Coastal and Estuarine Processes

http://ecowin.org/aulas/mega/pce

Primary production

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Primary production and how to model it

Topics

- Types of producers and production rates
- Measurement of primary production
- Mechanisms and models – PI curves and blooms
- Models of nutrient limitation, succession and biodiversity
- Budgets and climate change
- Synthesis

$$CO_2 + 2H_2A \xrightarrow[\text{Pigments}]{\text{Light}} CH_2O + 2A + H_2O$$

Types of primary producers

Pelagic and benthic, microscopic and macroscopic

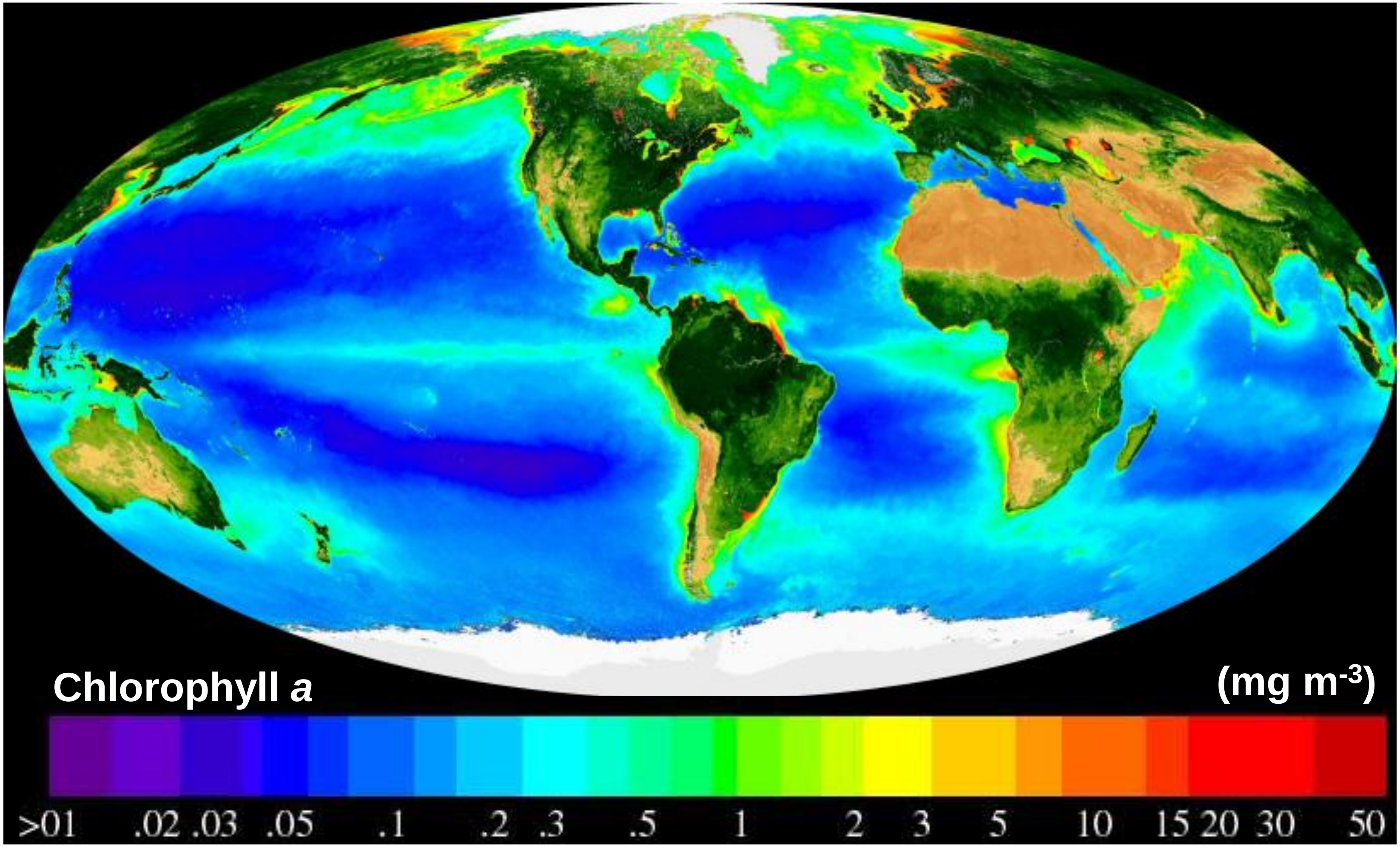
Producer	Nutrient source	Examples
Phytoplankton	Water column	Diatoms/dinoflagellates
Microphytobenthos	Water column, sediment pore water	Penate diatoms
Macroalgae (seaweeds)	Water column	*Fucus, Laminaria, Ulva*
Saltmarsh plants	Sediment	*Spartina*
Seagrasses (SAV)	Sediment and water	*Zostera, Posidonia*

Phytoplankton and microphytobenthos: microscopic, high P/B ratio (>50)

Others: macroscopic, low P/B ratio, shallow waters or intertidal

Ecosystem-scale relevance

Global distribution of chlorophyll from satellite data

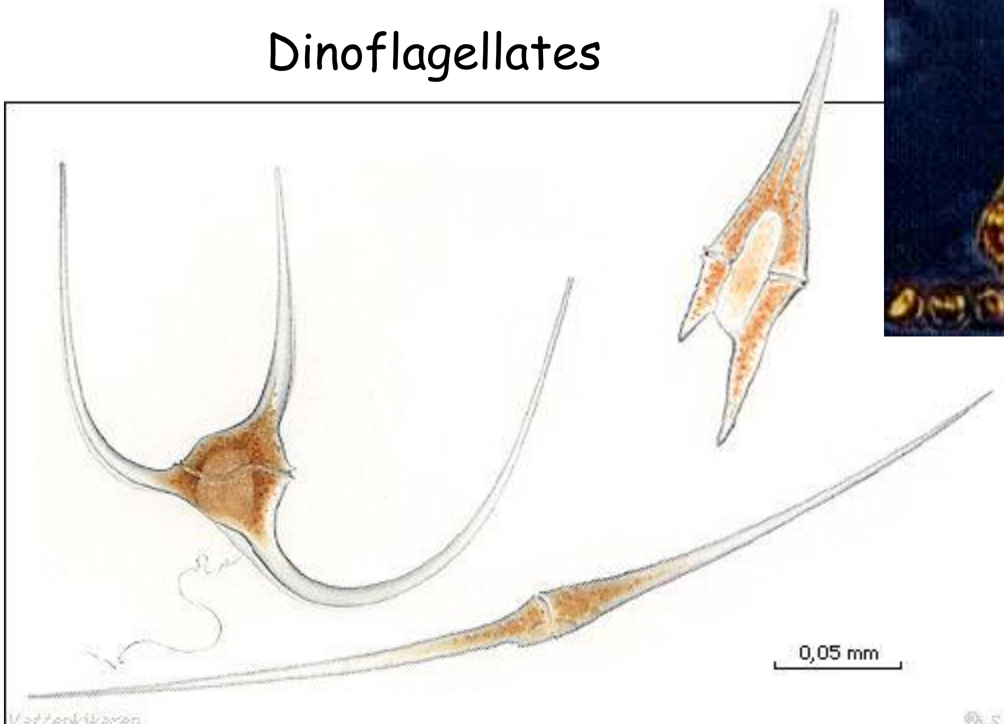


Data fromSEAWIFS, Summer in the northern hemisphere (1998-2001)

Phytoplankton primary prod. 200-360 X 10^{14} gC y^{-1} (98.9%).

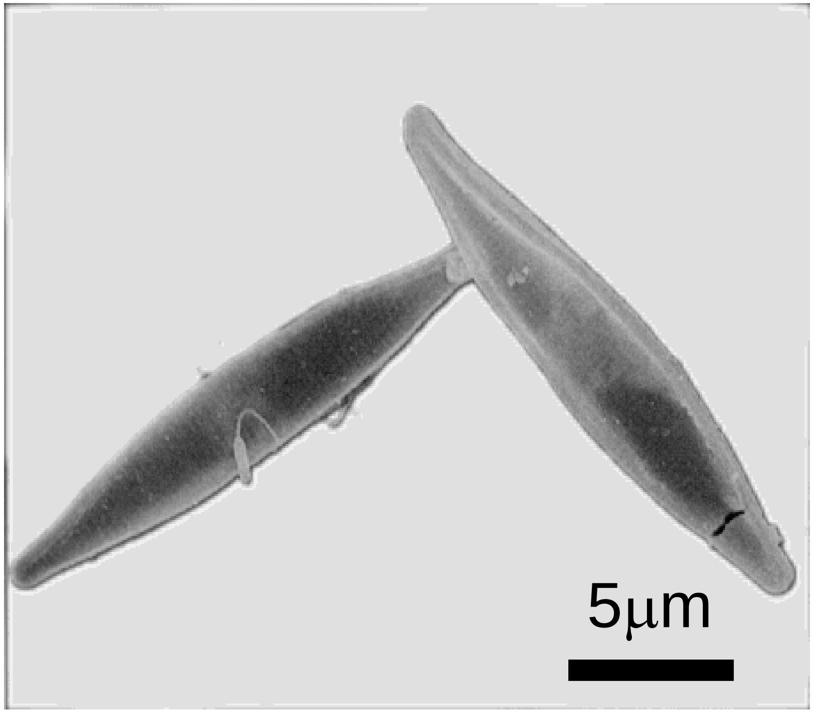
Phytoplankton
Some examples

Dinoflagellates



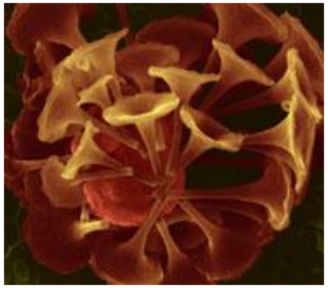
Coccoliths

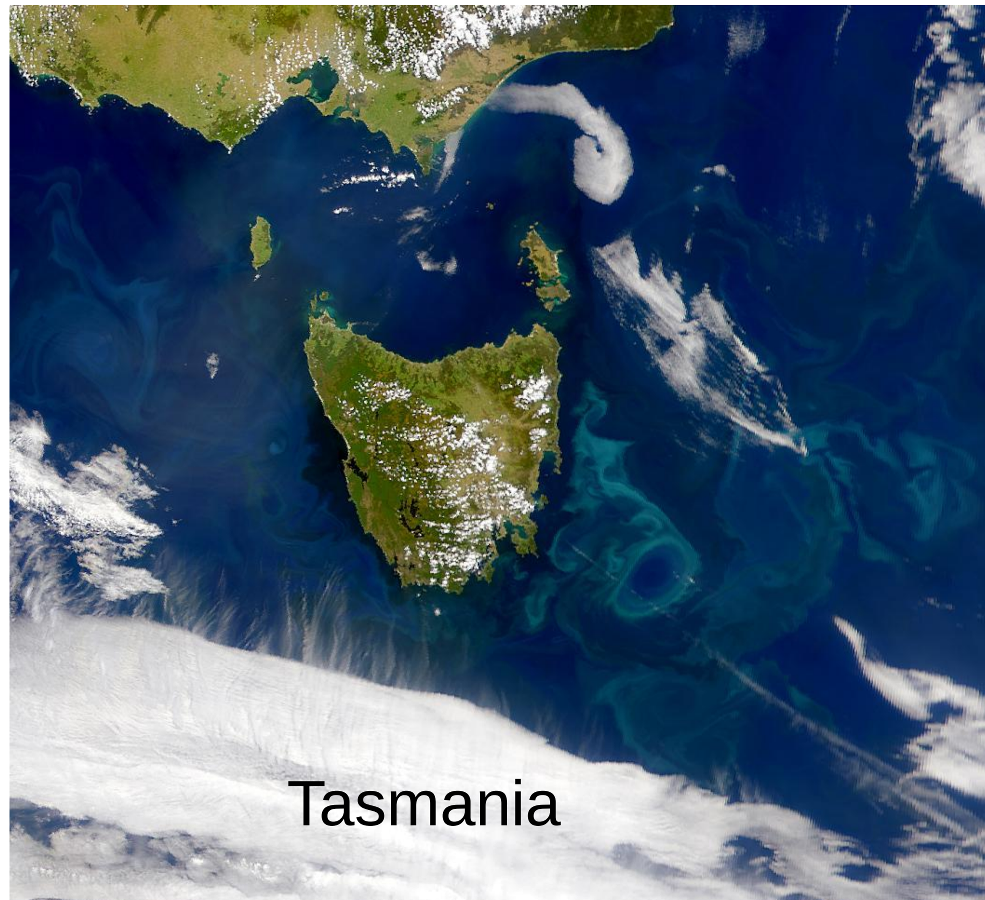
Phytoplankton - diatoms
Nitzchia bicapitata



- Chavez *et al*., 1991 - Limnol. & Oceanog. 36, p. 1816-33

SeaWifs images of cocollith blooms





Management relevance
Noctiluca bloom – California, U.S.A.

