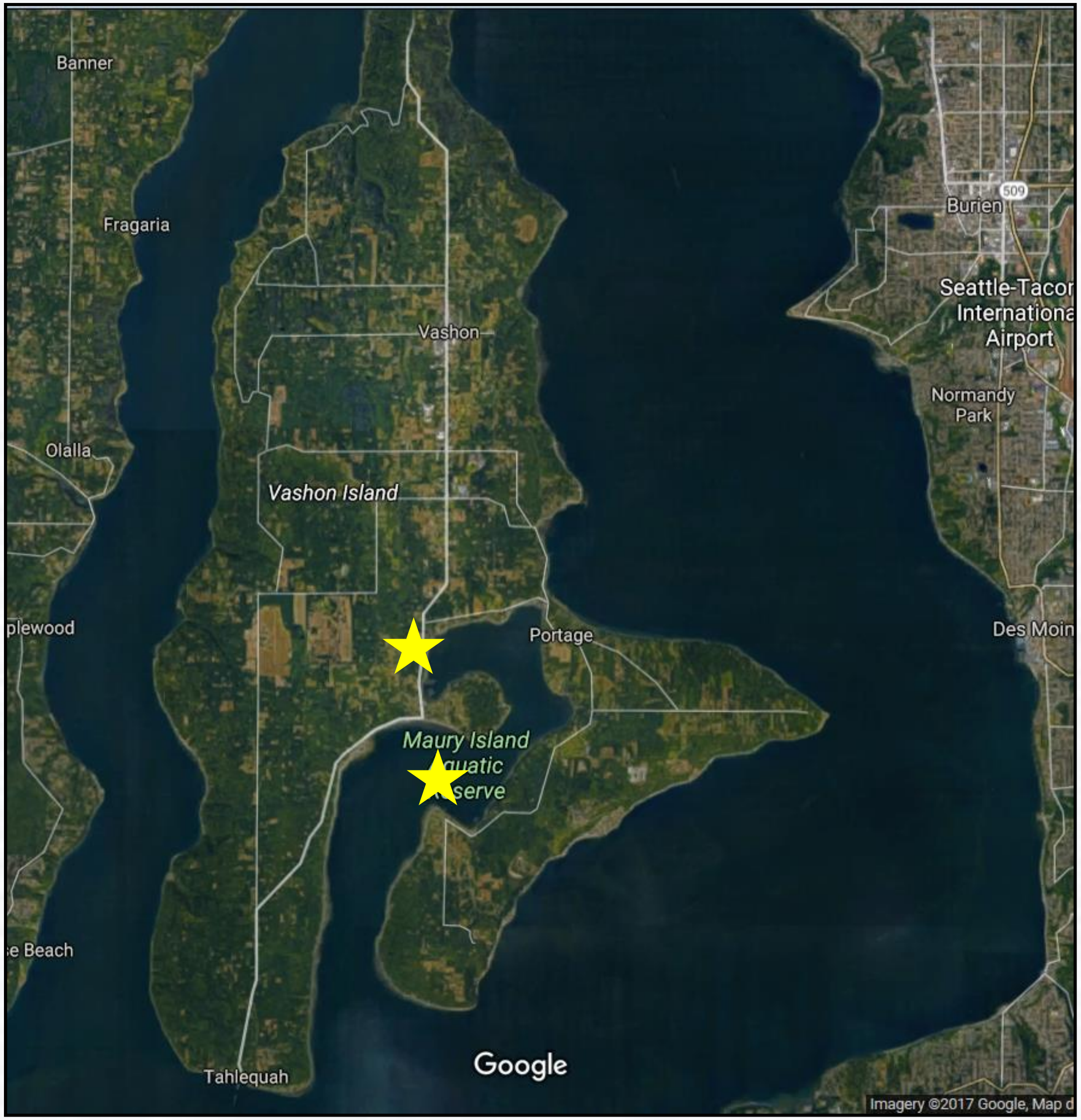
Outer Quartermaster: Near-Surface (<2-m) Monthly Average (2006 – 2017)



King County

Error bars are ± 1 std. dev.

Quartermaster Harbor: shallow, poorly flushed embayment in Central Sound

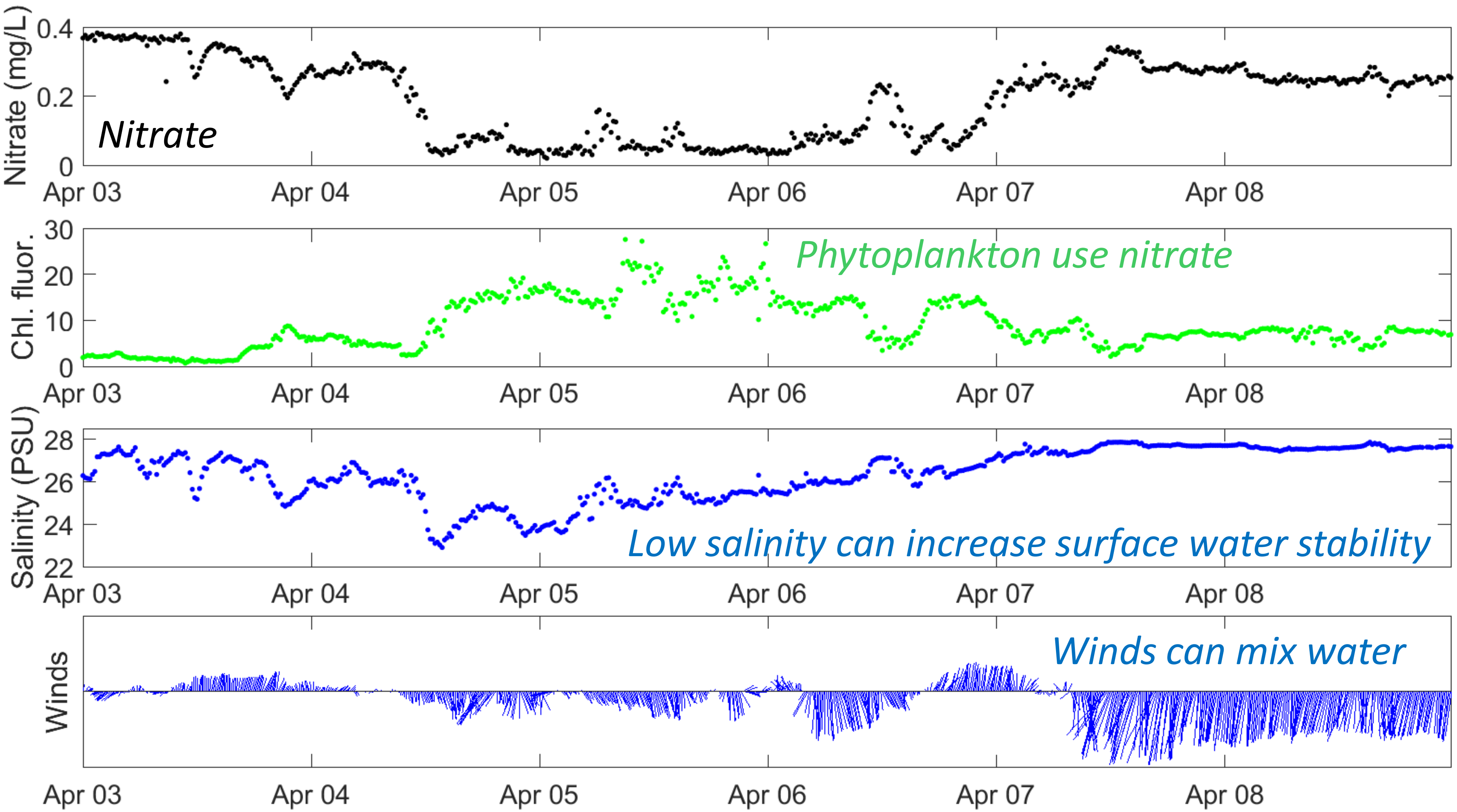


- Shorter data record (began 2006)
- Too variable for trends from once or twice monthly sampling
- Nitrogen management study completed 2007-2013
  - Sediment flux and groundwater nitrate likely play large roles

King County

Daily & weekly variability can be high near the surface

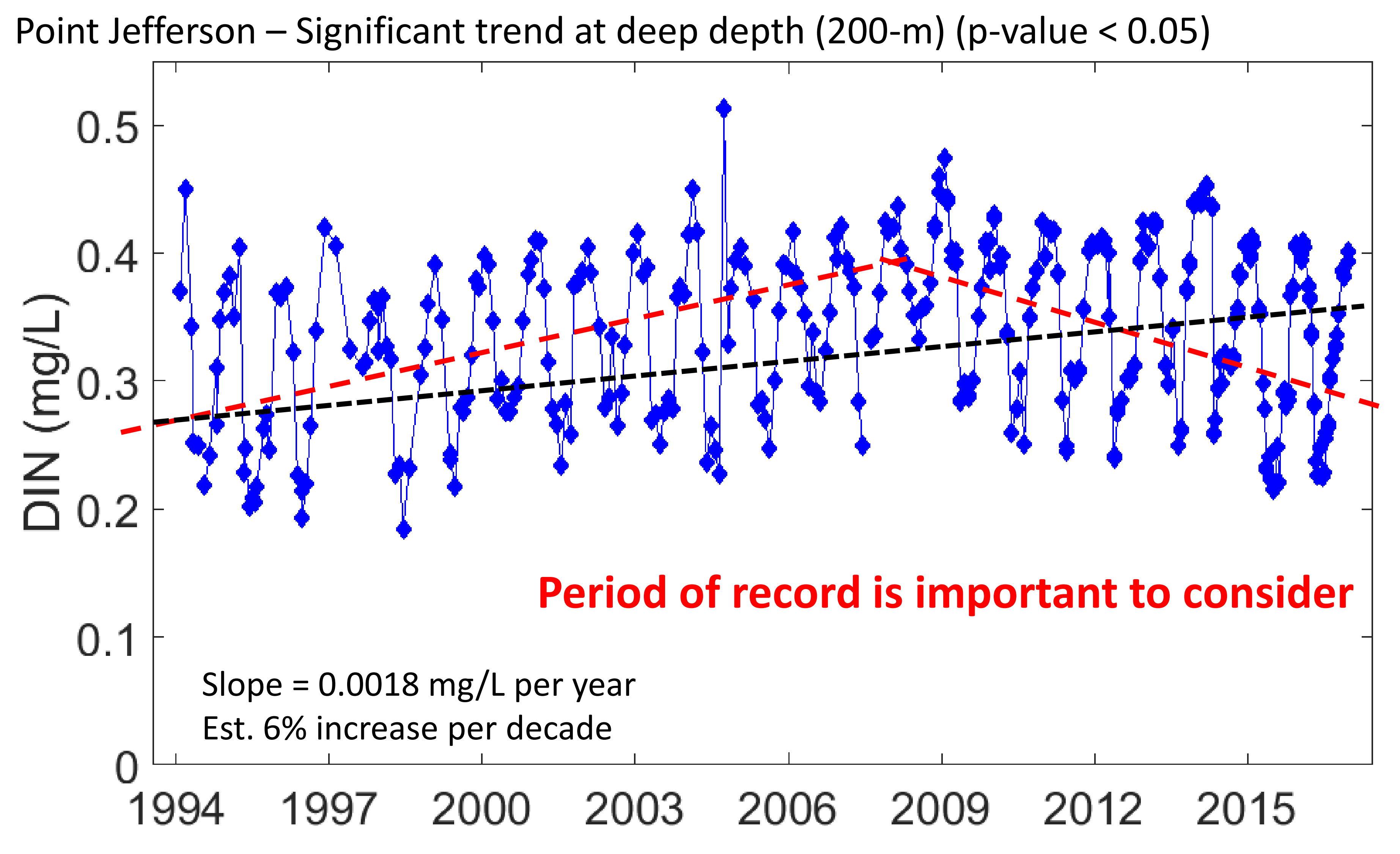
Early April 2017- Pt. Williams buoy at 1-m

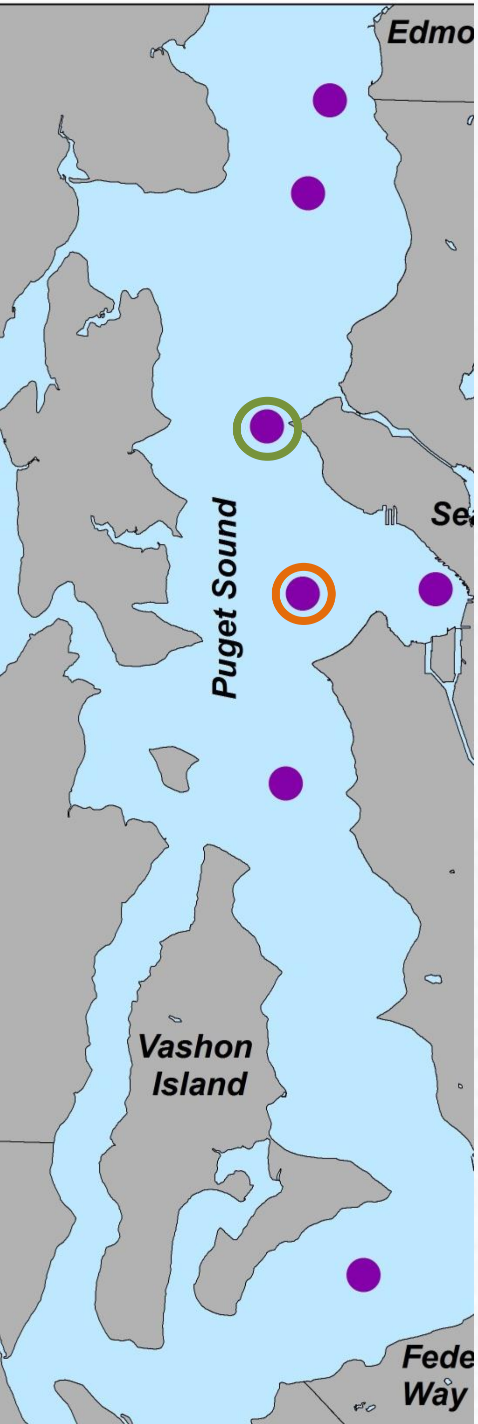


Wind vectors show relative speed and direction wind is coming from

How can we measure trends with high seasonal variability?

- One method = Non-parametric linear trend test by month (seasonal Mann-Kendall)





Dissolved Inorg. Nitrogen: Trends over 2 decades

Site	Years of Data	<3-m	Σ0-35-m	Deep (>55-m)
Brightwater TP	19	NS	NS	↗
Pt. Jefferson	24	↗	↗	↗
West Point TP	21	NS	NS	NS
South TP	21	NS	↗	↗
Pt. Williams	24	↗	↗	↗
Elliott Bay	21	NS	↗	↗
East Passage	15	↘	NS	NS

Legend: %Change over period of record

	0-5%	5-25%	25-50%
+	→	↗	↗
-	→	↘	↘

NS = Not Significant (p>0.05)

Which season is driving this trend?

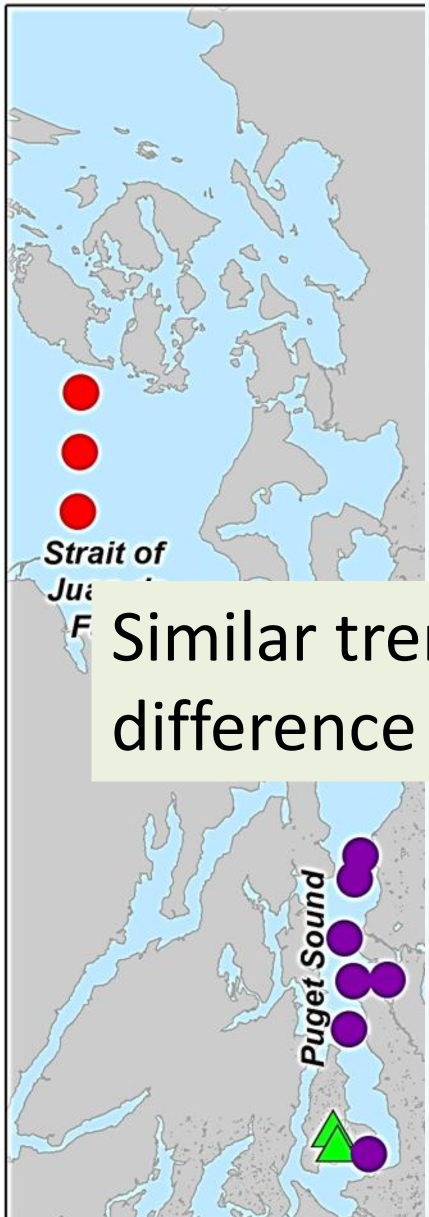
Central Basin Depth-integrated Σ0 - 35-m

	Dissolved Inorg. Nitrogen (DIN)	Silica	Silica:DIN Ratio	DIN:TP Ratio*	Salinity
Winter	↗	↗	NS	NS	NS
Spring	NS	↗	↗	NS	→
Summer	NS	NS	NS	NS	→
Fall	NS	NS	NS	NS	NS

King County

* = TP data thru 2010

Trends over 2 decades – stations combined



Central Basin

Depth Bin	Dissolved Inorg. Nitrogen (DIN)	Silica	Total Phosphorus*	Silica:DIN Ratio	DIN:TP Ratio*	Salinity
<3-m	NS	↗	↗	↗	NS	→
Σ0-35-m	↗	↗	↗	↗	NS	NS
Deep (>55-m)	↗	↗	↗	↗	NS	NS

Similar trends for all nutrients within each basin suggests difference in watershed/ocean balance over this record

Depth Bin	Dissolved Inorg. Nitrogen (DIN)	Silica	Total Phosphorus*	Silica:DIN Ratio	DIN:TP Ratio*	Salinity
<3-m	↘	↘	↘	NS	NS	→
30-m	↘	↘	↘	NS	NS	→
>140-m	↘	↘	↘	NS	NS	NS

Years of Data = 12 – 24 for Central Basin
= 19 yrs for Juan de Fuca

* = TP data thru 2010

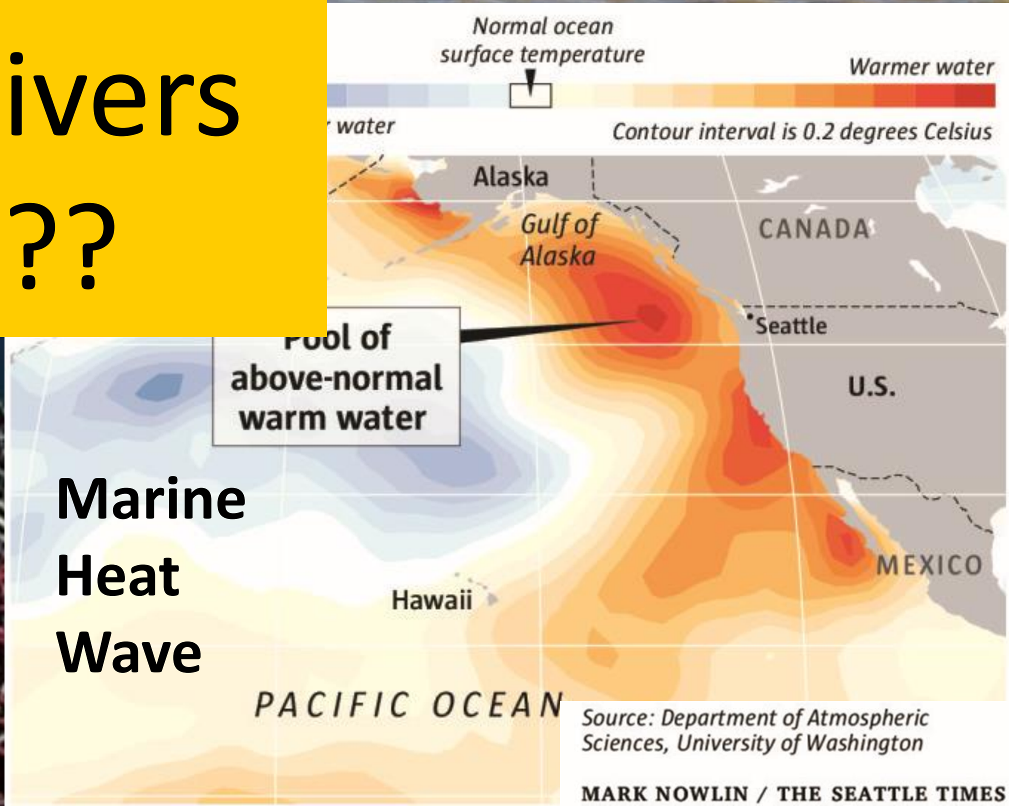
Potential Drivers ??

Fraser River freshet meets saltwater

(Source: A. Perea)

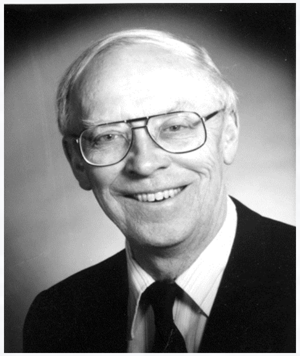
El Niño

(Source: SNL)

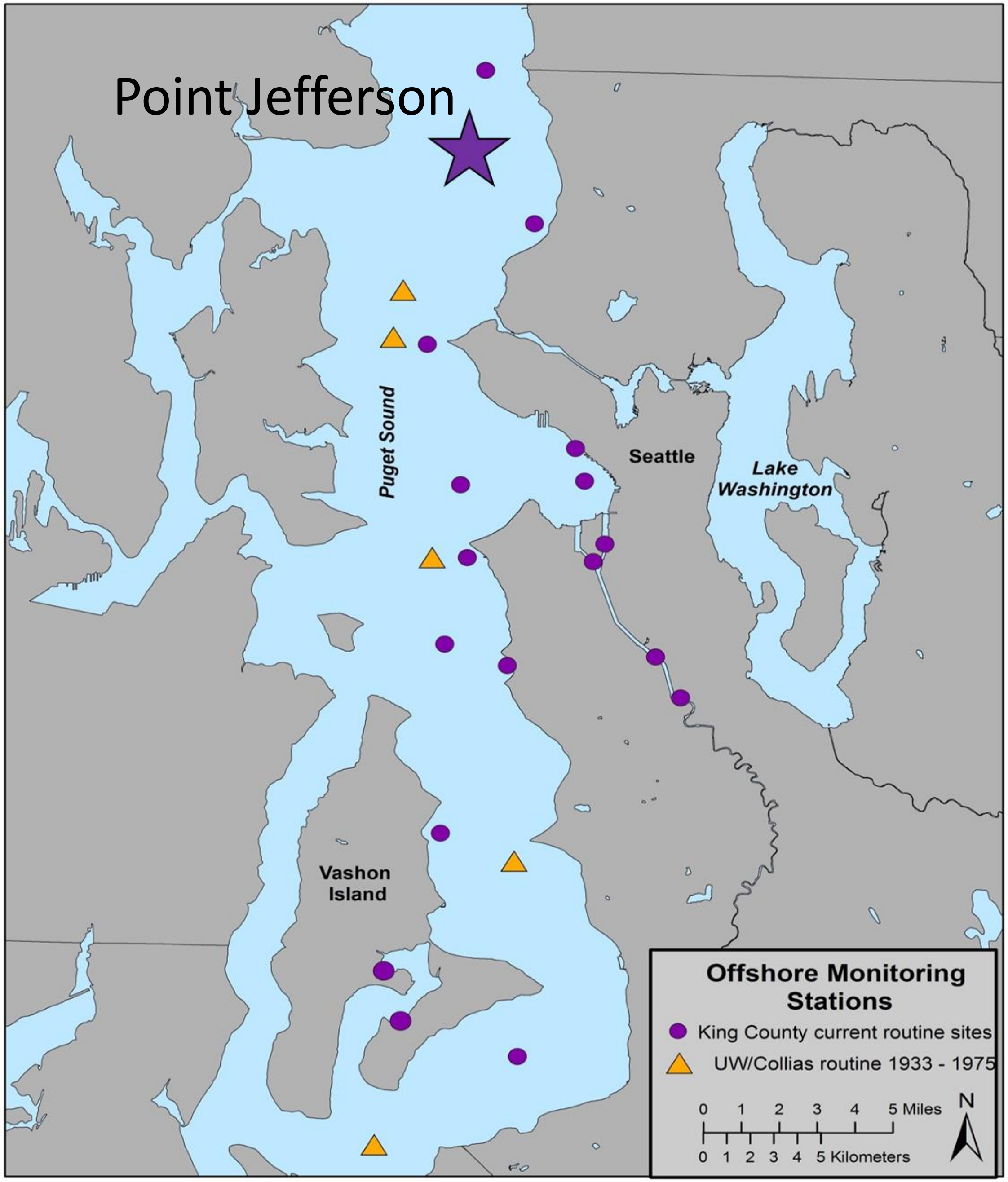


Marine Heat Wave

How does this compare to historical data collected from 1933 – 1975?

