Phytoplankton and hydrology: in a changing world

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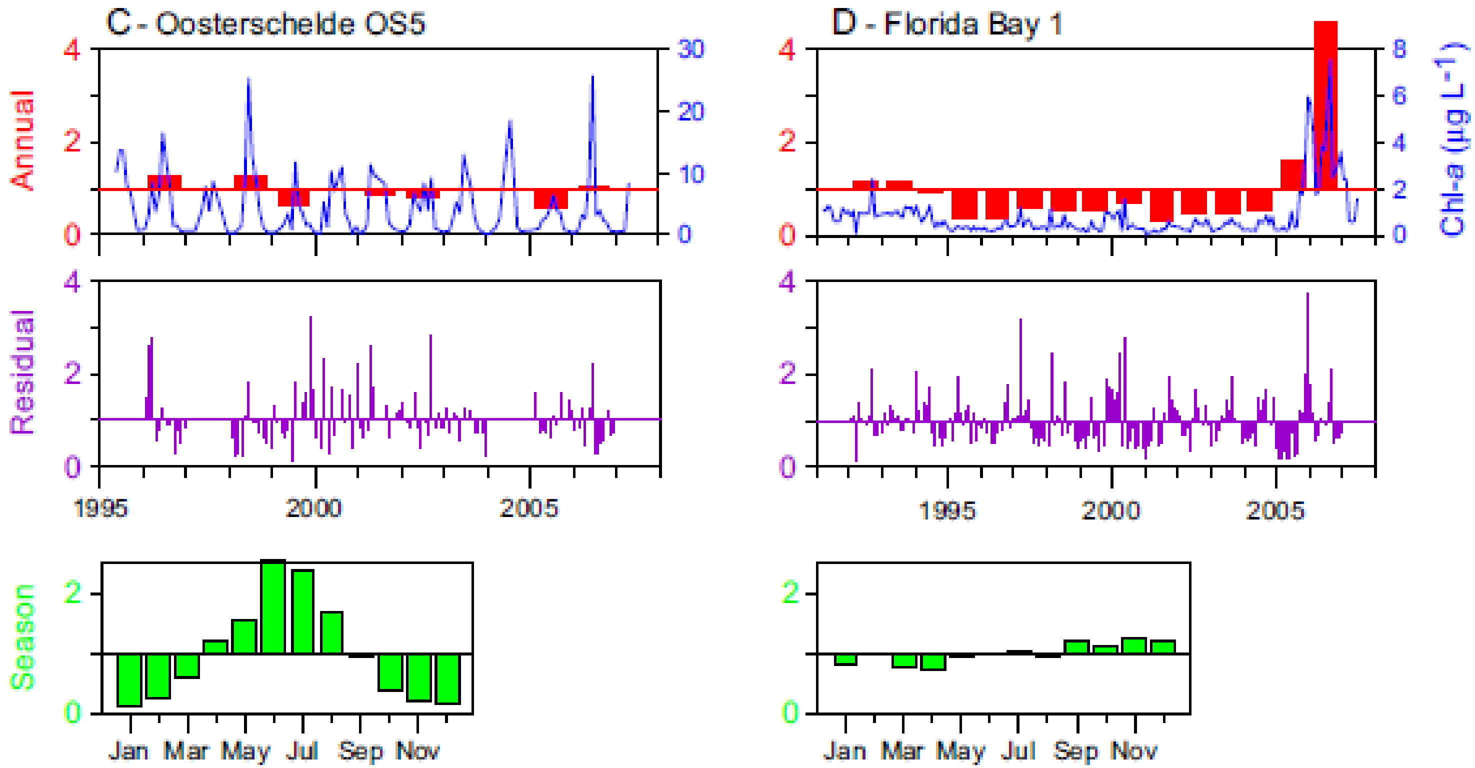
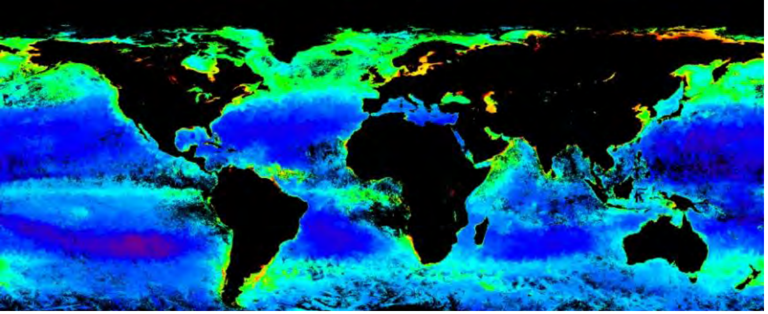
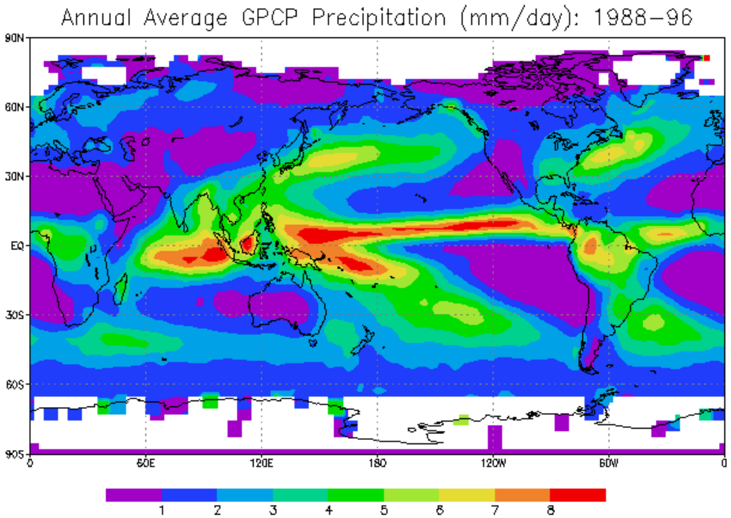
Motivations

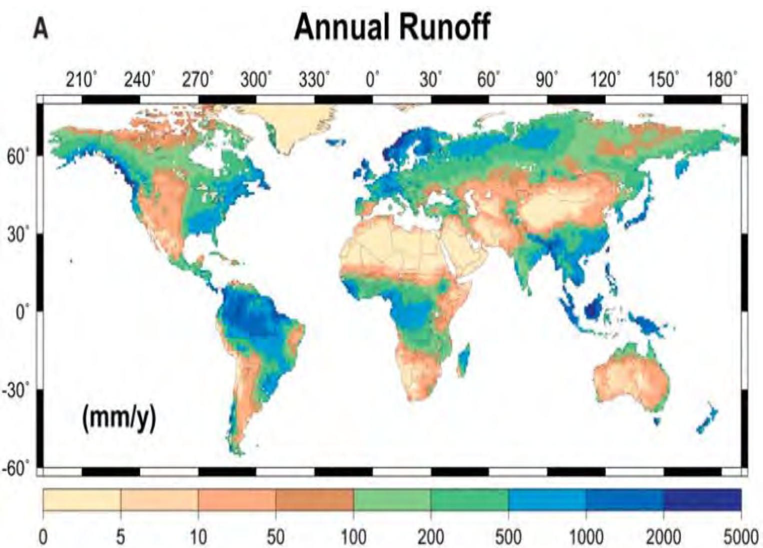


- Cloern and Jassby (2010) asked *"Why does phytoplankton biomass fluctuate mildly in some places and wildly in others?"*

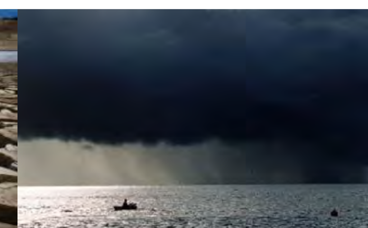
Australia

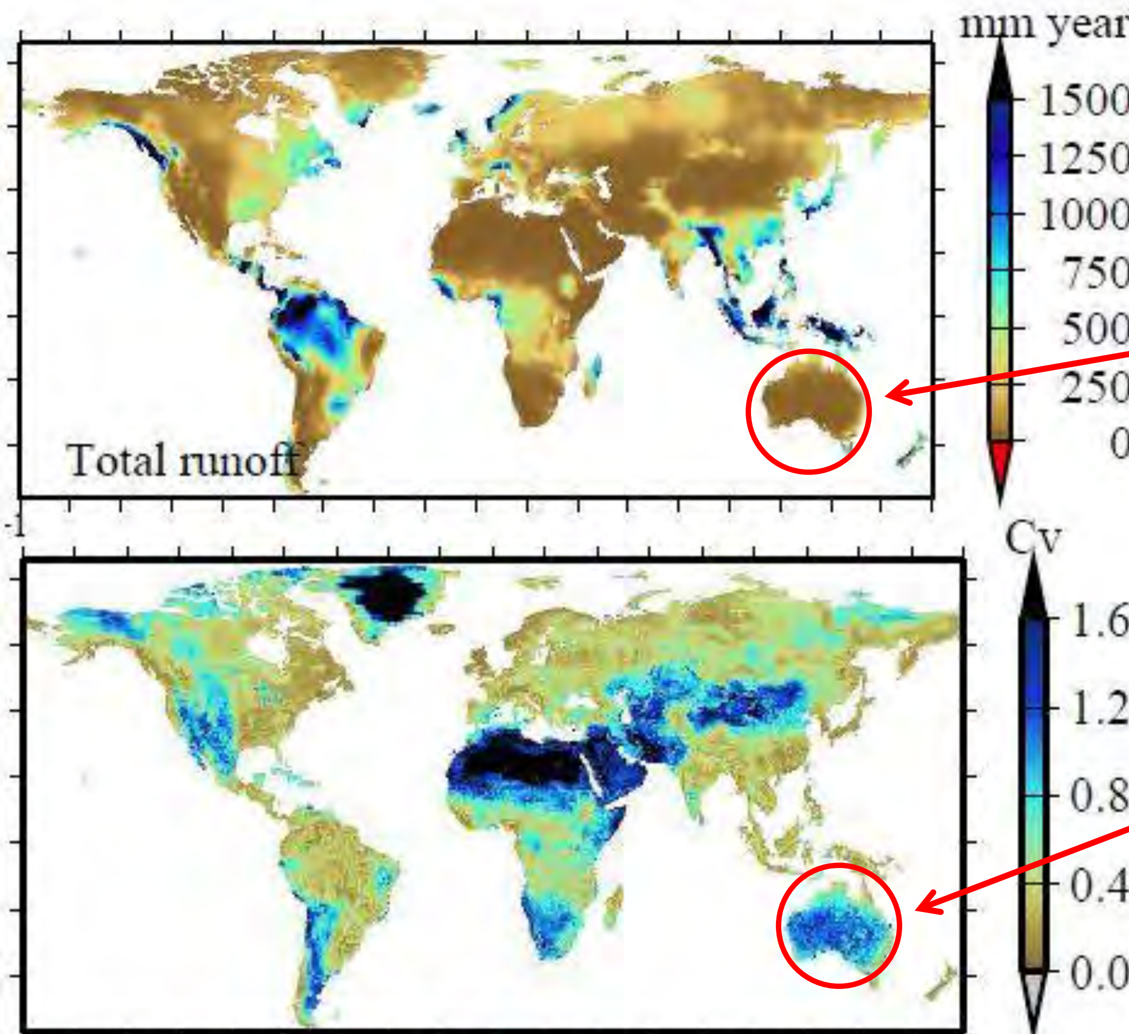






- *"Low, erratic rainfall patterns over much of the country combined with small coastal catchments and high evaporation rates mean that annual discharges from Australian rivers are the lowest and most variable in the world"* (McMahon, 1982).