Courtesy P.J.S. Franks, WHOI

Cyanobacteria bloom – Potomac estuary

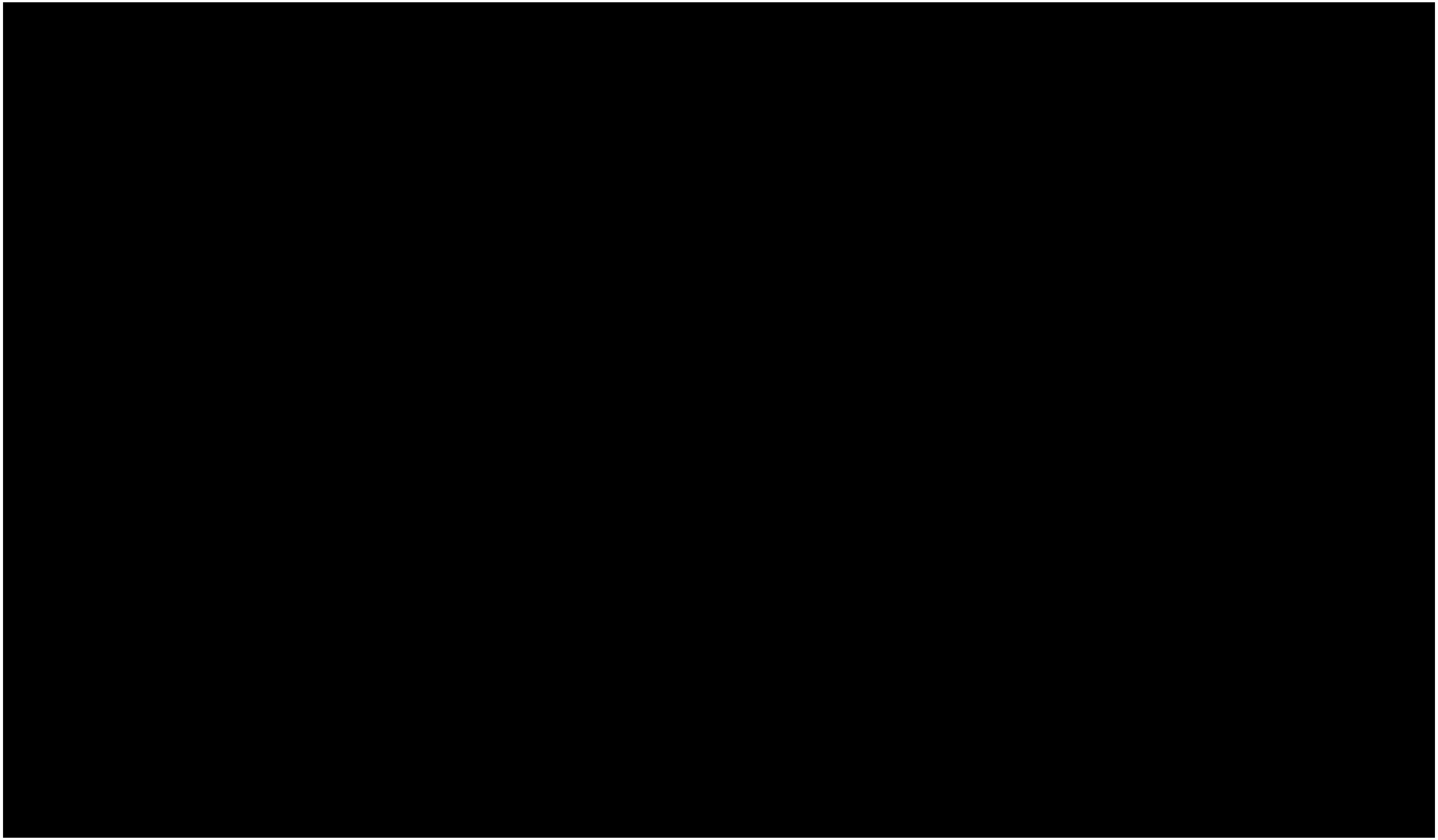
This dense bloom of cyanobacteria (blue-green algae) occurred in the Potomac River estuary downstream of Washington, D.C. Photo courtesy of W. Bennett USGS.

Management relevance – macroalgal bloom, Florida

In Florida Bay, this seaweed bloom smothered seagrasses, leading to disappearance of SAV. Brian Lapointe, Harbor Branch Oceanographic Institute.

Management relevance

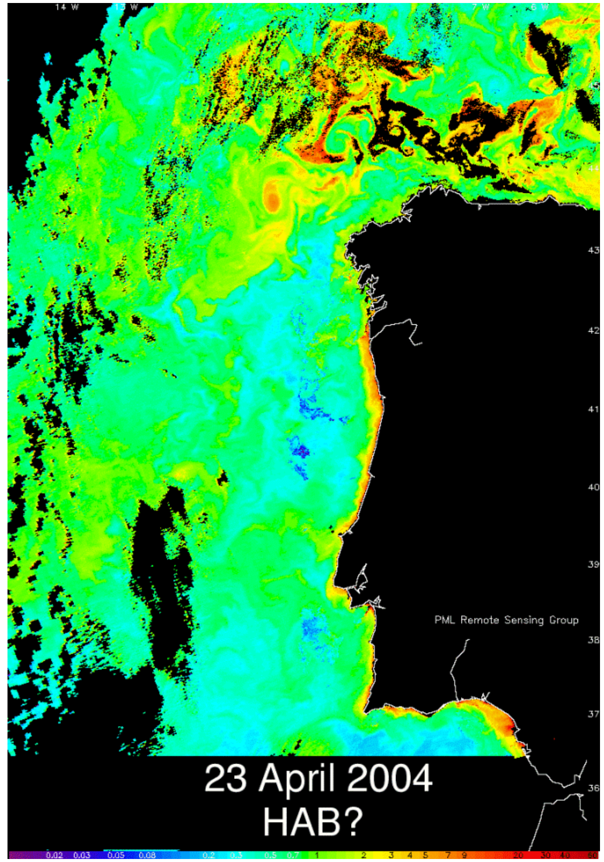
Ulva prolifera in Jiaozhou Bay, NE China, 2008



These macroalgal blooms have occurred annually for the last five years

Management relevance

Advection of potential HAB towards the coast from an offshore front



PML Remote Sensing Group

Courtesy Plymouth Marine Laboratory, UK

http://pml.ac.uk/

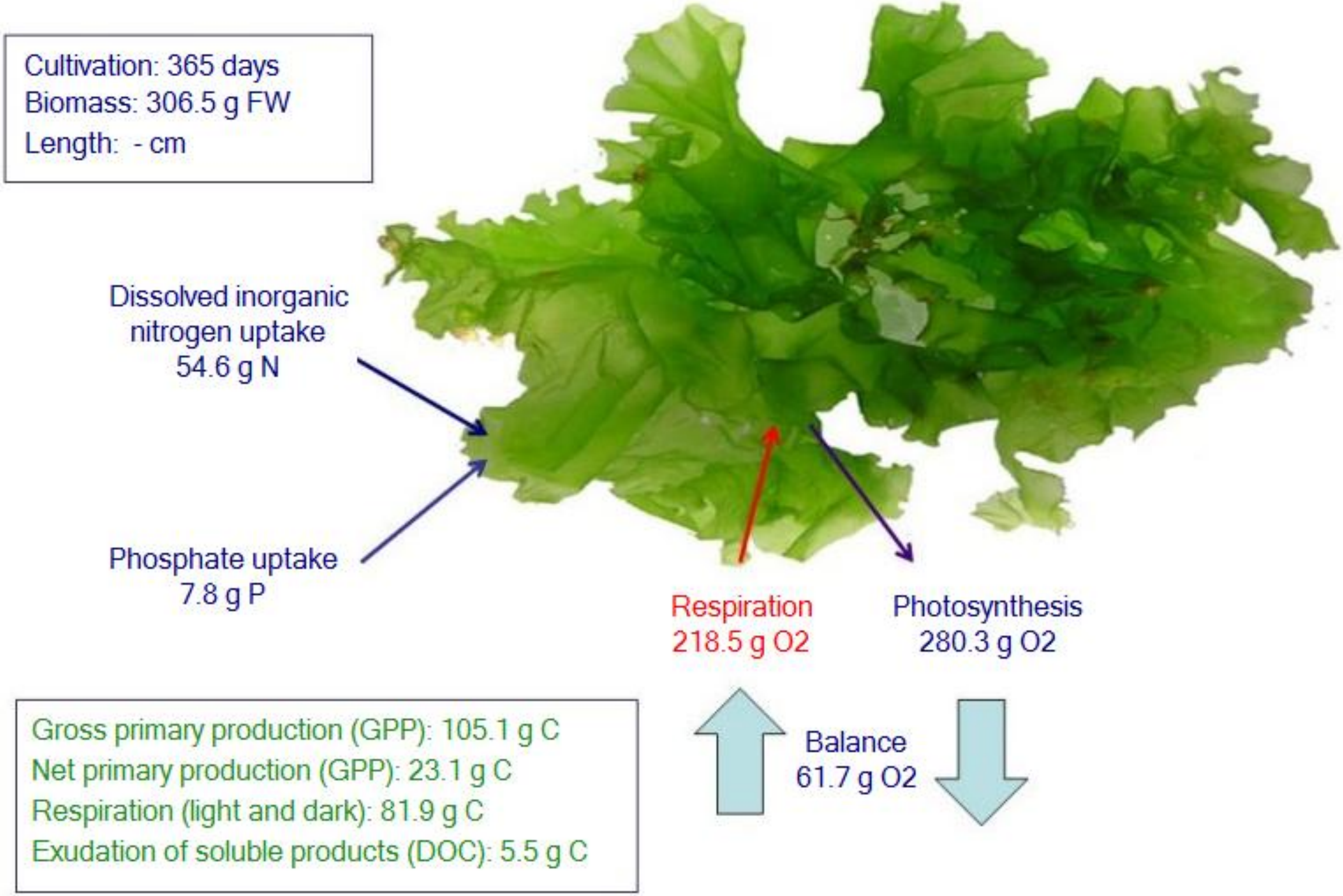
Multi-sensor discrimination of harmful algal blooms, P. I. Miller, J. D. Shutler, G. F. Moore and S. B. Groom, *Remote Sensing and Photogrammetry Society annual conference RSPSoc 2004*, 7-10 September 2004, Dundee U.K.

Kelp (*Laminaria japonica*) in Sanggou Bay, China

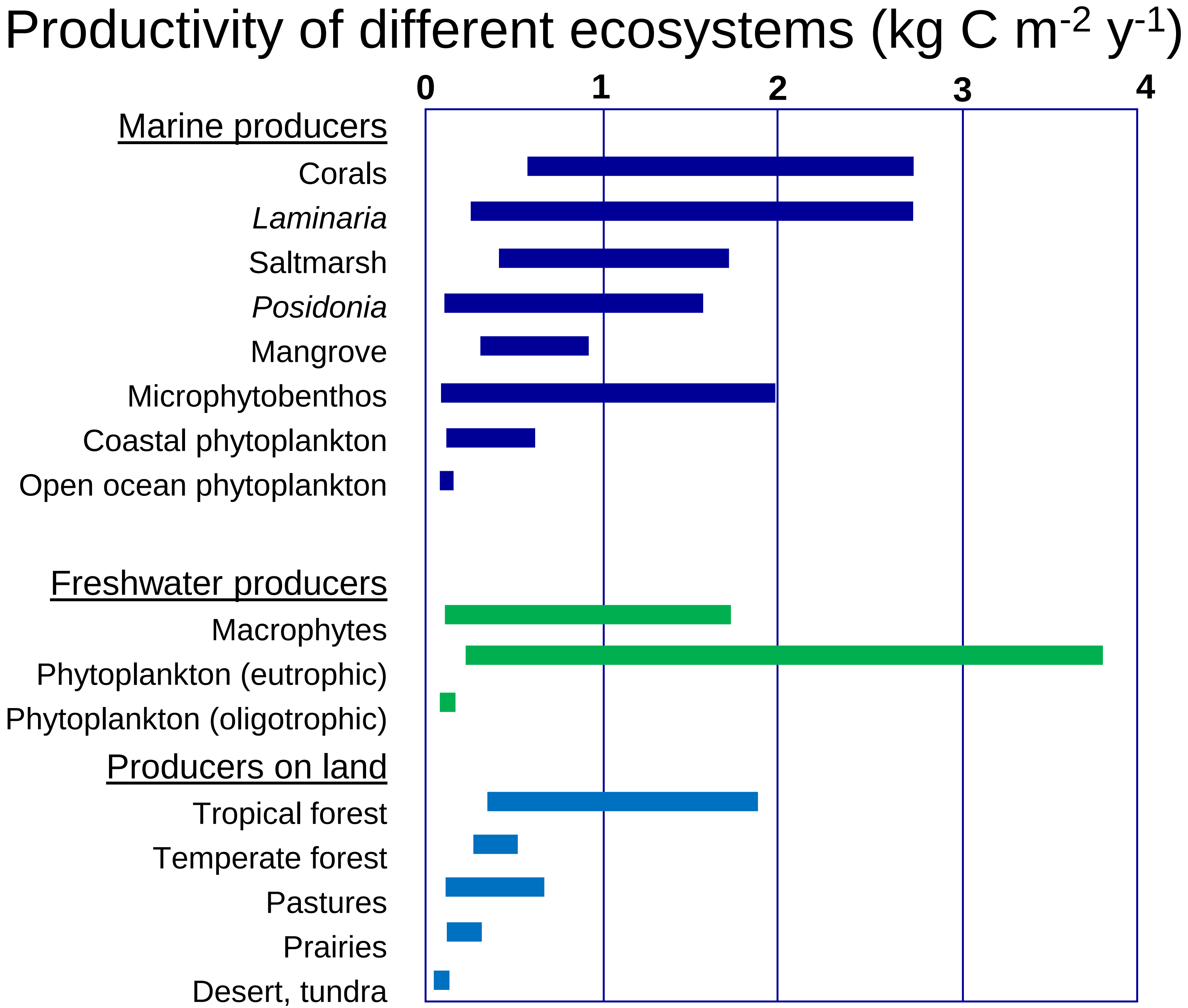
Kelp cultivation yields eighty-five thousand tons per year in this 140 km^2 bay.