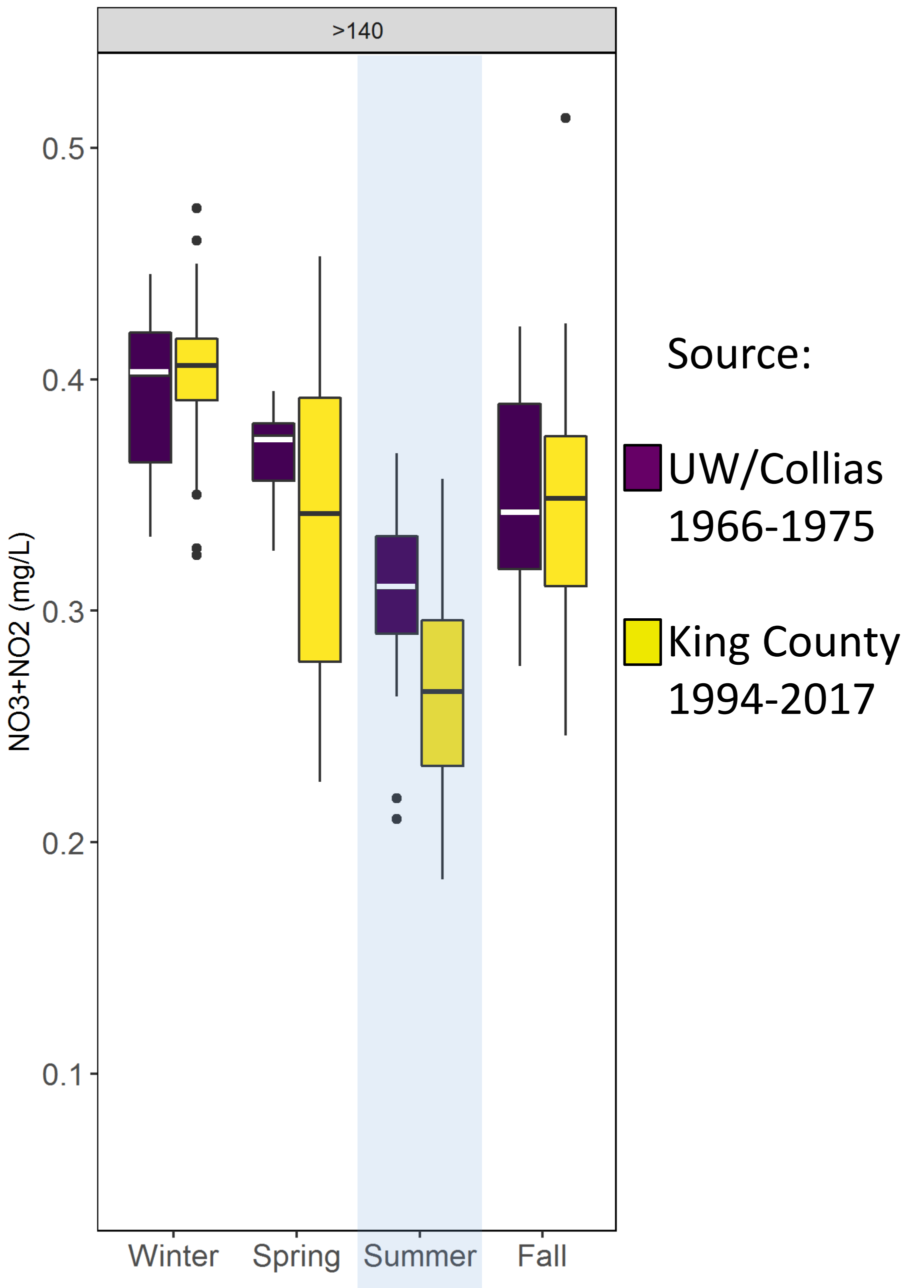


Eugene E. Collias (1926-2017) (Source: Eugene and Dorothy Collias Collection)

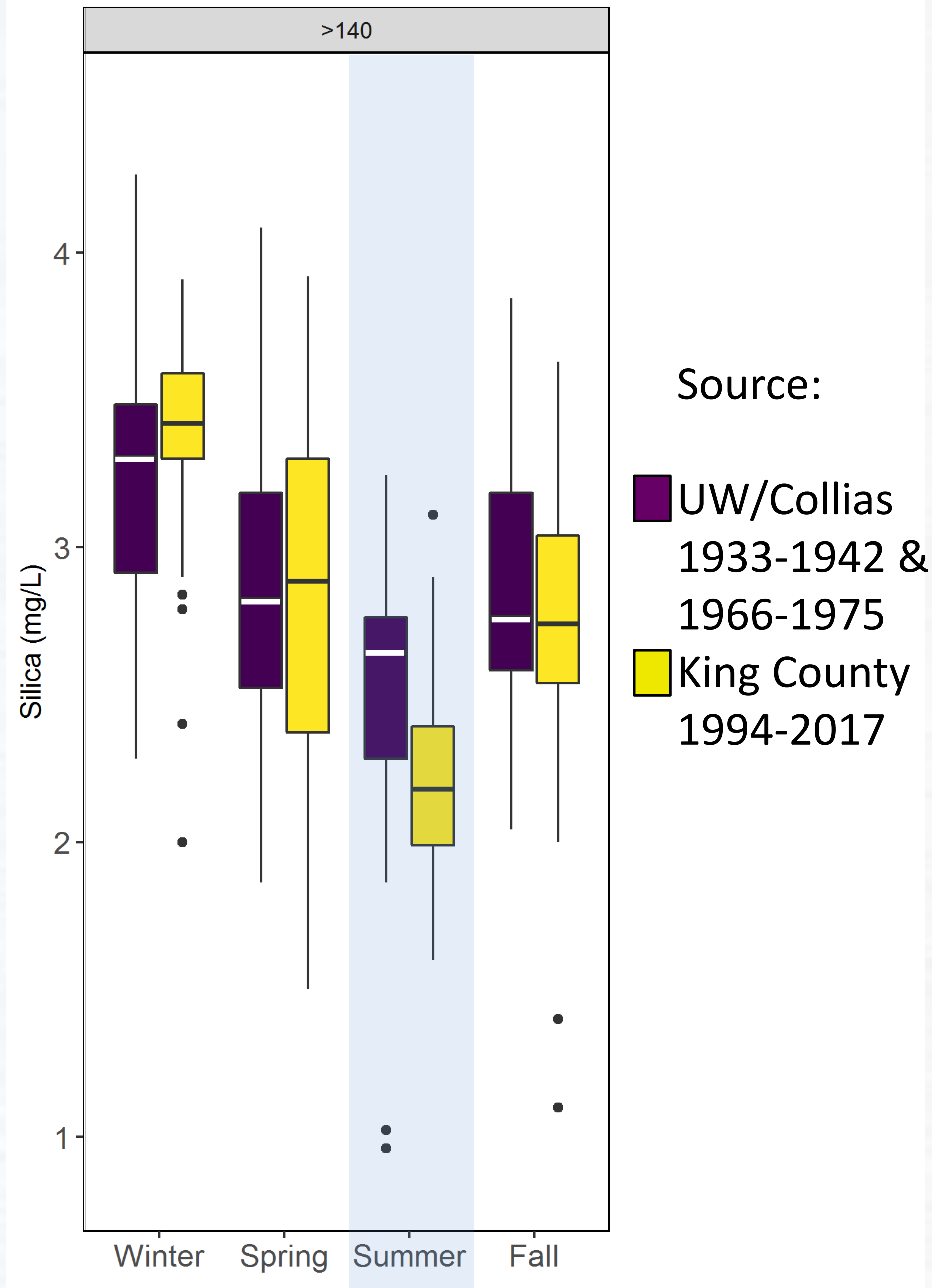


King County

Deep Nitrate at Point Jefferson



Deep Silica



Information gaps:

- Variability on short time scales – can we link to drivers over time?
- No complete record of organic nutrient and carbon pools
- Possible that nutrient cycling and remineralization rate changes may play a role

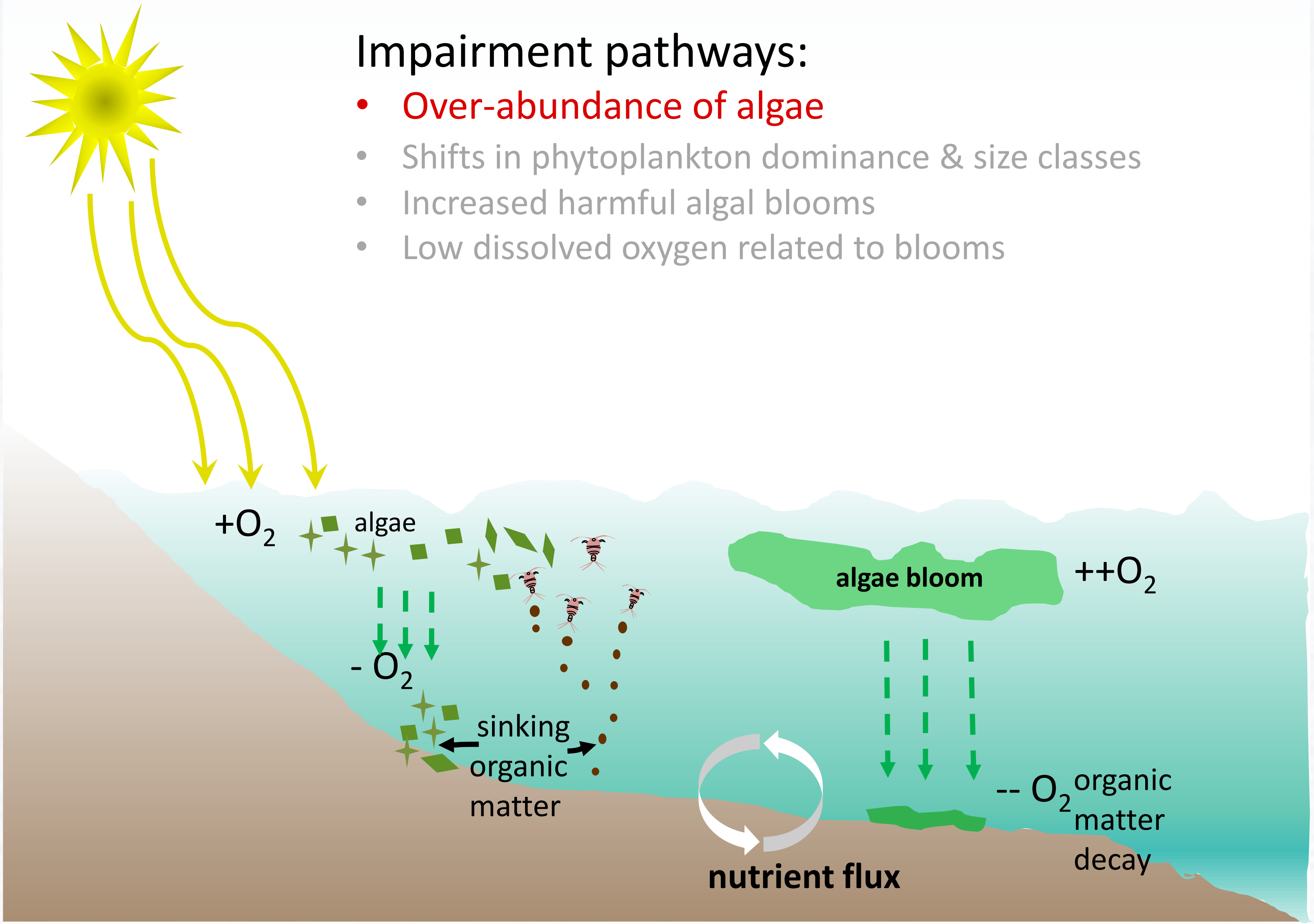
Summary:

- Some increases in all nutrients over last 2 decades in Central Basin and decreases in Strait of Juan de Fuca; though limited to period of record
  - Increase or no change in Si:DIN nutrient ratio across sites
  - Similar deep nutrient ranges compared to historical observations, except for lower nutrients in summer in recent decades
  - Suggest drivers related to circulation, climate, & hydrological cycle, rather than anthropogenic inputs → Needs exploration

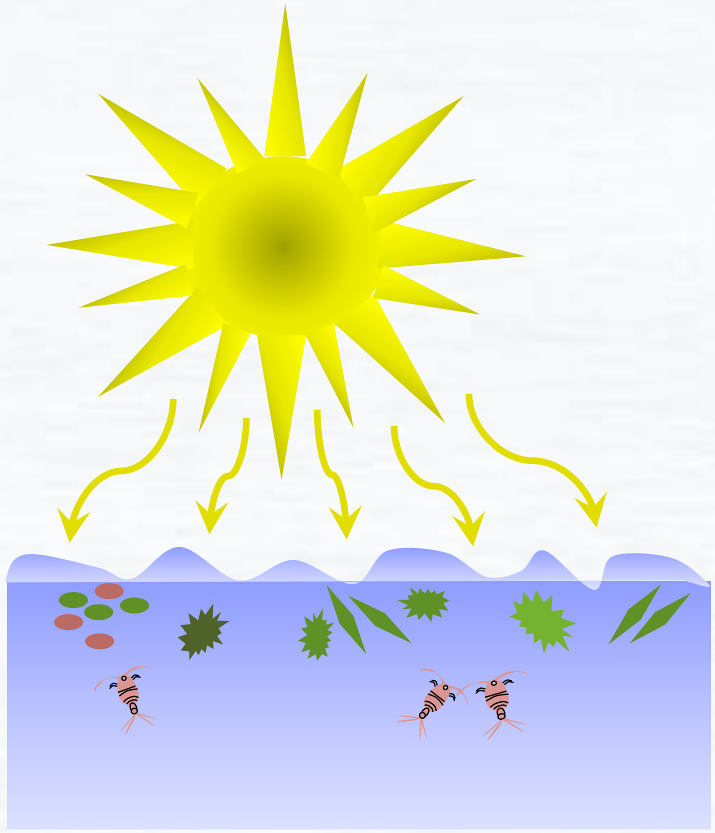
Eutrophication

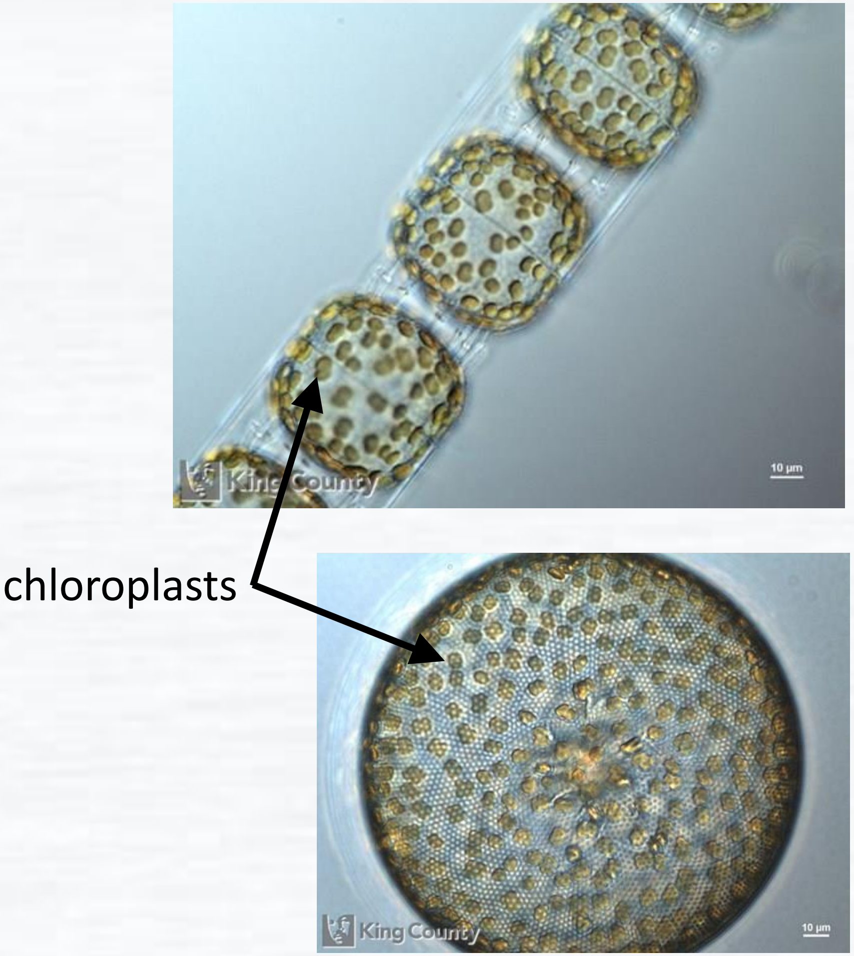
Impairment pathways:

- Over-abundance of algae
- Shifts in phytoplankton dominance & size classes
- Increased harmful algal blooms
- Low dissolved oxygen related to blooms



Why Measure Chlorophyll-a?



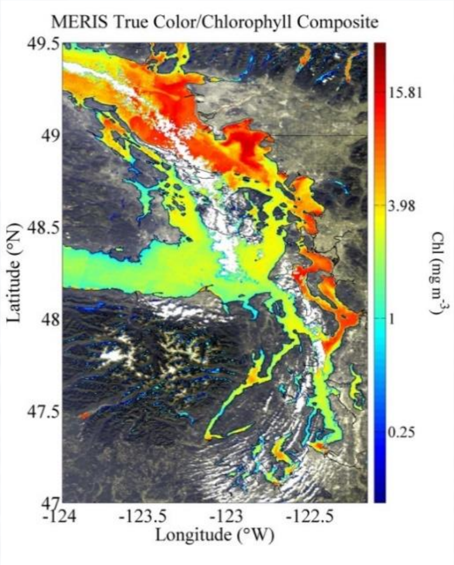


Chlorophyll-a

- A lot of seasonal/interannual variation
- Concentrations and timing of spring bloom are generally similar over past 20 years
- Quartermaster Harbor different dynamics

Overall, long-term chlorophyll-a levels in the Central Basin (QMH excluded) do not indicate signs of eutrophication but do show climate anomaly effects.