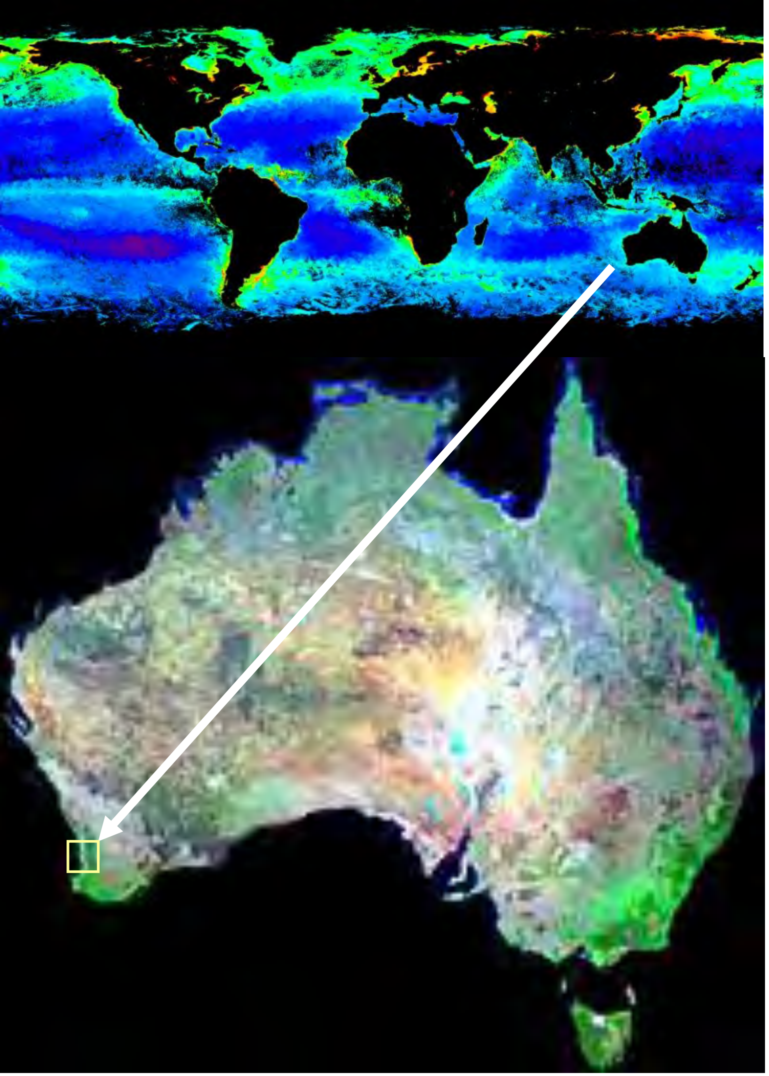


Top panel shows mean annual runoff, as an average of 10 model simulation results. Bottom panel shows the coefficient of variation of the model results.

Australia: Low runoff and high inter annual variability

Water and Global Change (EU FP6)

Swan Estuary



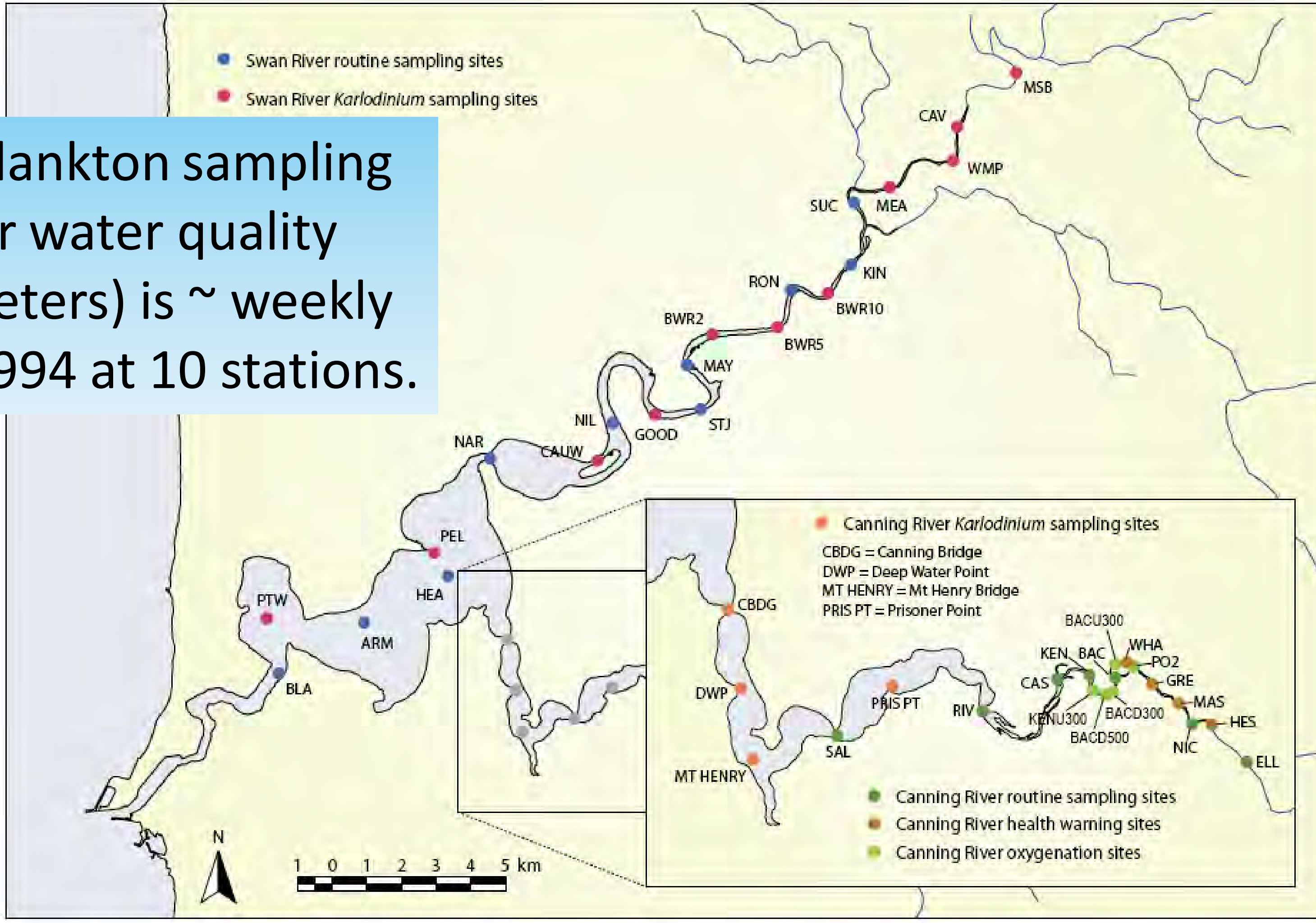
- Eutrophic
- Productive
- Blooms
  - *Karlodinium veneficum*
  - *Microcystis aeruginosa*