Mass balance for Droop-Solidoro nutrient uptake

Illustration for *Ulva lactuca*



Modified cell-quota model shows lower nutrient uptake.



Productivity of different ecosystems (kg C m-2 y-1)
0
1
2
3
4
Marine producers
Corals
Laminaria
Saltmarsh
Posidonia
Mangrove
Microphytobenthos
Coastal phytoplankton
Open ocean phytoplankton
Freshwater producers
Macrophytes
Phytoplankton (eutrophic)
Phytoplankton (oligotrophic)
Producers on land
Tropical forest
Temperate forest
Pastures
Prairies
Desert, tundra

Productivity, mean biomass, turnover, and chlorophyll in different ecosystems

	Area (10^6 km^2)	Net production (g C m^{-2} y^{-1})	Biomass (kg C m^{-2})	Turnover (P/B, y^{-1})	Chlorophyll (g m^{-2})
Open ocean	332	125	0.003	42	0.03
Upwelling	0.4	500	0.02	25	0.3
Shelf	27	300	0.001	300	0.2
Macroalgae/reefs	0.6	2500	2	1.3	2
Estuaries	1.4	1500	1	1.5	1
Total marine	*361*	*155*	*0.01*		*0.05*
Terrestrial ecosystems	145	737	12	0.061	1.54
Marshes	2	3000	15	0.2	3
Lakes and rivers	2	400	0.02	20	0.2
Total continental	149	782	12.2	0.064	1.5

Productivity per unit area is much higher inshore, but the open ocean is much more vast.

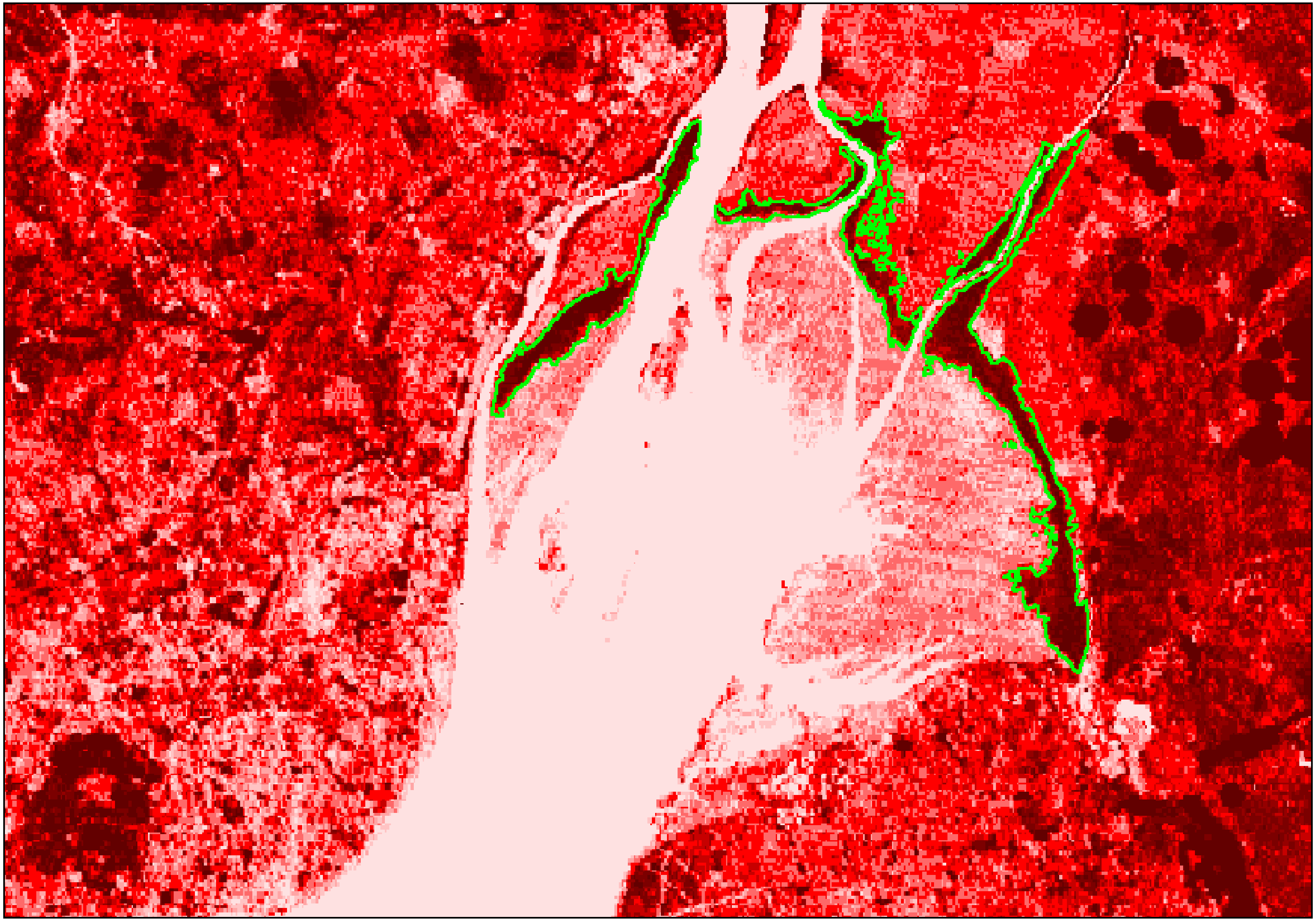
Whittaker & Likens, 1975. The Biosphere and Man. Primary productivity of the biosphere. Springer-Verlag.

Measurement of primary production in marine and freshwater systems

Producer	Indicator	Method	Units
Phytoplankton &	Biomass	Chlorophyll *a* (filtered sample)	$\mu g\ L^{-1}$
microphytobenthos	Production	^{14}C, O_2 (incubation)	d^{-1}
Seaweeds	Biomass	Cropping	$g\ DW\ m^{-2}$
Seagrasses	Production	O_2 (incubation), cropping	$g\ C\ m^{-2}\ d^{-1}$
Saltmarsh	Biomass	Cropping	$g\ DW\ m^{-2}$
	Production	O_2 (incubation), cropping	$g\ C\ m^{-2}\ d^{-1}$

Different methods are used for different producers. Upscaling may be done using models, including GIS, remote sensing, and dynamic simulation.

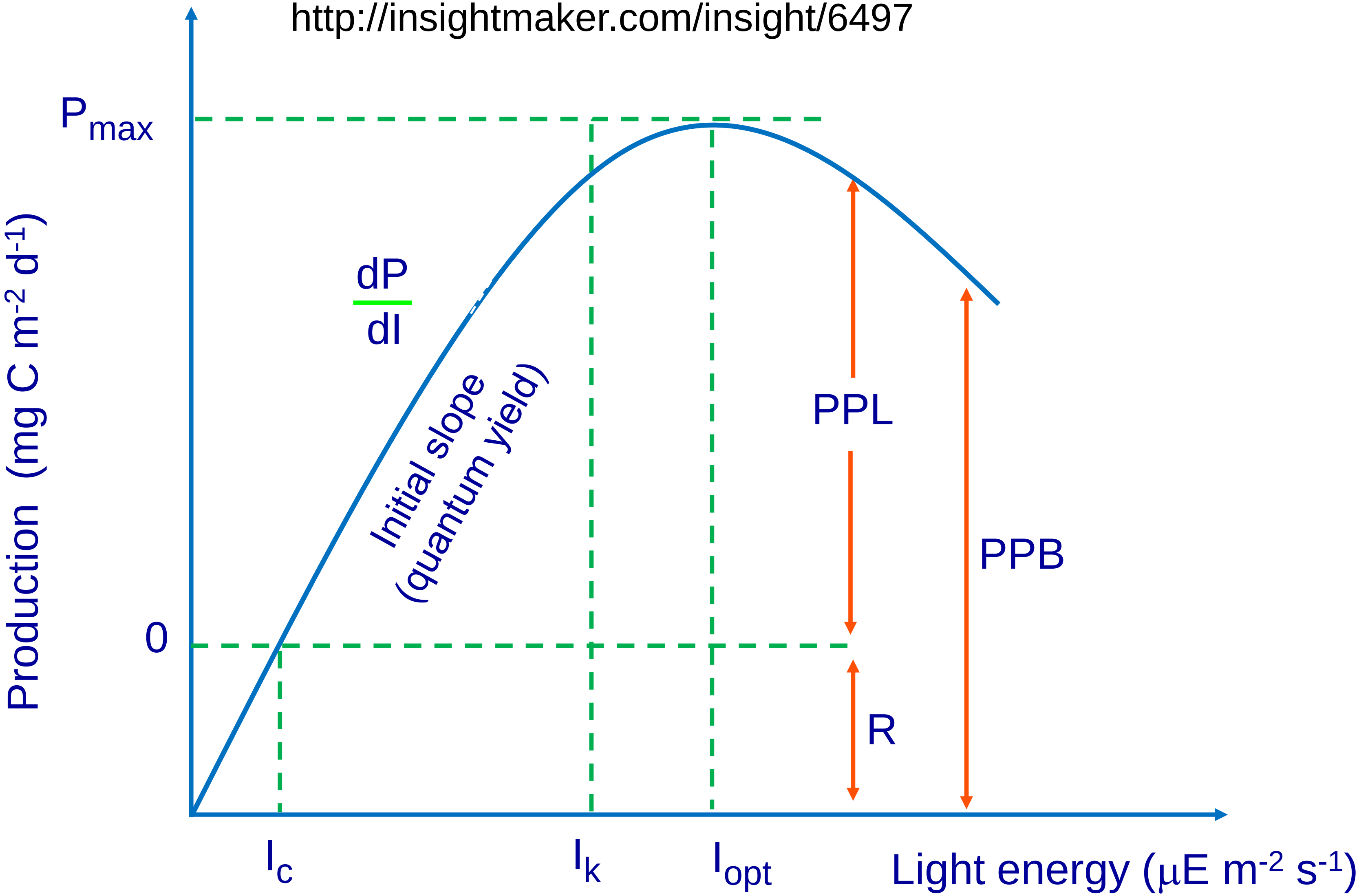
Saltmarsh production estimated by cropping, NDVI, and bathymetry



NDVI = (Near_Infrared - Red) / (Near_Infrared + Red) Near_Infrared and Red are two satellite image bands. NDVI ranges between -1 and 1. Pigments absorb lots of energy in R, but barely any in NIR. Other objects absorb both spectra identically.