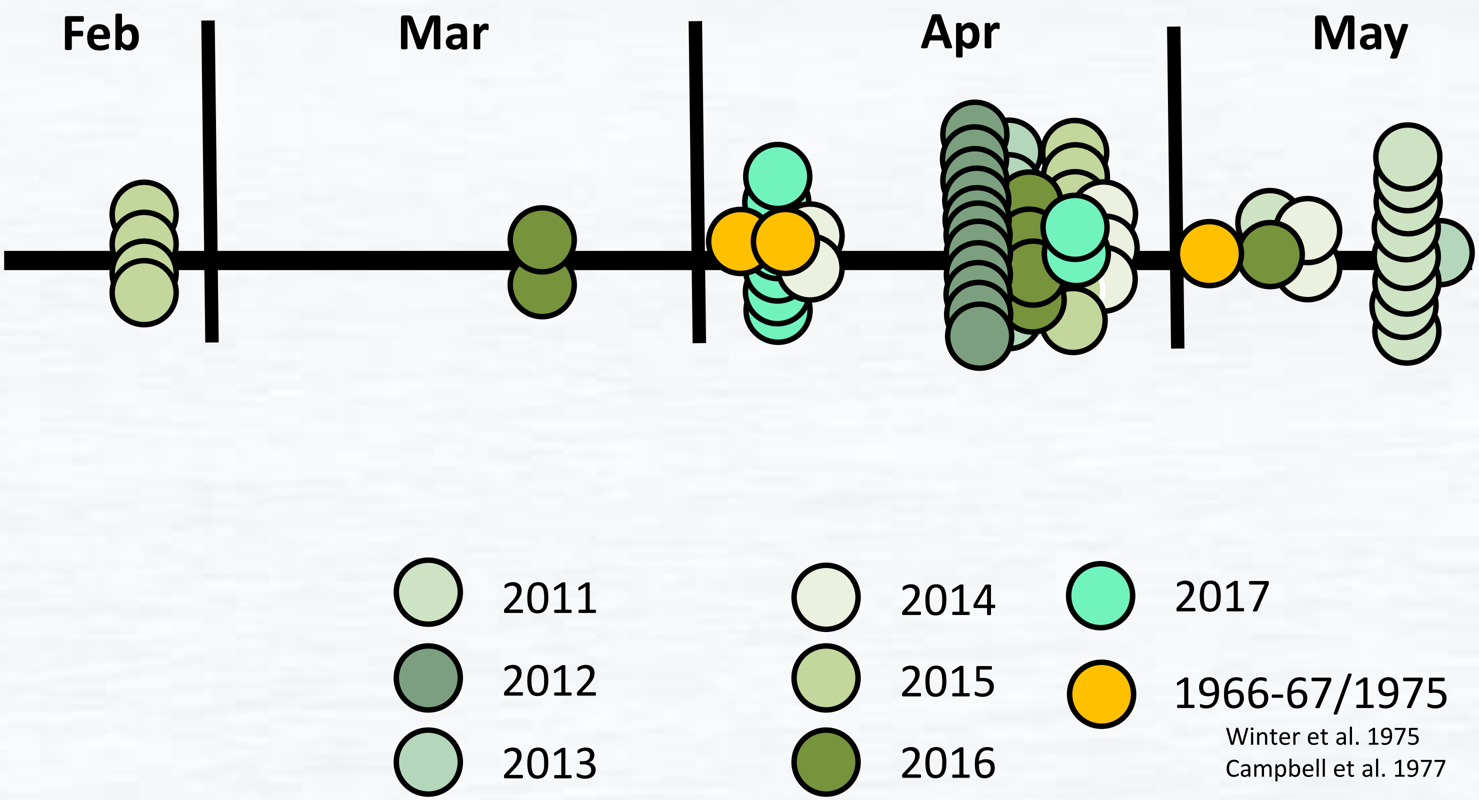
Chlorophyll-a



King County

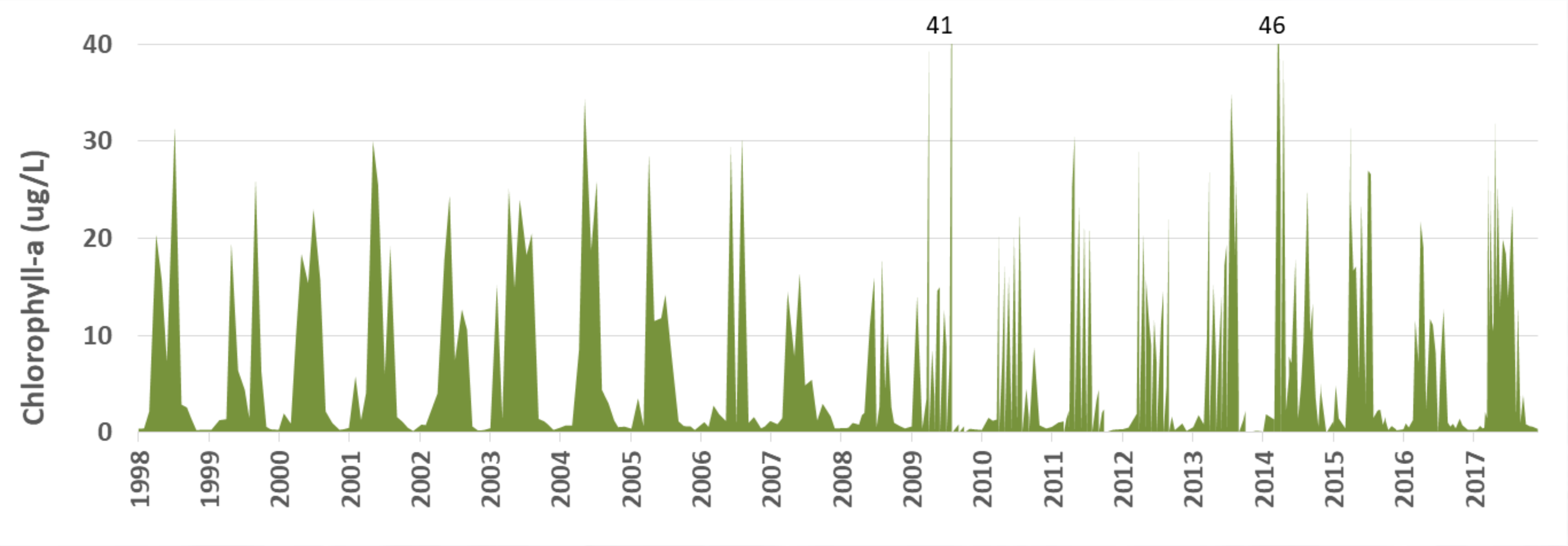
Seasonal Dynamics

Spring bloom timing



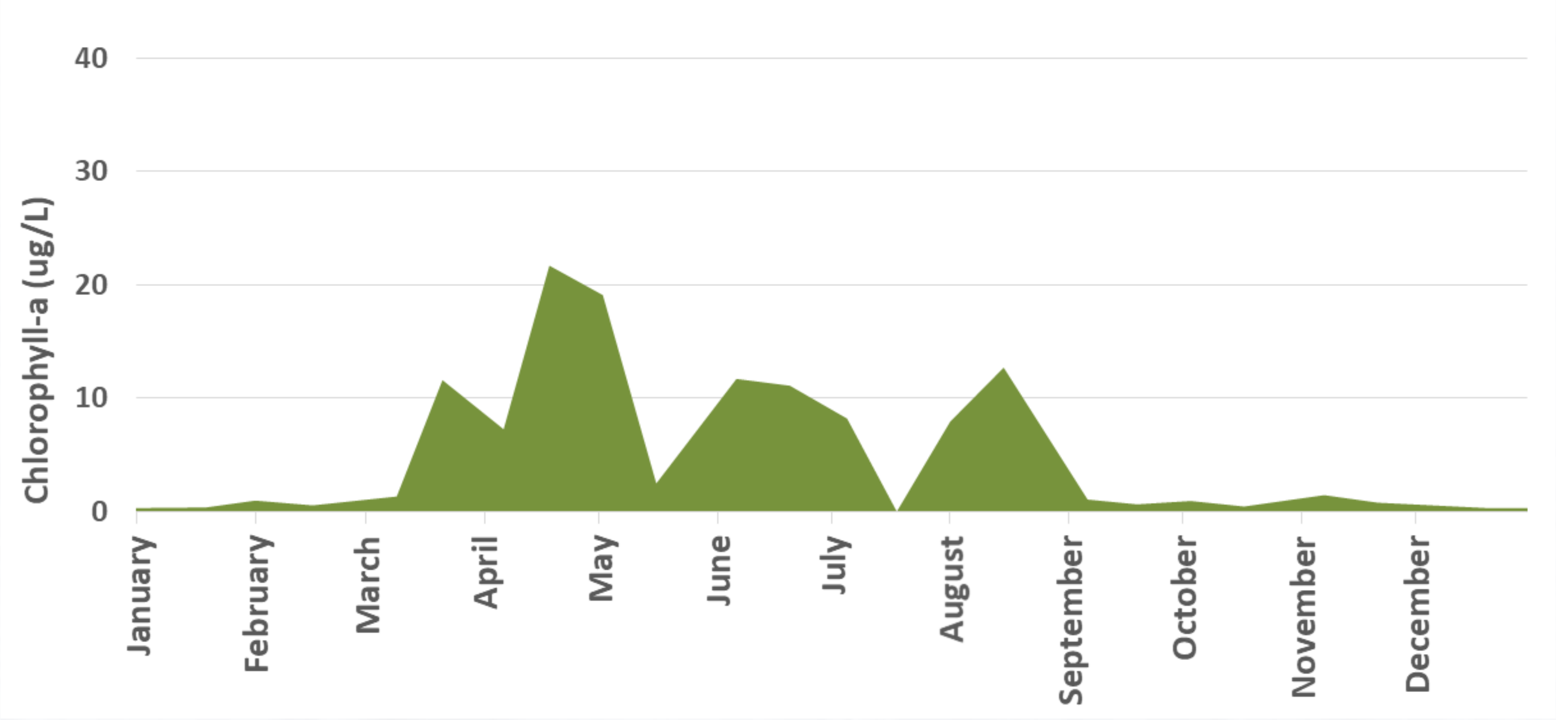
Seasonal Dynamics

Point Jefferson last 20 years



Seasonal Dynamics

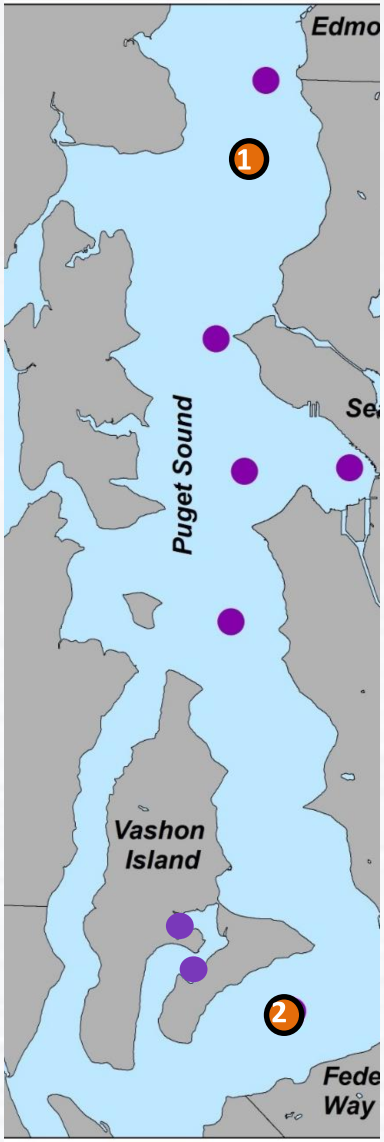
Point Jefferson: annual cycle in 2016



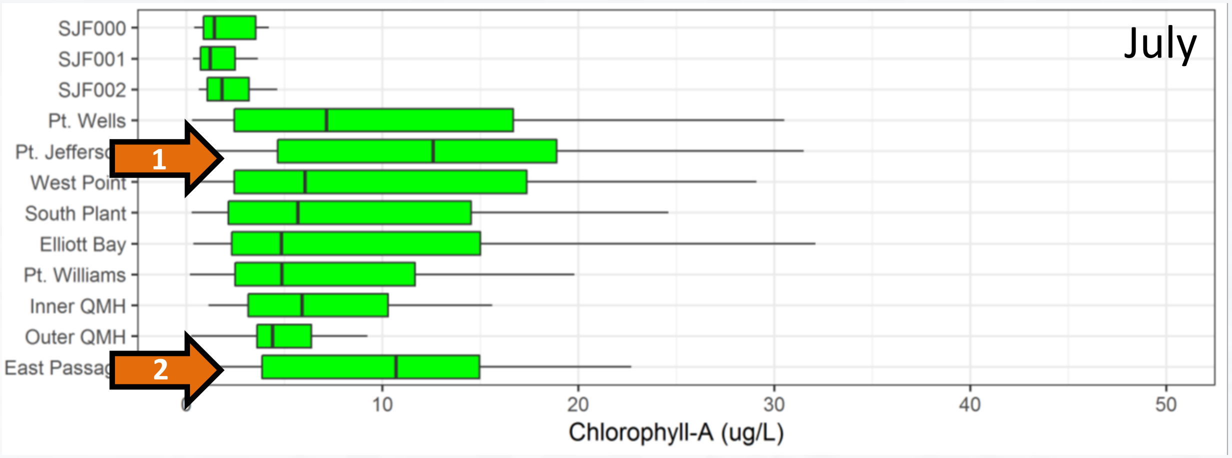
Seasonal Dynamics

By location

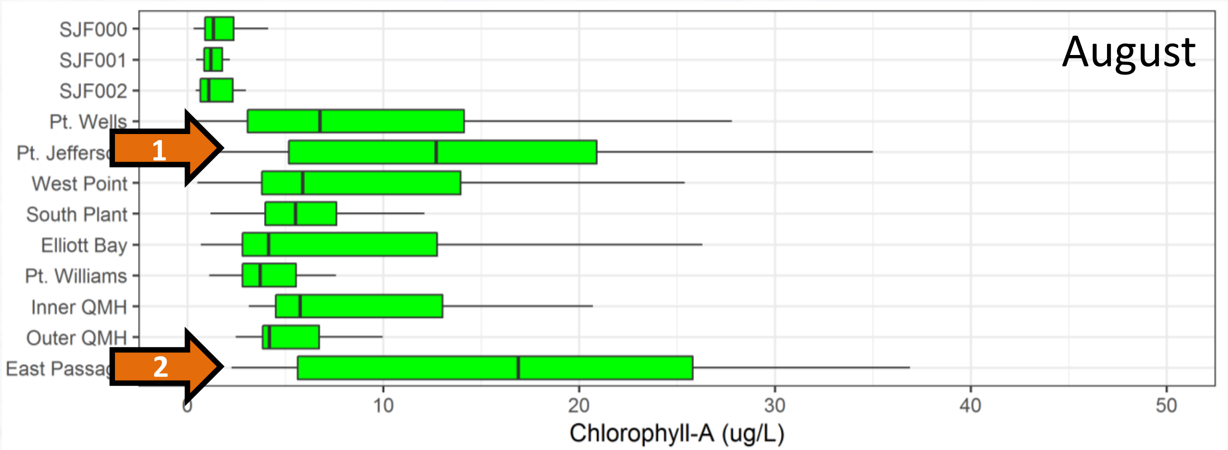
	Pt. Wells	Pt. Jefferson	West Pt.	South Plant	Elliott Bay	Pt. Williams	inner QMH	outer QMH	East Passage
JAN	1	1	1	1	0	0	1	2	1
FEB	2	3	1	1	1	1	6	5	2
MAR	2	1	1	1	1	1	10	11	2
APR	14	14	12	11	8	8	12	16	16
MAY	16	16	14	13	11	13	7	9	19
JUN	13	15	10	12	8	9	8	9	17
JUL	9	13	10	9	9	8	7	5	10
AUG	10	14	8	7	8	4	10	9	16
SEP	4	6	6	5	5	4	19	11	10
OCT	2	2	2	2	1	2	24	12	3
NOV	1	1	1	1	1	1	3	3	1
DEC	0	0	0	0	0	0	1	1	0



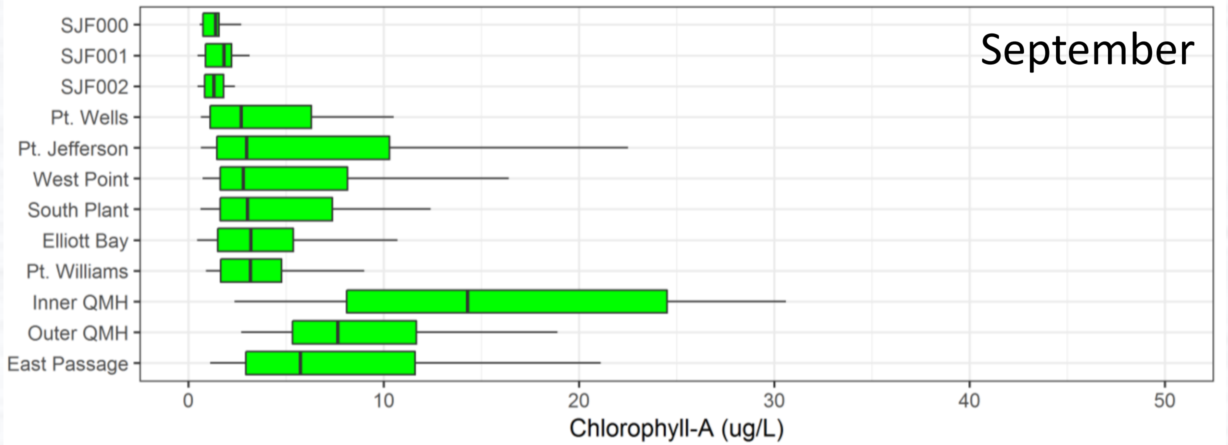
Edmo
1
Puget Sound
Se
Vashon Island
2
Fede Way



July
SJF000
SJF001
SJF002
Pt. Wells
Pt. Jefferso
West Point
South Plant
Elliott Bay
Pt. Williams
Inner QMH
Outer QMH
East Passag
1
2
0
10
20
30
40
50
Chlorophyll-A (ug/L)



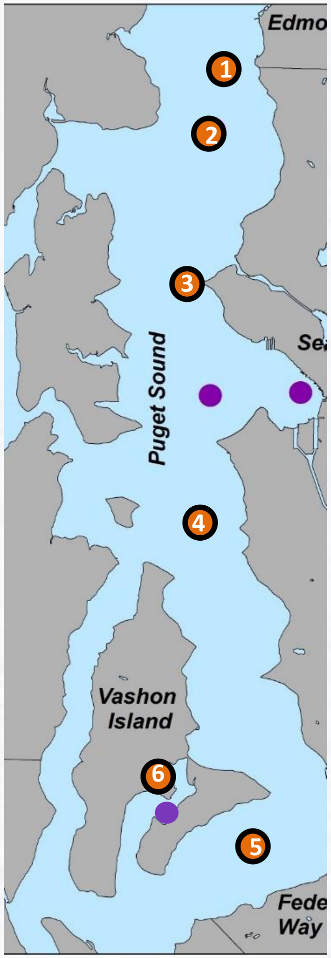
August
SJF000
SJF001
SJF002
Pt. Wells
Pt. Jeffers
West Point
South Plant
Elliott Bay
Pt. Williams
Inner QMH
Outer QMH
East Passag
1
2
0
10
20
30
40
50
Chlorophyll-A (ug/L)

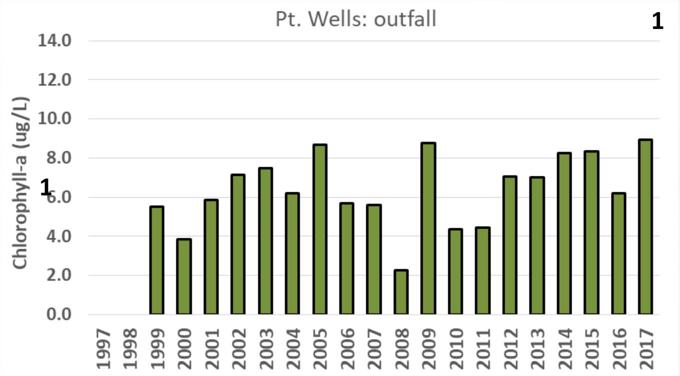


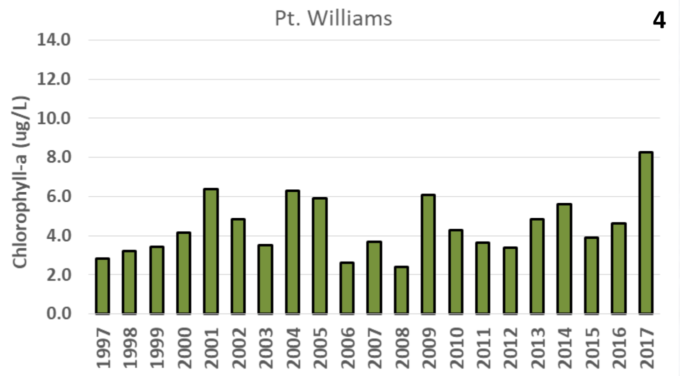
September
SJF000
SJF001
SJF002
Pt. Wells
Pt. Jefferson
West Point
South Plant
Elliott Bay
Pt. Williams
Inner QMH
Outer QMH
East Passage
0
10
20
30
40
50
Chlorophyll-A (ug/L)

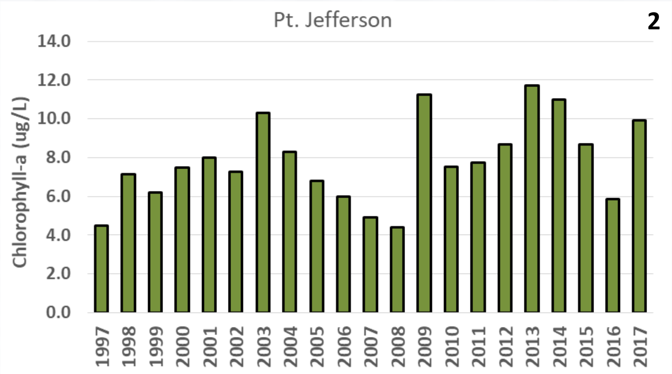
King County

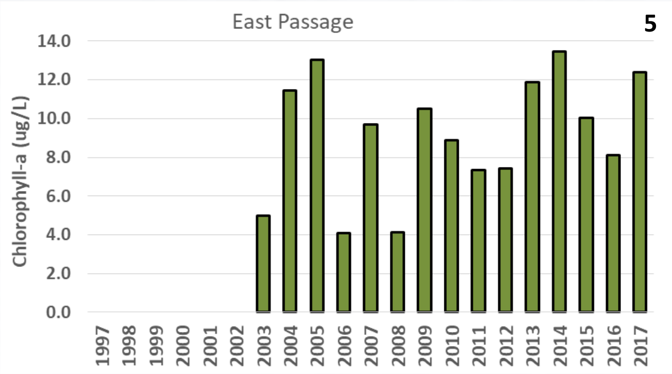
Annual Variability

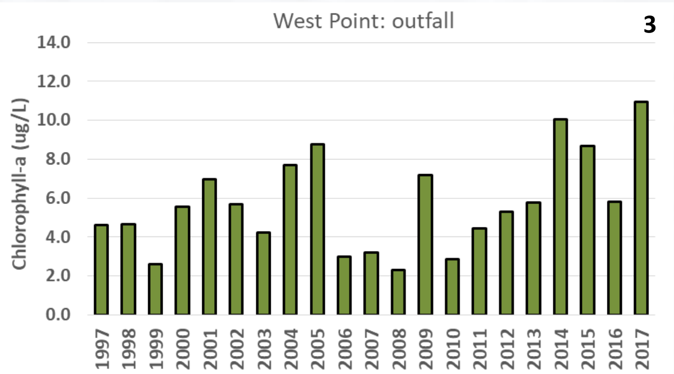


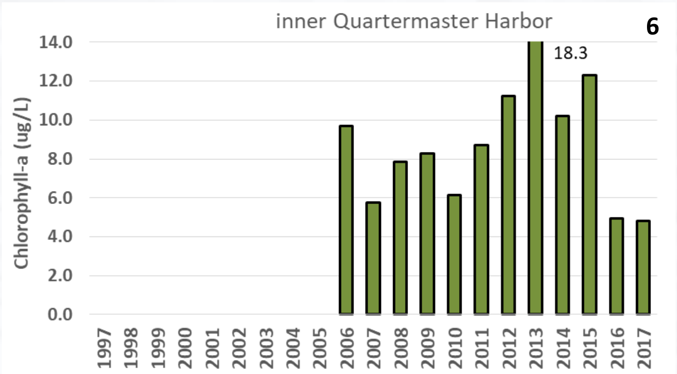




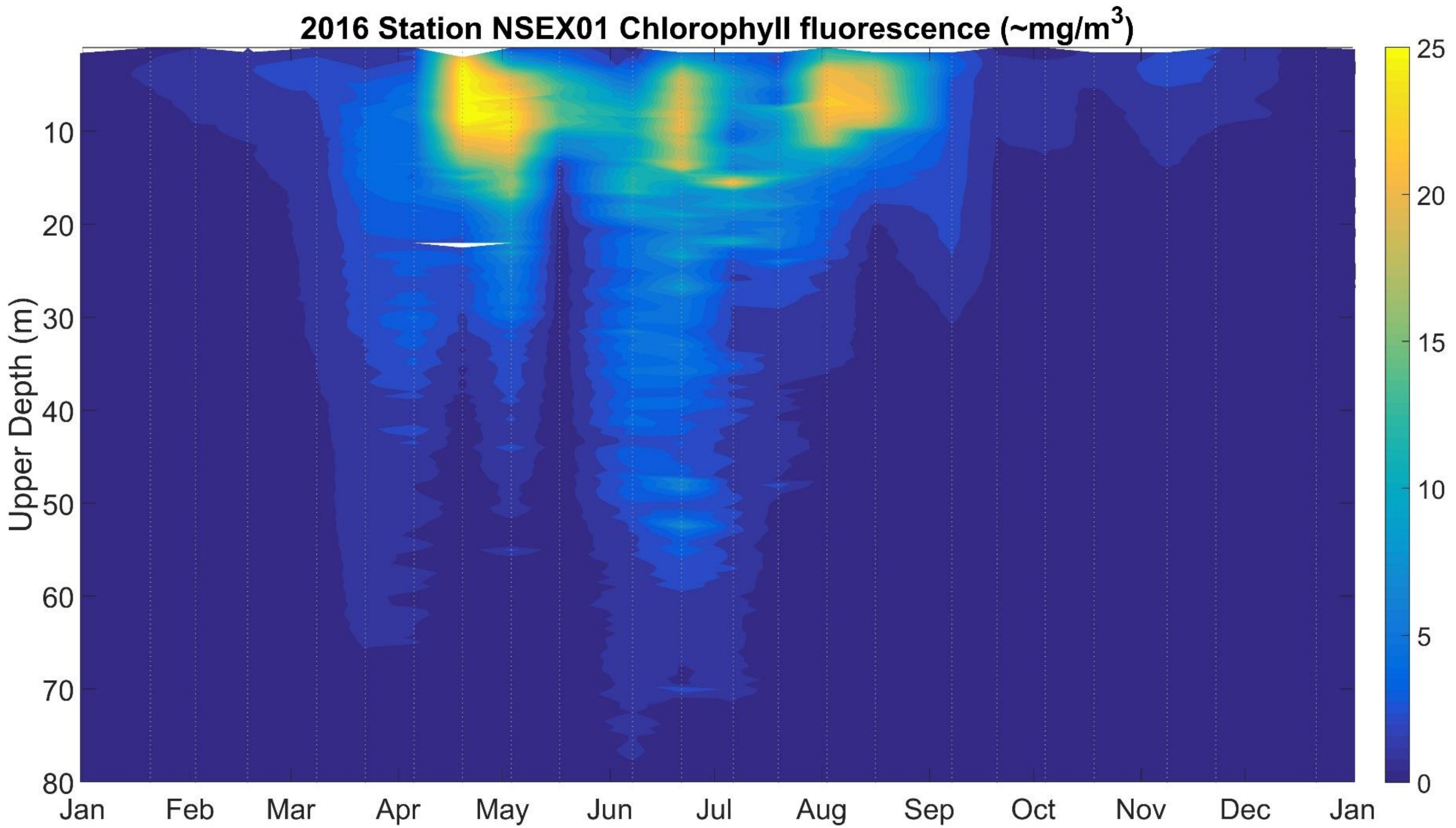








Chlorophyll-a



King County

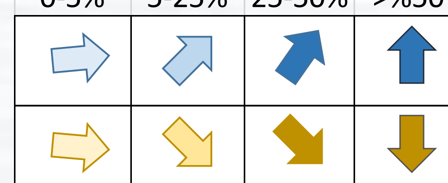
Chlorophyll-a trends over time

0-3m Depth

Site	Years of data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pt. Wells	19			NS	NS	NS	NS	NS	NS	NS	NS			NS
Pt. Jefferson	24			NS	NS	NS	NS	NS	NS	NS	NS			NS
West Point	21			NS	NS	NS	NS	NS	NS	NS	NS			
South Plant	21			NS	NS	NS	NS	NS	NS	NS	NS			NS
Elliott Bay	21			NS	NS	NS	NS	NS	NS	NS	NS			NS
Pt. Williams	24			NS	NS	NS	NS	NS	NS	NS	NS			NS
East Passage	15			NS	NS	NS	NS	NS	NS	NS	NS			NS
inner QMH	12													NS
outer QHM	12													NS

Legend: % Change over record
NS = Not Significant (p>0.05)

0-5%	5-25%	25-50%	>%50



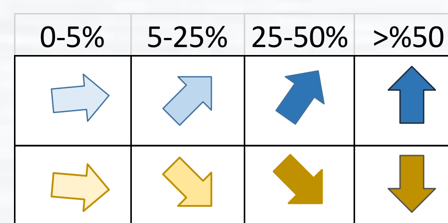
King County

Chlorophyll-a trends over time

Depth integrated average (1-35m)

Site	Years of data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pt. Wells	19			NS	NS	NS	NS	NS	NS	NS	NS			NS
Pt. Jefferson	24			NS	NS	NS	NS	NS	NS	NS	NS			NS
West Point	21			NS	NS	NS	NS	NS	NS	NS	NS			NS
South Plant	21			NS	NS	NS	NS	NS	NS	NS	NS			NS
Elliott Bay	21			NS	NS	NS	NS	NS	NS	NS	NS			NS
Pt. Williams	24			NS	NS	NS	NS	NS	NS	NS	NS			NS
East Passage	15			NS	NS	NS	NS	NS	NS	NS	NS			NS
inner QMH	12													NS
outer QHM	12													NS

Legend: % Change over record
NS = Not Significant (p>0.05)



King County

Chlorophyll-a trends over time

June-August combined: 0-3m Depth

Site	Years of data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Summer
Pt. Wells	19													NS
Pt. Jefferson	24													NS
West Point	21													NS
South Plant	21													NS
Elliott Bay	21													NS
Pt. Williams	24													NS
East Passage	15													NS
inner QMH	12													
outer QHM	12													

NS = Not Significant (p>0.05)

King County

Chlorophyll-a trends over time

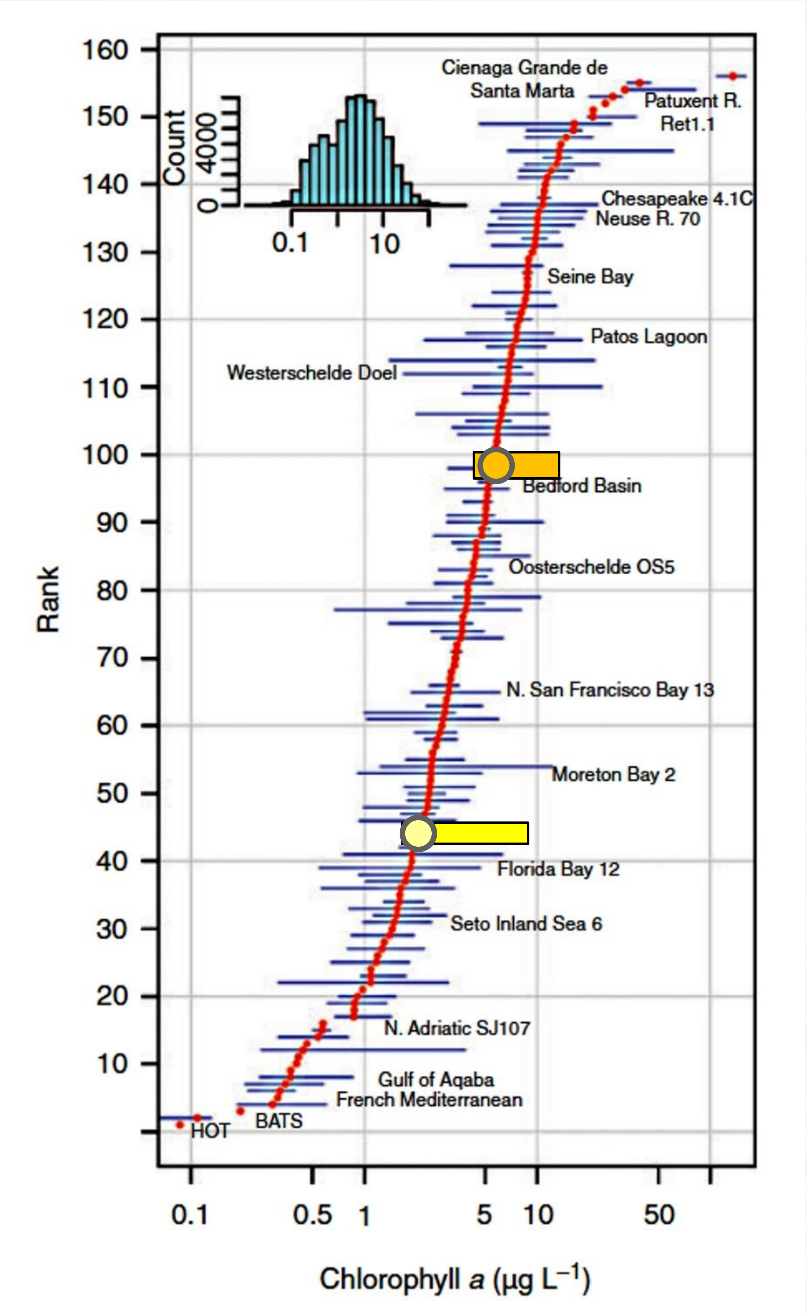
April-September combined: 0-3m Depth

Site	Years of data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Growing season
Pt. Wells	19													NS
Pt. Jefferson	24													NS
West Point	21													NS
South Plant	21													NS
Elliott Bay	21													NS
Pt. Williams	24													NS
East Passage	15													NS
inner QMH	12													
outer QHM	12													

NS = Not Significant (p>0.05)

King County

How Does Central Basin compare?