- The Swan Estuary has a catchment area of ~ 121,000 km^2

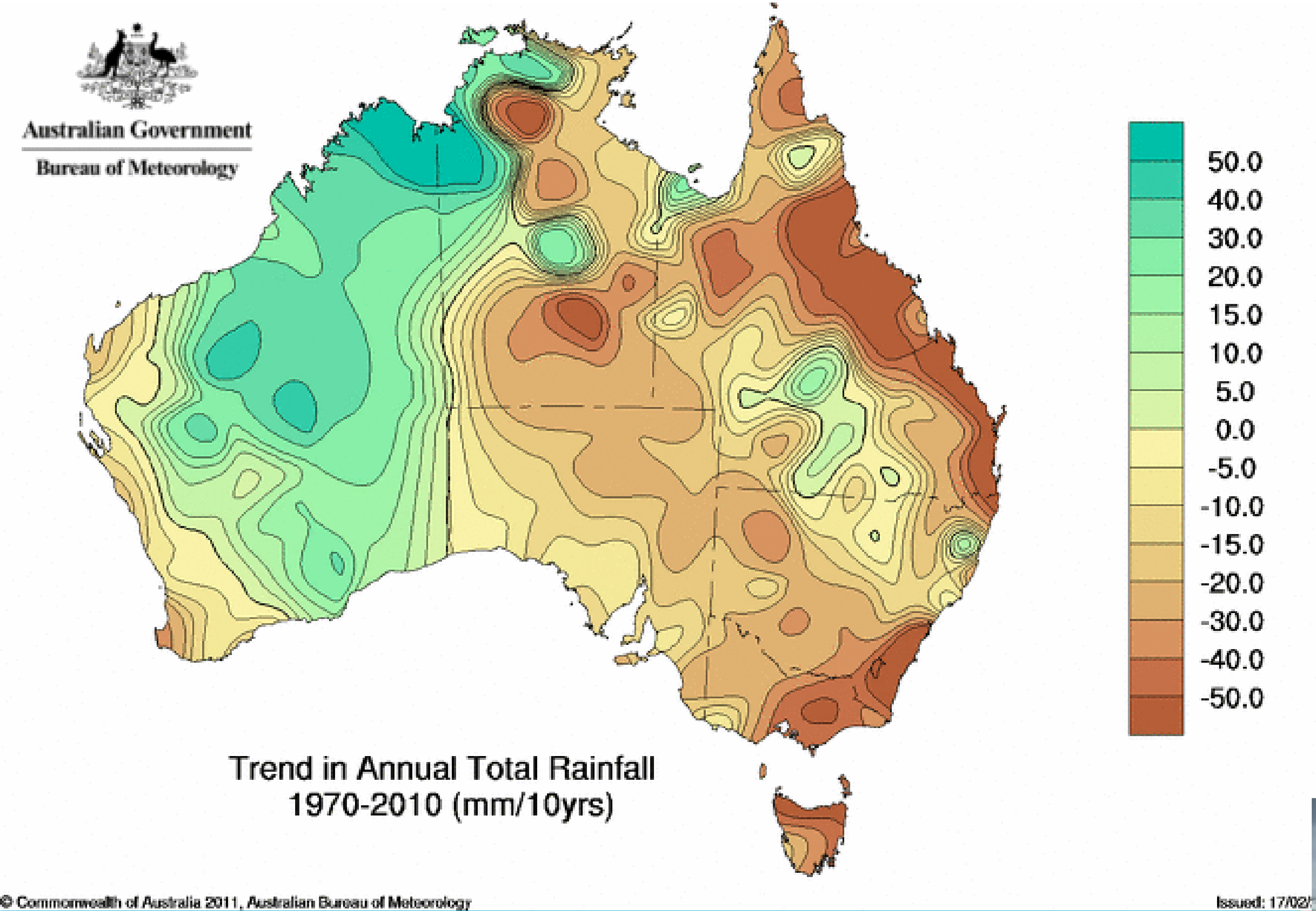
Swan River sampling stations

Phytoplankton sampling (+ other water quality parameters) is ~ weekly since 1994 at 10 stations.

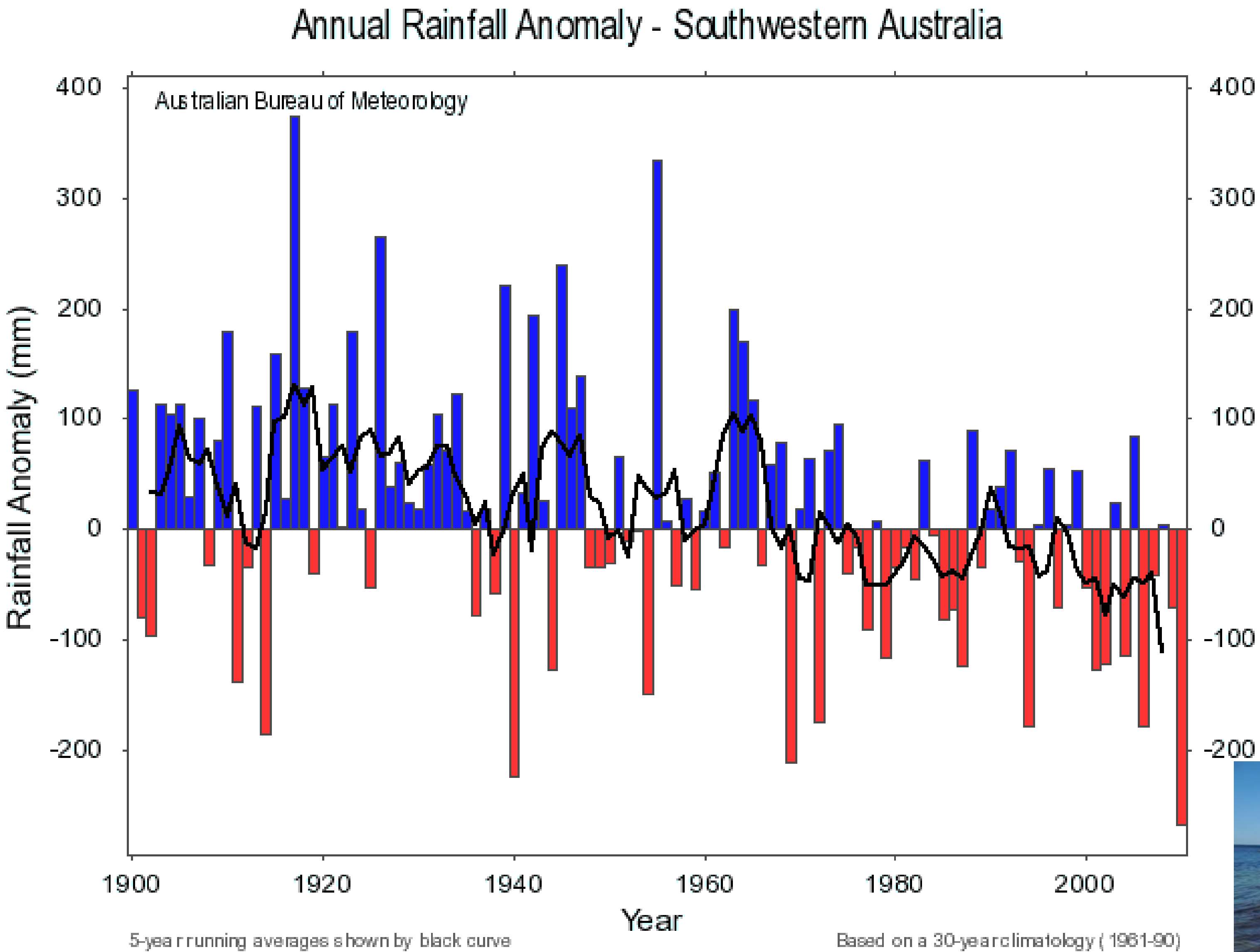
Indian Ocean



Climate

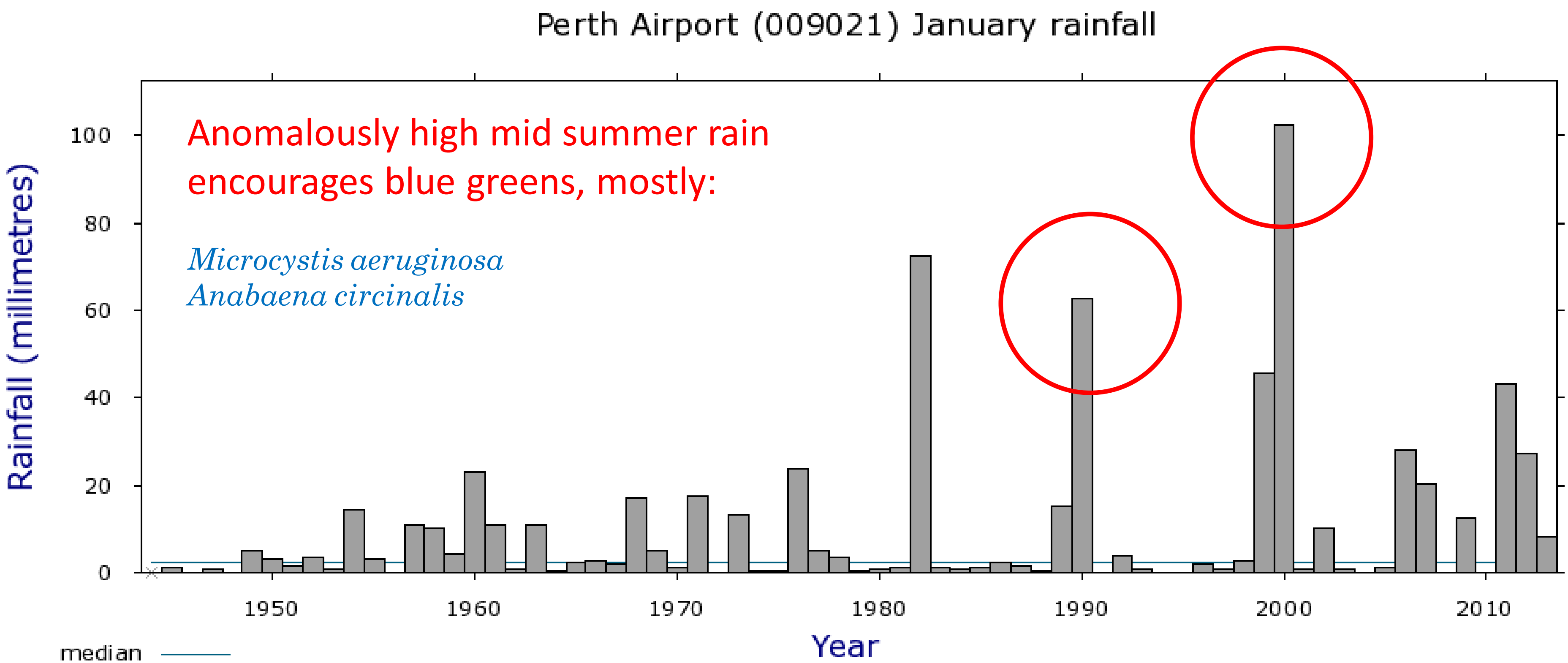

Australian Government
Bureau of Meteorology
50.0
40.0
30.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-30.0
-40.0
-50.0
Trend in Annual Total Rainfall
1970-2010 (mm/10yrs)
© Commonwealth of Australia 2011, Australian Bureau of Meteorology

SW Australia: Long term drying trend



Rainfall has considerable inter annual variability but shows a significant long term decline.