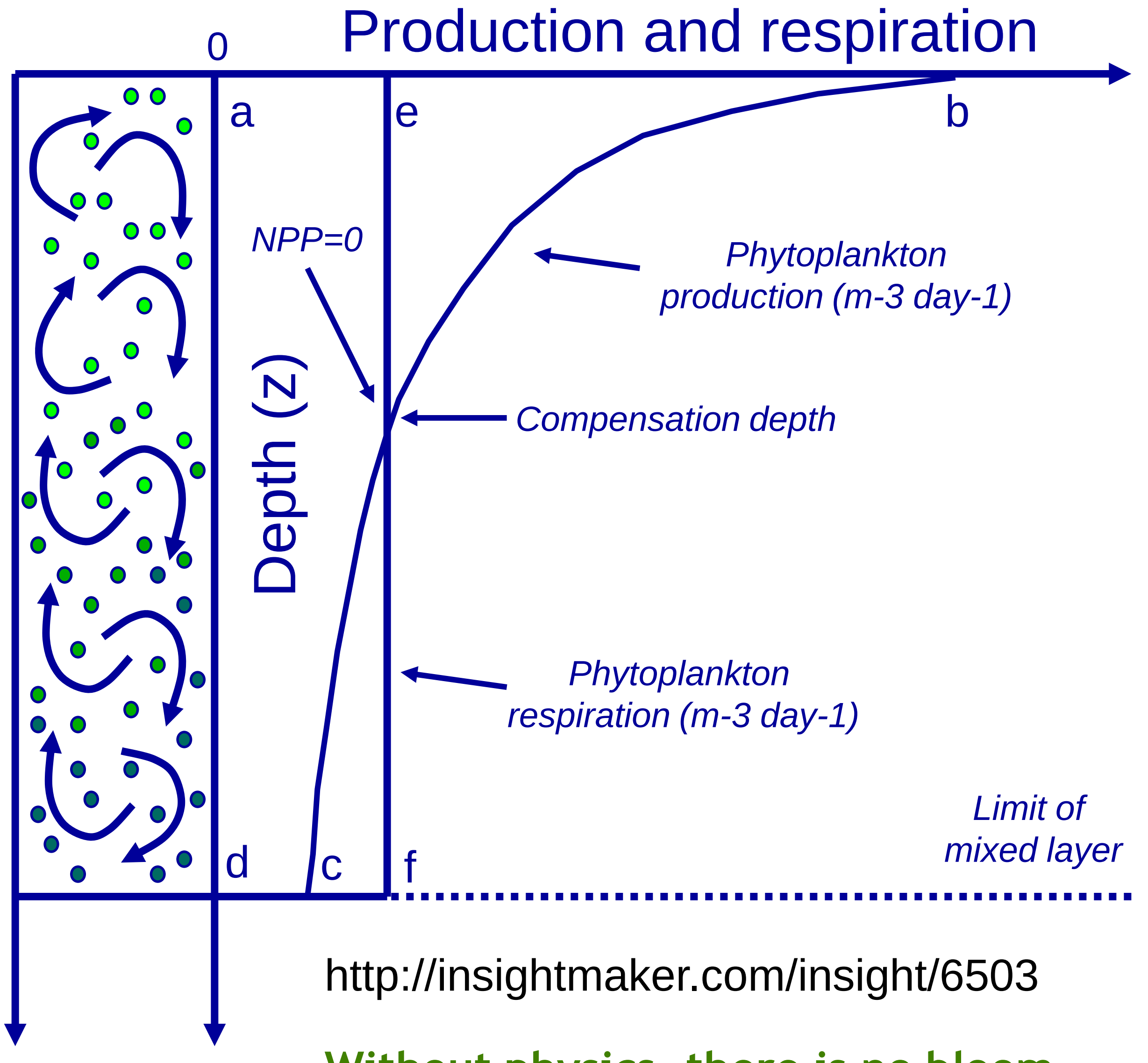
The PI curve – relationship between photosynthesis (P) and light energy (I)

http://insightmaker.com/insight/6497



Some producers display photosaturation, others display photoinhibition.

Phytoplankton blooms and vertical mixing



Integrated production(GPP)
abcd

Integrated respiration
aefd

Conditions for blooming
abcd > aefd

http://insightmaker.com/insight/6503

Without physics, there is no bloom.

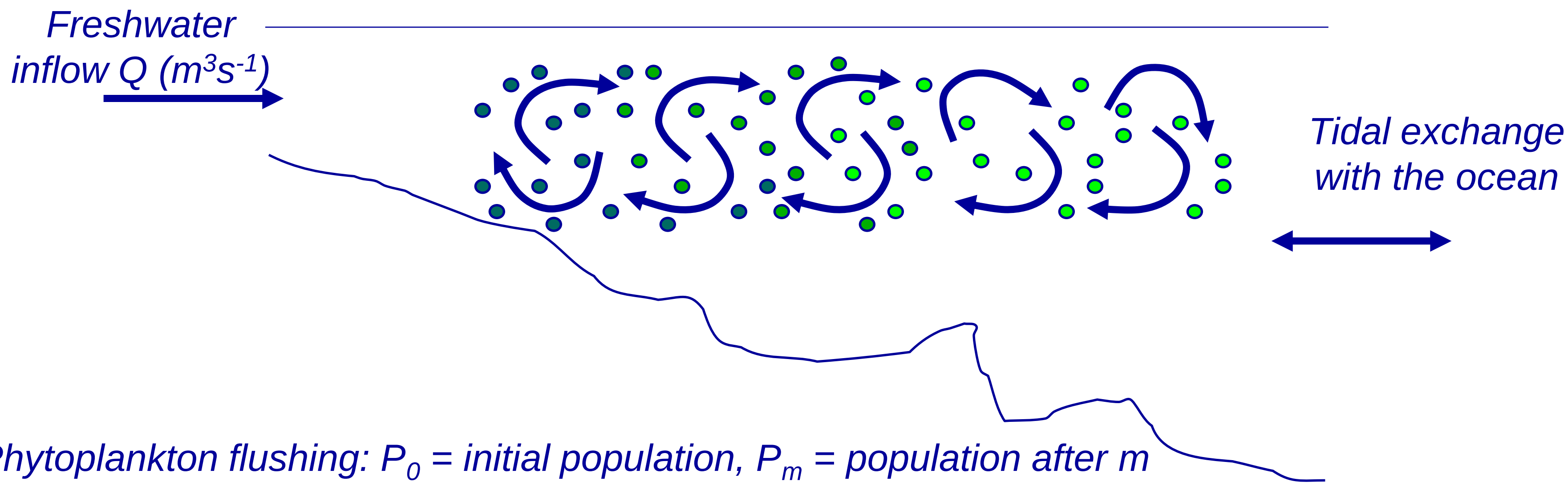
Sverdrup, H.U., 1953. On conditions for the vernal blooming of phytoplankton. J. Cons. Perm. Int. Exp. Mer, 18: 287-295

Phytoplankton blooms and tidal mixing in estuaries

http://insightmaker.com/insight/6531

Phytoplankton growth: P_0 = initial population, P_t = population at time t

$$P_t = P_0 e^{kt}$$



Phytoplankton flushing: P_0 = initial population, P_m = population after m tidal cycles, r = exchange ratio (proportion of estuary water which does not return each tidal cycle)

$$P_m = P_0 (1-r)^m$$

Without physics, there is no bloom.

Ketchum (1954) Relation between circulation and planktonic populations in estuaries. Ecology 35: 191-200.

Phytoplankton blooms and tidal mixing in estuaries

Combining the two equations (and expressing t in terms of m):

Growth	Flushing
$P_t = P_0 e^{kt}$	$P_m = P_0 (1-r)^m$

$$P_m = P_0 e^{mk}(1-r)^m$$

For a steady-state population , $P_m = P_0$*:*

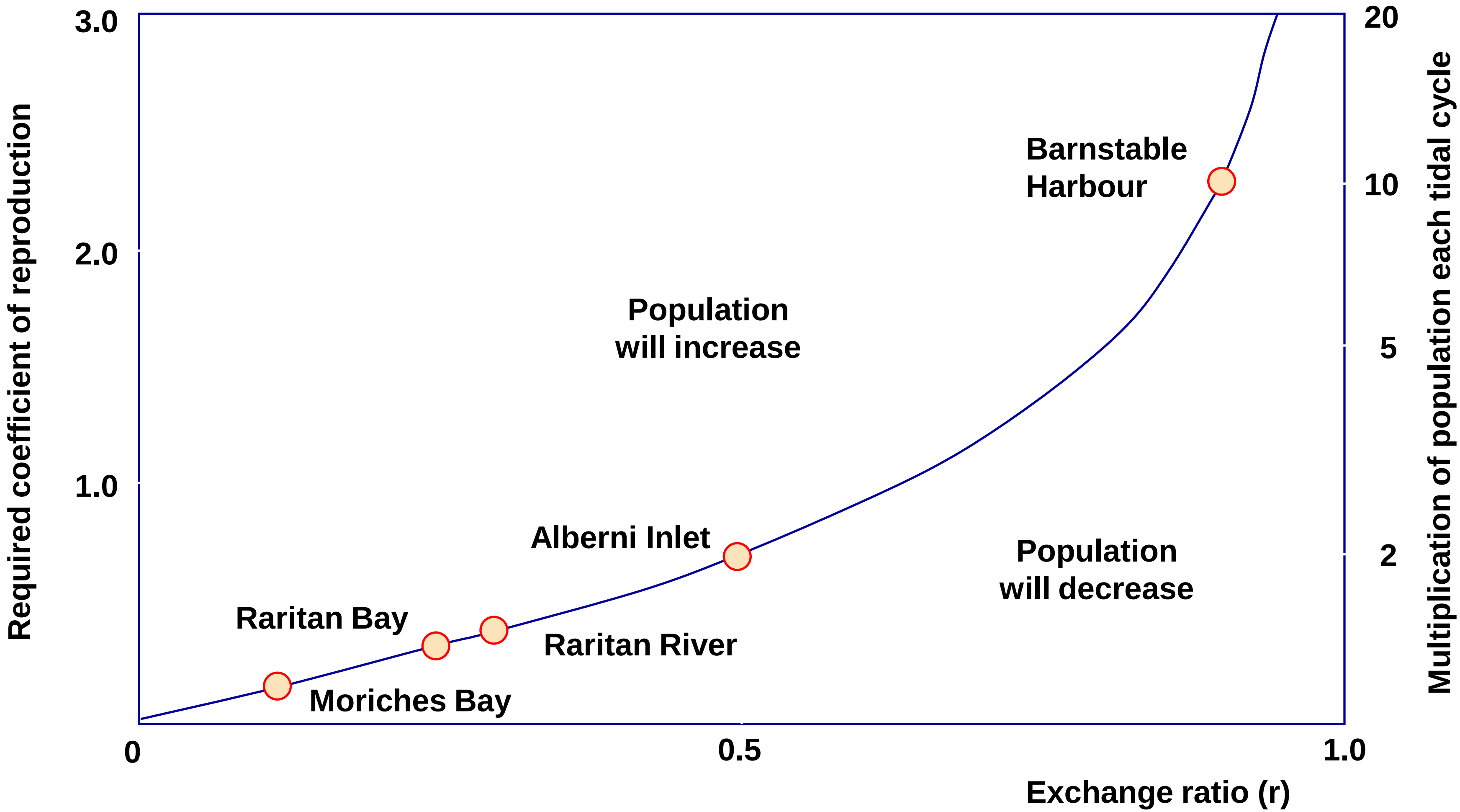
$$\frac{1}{(1-r)^m} = e^{mk}$$

$$k = -ln(1-r)$$

For phytoplankton to exist and potentially bloom in an estuary, growth must balance flushing, i.e. $k \geq -\ln(1-r)$

Ketchum (1954) Relation between circulation and planktonic populations in estuaries. Ecology 35: 191-200.