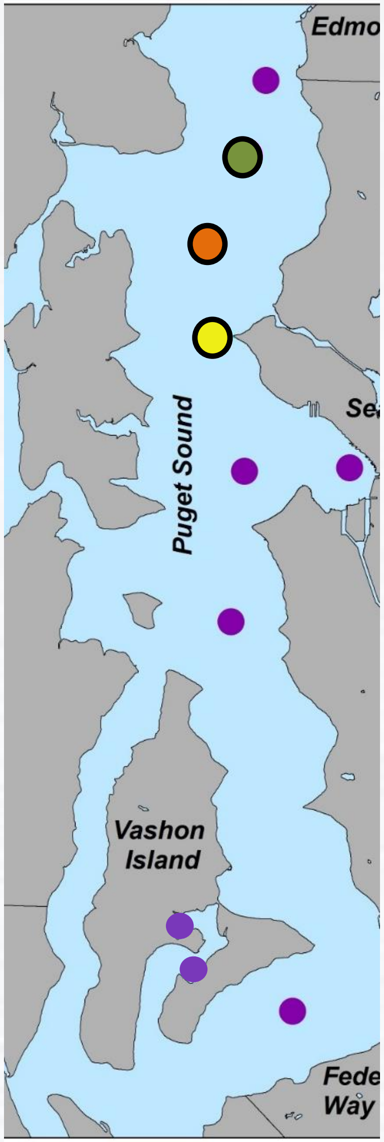


Quartermaster Harbor

Central Basin

Cloern & Jassby, 2008

King County



Historical Data Comparison

ug/L for surface layer

	Station 1		Pt. Jefferson		West Point	
	1966 & 1967 range	1975 range	1994-2017 Avg	1994-2017 range	1997-2017 Avg	1997-2017 range
April-June	8		15	0.3 - 46	9	0.7 - 40
May-June		28 - 82	14	0.3 - 38	9	0.7 - 33
August-September		1.4 - 18	10	0.6 - 58	14	0.5 - 32

Winter et al. 1975
Campbell et al. 1977

King County

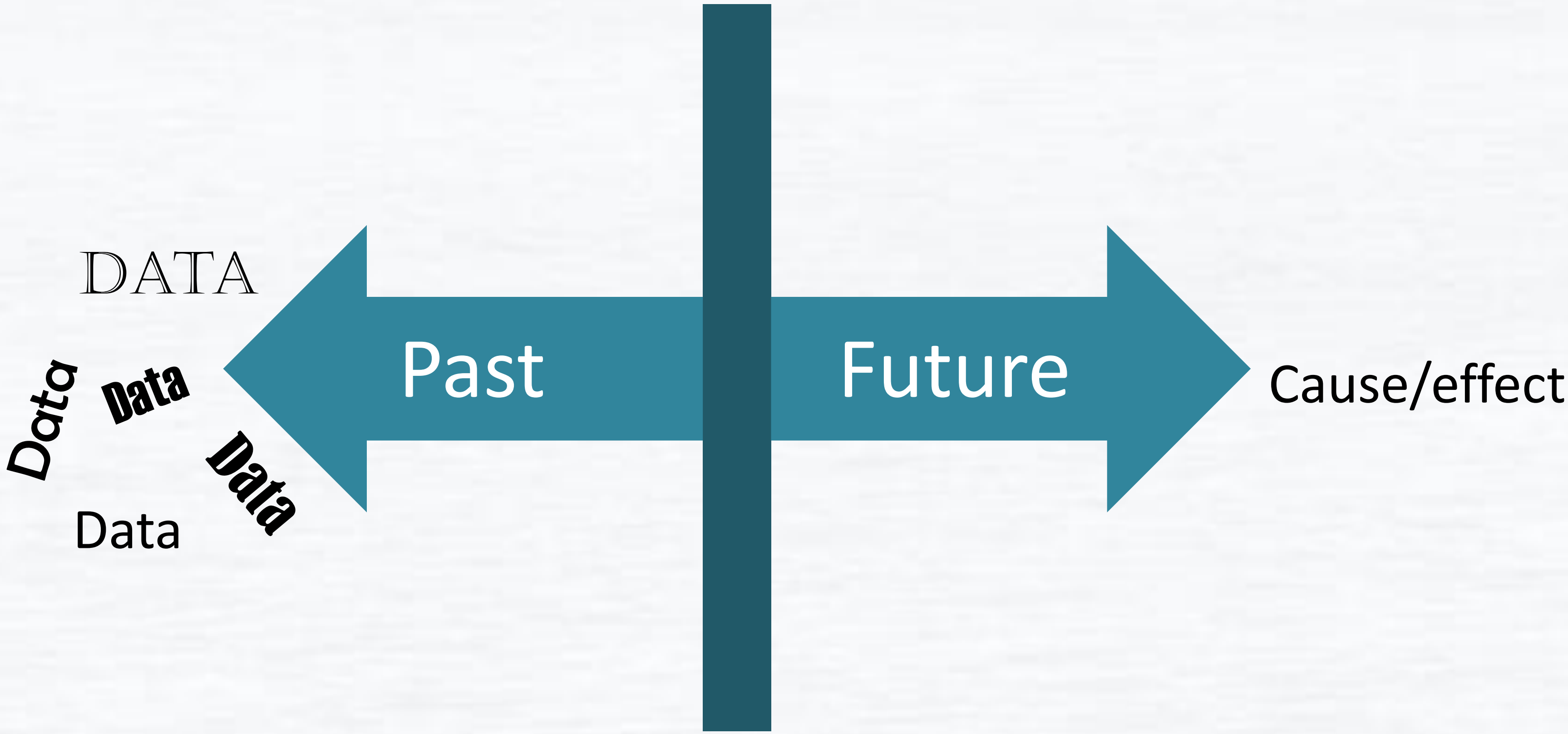
Phytoplankton/Physical Relationships

Weather/climate anomaly

Early stratification	Cold and wet	Strong spring stratification	Marine heat wave	Early southerly winds	Persistent stratification
Early bloom	Delayed spring bloom	Early bloom	Late fall bloom	No fall bloom	Sustained bloom
2009	2011	2014, 2015	2014	2016	2017

King County

Information Gaps



Chlorophyll-a Central Basin Summary

- No observed consistent shift in timing of spring bloom; observed variance corresponds to weather/climate anomalies.
- Interannual variability is observed but no large long-term increase.
- Do not see sustained levels throughout growing season (2017 weather anomaly exception) for all but QMH sites.
- Quartermaster Harbor has issues in the fall.
- Statistical analyses indicate no increasing trend in the surface layer in any month, but there was an increase in annual trend at West Point.
- Statistical analyses indicate no increasing trend during the summer months or throughout the entire growing season.

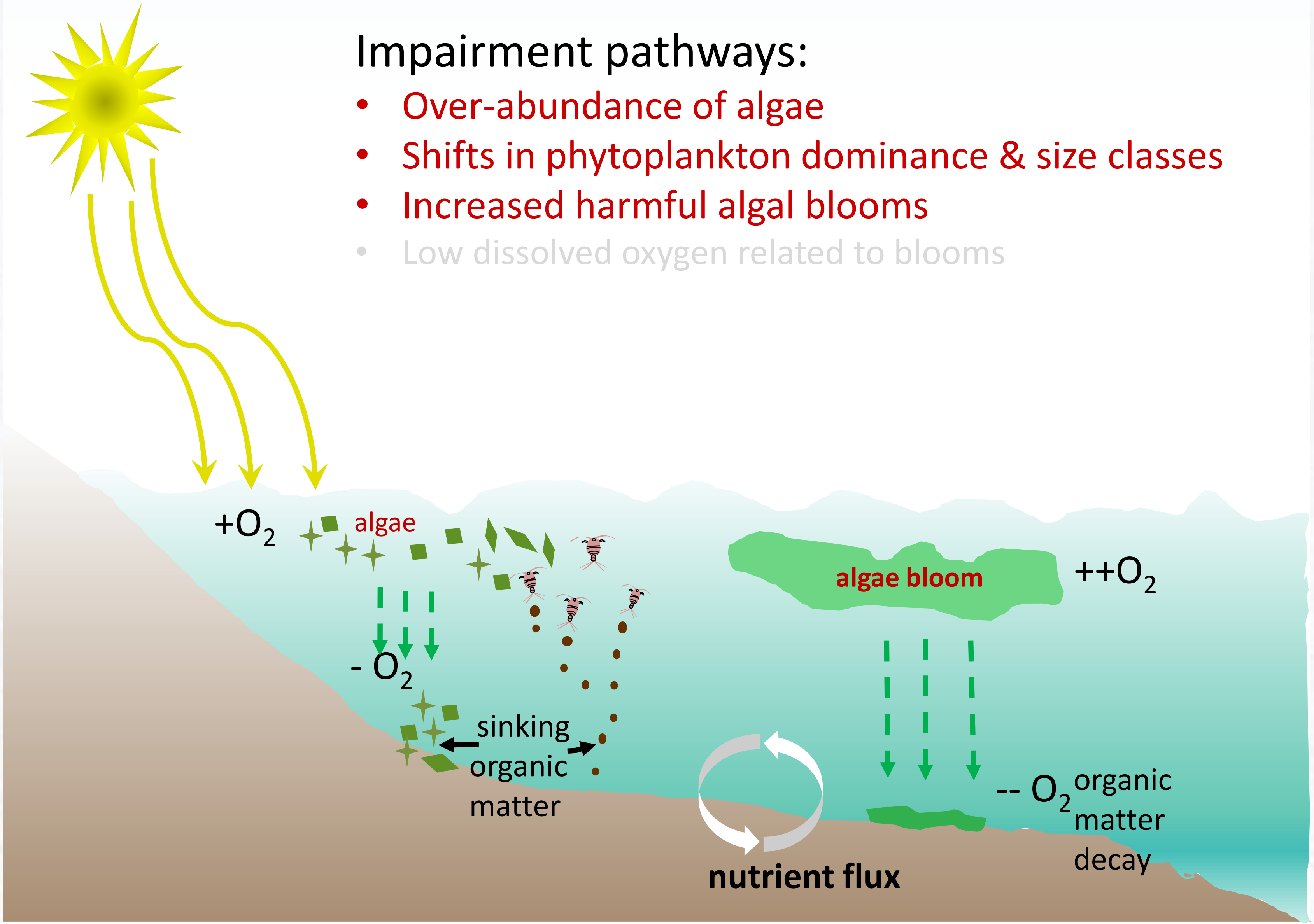
Overall, long-term chlorophyll-a levels in the Central Basin (QMH excluded) do not indicate signs of eutrophication but do show climate effects.

What do we observe in phytoplankton?

Eutrophication

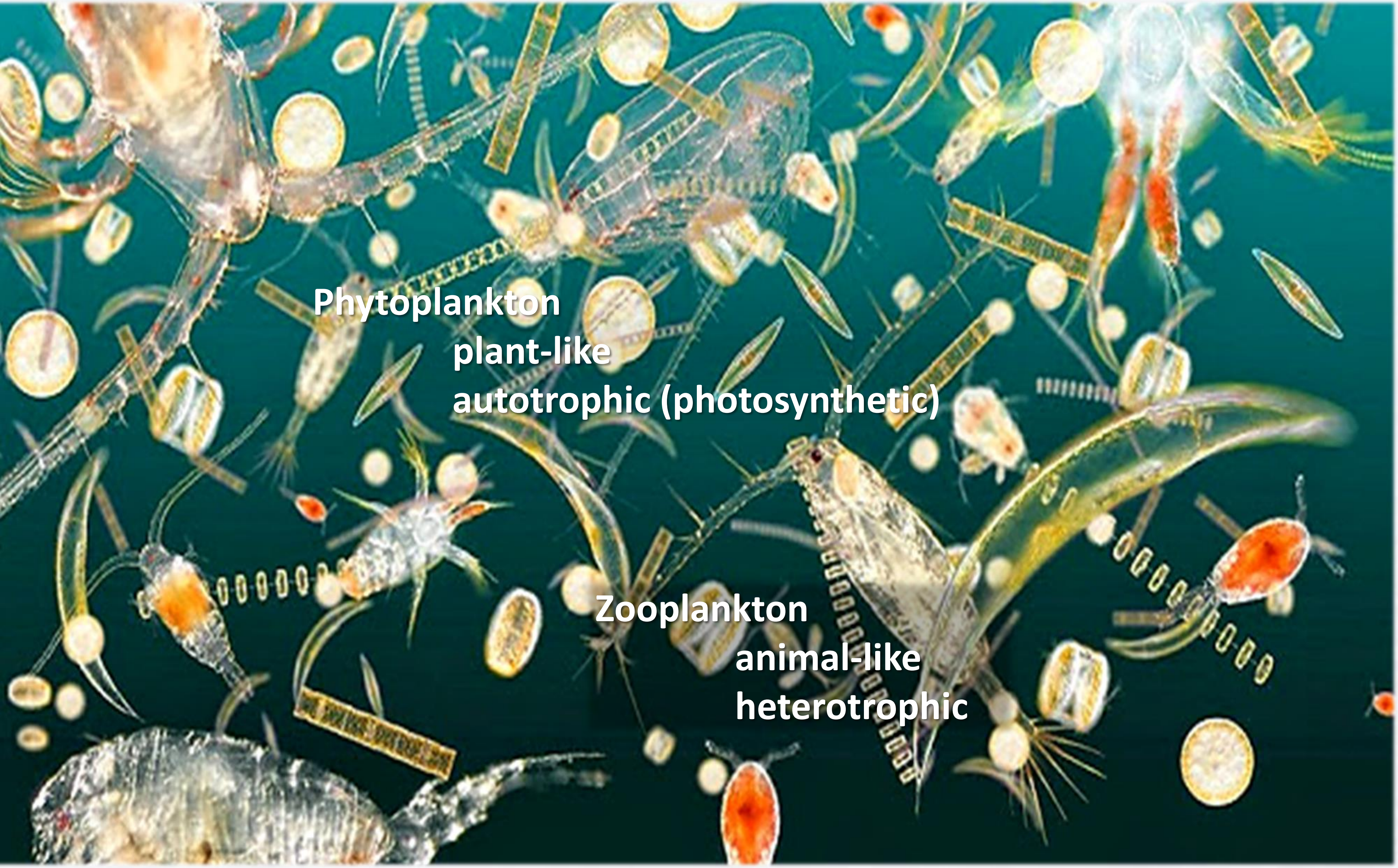
Impairment pathways:

- Over-abundance of algae
- Shifts in phytoplankton dominance & size classes
- Increased harmful algal blooms
- Low dissolved oxygen related to blooms



King County

Plankton – drifting organisms



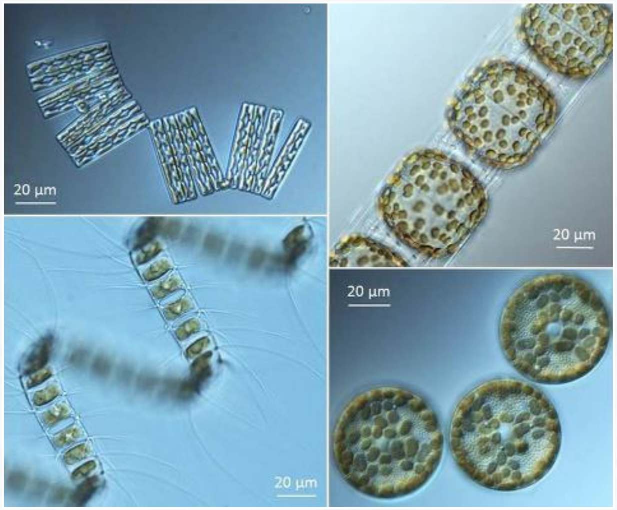
Phytoplankton
plant-like
autotrophic (photosynthetic)

Zooplankton
animal-like
heterotrophic

So…

what is phytoplankton?

Diatoms



No active locomotion - drift
Often in chains, large
Glass case → need silica

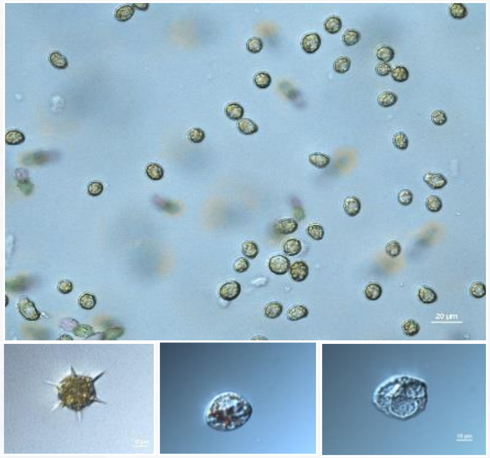
Autotrophic

Dinoflagellates

Flagella – swim up and down
Usually single, often small

Autotrophic
Heterotrophic
Mixotrophic

Other



Mostly small flagellates

Autotrophic
Heterotrophic
Mixotrophic

How do we quantify phytoplankton?

Biomass In food webs, **carbon biomass** is considered a currency of energy transfer.

But … it's difficult to measure.

So we use proxys:

Chlorophyll *a* Universal photosynthetic pigment, extracted from cells

Most practical but not easily related to cell biomass

Abundance Count cells or particles

Often the most practical but can be difficult to relate to carbon biomass

Biovolume Can be related to carbon and biomass

Good proxy

King County

What are the potential impacts of nitrogen enrichment on Puget Sound phytoplankton assemblages?

Growth	↑	Increased biomass production
Seasonality	≠	Longer growth period, fewer dips, more persistent
Total biomass	↑	Increased cumulative biomass
Species richness	↓	May decrease if certain nutrients become limiting (e.g. silica)
Species composition	≠	

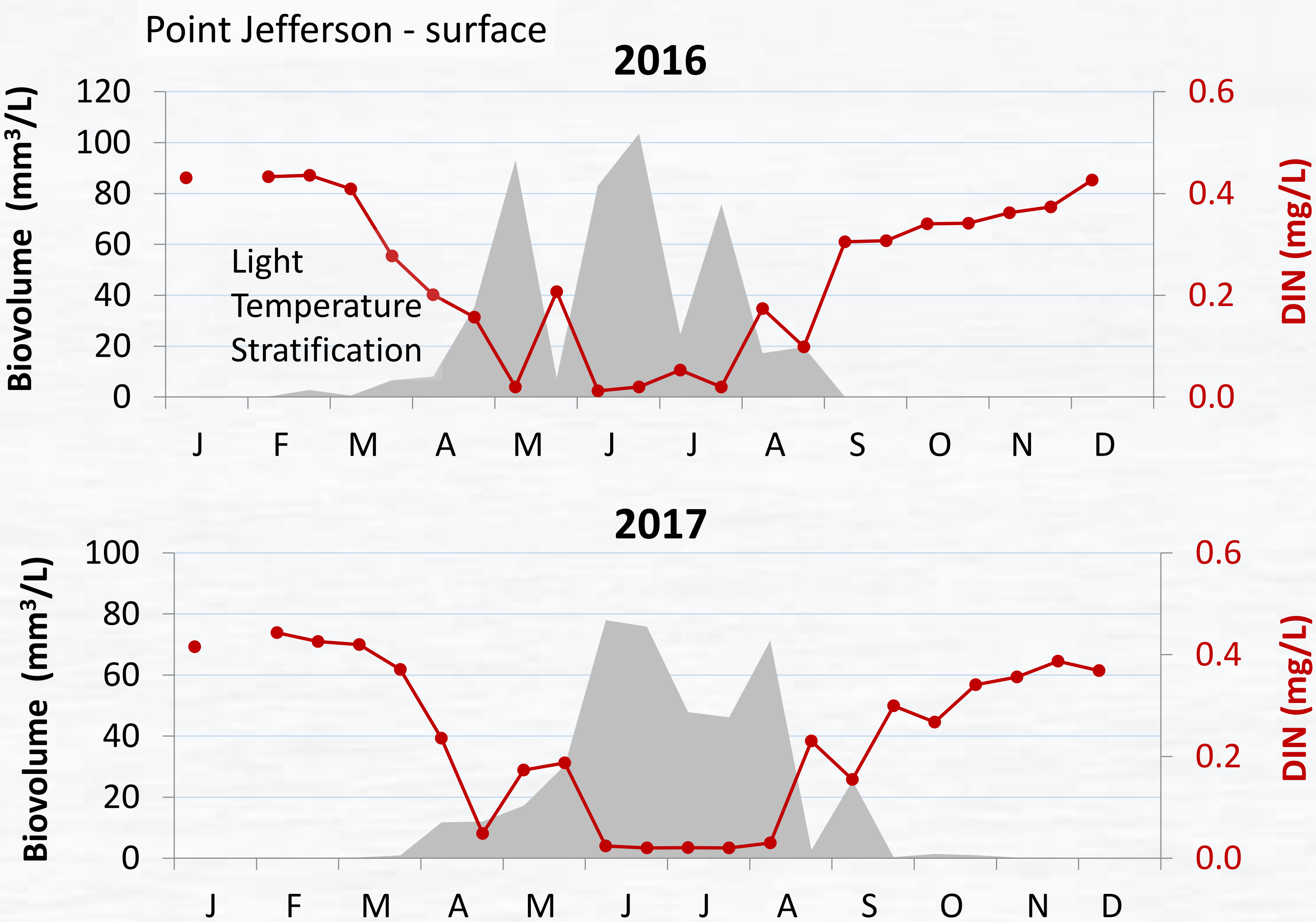
- Cell size — - nutrient-rich environments favor larger cells
- Diatoms vs. dinoflagellates — - diatoms may be Si-limited (lower Si:DIN)
- Autotrophic vs. heterotrophic — - heterotrophic dinos may do well if food source is more abundant
- Increase in HABs (harmful species)

King County

Phytoplankton – Major Findings

- Puget Sound phytoplankton is dominated by diatoms
- Seasonal patterns in phytoplankton biomass vary year to year with environmental conditions
- Inter-annual variability in bloom timing, magnitude and species composition make it difficult to assess trends
- 10-yr record of central basin taxa shows a large group of common taxa present every year, but some changes in 2017

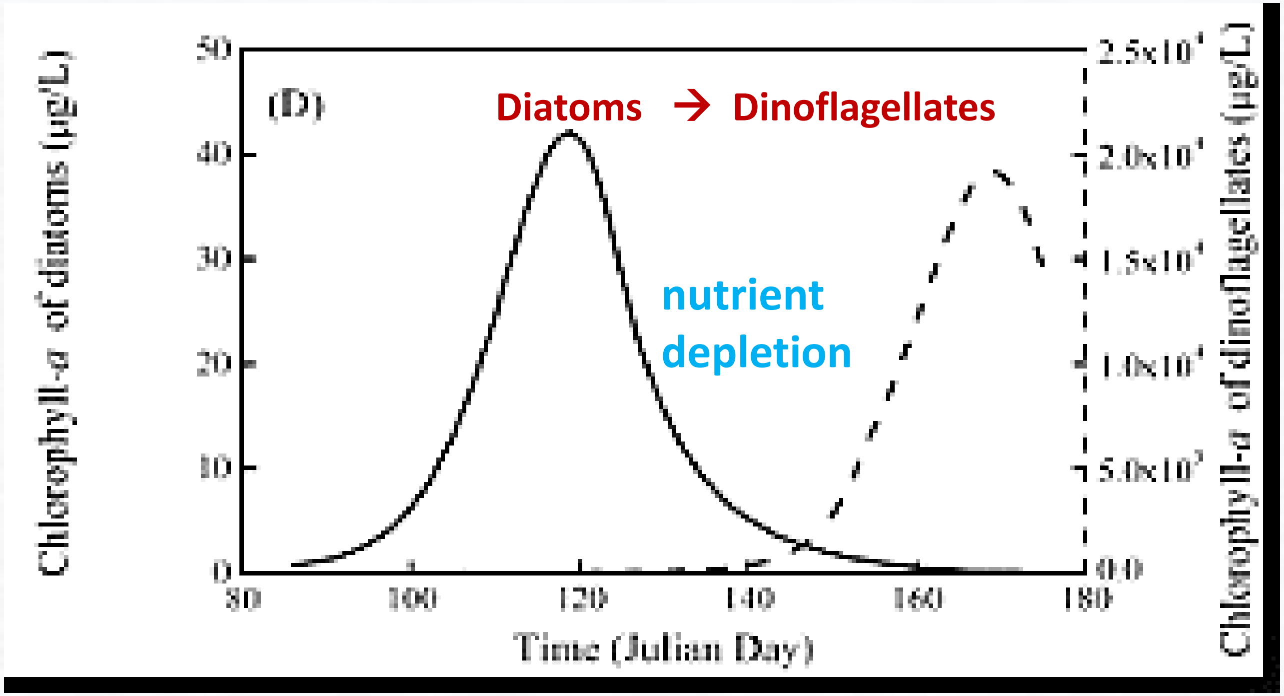
How does seasonal phytoplankton growth relate to nitrogen levels in the water?