Swan River: Cyanobacteria



SCOR WG 137

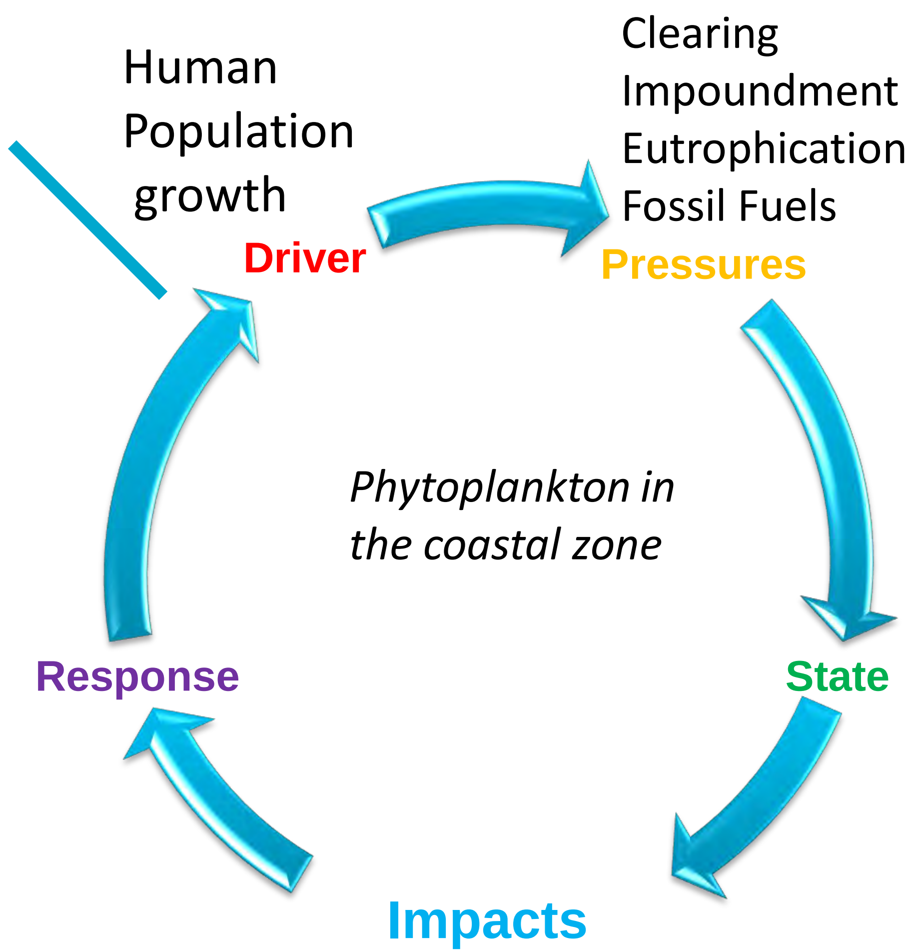
Diverse group from around the planet

Data managed by Todd O'Brien (NOAA)

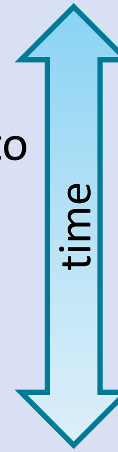
Basic data analysis is available online using tools Todd has built.

A subset of the WG investigated hydrology. The diversity of sites, methods and data was both a challenge and a strength.

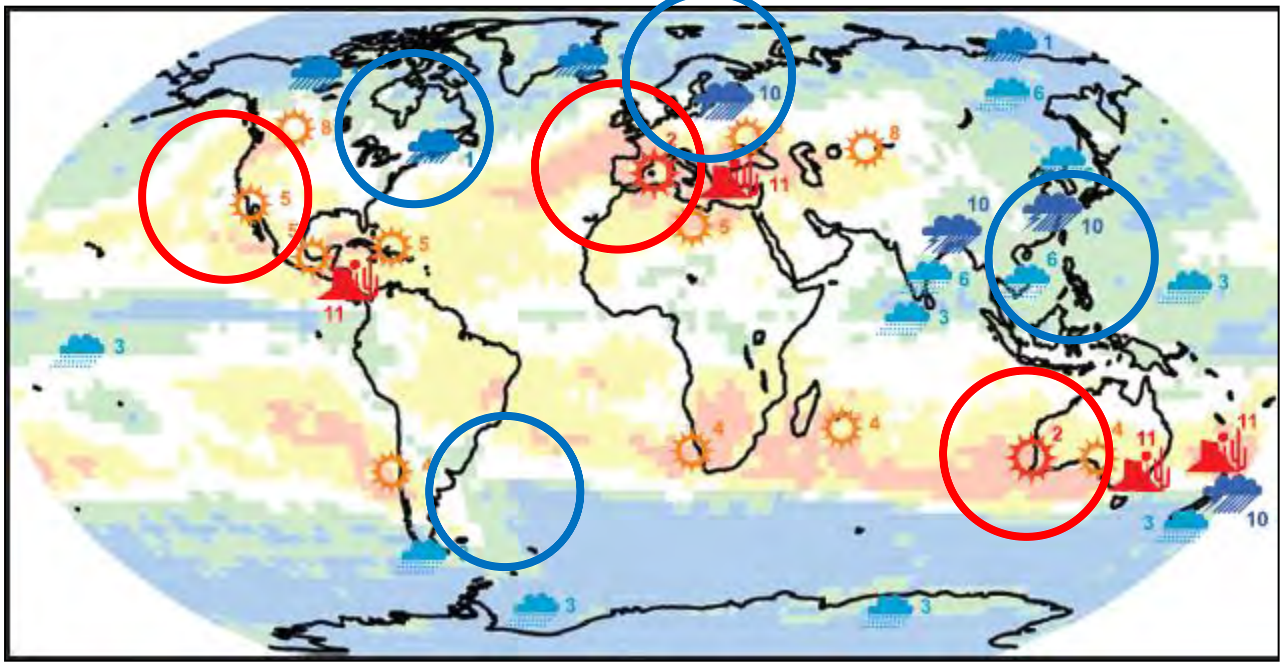
DPSIR model (1979)



- States (for fossil fuels)
  - CO_2, pH, temperature, precipitation, flow, residence time, salinity, nutrients
- Impacts (for precipitation)
  - Dilution
  - Advection
  - Stratification potentially leading to variation in turbulence,
  - Mixed layer depth and therefore irradiance
  - Growth
  - Grazing
  - Covariates: temperature and insolation
- Responses
  - biomass, taxa