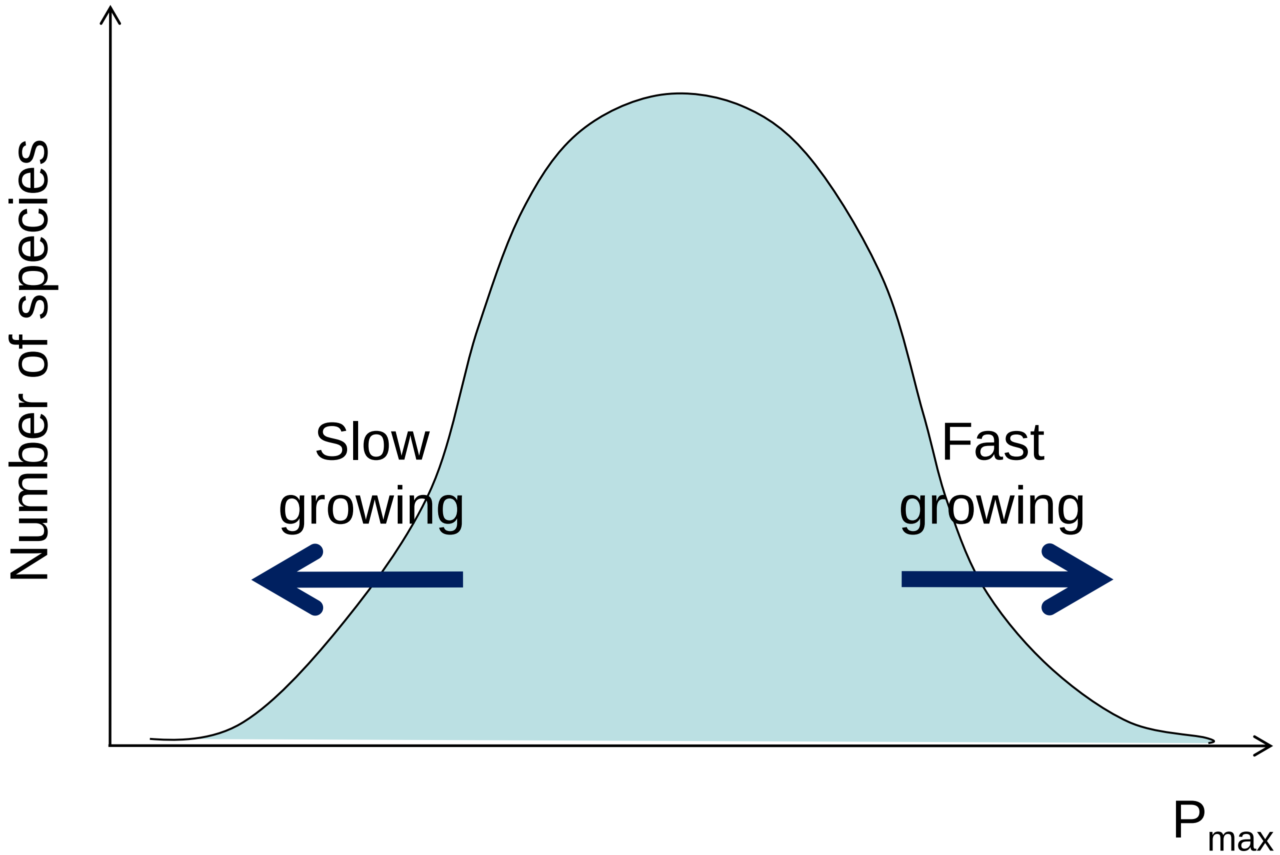
Phytoplankton blooms and tidal mixing in estuaries



Lower growth rate required for systems with longer water residence time.

Ferreira et al., 2005. Ecological Modelling, 187(4) 513-523.

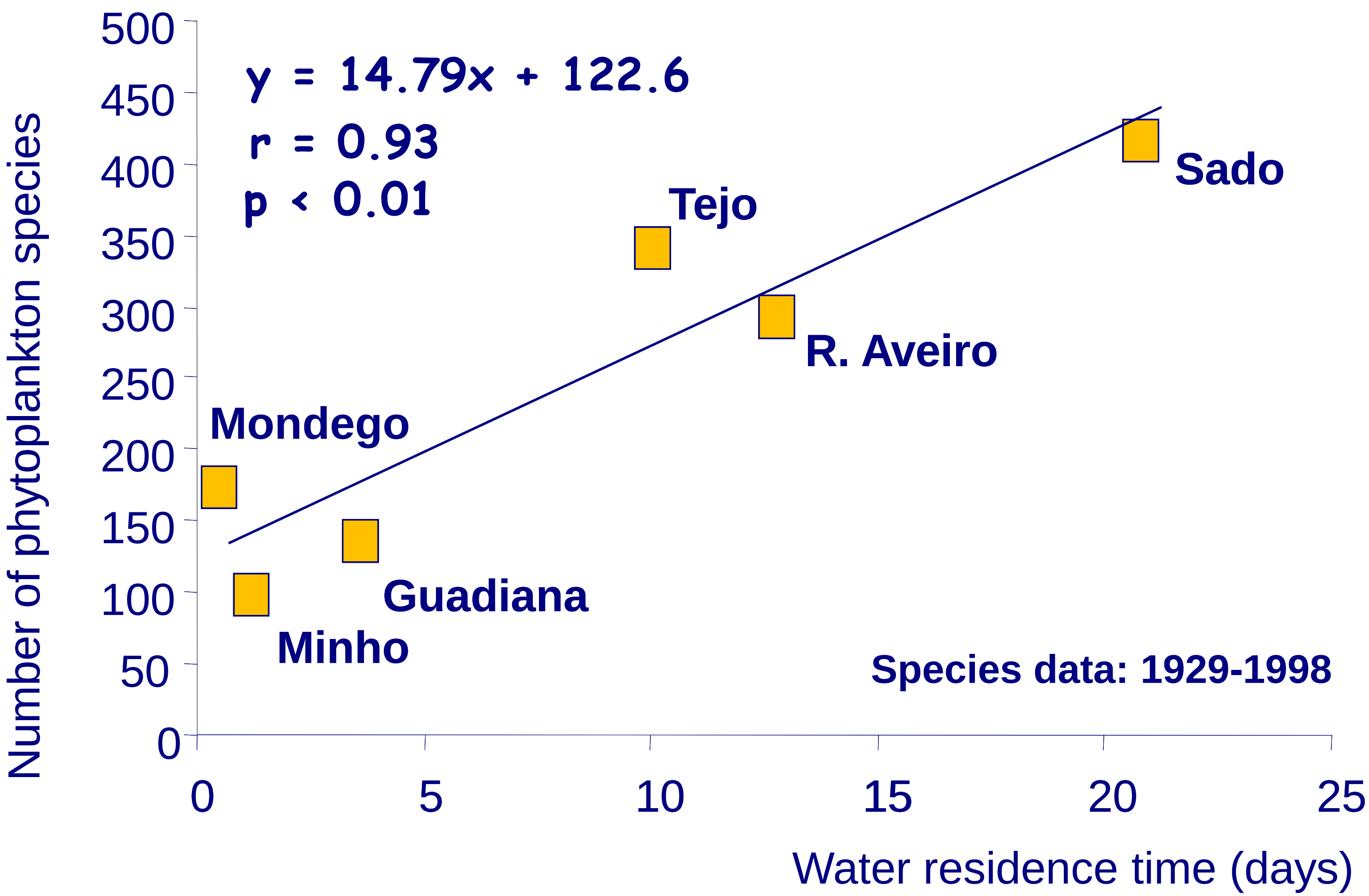
Biodiversity of phytoplankton in estuaries



Distribution of phytoplankton production across different species may follow a gaussian function.

Ferreira, J.G., Wolff, W.J., Simas, T.C., Bricker, S.B., 2005. Does biodiversity of estuarine phytoplankton depend on hydrology? Ecological Modelling, 187(4) 513-523.

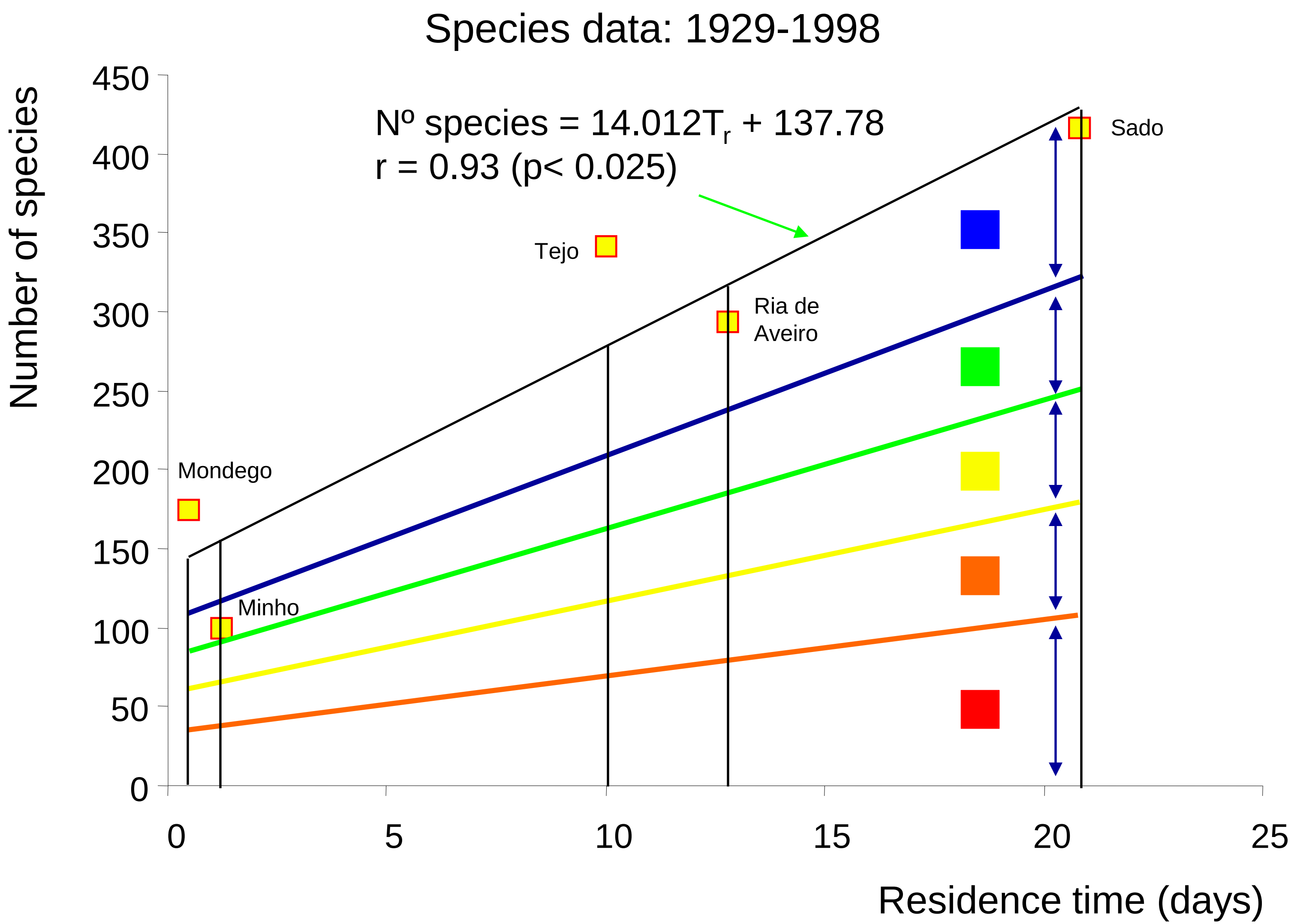
Number of phytoplankton species as a function of water residence time



Greater phytoplankton diversity with longer water residence time.

Ferreira et al., 2005. Ecological Modelling, 187(4) 513-523.

Water residence time and number of species



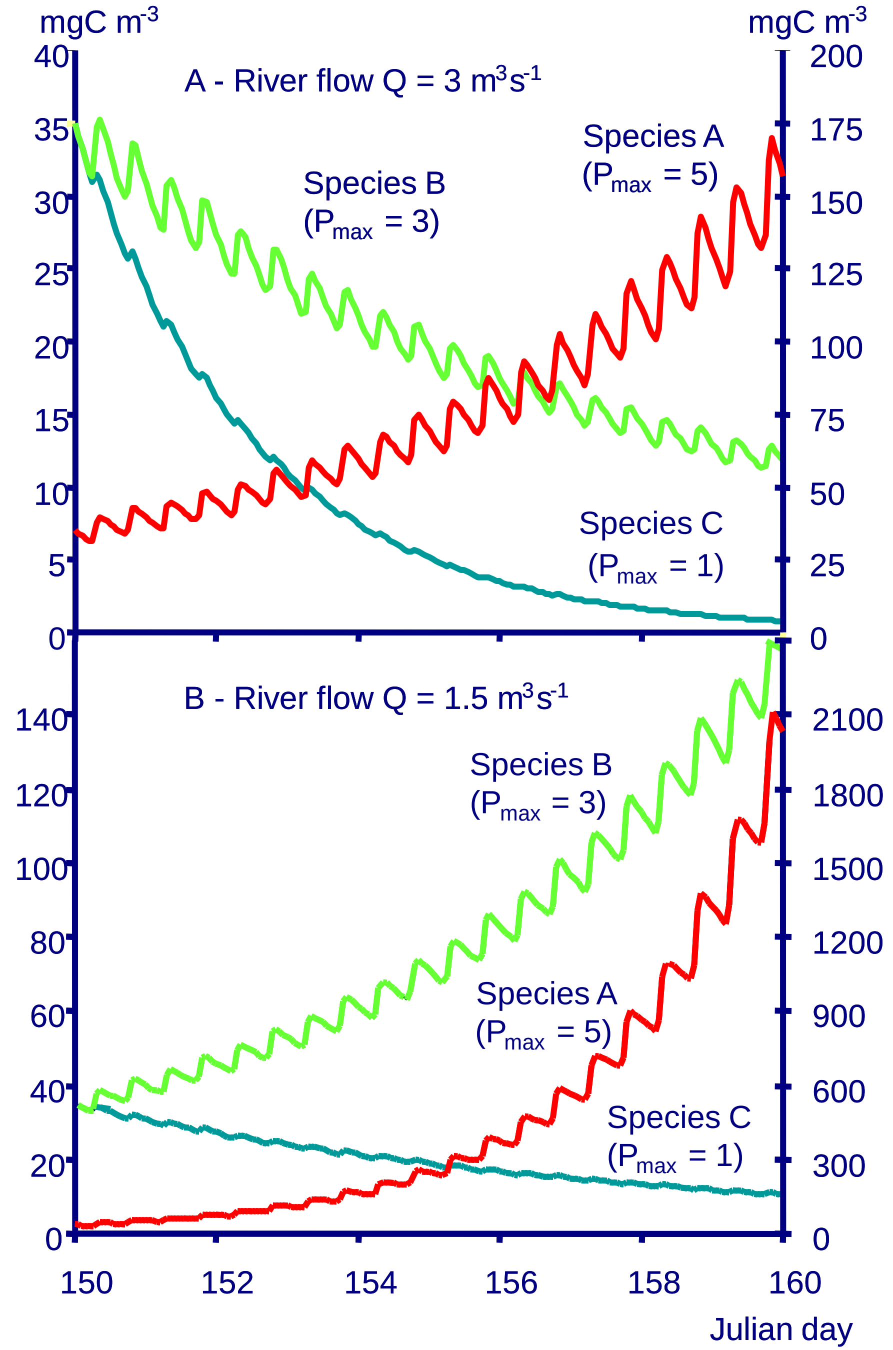
Greater phytoplankton diversity with longer water residence time.