King County

Phytoplankton Seasonal Succession:
Is there a universal seasonal pattern?

East China Sea
Example of classical succession pattern

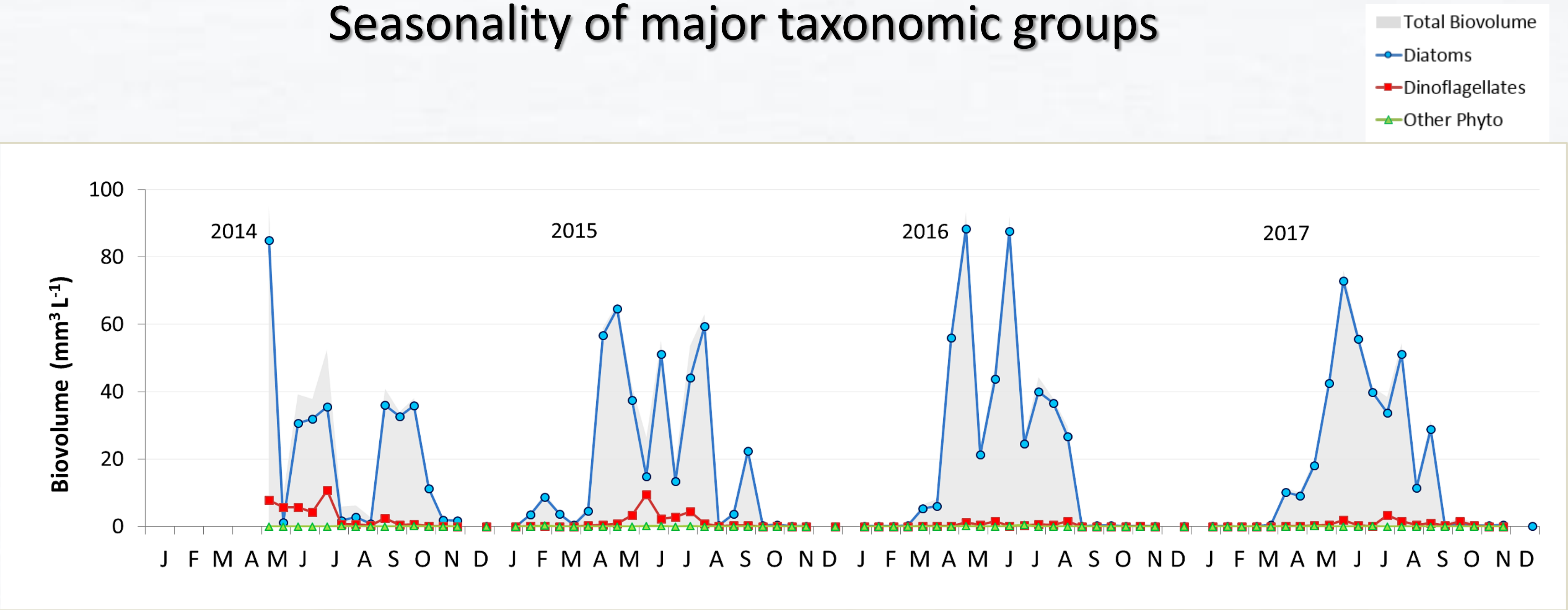


But Puget Sound is different:
There are abundant nutrients that favor large-celled diatoms year round, as long as silica is present (it is seldom limiting).

King County

Zheng-XiZhou et al. 2017. Ecological Modelling 360:150-162.

Puget Sound central basin: Seasonality of major taxonomic groups



Biovolume means of 6 offshore stations (imaging technology)

- Year to year variations in seasonal pattern
- Diatoms always dominate – typical of many estuarine areas

King County

Historical data for South Central Basin

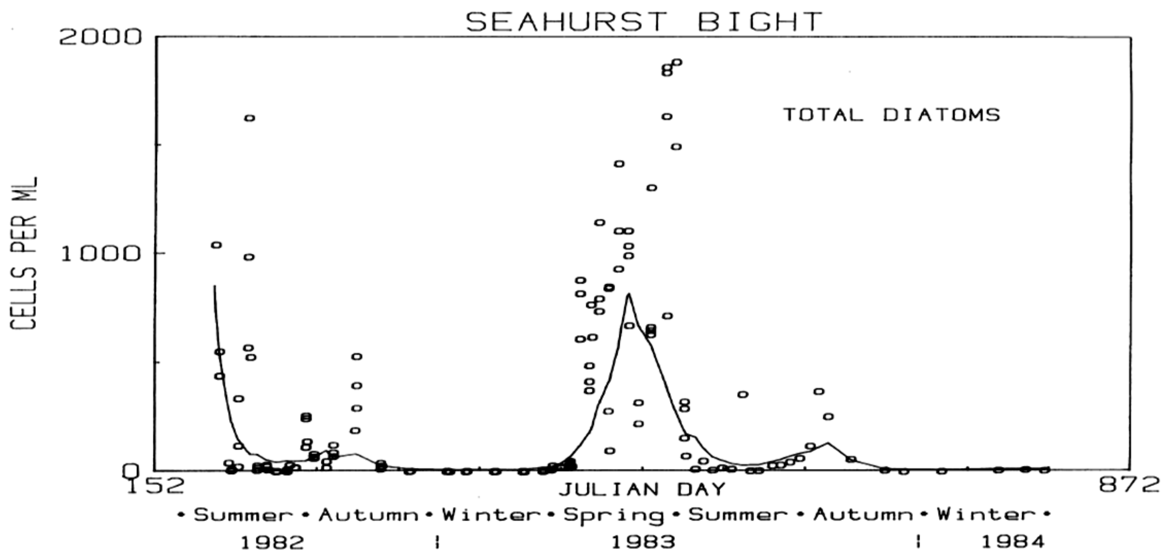


Figure 4.24a. Total diatom numbers from 50% light depth in Seahurst Bight with smooth distribution.

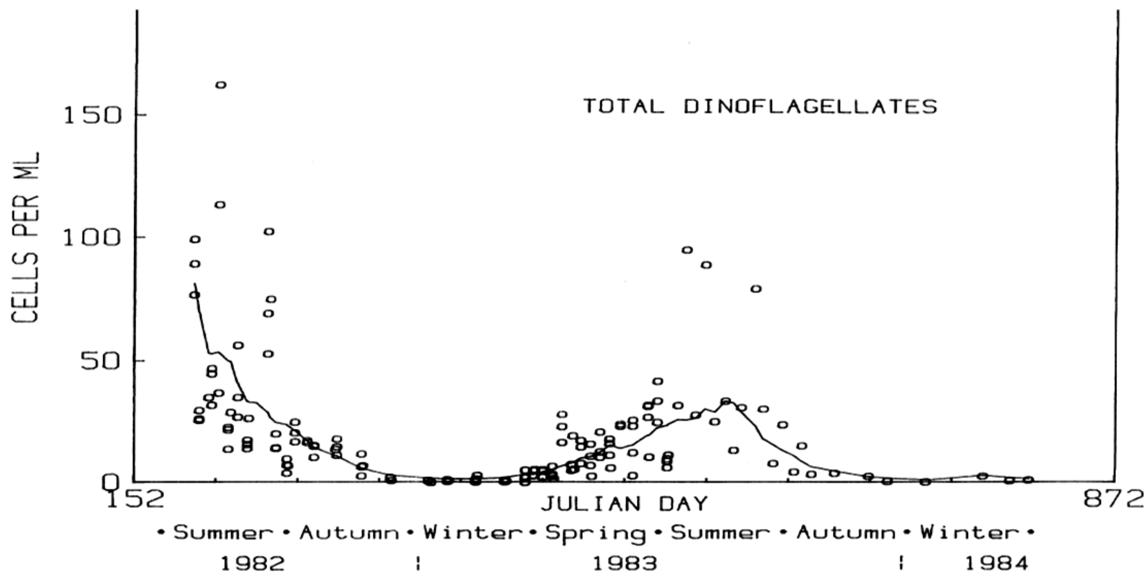
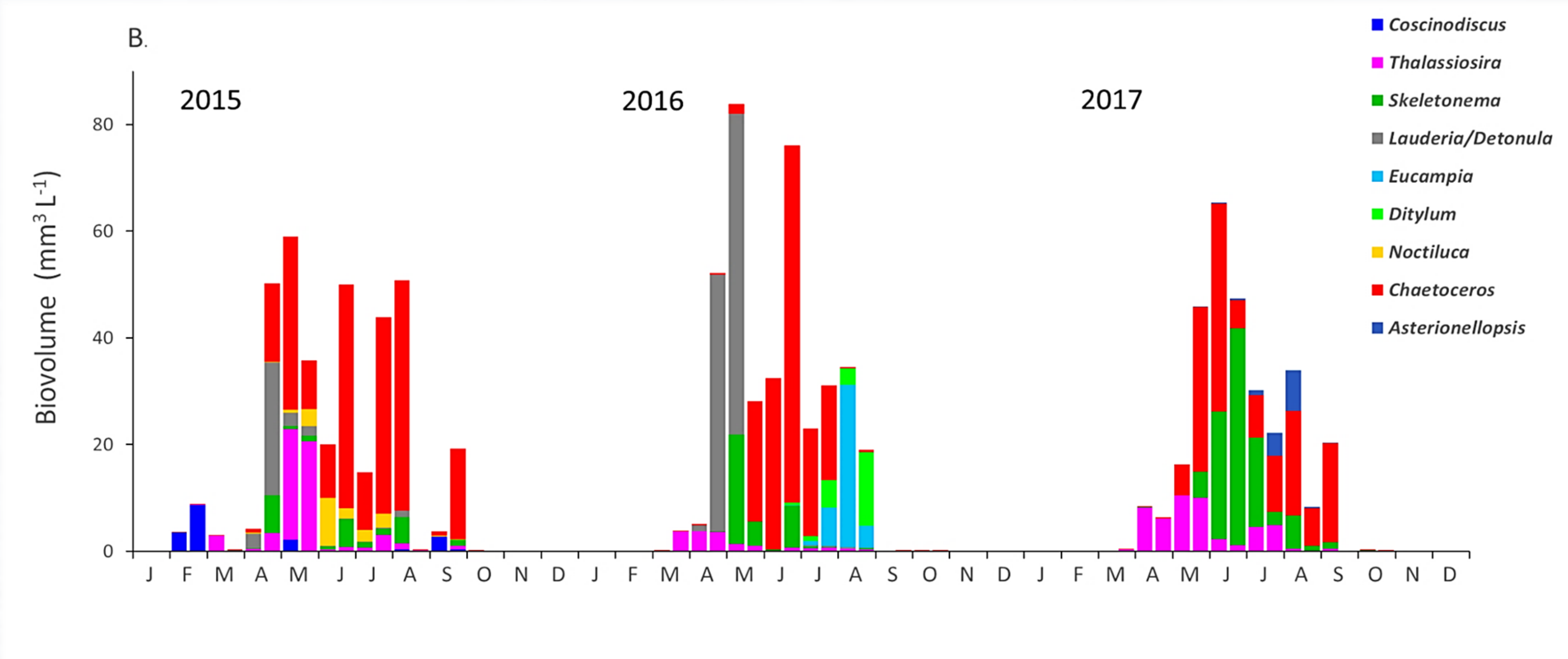


Figure 4.25a. Total dinoflagellate numbers from 50% light depth in Seahurst Bight with smooth distribution.

Similar pattern to what we observe

Anderson et al. 1984

Puget Sound central basin: Seasonality of 6 top taxa for last 3 years



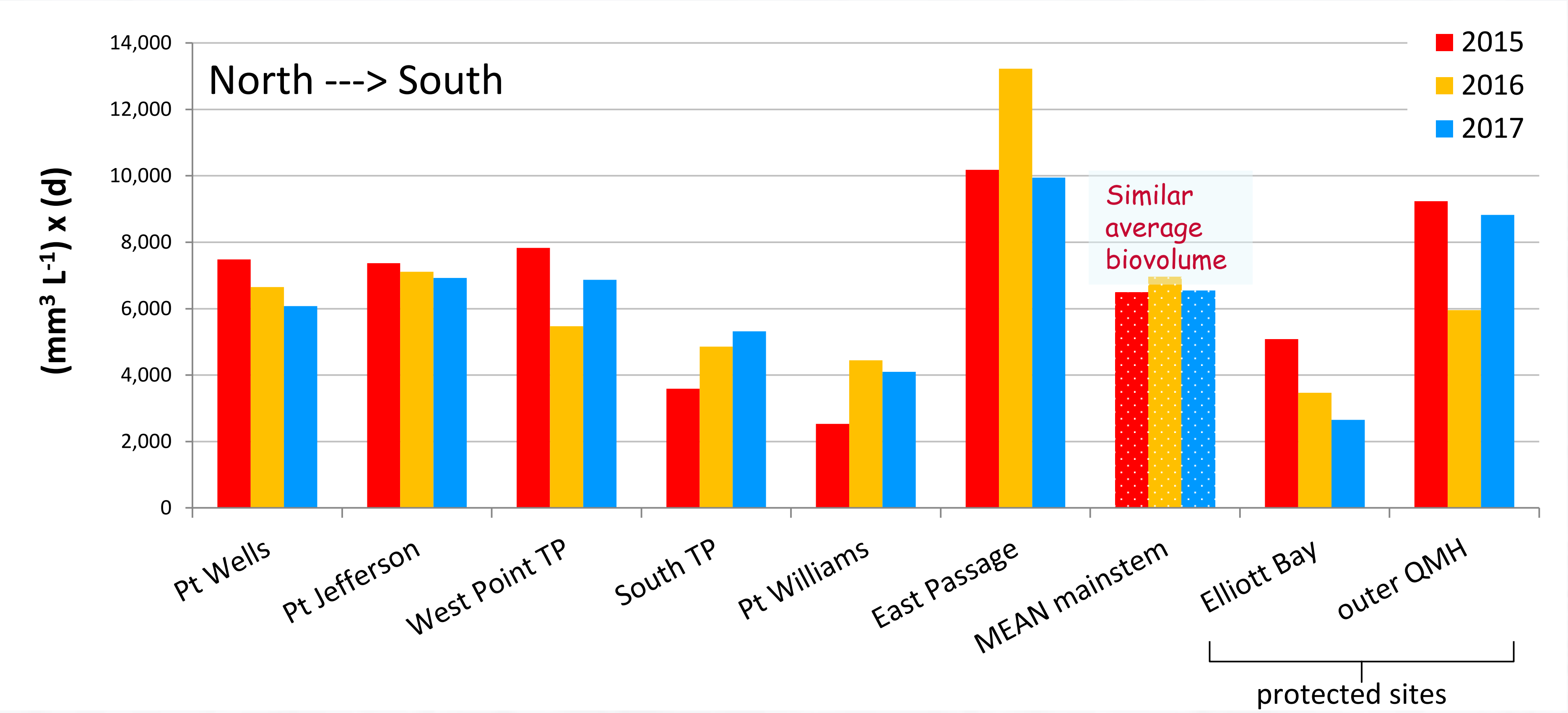
Biovolume means of 8 offshore stations

- Characteristic seasonal succession (mostly chain-forming diatoms)

  Thalassiosira spp. → Other Diatoms -> *Chaetoceros* spp
- Year to year variations are likely the norm
- Some taxa are abundant every year, others unpredictable

King County

Puget Sound central basin: 12-Month Cumulative Biovolume

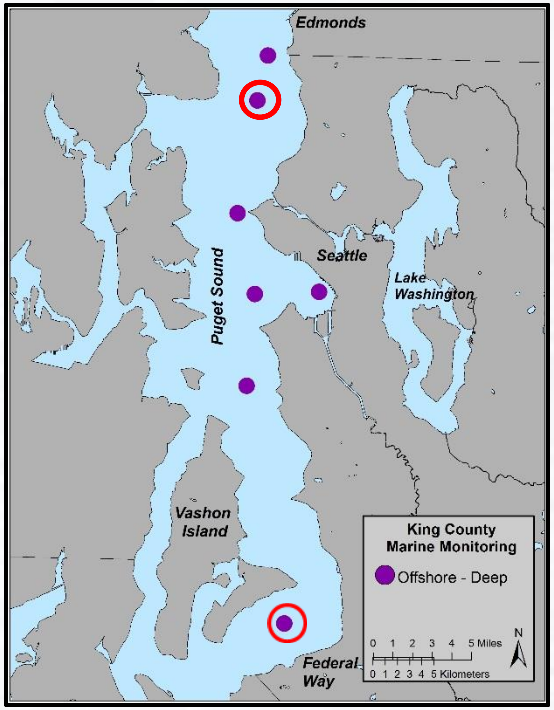


- Consistent spatial pattern in total biomass – the central basin is not homogenous
- Central Basin annual totals are similar year to year – no indication of changes in phytoplankton biomass (but short time series)

King County

Has phytoplankton species composition changed in the last 10 years?

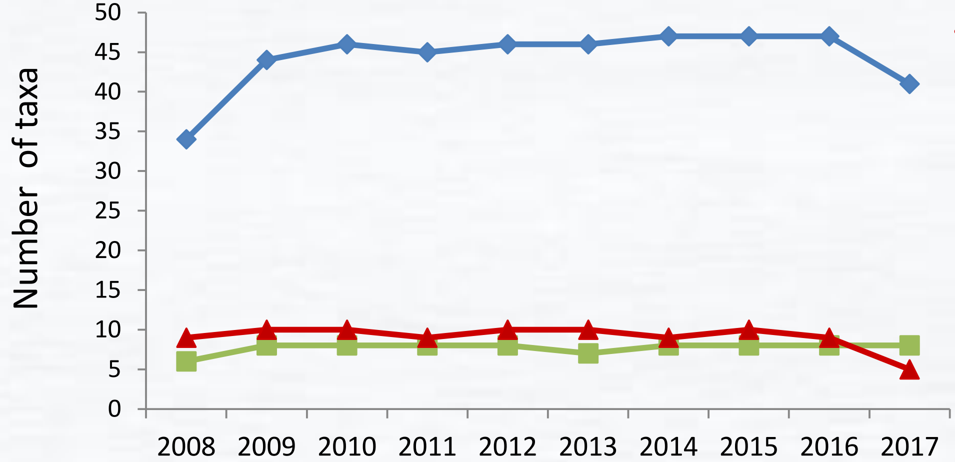
- 2008 – 2017 microscopic observations in central basin
- Presence / Absence at Pt Jefferson and/or East Passage



King County

Number of taxa identified 2008-2017

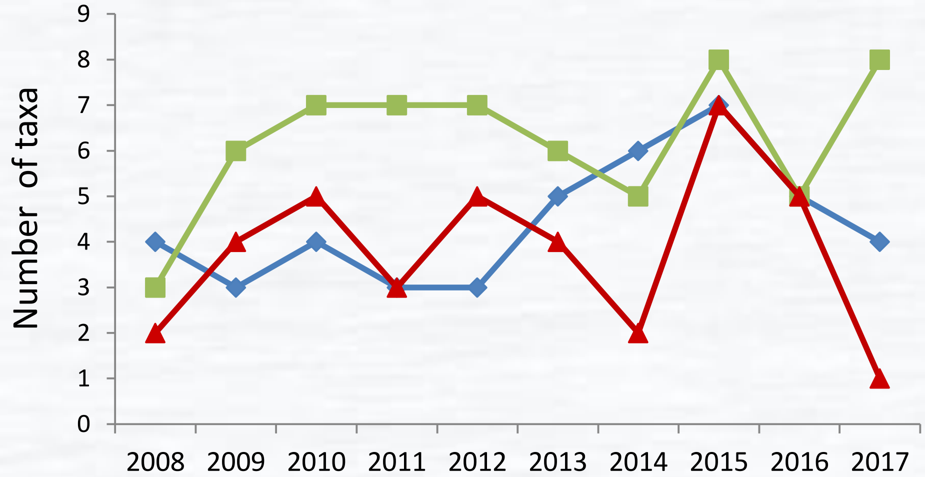
Common Taxa (65)



Most were present every year
→ no change

2017
General decline in # of taxa

Less common Taxa (33)

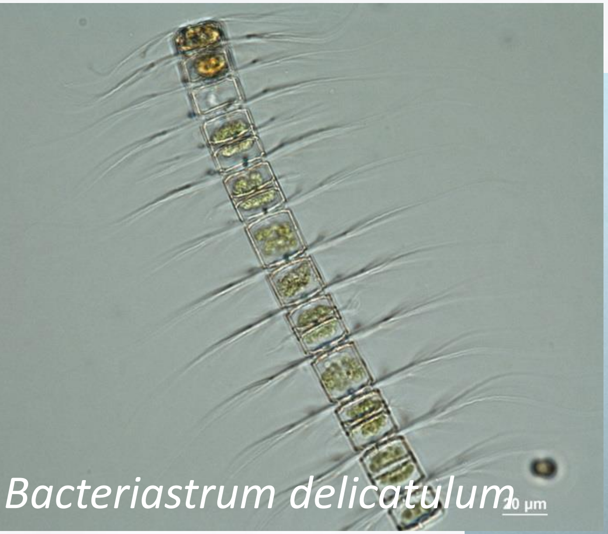


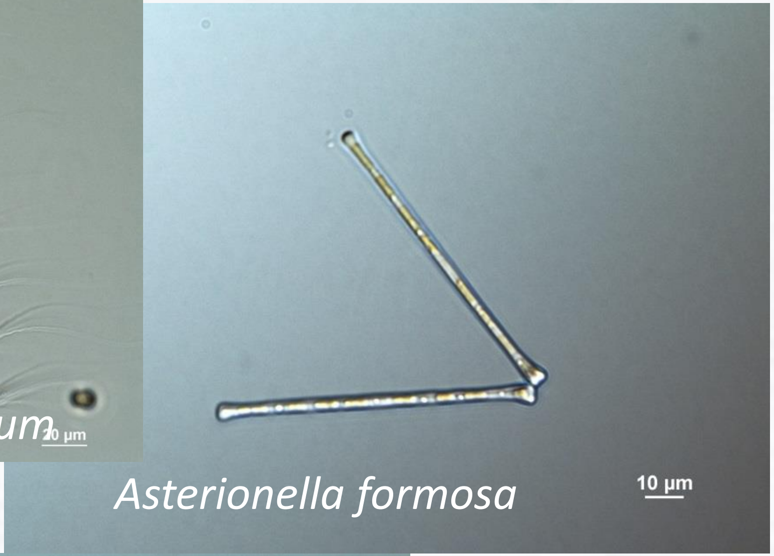
Present 1-7 of 10 years
→ no trend

King County

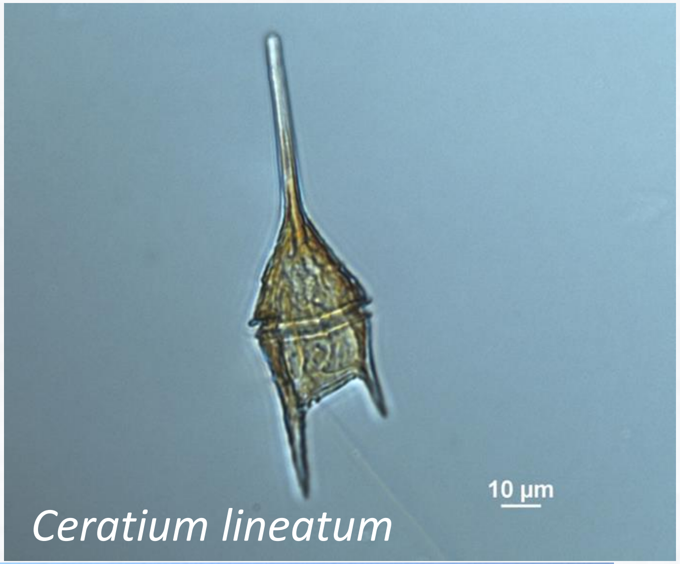
Some "new" common taxa in 2017
Previously very uncommon or absent from our records