IPCC 2014 Jun – Jul - Aug



Precipitation increase in ≥90% of simulations

Precipitation increase in ≥66% of simulations

Precipitation decrease in ≥66% of simulations

Precipitation decrease in ≥90% of simulations

Precipitation decrease – very likely

Precipitation decrease – likely

Precipitation increase – very likely

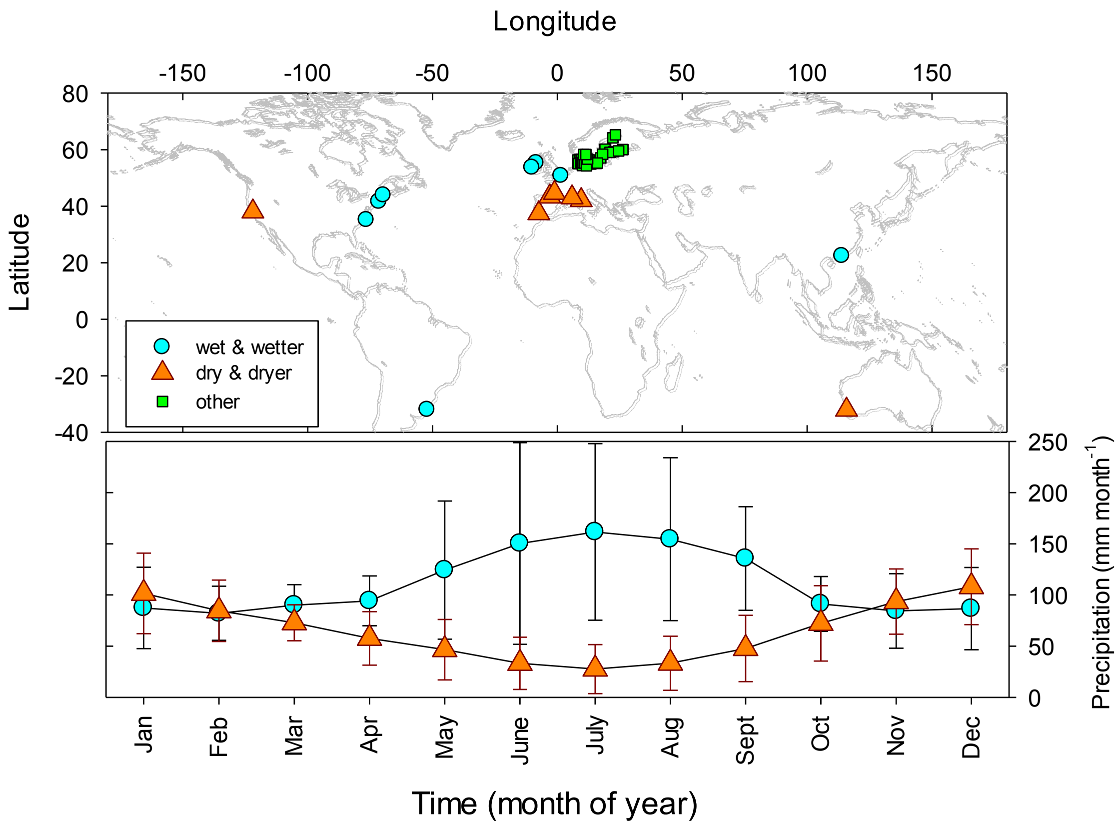
Precipitation increase – likely

Precipitation extreme increase – likely

Increased drought – likely

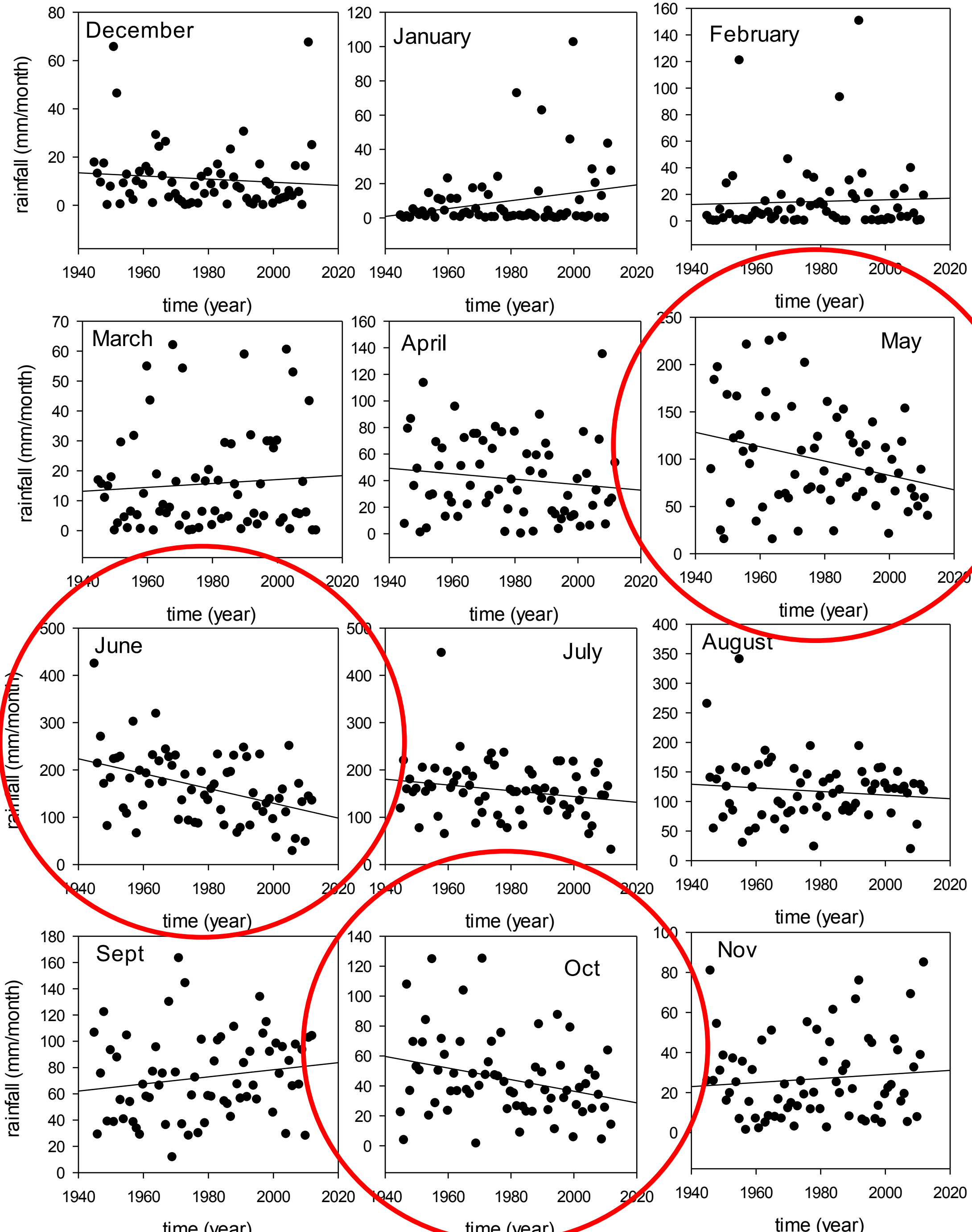
Less snow – very likely

Sites



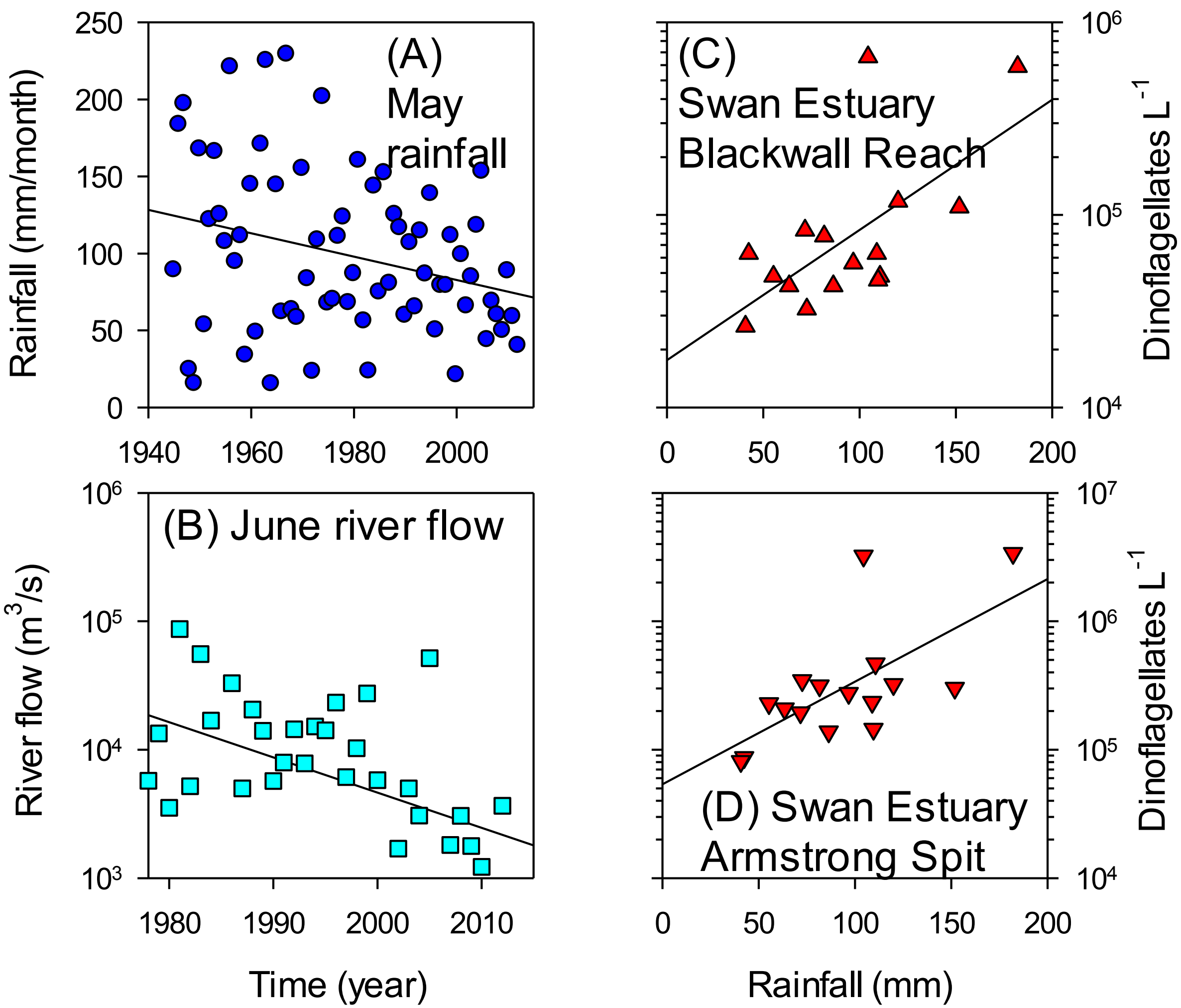
- Other = regions where lag between precipitation and flow was expected to be very long in winter
- Precipitation data from NOAA's Earth System Research Laboratory quality controlled precipitation data set based on 67,200 rainfall stations worldwide (Schneider et al., 2011).

Continent	area	Water body (number of sites within)
Asia	SE	Hong Kong waters, (n = 10)
Australia	SW	Swan River estuary, (n = 5)
North America	SW	San Francisco Bay, (n = 7)
	SE	Neuse River and Pamlico Sound, (n = 20)
	NE	Narragansett Bay, (n = 1)
	NE	Booth Bay, Maine, (n = 1)
	NE	Bay of Fundy, n = 5)
South America	SE	Patos Lagoon Estuary, (n = 1)
Europe	N	Skagerrak, Kattegat, (n=3)
	NW	North Sea, English Channel, Irish Sea, (n = 8)
	N	Baltic Sea, (n = 37)
	SW	Guadiana Estuary, (n = 1)
	SW	Nervion River Estuary, (n = 2)
	SW	Bay of Biscay, (n = 5)
	SW	Mediterranean, (n = 5)



- Drying, yes….BUT this often has a seasonal component
  - Strongest declines are:
    - **May** (-0.8mm/y, *p=0.02*)
    - **June** (-1.6mm/y, *p=0.003*)
    - **October** (-0.38mm/y, *p=0.02*).
  - Less in May, June and October = a longer dry season

Swan River



- Lower precipitation in May and June
- Less river flow
- Fewer dinoflagellates at the most oceanic sites

Seasonal Patterns for dinoflagellates in the Swan Estuary

			Autumn			*Winter*			*Spring*			
	Jan	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Swan River Estuary - S01 Blackwall Reach (Australia)	0.1758 p>0.10	-0.4540 p>0.10	-0.3563 p>0.10	0.4578 p<0.10	**0.6478 p<0.01**	0.5425 p<0.05	-0.4499 p<0.10	0.0144 p>0.10	0.2368 p>0.10	0.4502 p<0.10	-0.5314 p<0.05	-0.4574 p<0.10
Swan River Estuary - S02 Armstrong Spit (Australia)	0.1269 p>0.10	-0.1701 p>0.10	-0.3705 p>0.10	0.2901 p>0.10	**0.6645 p<0.005**	0.5712 p<0.05	-0.4180 p>0.10	0.1517 p>0.10	0.2619 p>0.10	0.4415 p<0.10	-0.2148 p>0.10	-0.4324 p<0.10
Swan River Estuary - S03 Narrows Bridge (Australia)	0.2169 p>0.10	0.1782 p>0.10	-0.2511 p>0.10	0.5257 p<0.05	0.3398 p>0.10	0.3677 p>0.10	-0.4763 p<0.10	0.2013 p>0.10	-0.1238 p>0.10	0.1360 p>0.10	-0.2840 p>0.10	-0.1213 p>0.10
Swan River Estuary - S04 Ron Courtney Island (Australia)	-0.6306 p<0.10	-0.5524 p<0.10	-0.0883 p>0.10	-0.3465 p>0.10	-0.1696 p>0.10	-0.1622 p>0.10	-0.4776 p<0.10	0.0474 p>0.10	0.2833 p>0.10	-0.5128 p<0.05	-0.4302 p<0.10	**-0.6477 p<0.01**
Swan River Estuary - S05 Success Hill (Australia)	-0.5098 p>0.10	-0.5320 p<0.10	-0.1763 p>0.10	-0.3949 p>0.10	-0.1870 p>0.10	-0.2535 p>0.10	-0.2743 p>0.10	0.0533 p>0.10	-0.3302 p>0.10	-0.5514 p<0.05	-0.1061 p>0.10	**-0.6865 p<0.005**

Dinoflagellates were positively correlated with autumn and early winter precipitation at lower estuary sites.