Ferreira et al., 2005. Ecological Modelling, 187(4) 513-523.

Simulation of growth for three hypothetical phytoplankton species

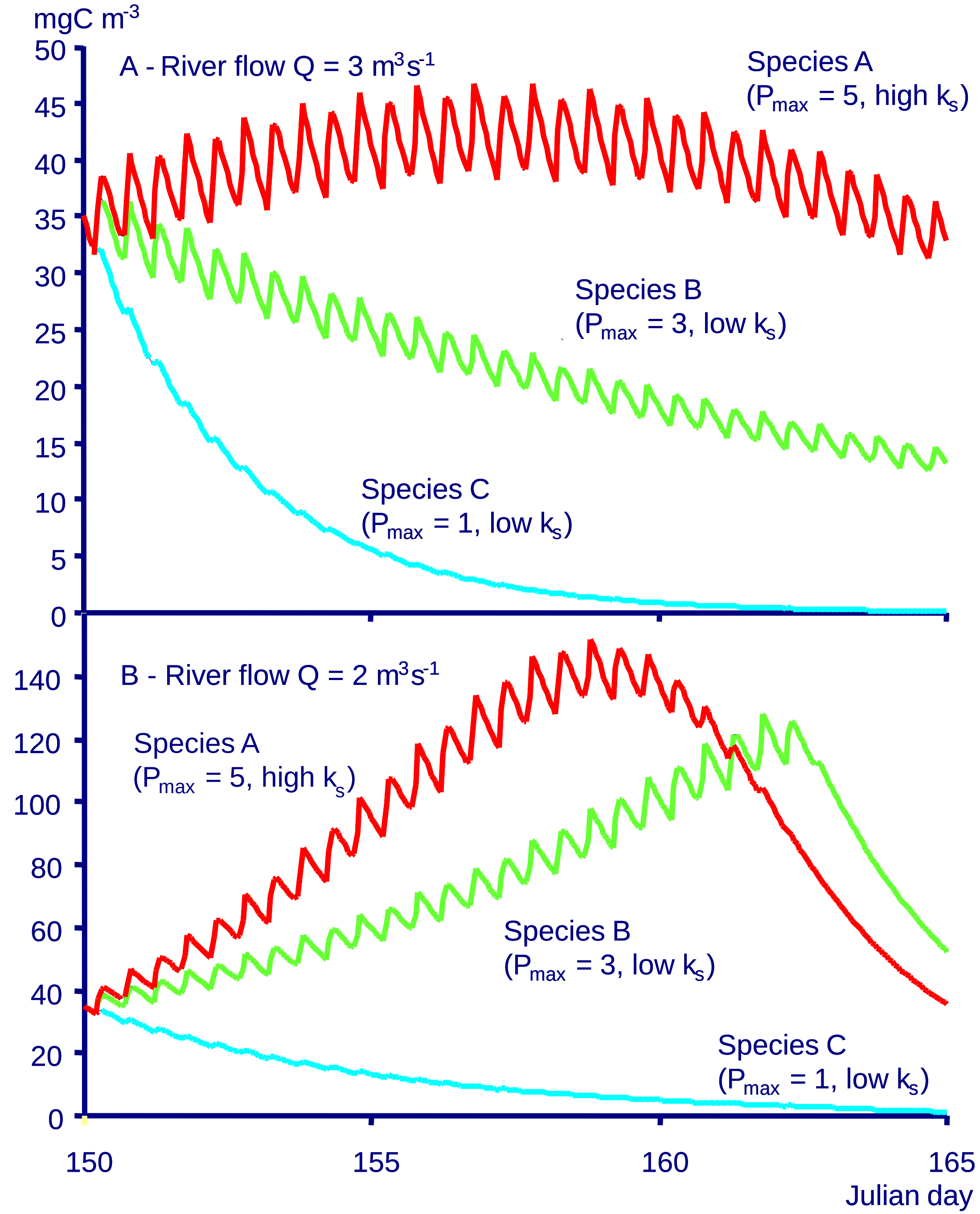
(species A on right axis)

No nutrient limitation



- Species B is slower growing, cannot compete at higher river flows;
- If residence time increases, e.g. through an impoundment, both species grow.

Simulation of nutrient limited growth for three hypothetical phytoplankton species

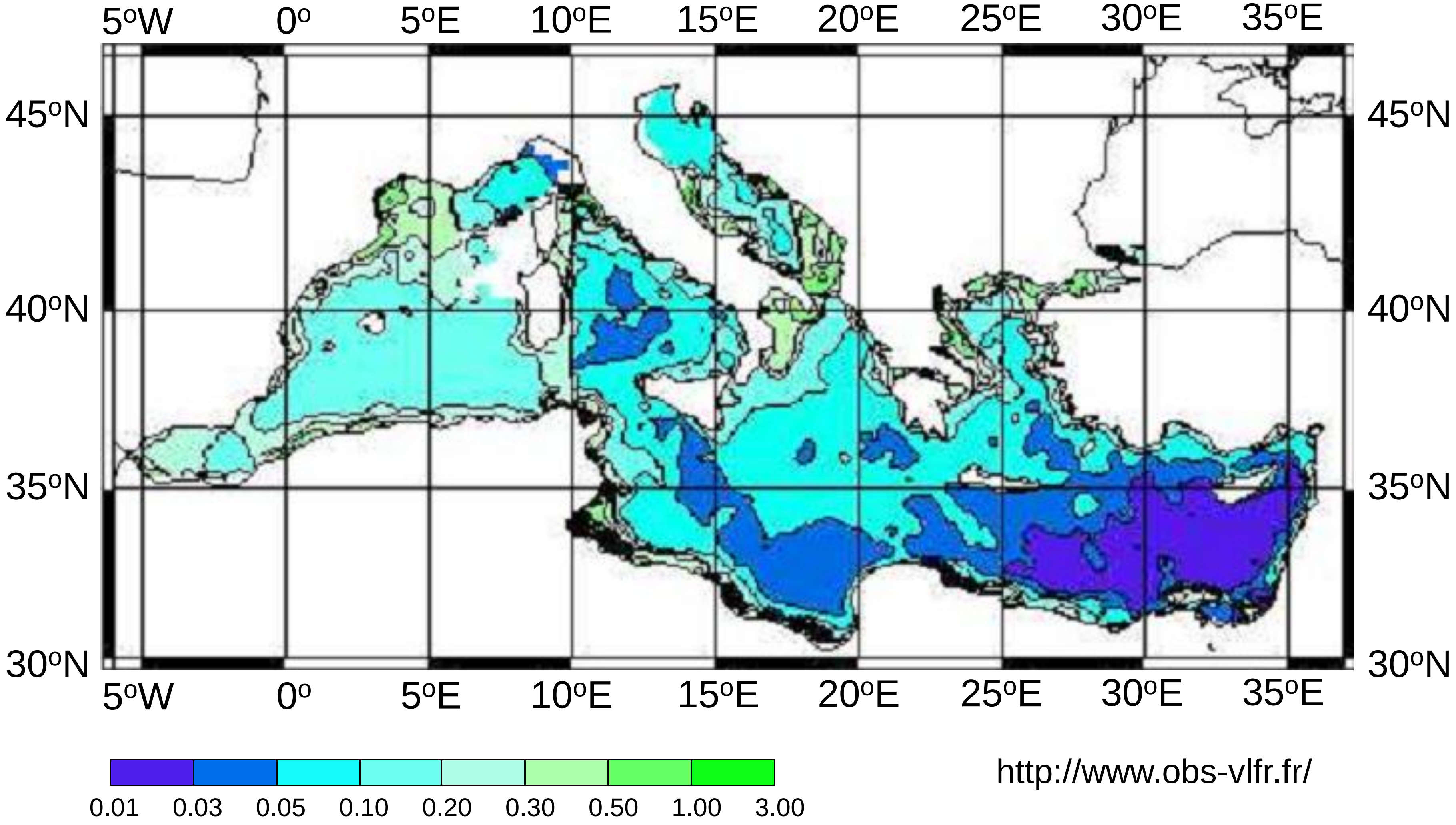


<u>Nutrient limitation</u>

- Species B is slower growing, cannot compete at higher river flows;

- If residence time increases, B can succeed A as nutrients decrease, due to its lower k_s

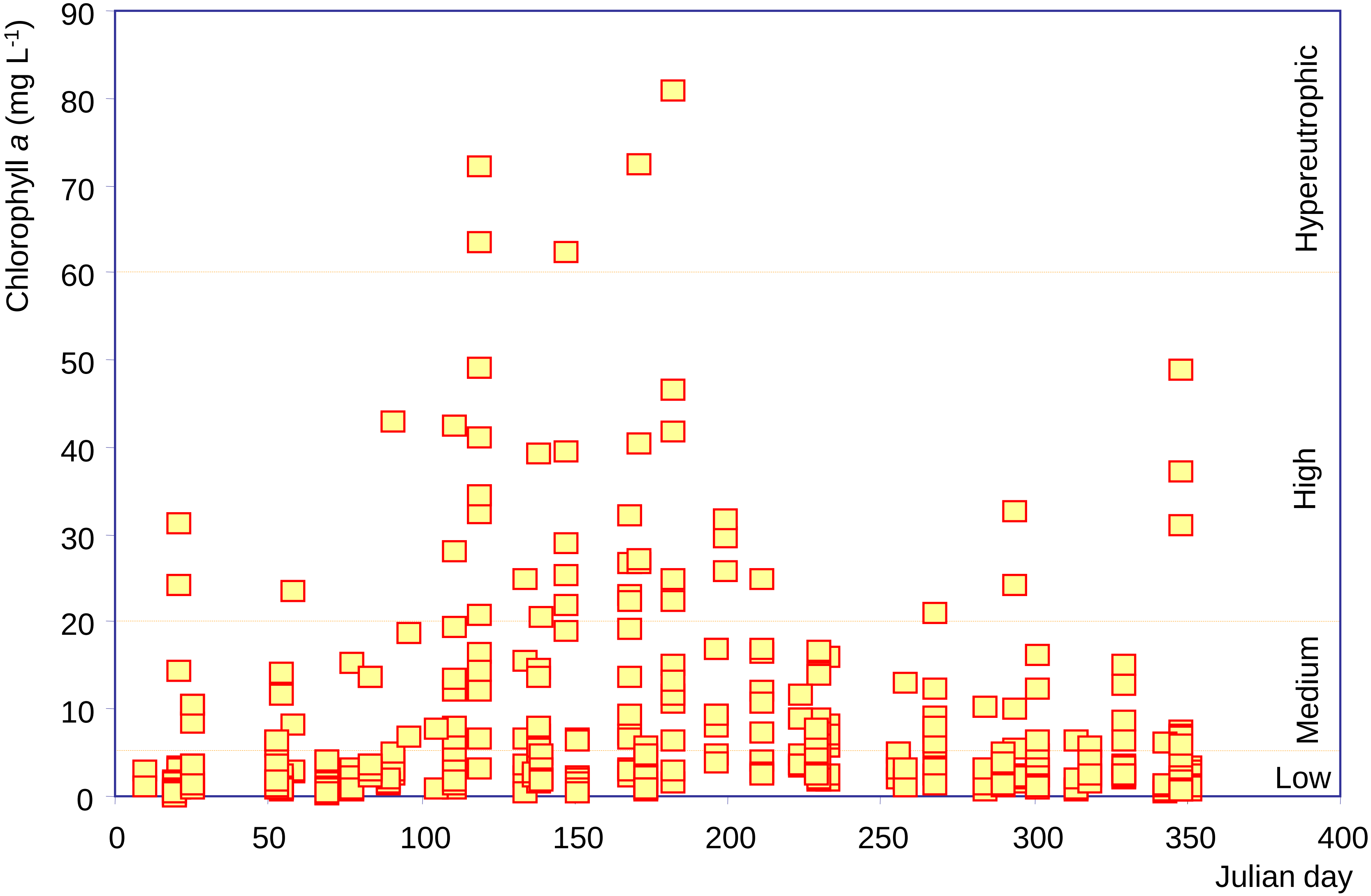
CZCS derived sea-surface pigments Mediterranean Sea



http://www.obs-vlfr.fr/

Since the construction of the Aswan dam, the eastern Mediterranean has become increasingly oligotrophic.