DIATOMS

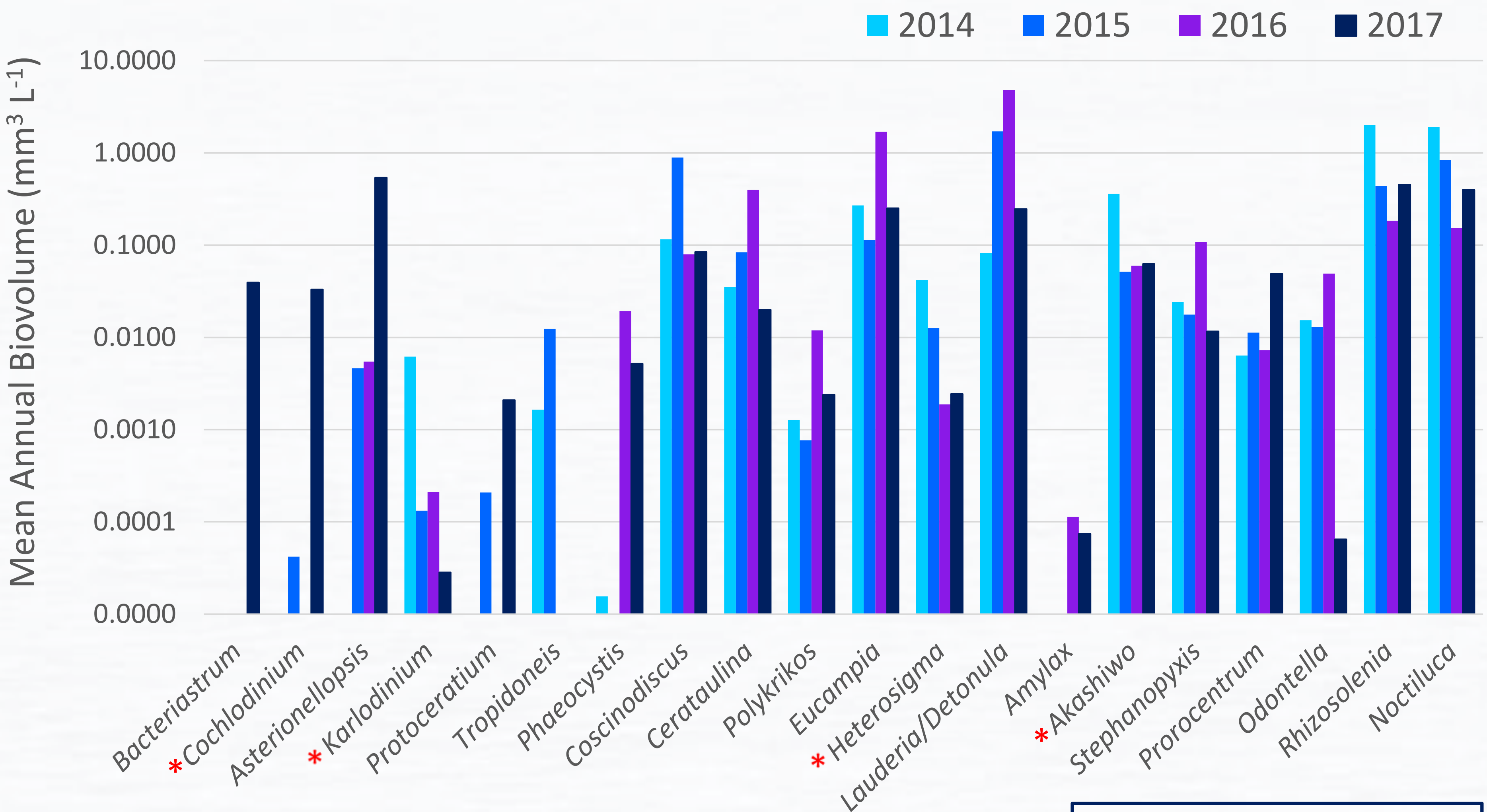




DINOFLAGELLATES



20 most variable taxa 2014-2017
(imaging technology)

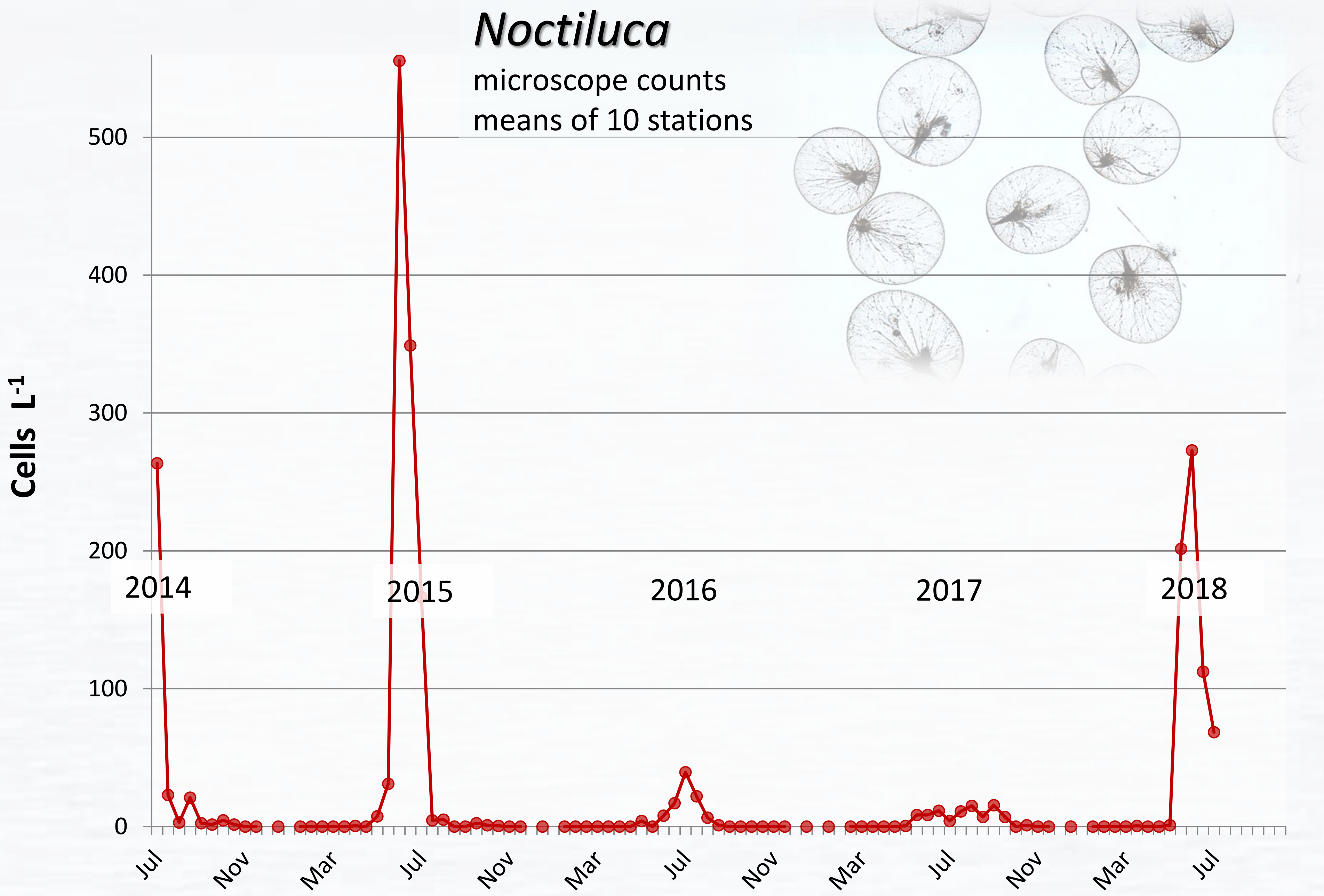


* 4 HABs

10 Diatoms: 59%
8 Dinoflagellates: 30%
2 Other Phyto: 20%

Interannual variability as CV = SD/mean

King County



Noctiluca
microscope counts
means of 10 stations
Cells L^-1
500
400
300
200
100
0
2014
2015
2016
2017
2018
Jul
Nov
Mar
Jul
Nov
Mar
Jul
Nov
Mar
Jul
Nov
Mar
Jul

King County

Noctiluca blooms

Three Tree Point

Photo C. Krembs, Ecology

King County

North of Des Moines marina

Brace Point?

????

Phytoplankton Summary

- Puget Sound phytoplankton is dominated by diatoms, as is typical of nutrient-rich estuarine areas

- Phytoplankton draw down most of the ambient nitrogen during the peak growth season

- Seasonal patterns in phytoplankton biomass can vary year to year with environmental conditions (e.g. stratification)

- Inter-annual differences in bloom timing, magnitude and species composition make it difficult to assess trends (need longer time series!)

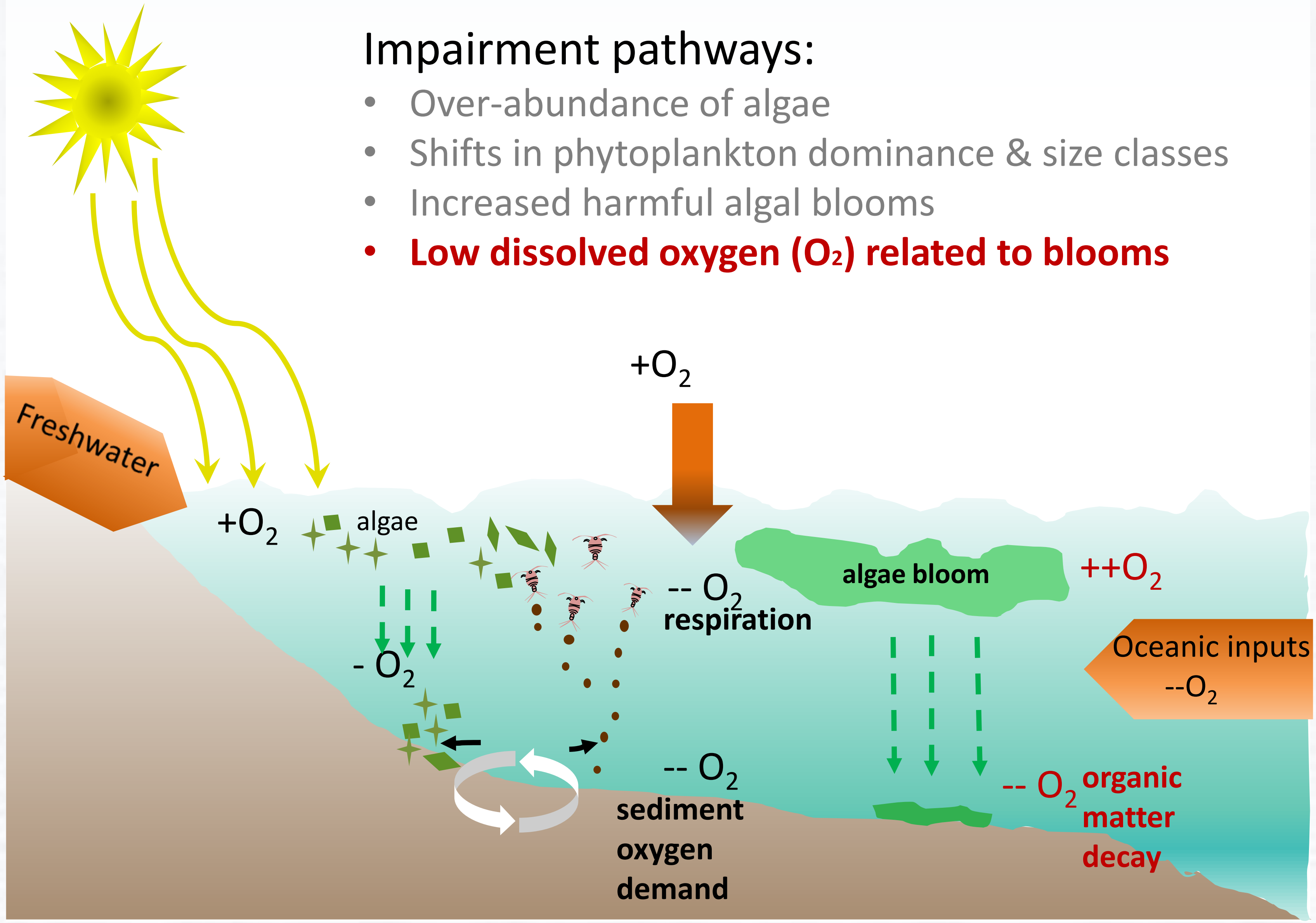
- 10-yr record of central basin taxa shows a large group of common taxa present every year, but some changes in 2017

- Noctiluca observations go back a long time, but there is no long-term data record

King County

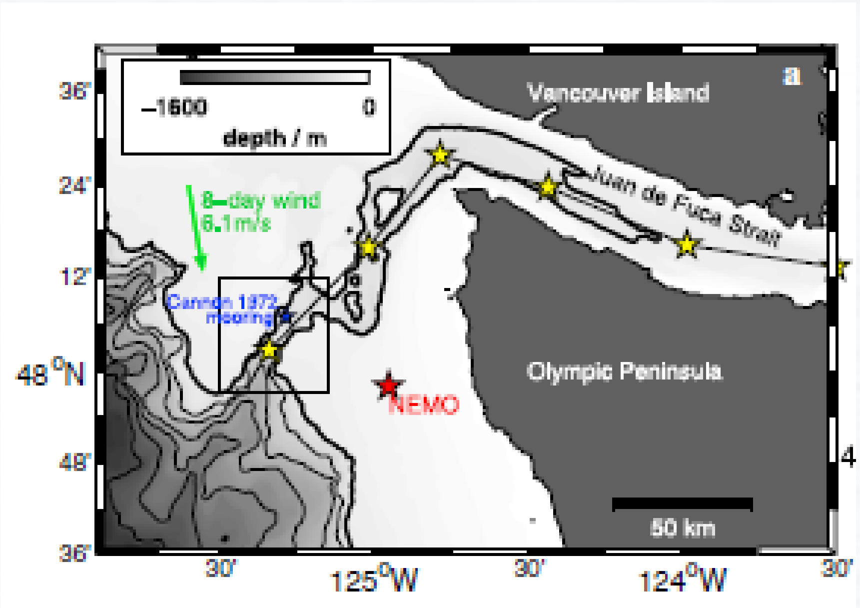
Impairment pathways:

- Over-abundance of algae
- Shifts in phytoplankton dominance & size classes
- Increased harmful algal blooms
- **Low dissolved oxygen (O_2) related to blooms**



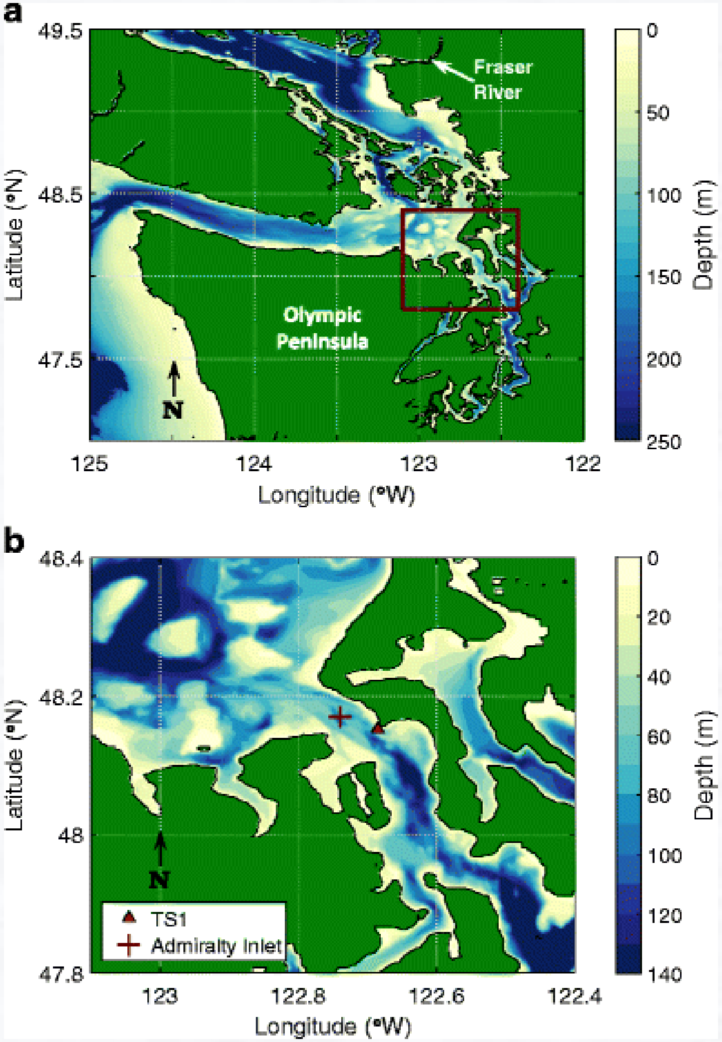
King County

Low dissolved oceanic water can funnel into Juan de Fuca Strait and intrude in Puget Sound



(Source: Alford & MacCready 2014)

Downwelling in winter reduces availability of lower DO over the Admiralty Sill while upwelling in summer increases availability of this lower DO bottom water.



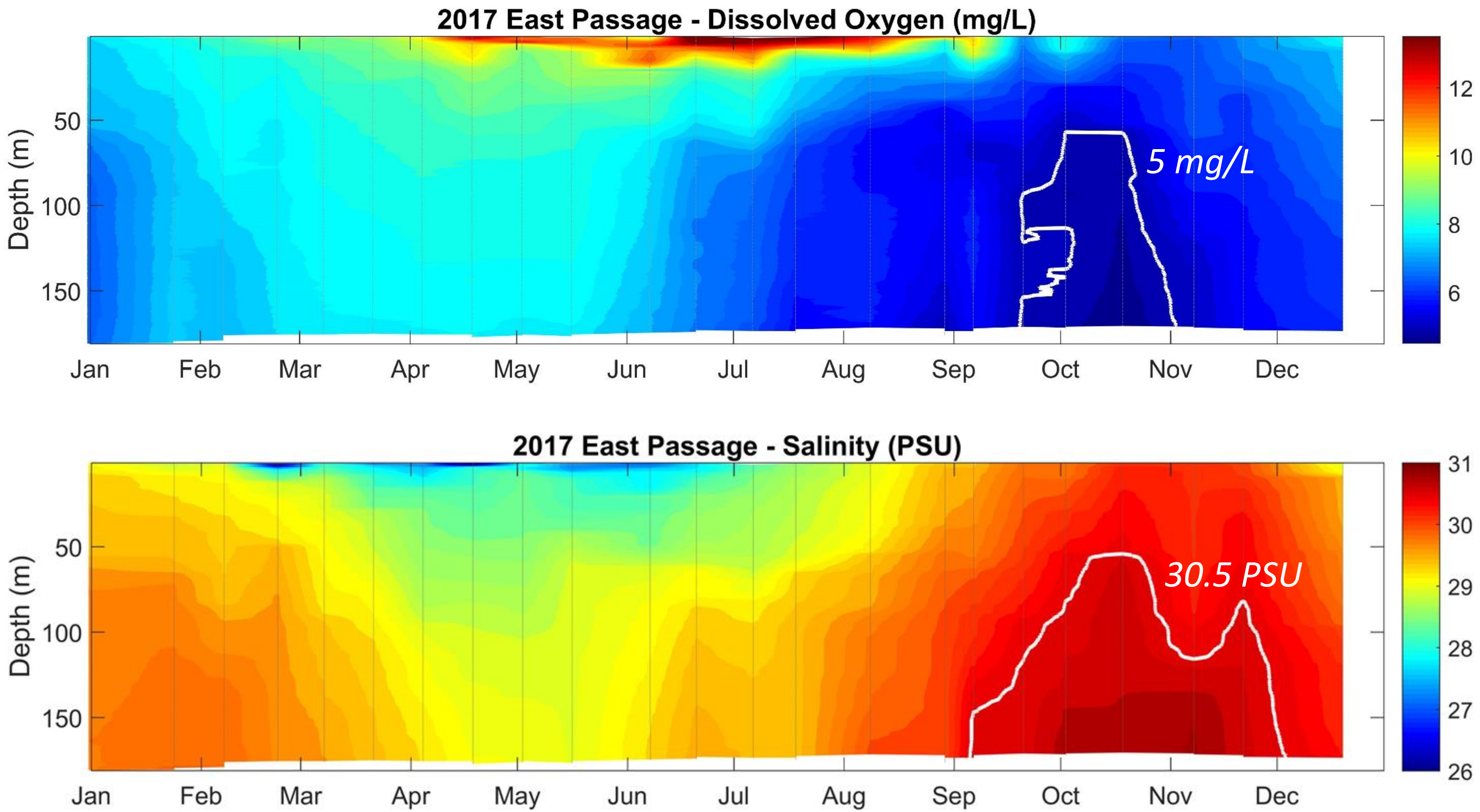
(Source: Deppe et. al 2018)

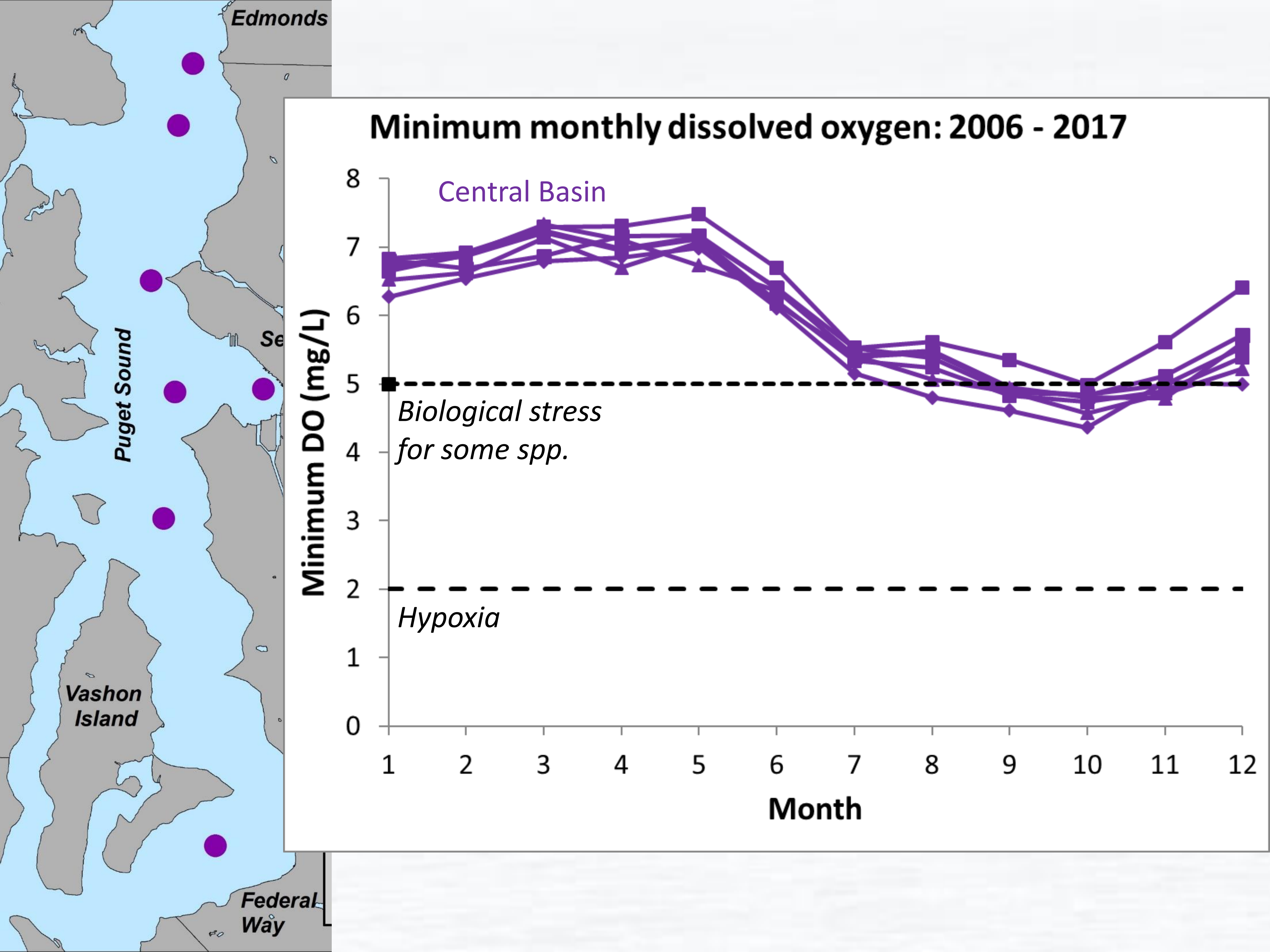
Dissolved Oxygen (DO) – Key Points

- Different processes dominate variability in DO in different areas
  - Low DO oceanic intrusions in the straits
  - Biological production/respiration in Quartermaster Harbor
  - Combination in Central Basin
- Consider DO levels with climate forcing and climate change
- No clear trends or changes in DO