A drying climate is reducing these blooms.

Is this true elsewhere?

Diatom example

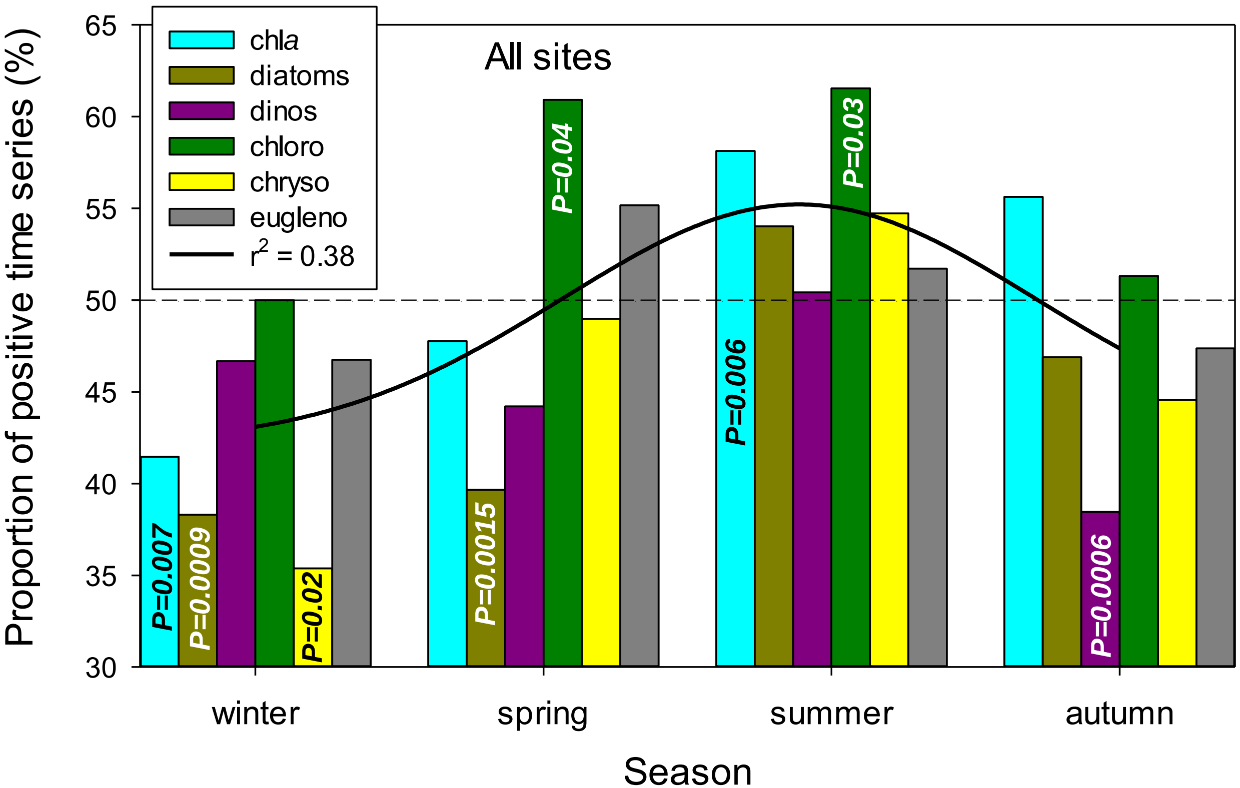
- 25 sites in 4 regions
- 12 monthly time series
- ~ 300 correlations

- Probability of getting 40% positive slopes from 292 is very small.

(assumes a normal distribution and random observations)

Z Test for the Proportion	
number of correlations	292
number of positive slopes	117
Sample Proportion	0.400685
Null Hypothesis p=	0.5
Standard Error	0.02926
α	0.05
Z Test Statistic	-3.39419
Two-Tailed Test	
Lower Critical Value	-1.95996
Upper Critical value	1.959964
p-value	0.000688
Decision	Reject

Timing of precipitation



- Generally there were positive responses during summer (*P = 0.018)*

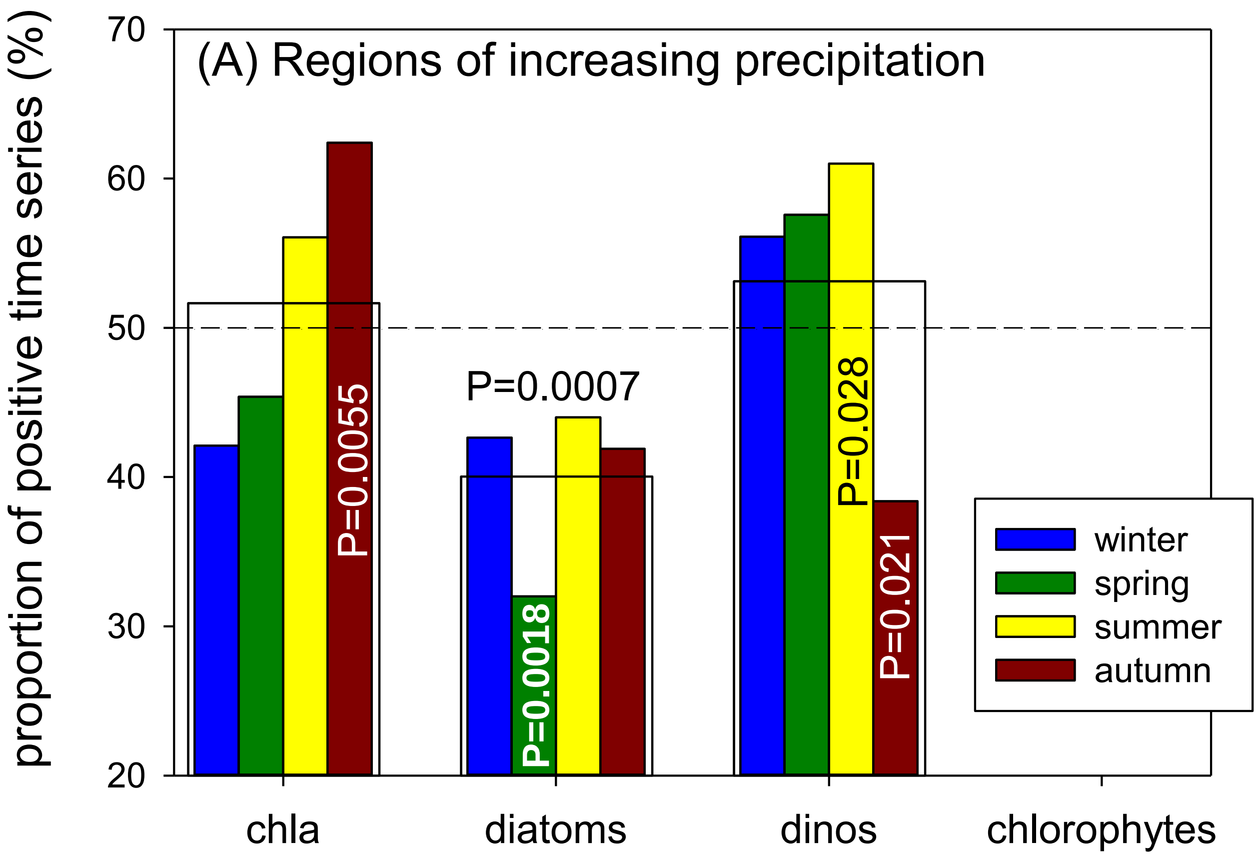
- *Winter*
- Winter precipitation was negatively associated with chlorophyll *a*, diatoms and chrysophytes.
- For diatoms negative associations with precipitation were dominant in January & February.

- *Spring*
- Diatoms were negatively associated with precipitation in March and April while chlorophyte abundances increased with precipitation.

- *Summer*
- Chlorophyll *a* and Chlorophytes were positively associated with precipitation.

- *Autumn*
- Dinoflagellates were negatively associated with increased precipitation, similarly diatoms during October.