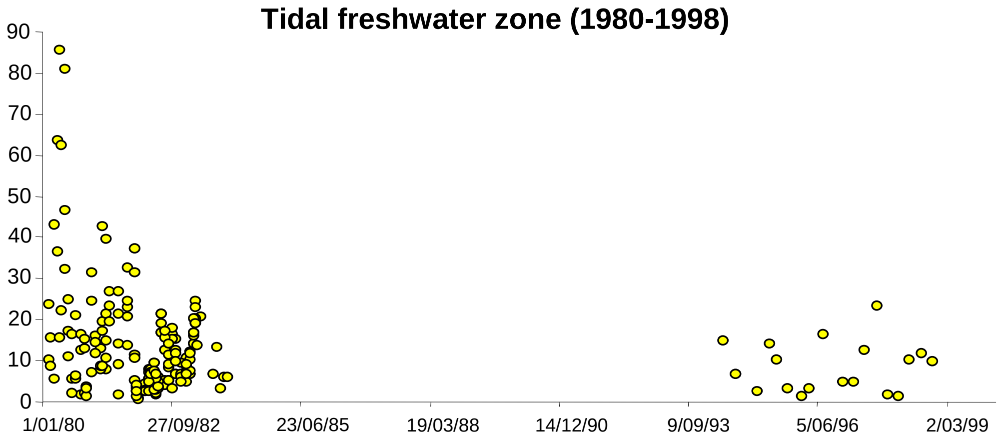
Chlorophyll a in the Tagus Estuary
Surface values along a longitudinal section

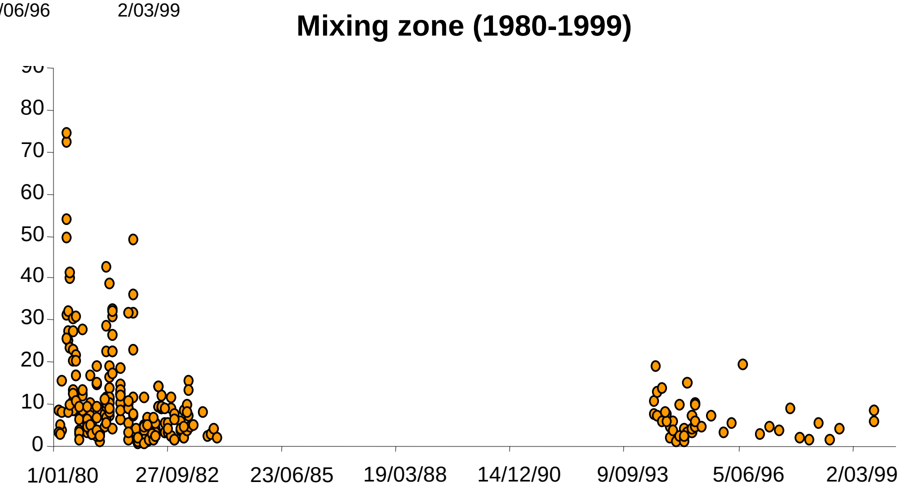


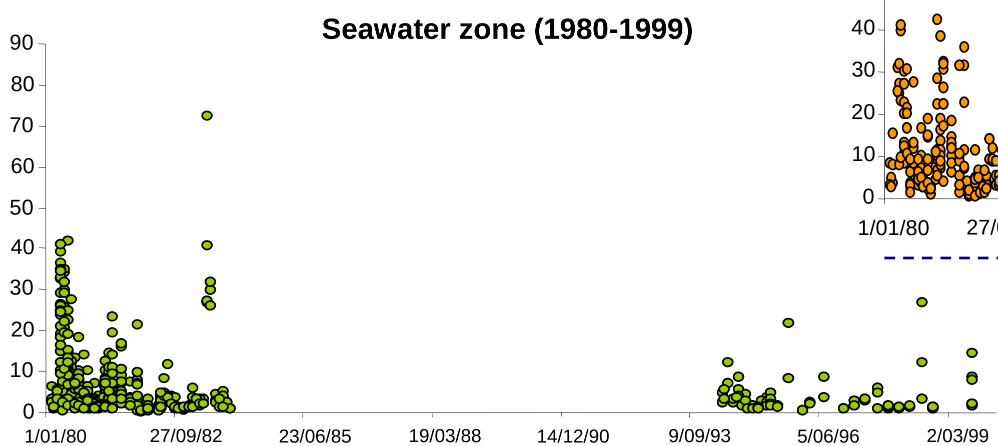
Data from BarcaWin2000 - Stations #1.0, #2.0, #3.9, #4.0, #5.0 and #8.0 – 385 values

In the early 1980s very high values occurred in spring.

Chlorophyll *a* trends in the Tagus Estuary

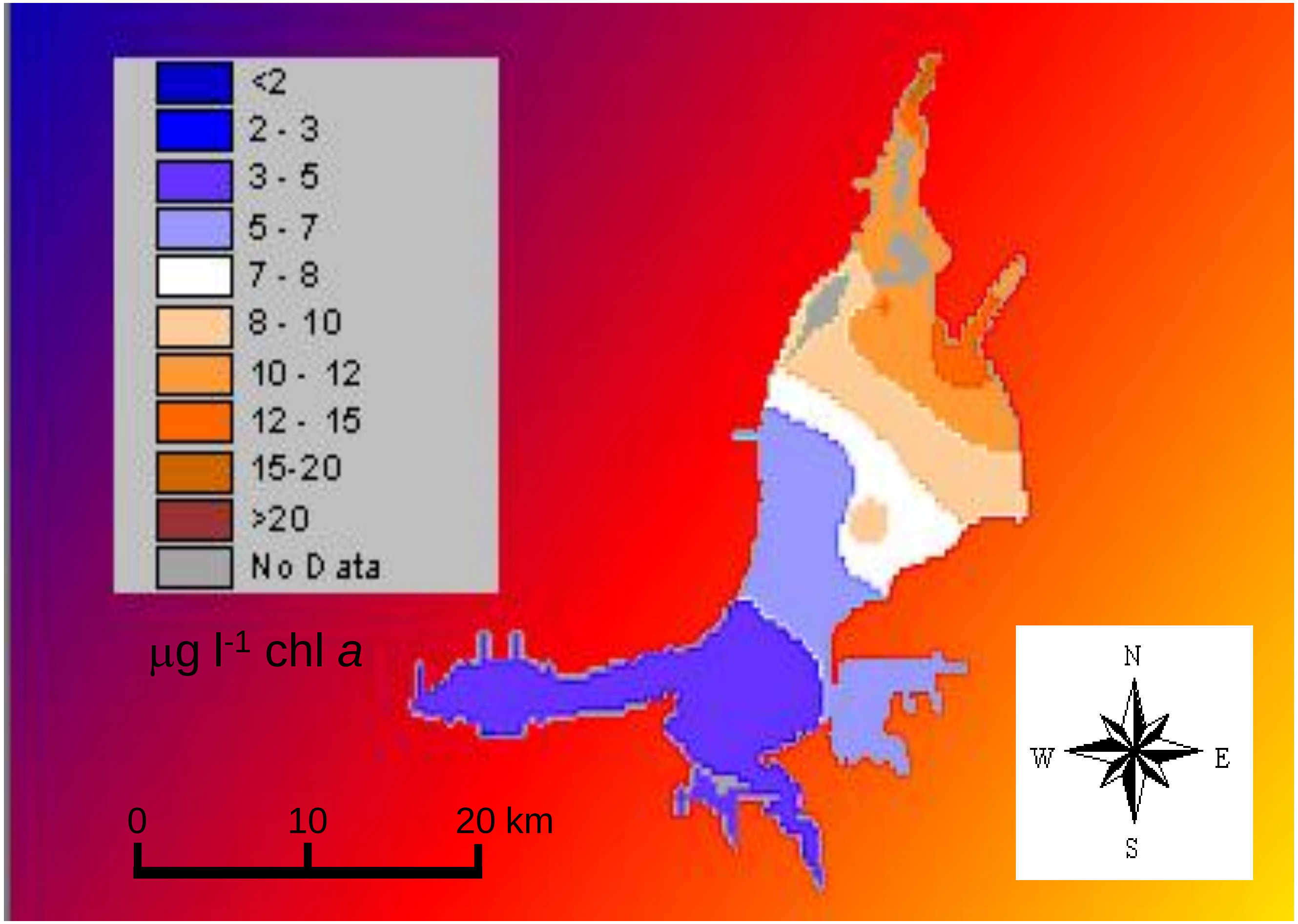






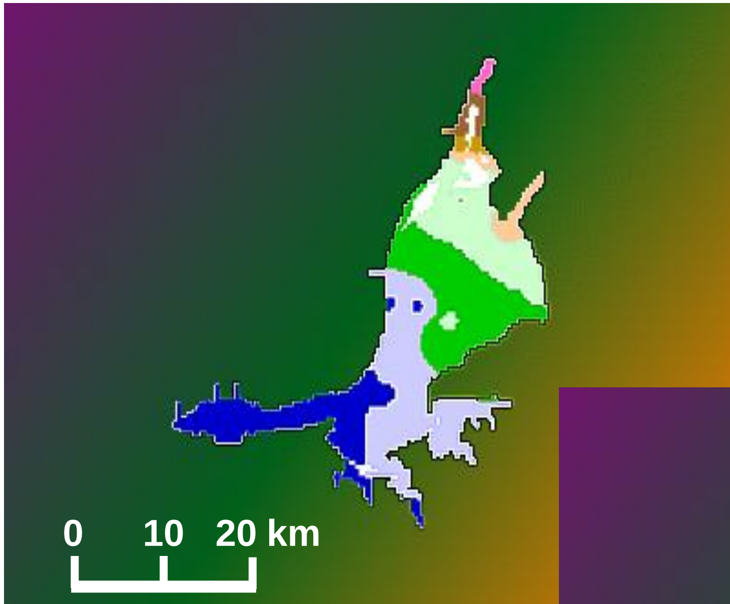
There appears to be a clear reduction in chlorophyll *a* concentrations over a period of 15 years.

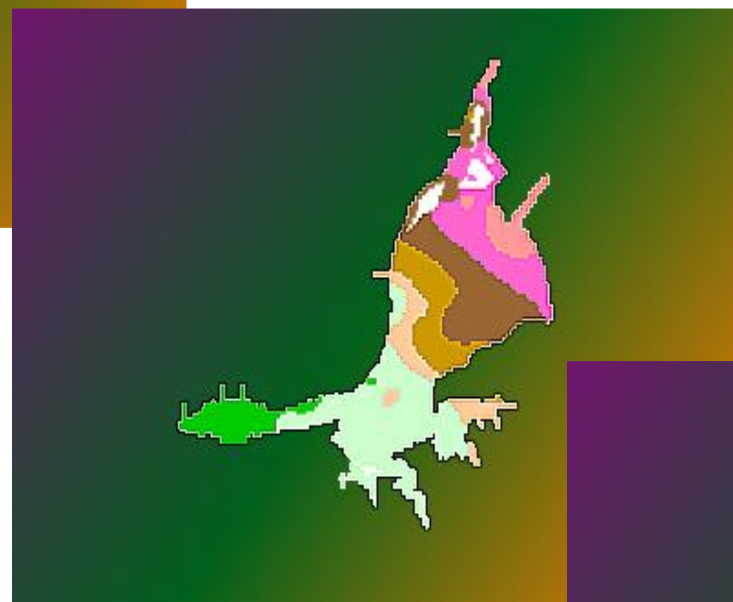
GIS – Chlorophyll a
Composite annual mean

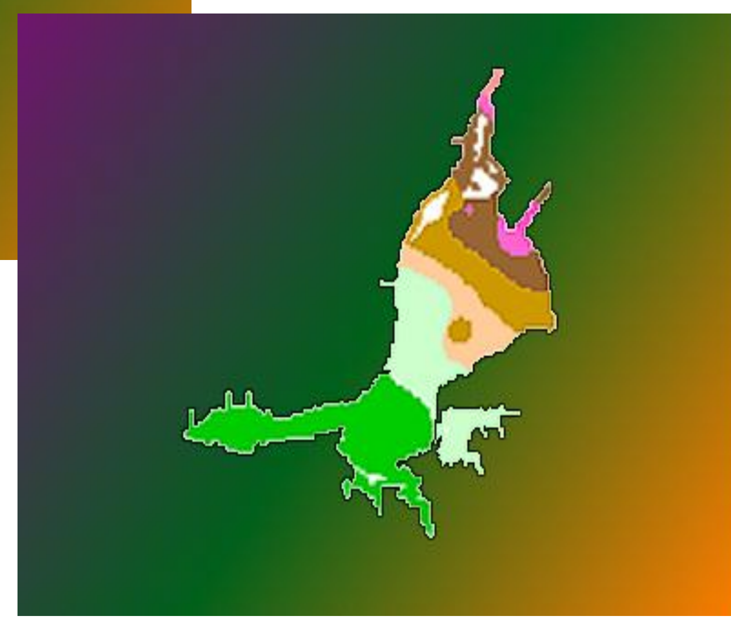


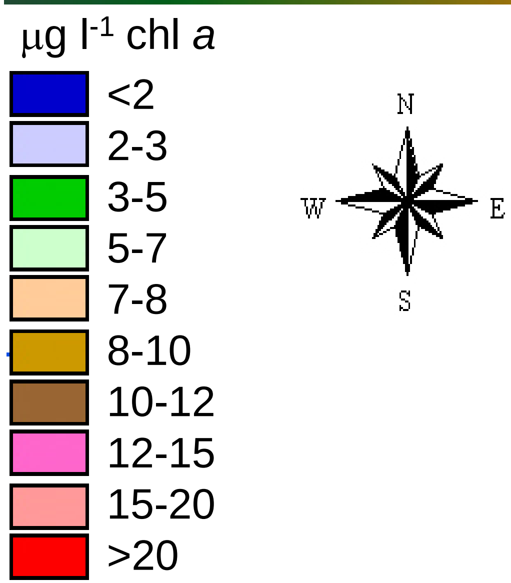
Elevated concentrations appear upstream, due to the pattern of nutrient loading.