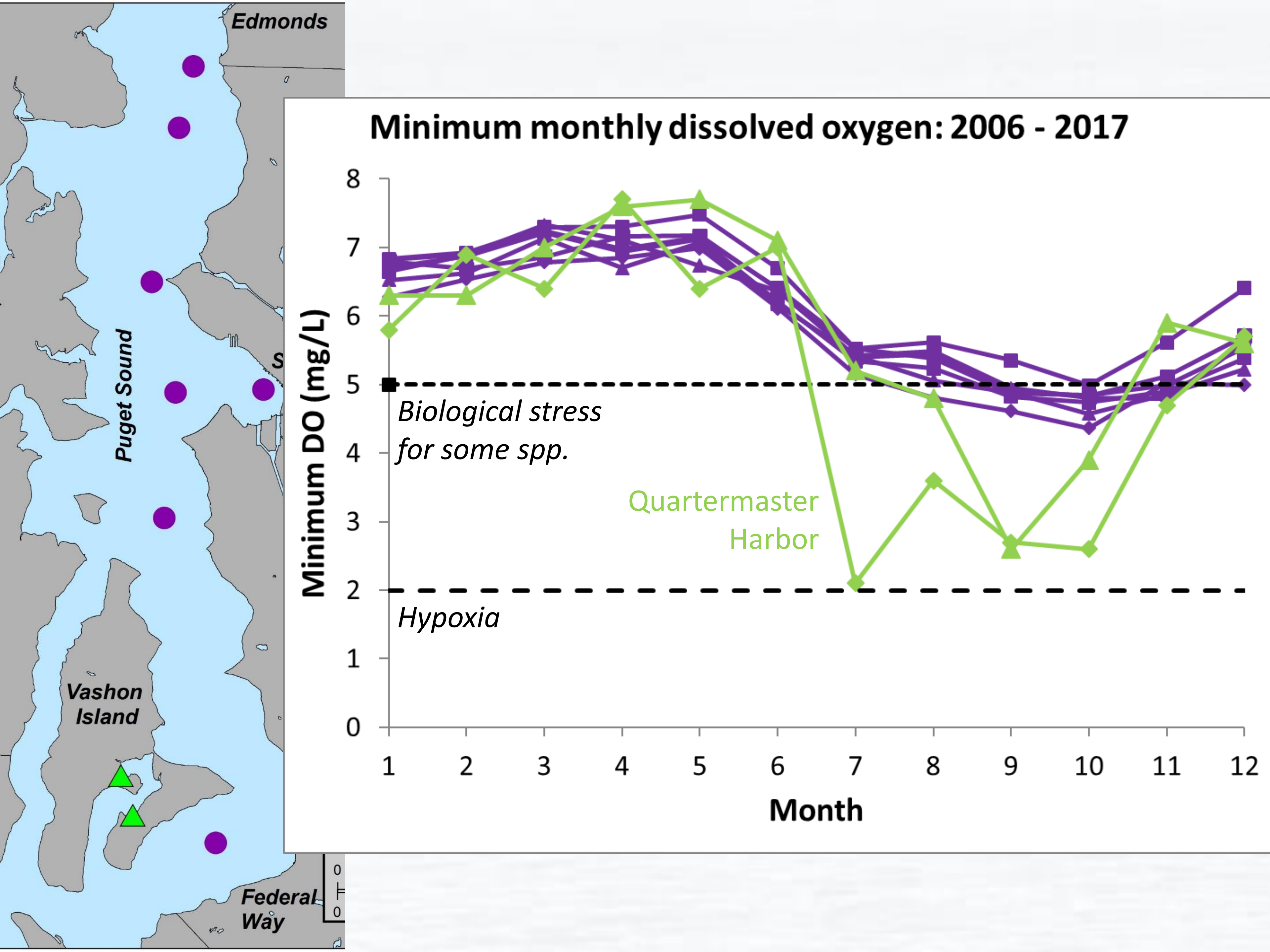
  → Needs further exploration in other areas of Puget Sound

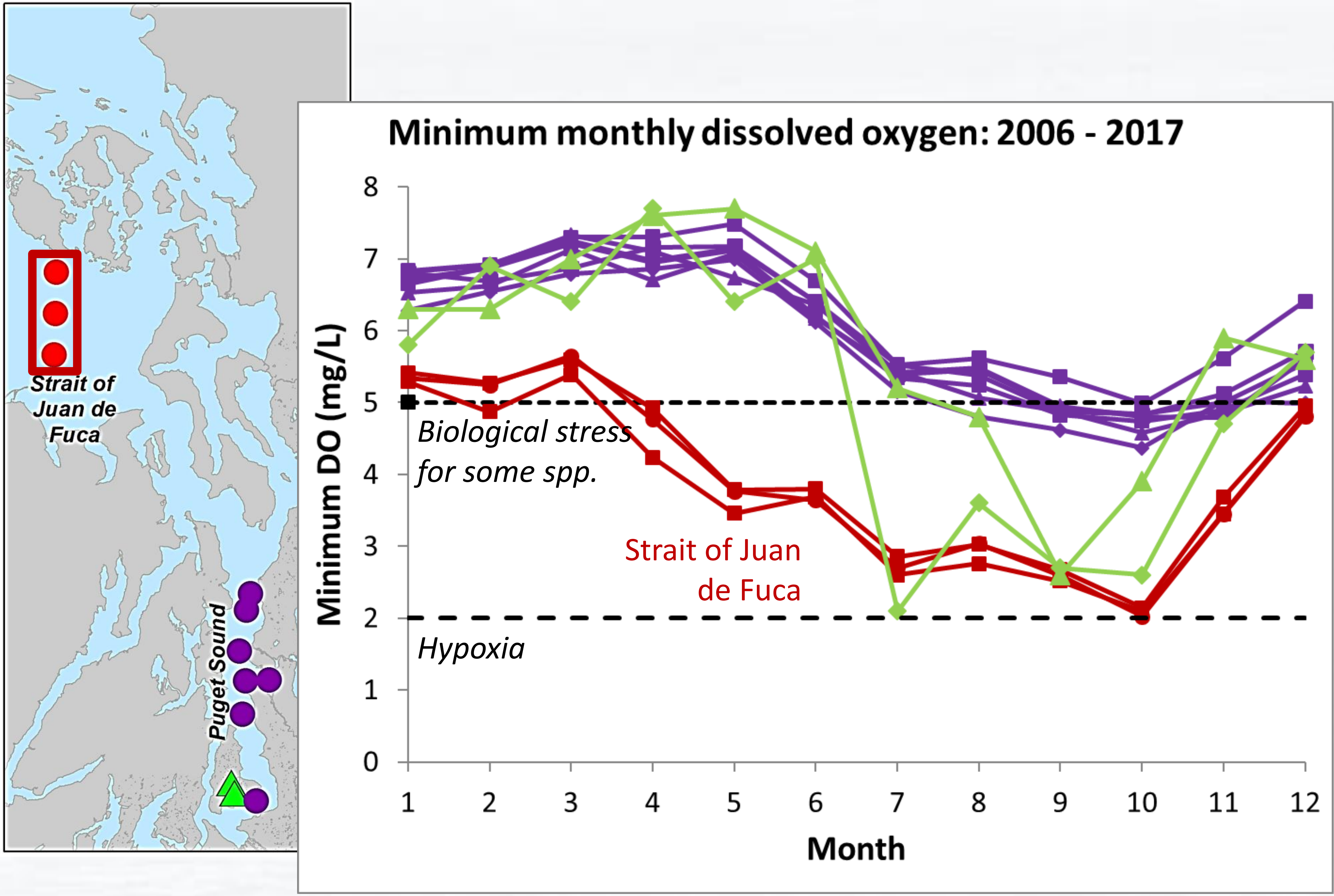
Dissolved oxygen varies seasonally with salinity





Edmonds
Puget Sound
Vashon Island
Federal Way
Minimum monthly dissolved oxygen: 2006 - 2017
Central Basin
Minimum DO (mg/L)
Biological stress for some spp.
Hypoxia
Month
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
9
10
11
12


Edmonds
Puget Sound
Vashon Island
Federal Way
Minimum monthly dissolved oxygen: 2006 - 2017
Minimum DO (mg/L)
8
7
6
5
4
3
2
1
0
Biological stress for some spp.
Quartermaster Harbor
Hypoxia
1
2
3
4
5
6
7
8
9
10
11
12
Month

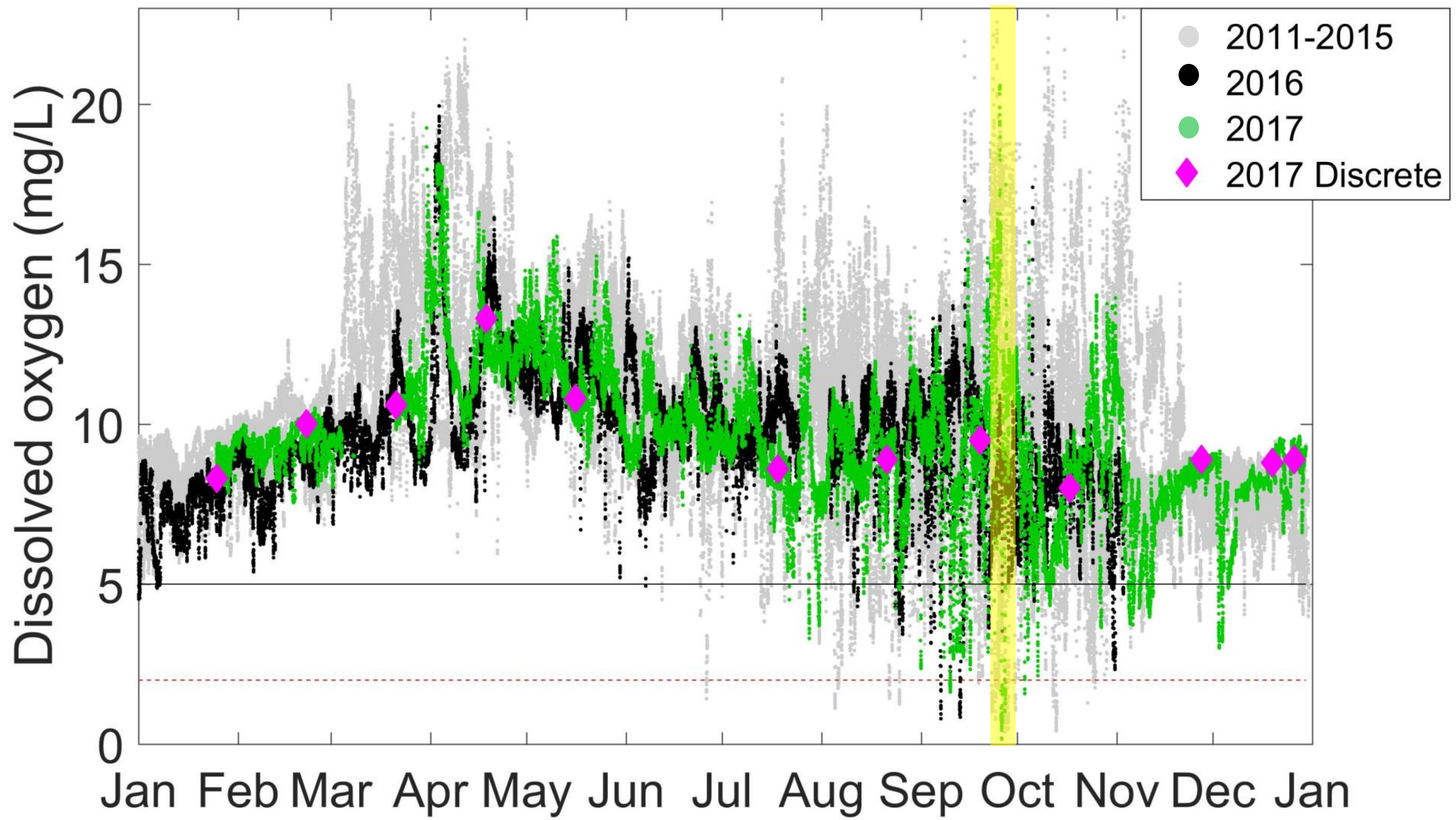


Strait of Juan de Fuca
Puget Sound
Minimum monthly dissolved oxygen: 2006 - 2017
Minimum DO (mg/L)
Month
Biological stress for some spp.
Hypoxia
Strait of Juan de Fuca

King County

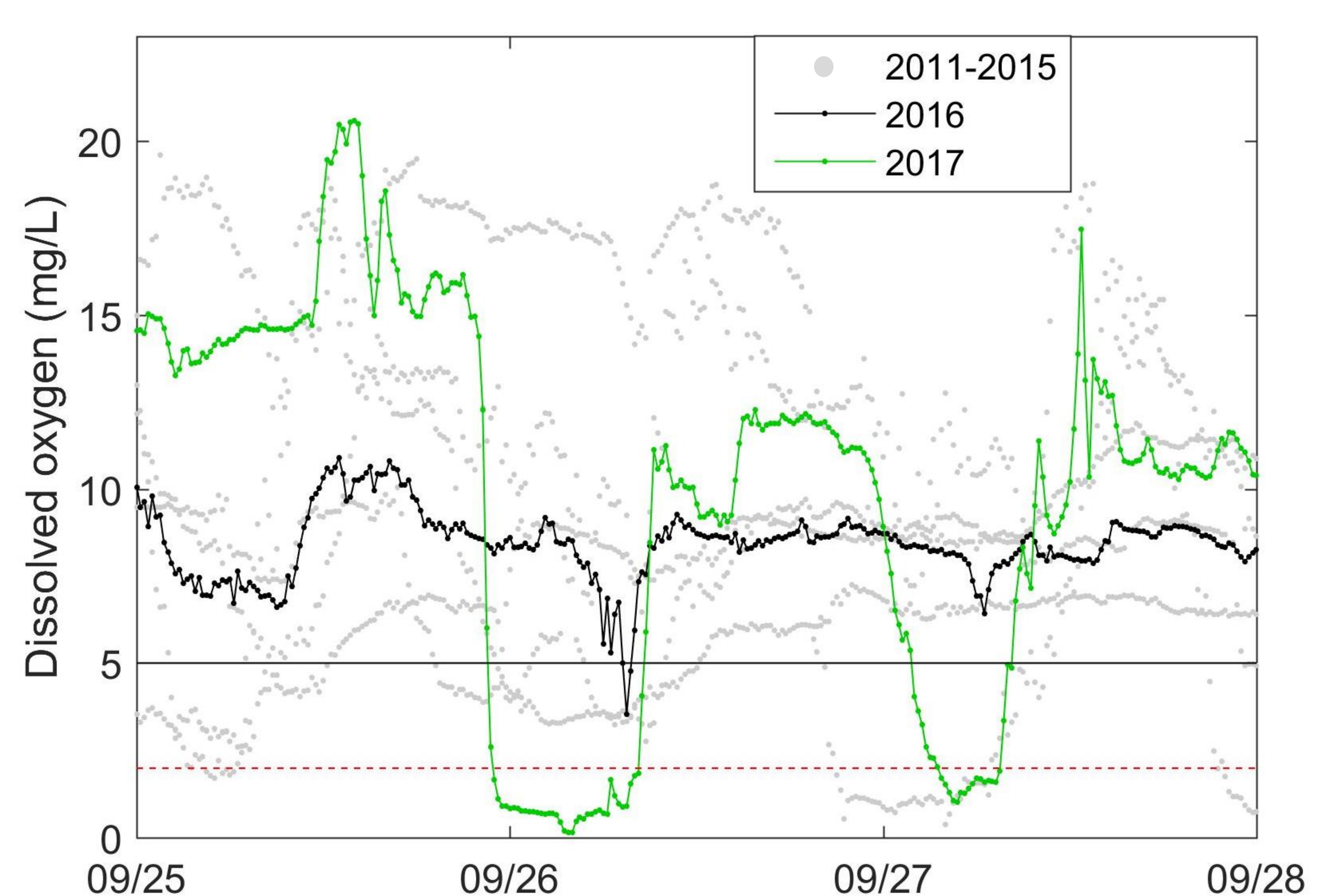
Inner Quartermaster Harbor

Inner Quartermaster Harbor – mooring at 1-m



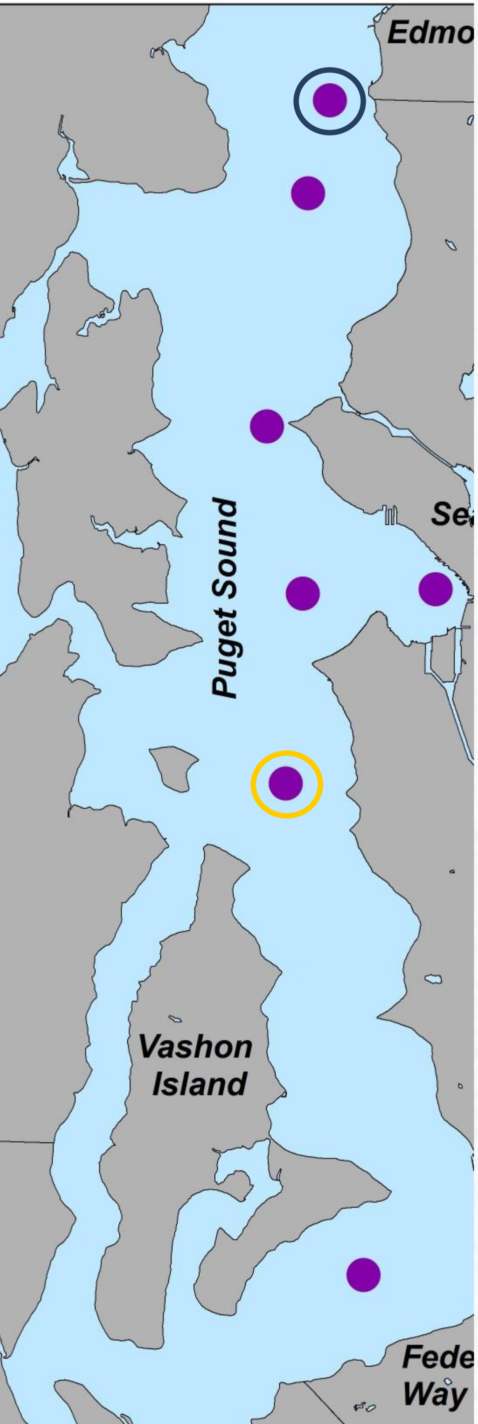
King County

Zooming in to 3 days – huge daily swings in DO



How have dissolved oxygen levels changed over time?

King County



Dissolved Oxygen Trends

Site	Years	Deep Target Depth	Deep	80-100-m
Brightwater TP	19	180-m	NS	
Pt. Jefferson	24	200-m	NS	NS
West Point TP	21	55-m	NS	
South TP	21	180-m	NS	NS
Pt. Williams	24	180-m		
Elliott Bay	21	75-m	NS	
East Passage	15	180-m	NS	NS

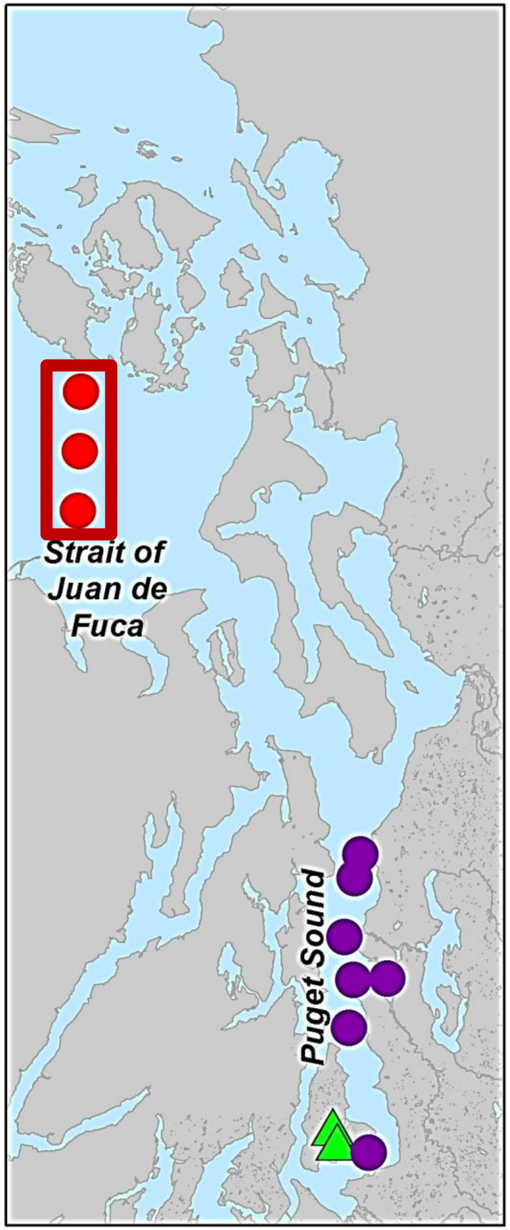
Temperature

80-100-m
NS
NS
NS

Legend: %Change over record

	0-5%	5-25%	25-50%
+			
-			

NS = Not Significant (p>0.05)



Dissolved Oxygen Trends

Strait of Juan de Fuca

		Years	Months	Deep Target Depth	Deep	80-100-m
North	SJF000	19	All	140-m	NS	NS
↓	SJF001	19	All	140-m	NS	NS
South	SJF002	19	All	140-m	NS	NS

Quartermaster Harbor

- Short-term variability too high to accurately assess trends
- From 15-min mooring data: inter-annual variability but no indication of increase in duration or intensity of low DO events (**caveat:** short data record).

King County

How does this compare to historical data collected from 1933 – 1975?

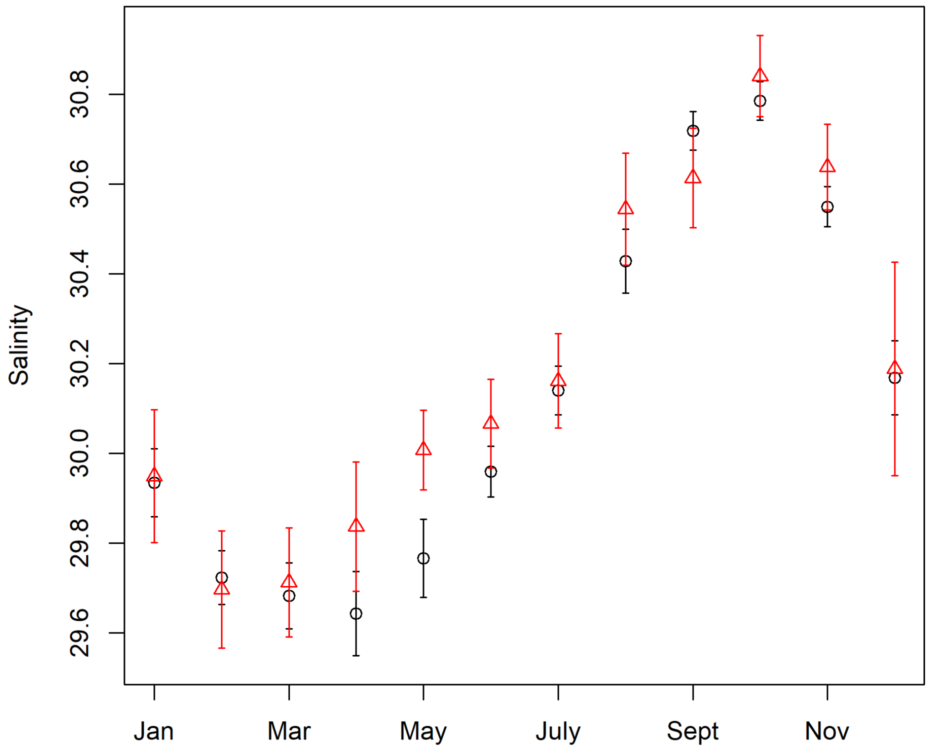
R/V Brown Bear (Source: Eugene and Dorothy Collias Collection)