Wet and getting wetter



Chlorophyll *a*

responds positively to precipitation in autumn

Diatoms

negative overall all seasons esp. spring

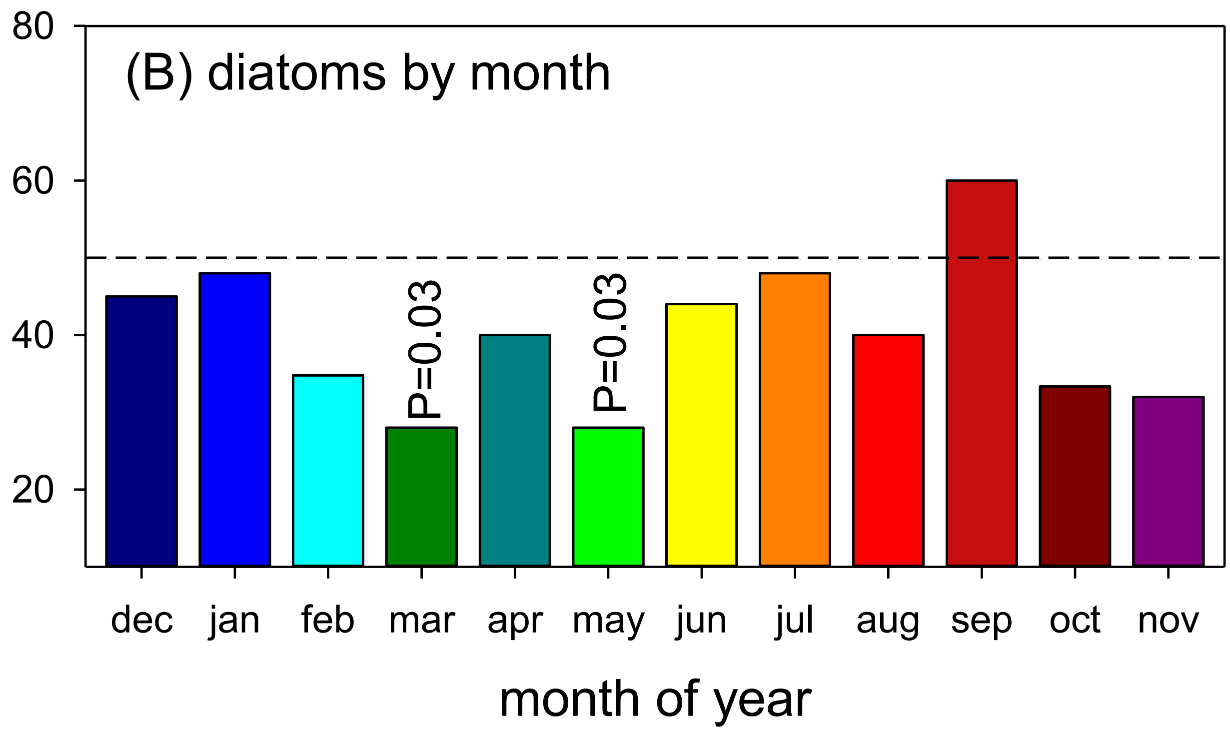
Dinos

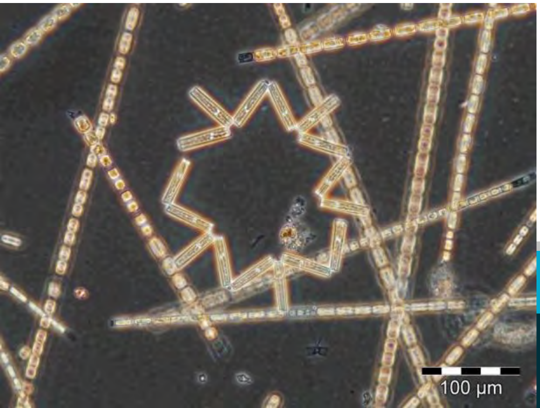
were mixed

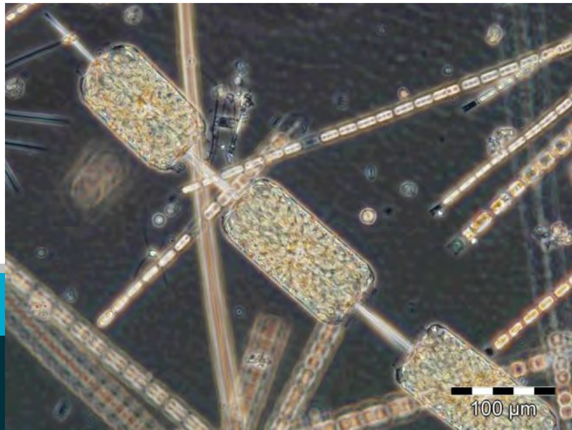
up in summer

down in autumn

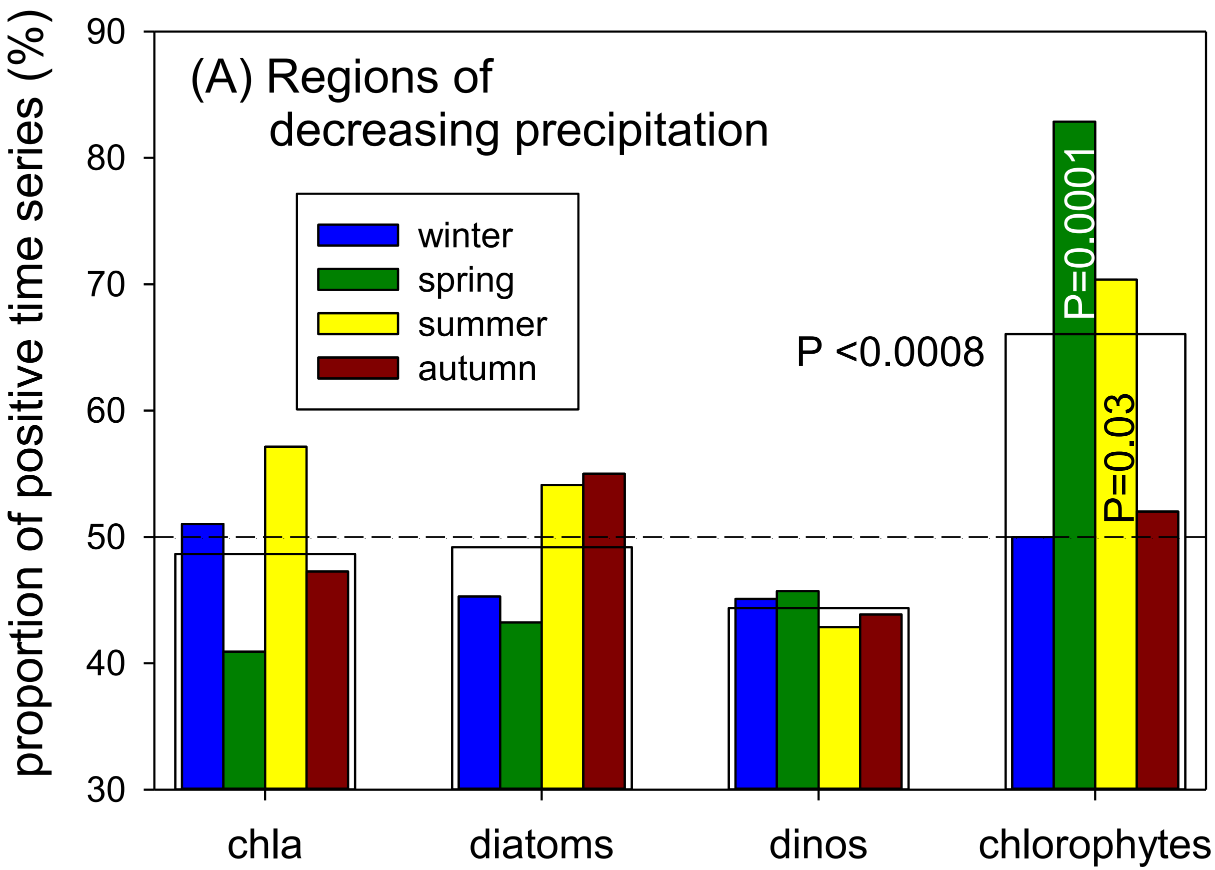
Regions of increasing precipitation





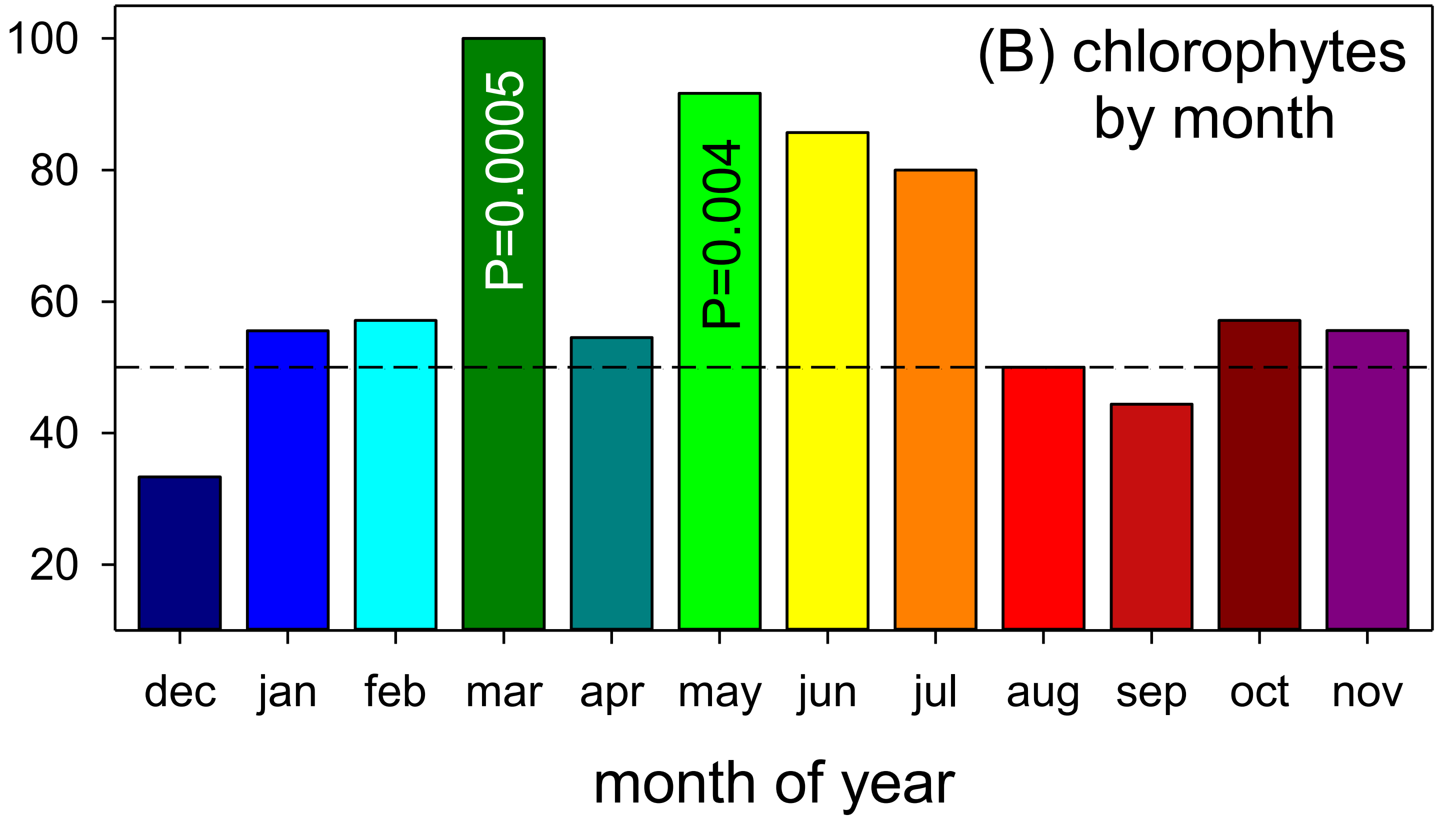


Drying regions

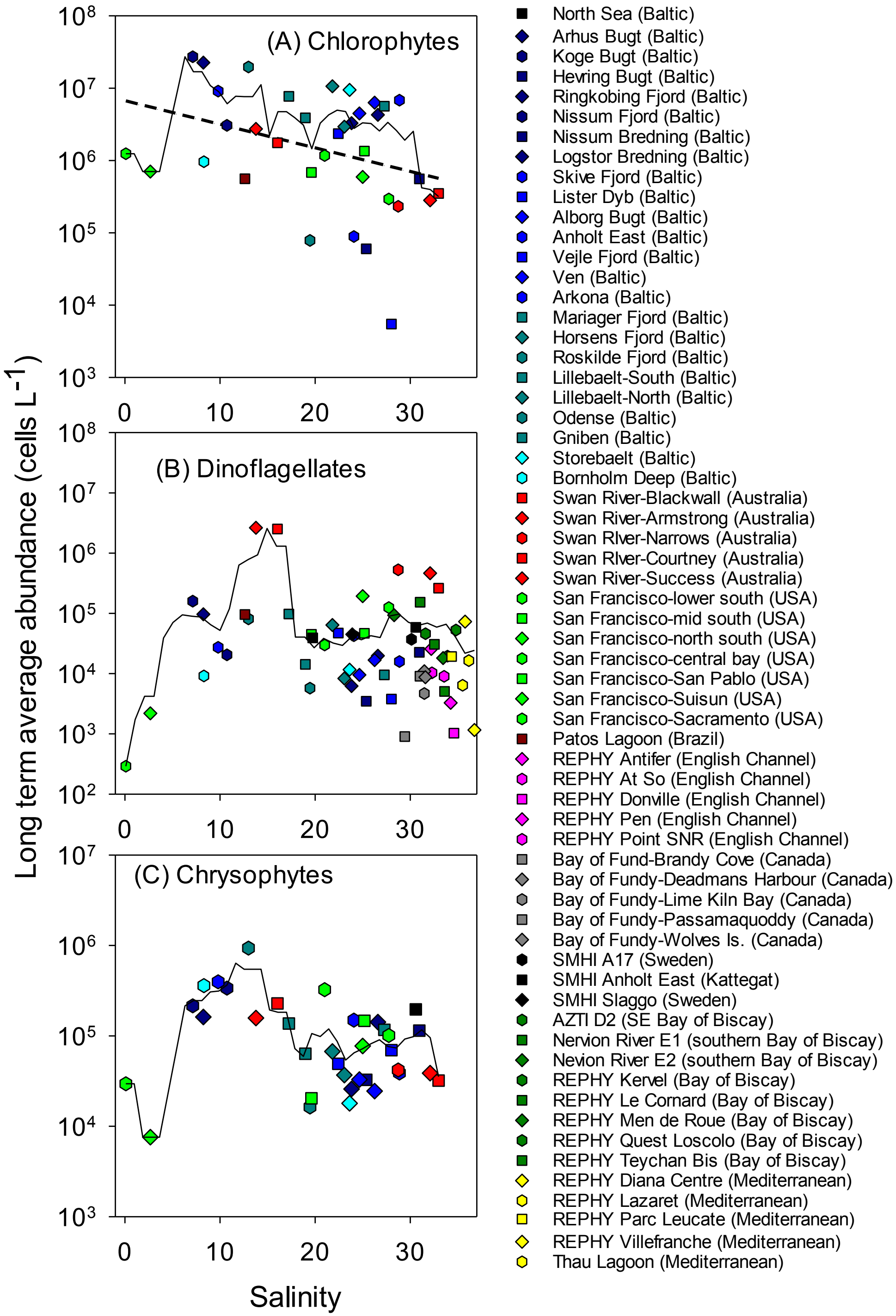


- Only *chlorophytes* showed a consistent response to more precipitation
- Over whole year (P=0.0008)
- Also during spring and summer

Drying regions: Chlorophytes by month

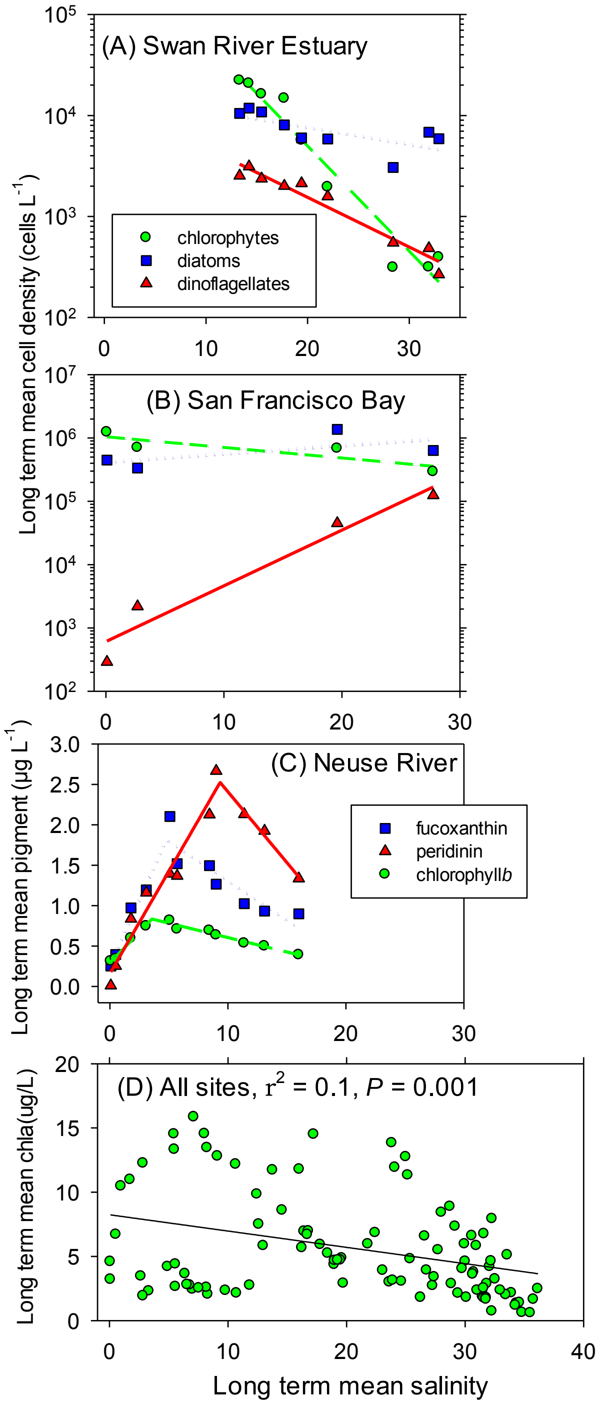


- 100% of sites showed a positive association of chlorophyte cell counts with precipitation in March.



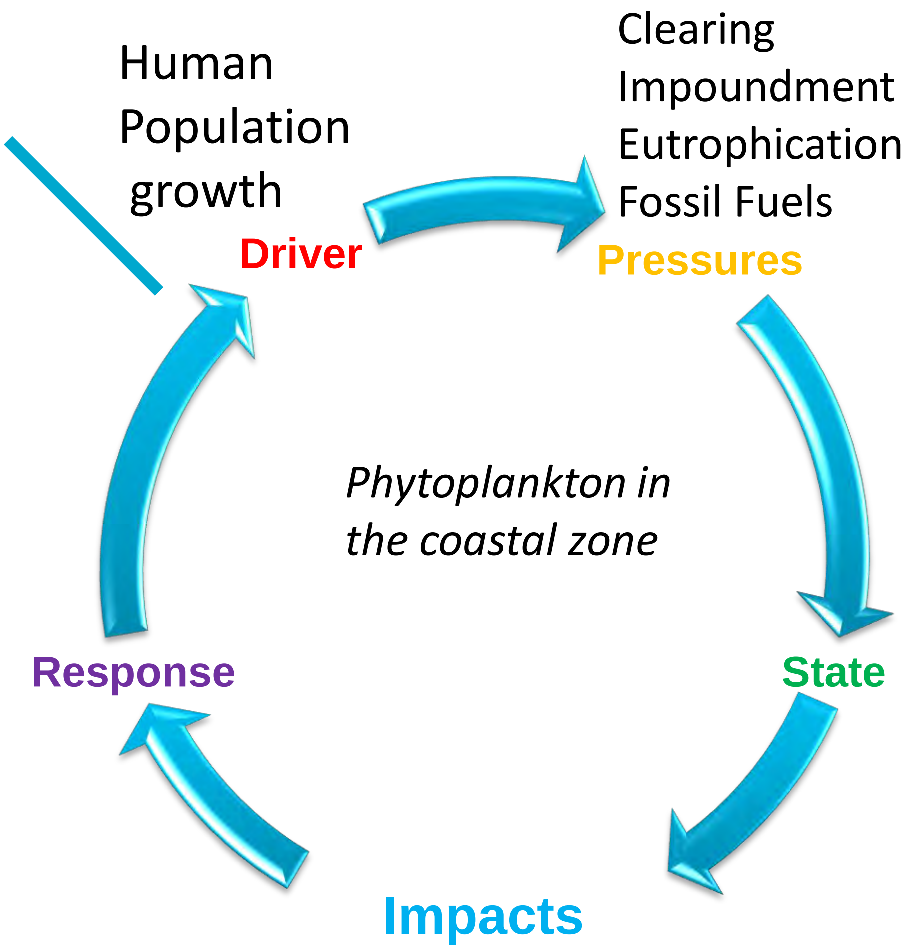
Using long term averaged values….

- Longest time series was 33 years of monthly sampling, n~ 396.
- A pattern of response for chlorophytes?
- (advection is unlikely to be the primary driver)



Some closing observations

- Generally abundance declines with salinity (nutrients?)
- Dinoflagellate abundance patterns were not consistent along different estuaries
  - Proximal cause is not precipitation or salinity for dinos (stratification?)
- Way forward?
  - Dynamic mechanistic model?
  - Improved statistical model (e.g. GAM)?



Conclusions

- Increasing winter precipitation is generally negative for phytoplankton biomass
- Winter and spring diatom blooms are susceptible to increased precipitation
- Drying ecosystems will experience less biomass and fewer chlorophytes