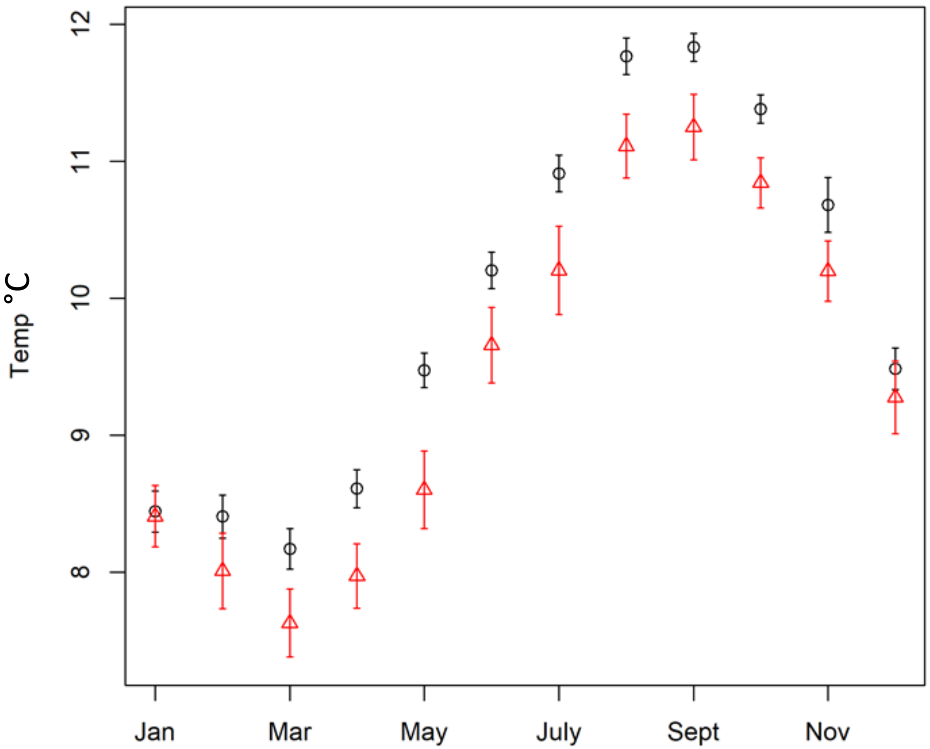
King County

Deep monthly means at Pt. Jefferson – Then & Now

Salinity at 200-m –
Similar pattern

Temperature at 200-m –
↑Increase of ~ 0.5 – 1 °C





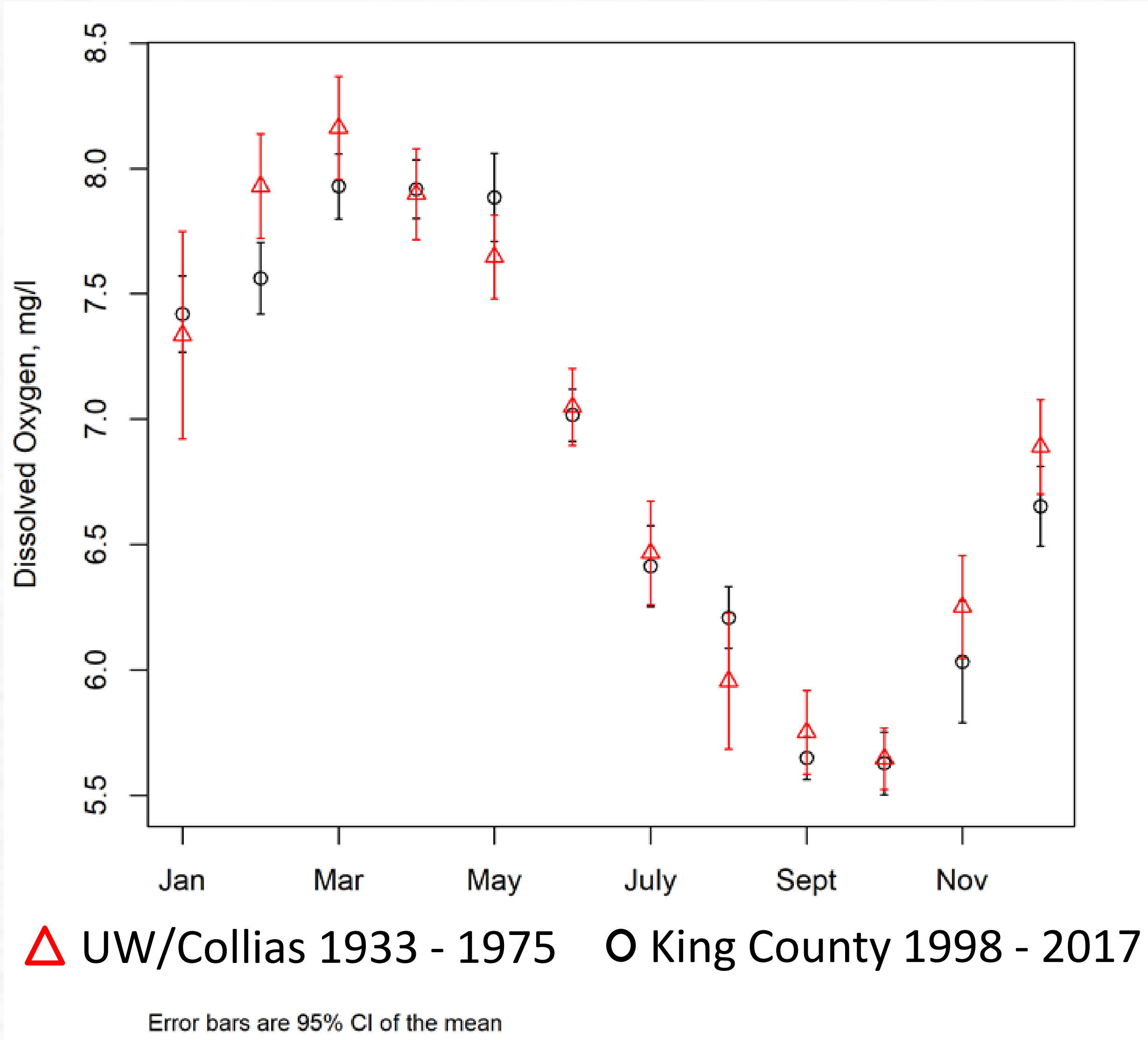
△ UW/Collias 1933 - 1975   O King County 2002 - 2017

Error bars are 95% CI of the mean

King County

Deep monthly means at Pt. Jefferson – Then & Now

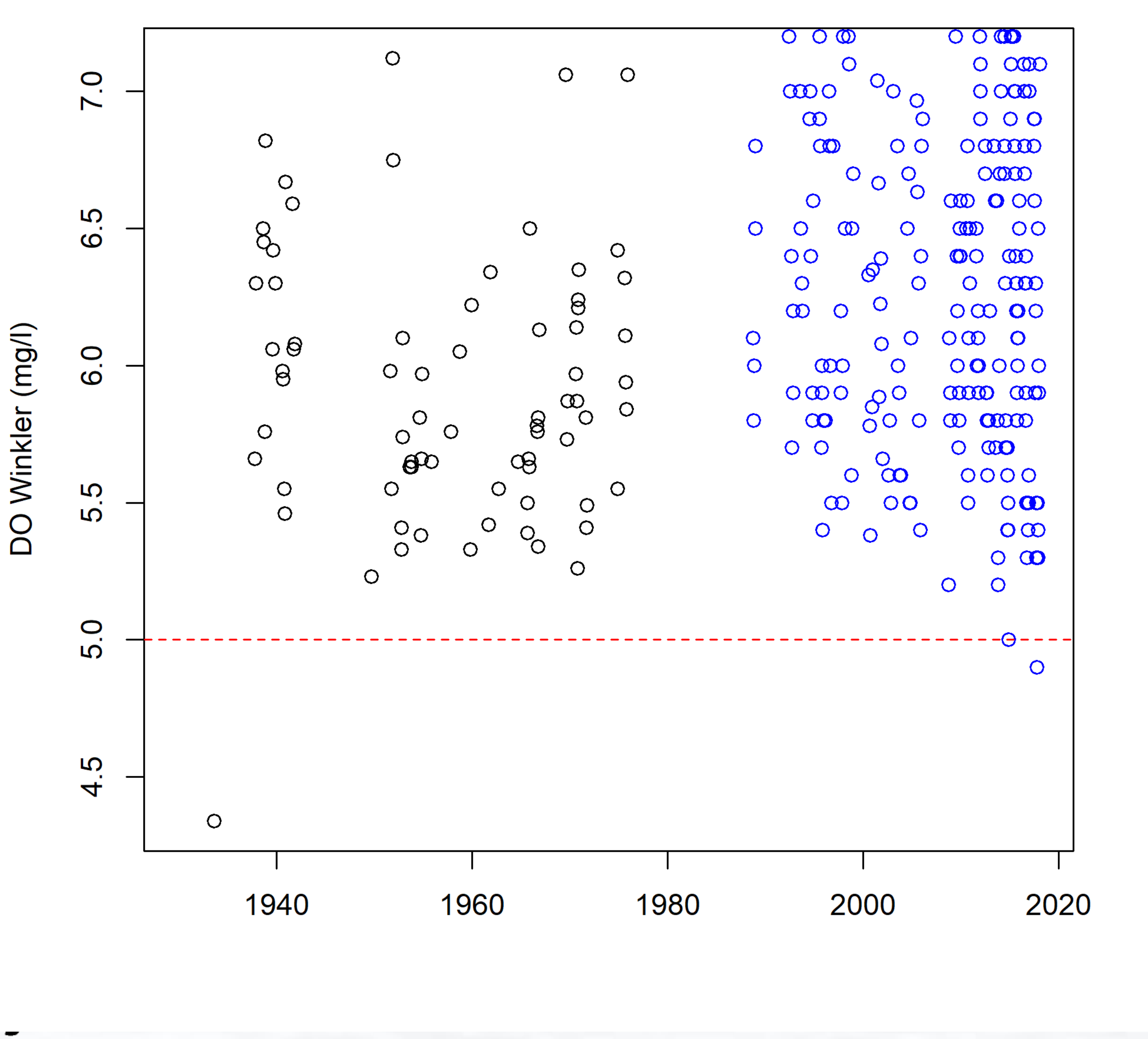
Dissolved oxygen at 200-m – Similar seasonal pattern, variable by month



King County

No clear shift in DO observed during late summer/fall

Aug. – Nov. DO time series for Point Jefferson at 200-m



King County

Overall Summary

- Large amounts of spatial and temporal variability
- Important to understand drivers of nutrient changes and evaluate potential impairment indicators beyond concentrations
- Chlorophyll-a observations do not indicate signs of eutrophication in Central Basin. Due to lack of historical data, Quartermaster Harbor story isn't clear.
- No clear trends or changes in DO.
- Inter-annual differences in phytoplankton bloom timing, magnitude and species composition make it difficult to assess trends (need longer time series)
- Hydrological cycle and circulation are important for assessing trends
- Need to understand variability within and between basins
  - → Could lead to different approaches and priorities for science and management.

King County

Thank you!

Contributors:

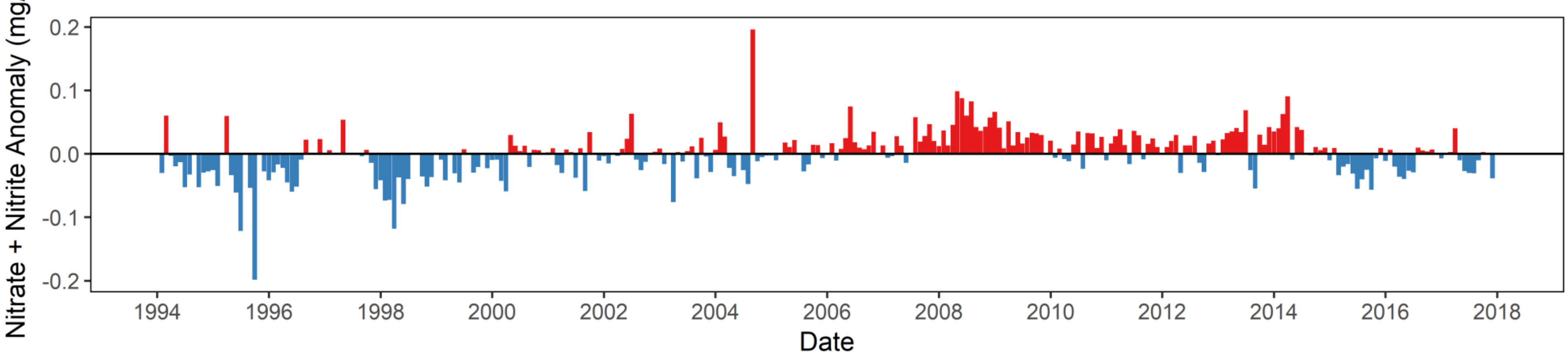
- King County Environmental Lab staff for field sampling and lab analysis
- Bruce Nairn: Dissolved oxygen explorations
- Lyndsey Swanson: Phytoplankton analyses

Appendix

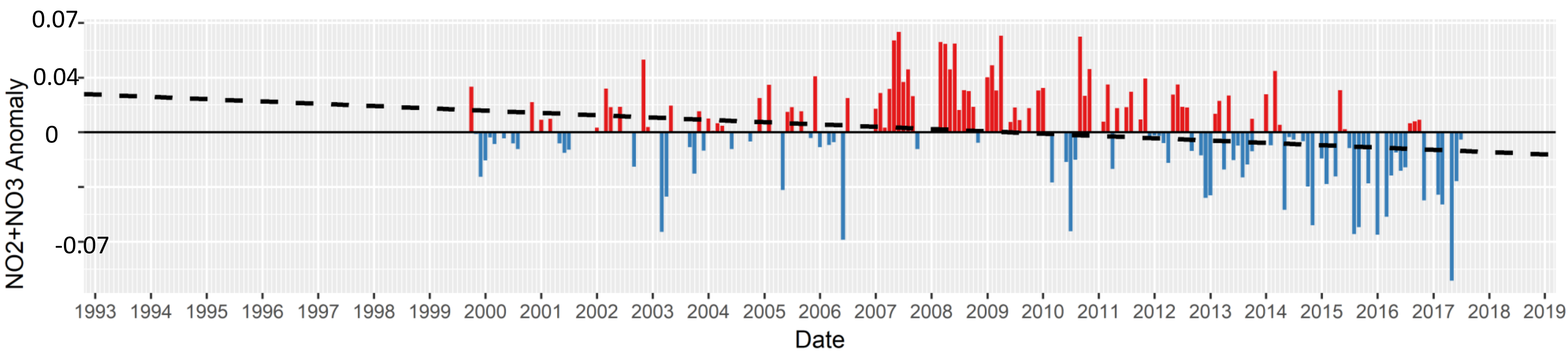
- Extra slides

Nitrate + Nitrite Anomalies: Central Basin vs. Strait

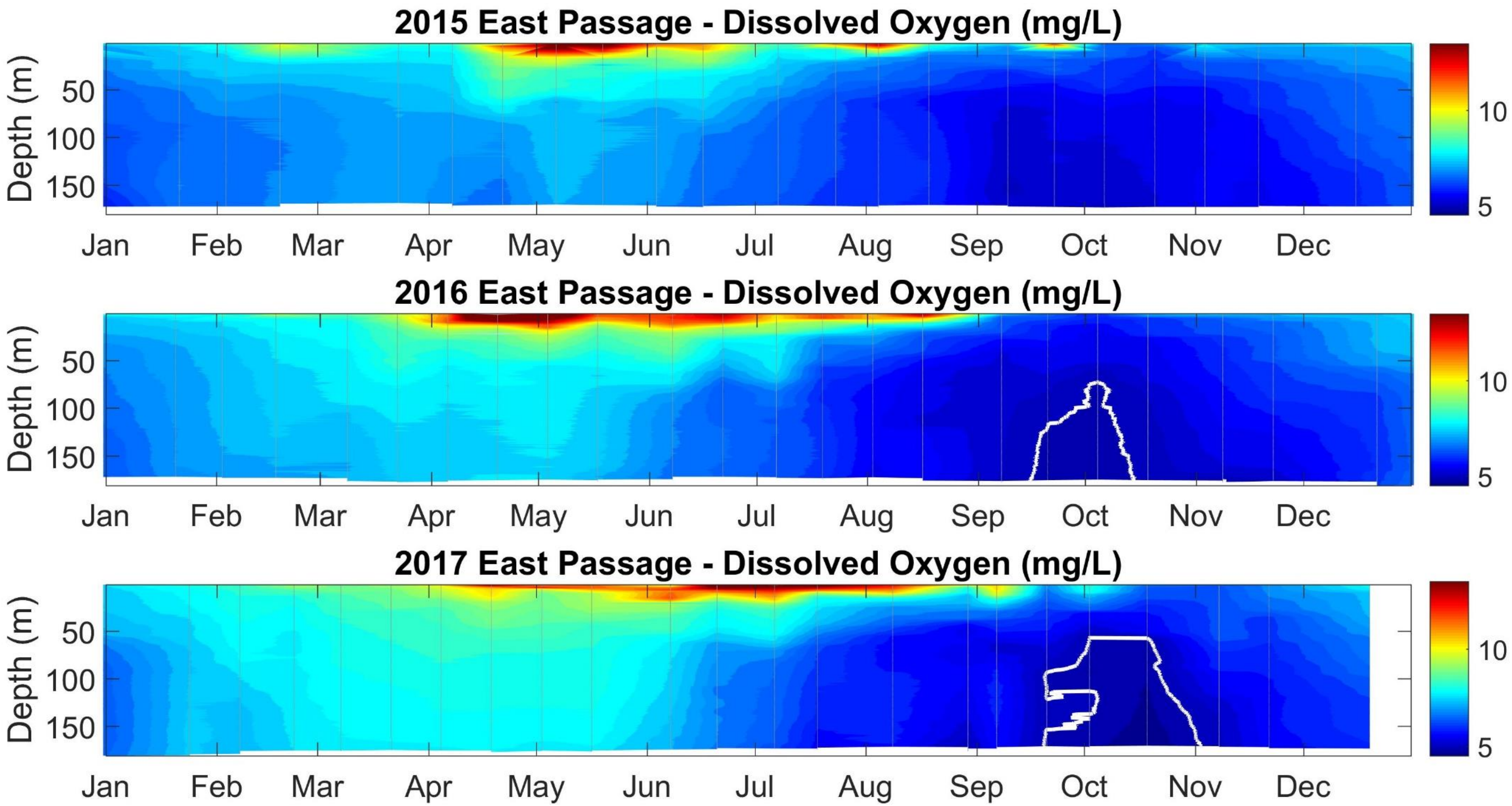
Pt. Jefferson – 200-m



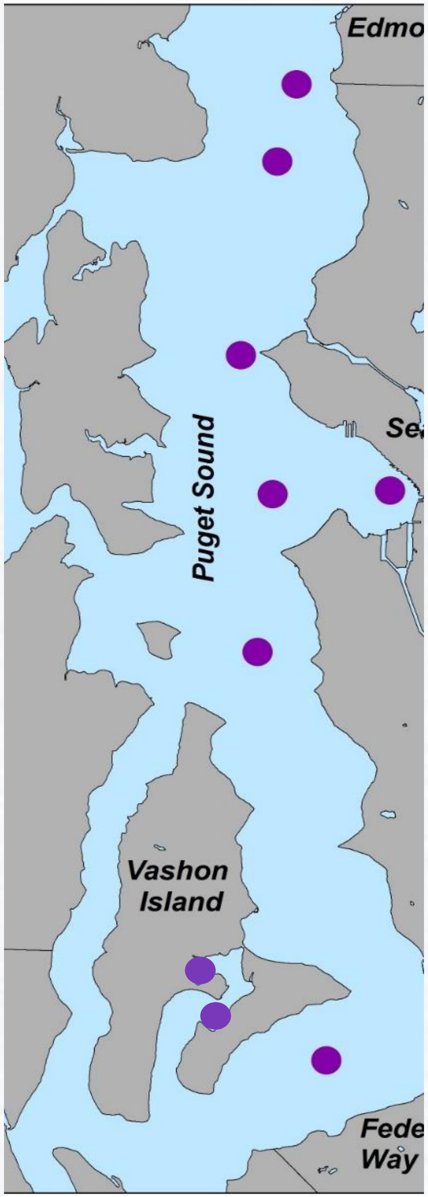
N. Juan de Fuca – 140-m



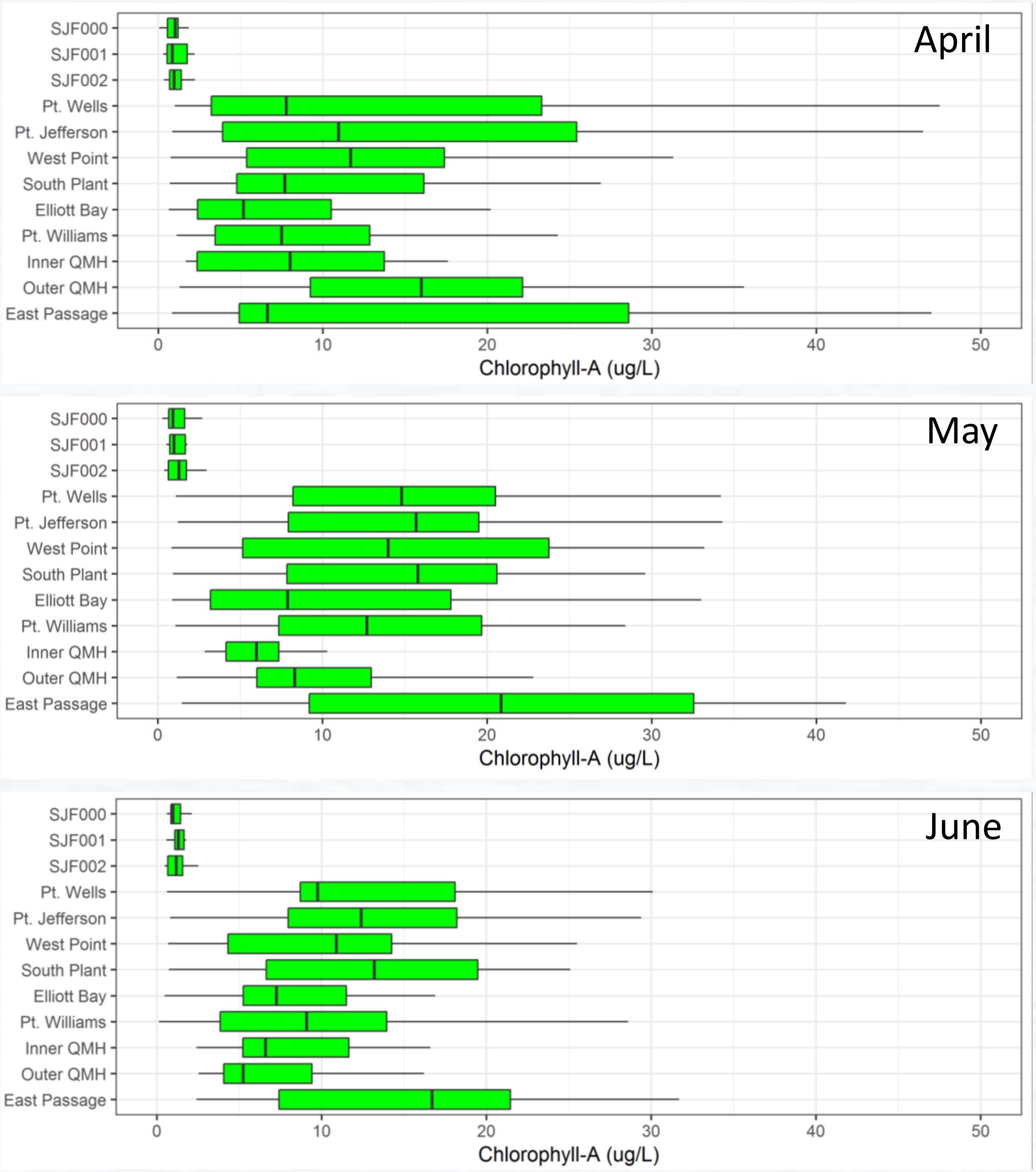
Similar pattern but different magnitude between years

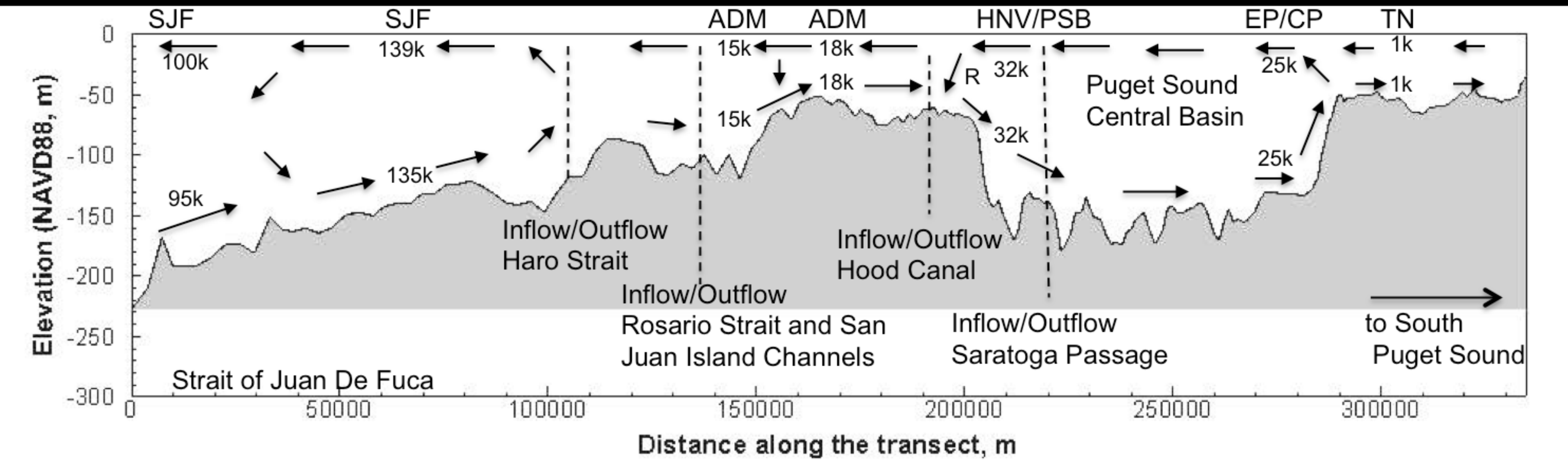


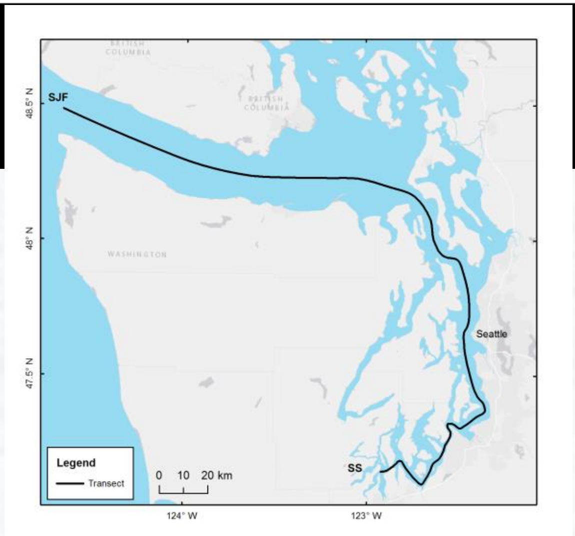
King County


Edmo
Puget Sound
Se
Vashon
Island
Fede
Way

King County


April
May
June
SJF000
SJF001
SJF002
Pt. Wells
Pt. Jefferson
West Point
South Plant
Elliott Bay
Pt. Williams
Inner QMH
Outer QMH
East Passage
0
10
20
30
40
50
Chlorophyll-A (ug/L)





Source: T. Khangaonkar, PNNL

King County