GIS mean chlorophyll a. Winter, summer, and global





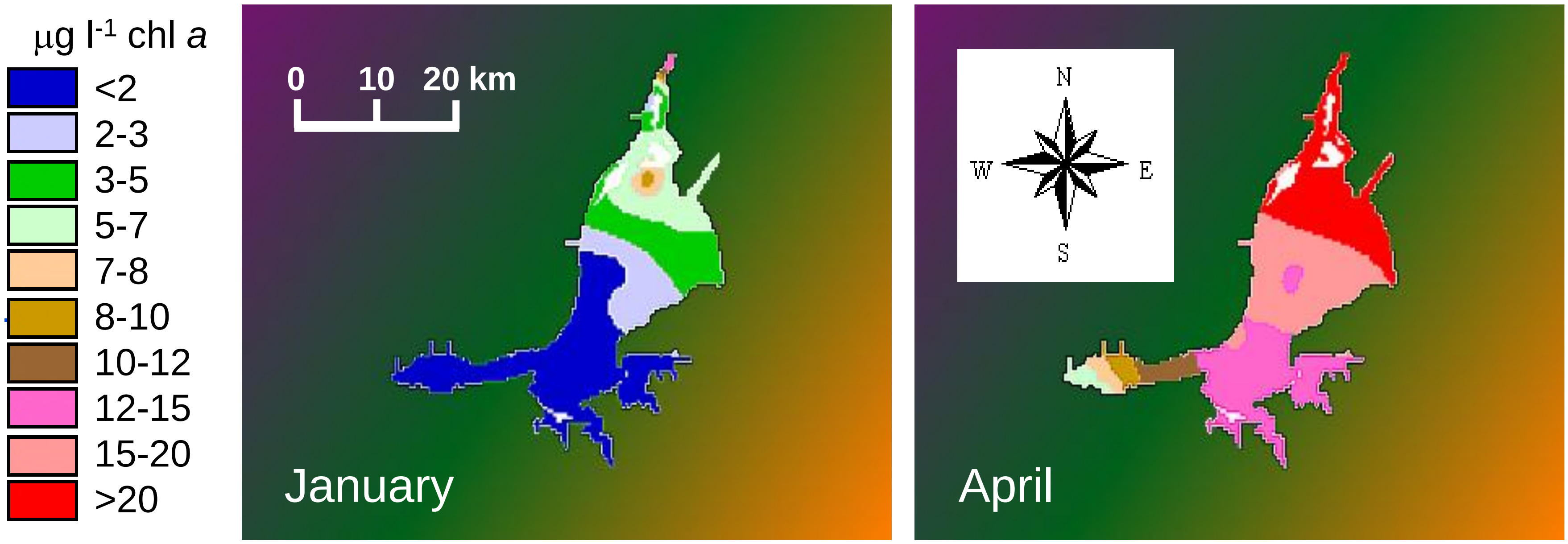




Data from 1980-1983, Tagus estuary, Portugal

High summer values upstream reflect the loading from the rivers.

GIS – Comparison between January and April chlorophyll *a*



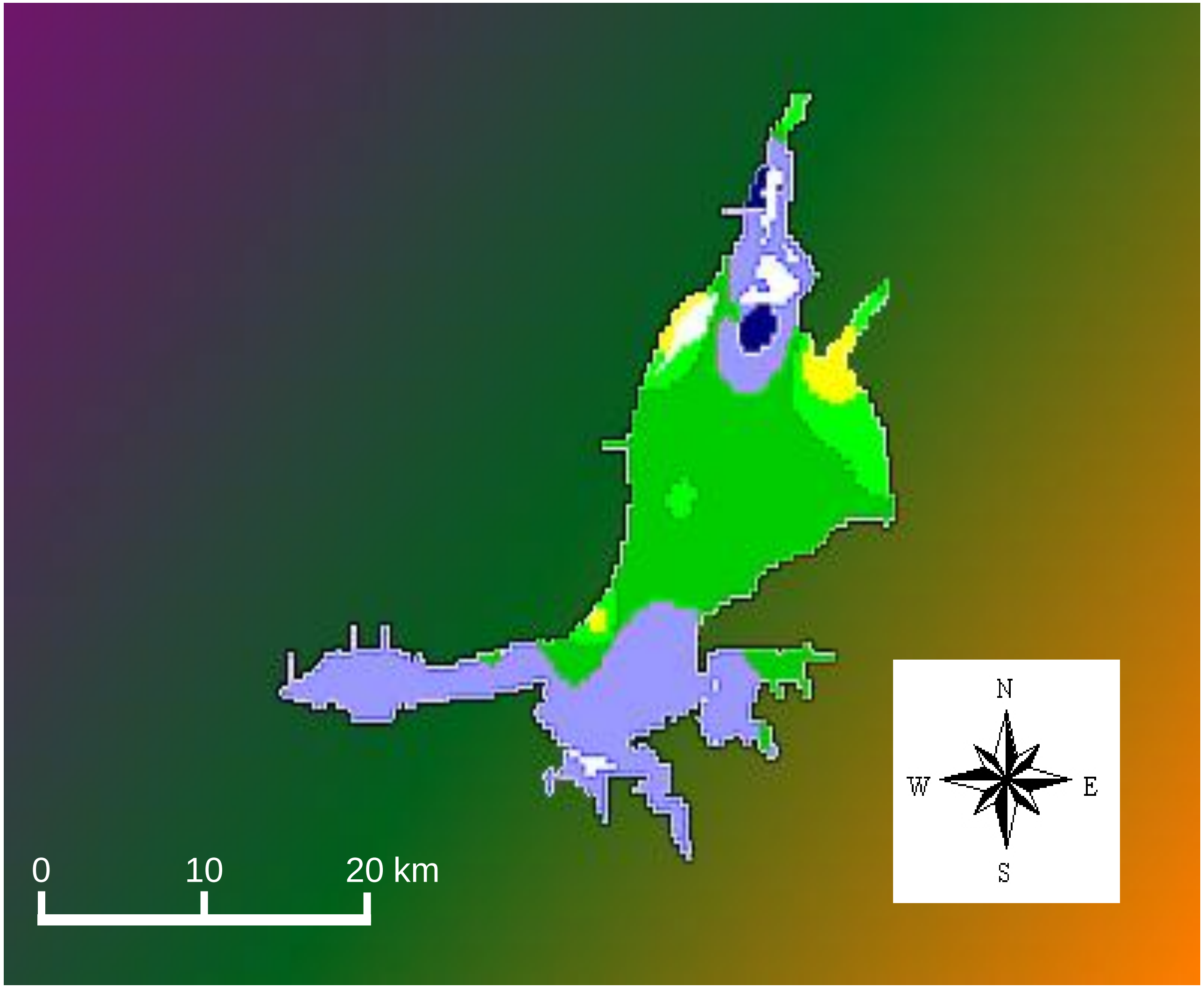
Data from 1980-1983, Tagus estuary, Portugal

Clear evidence of a spring bloom.

GIS – chlorophyll *a* surface-bottom

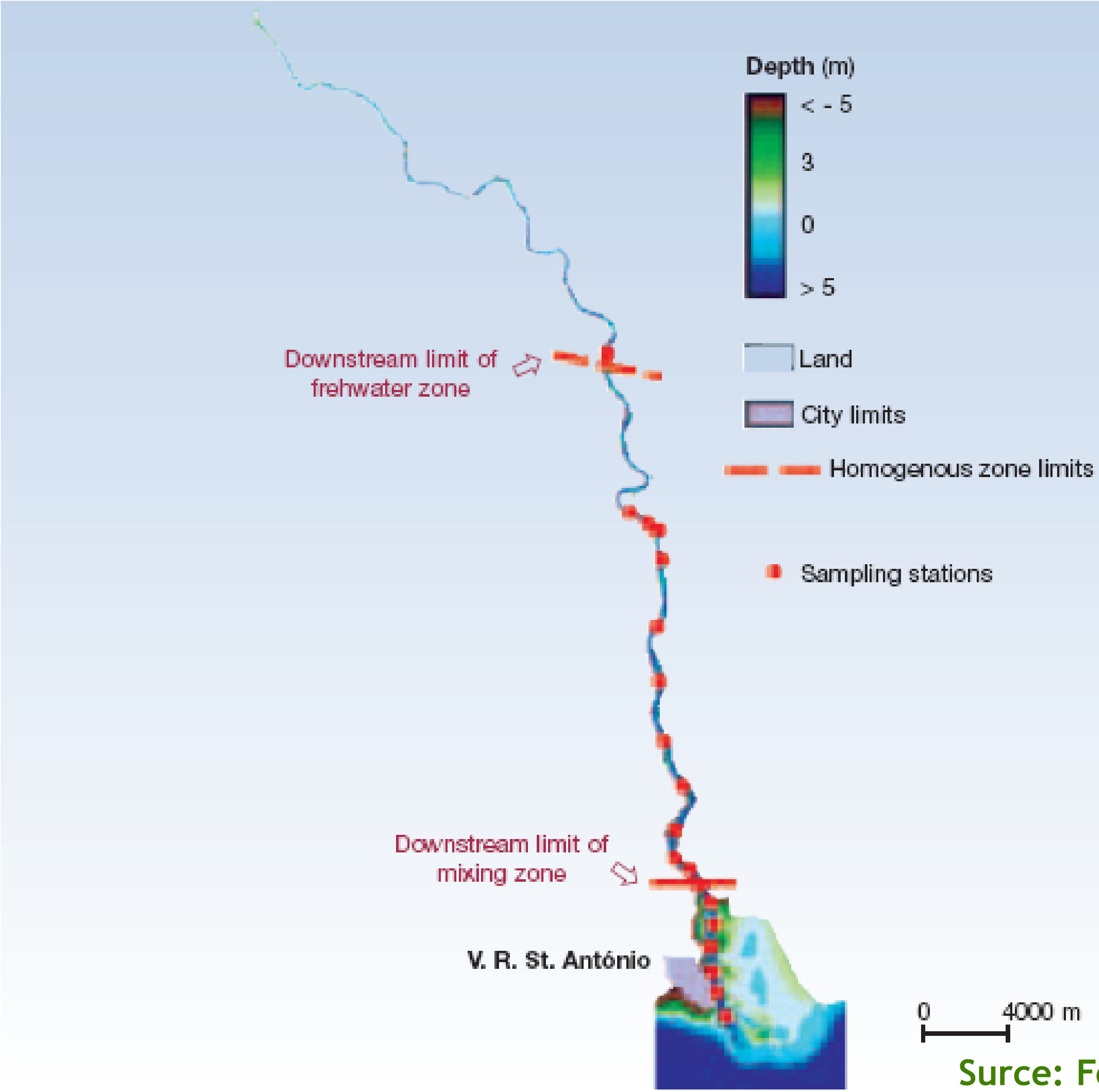
$\mu g\ l^{-1}$ chl *a*

(yellow)	-1.35- 0
(bright green)	0-0.5
(green)	0.5-1
(light blue)	1-2
(dark blue)	2-3.5



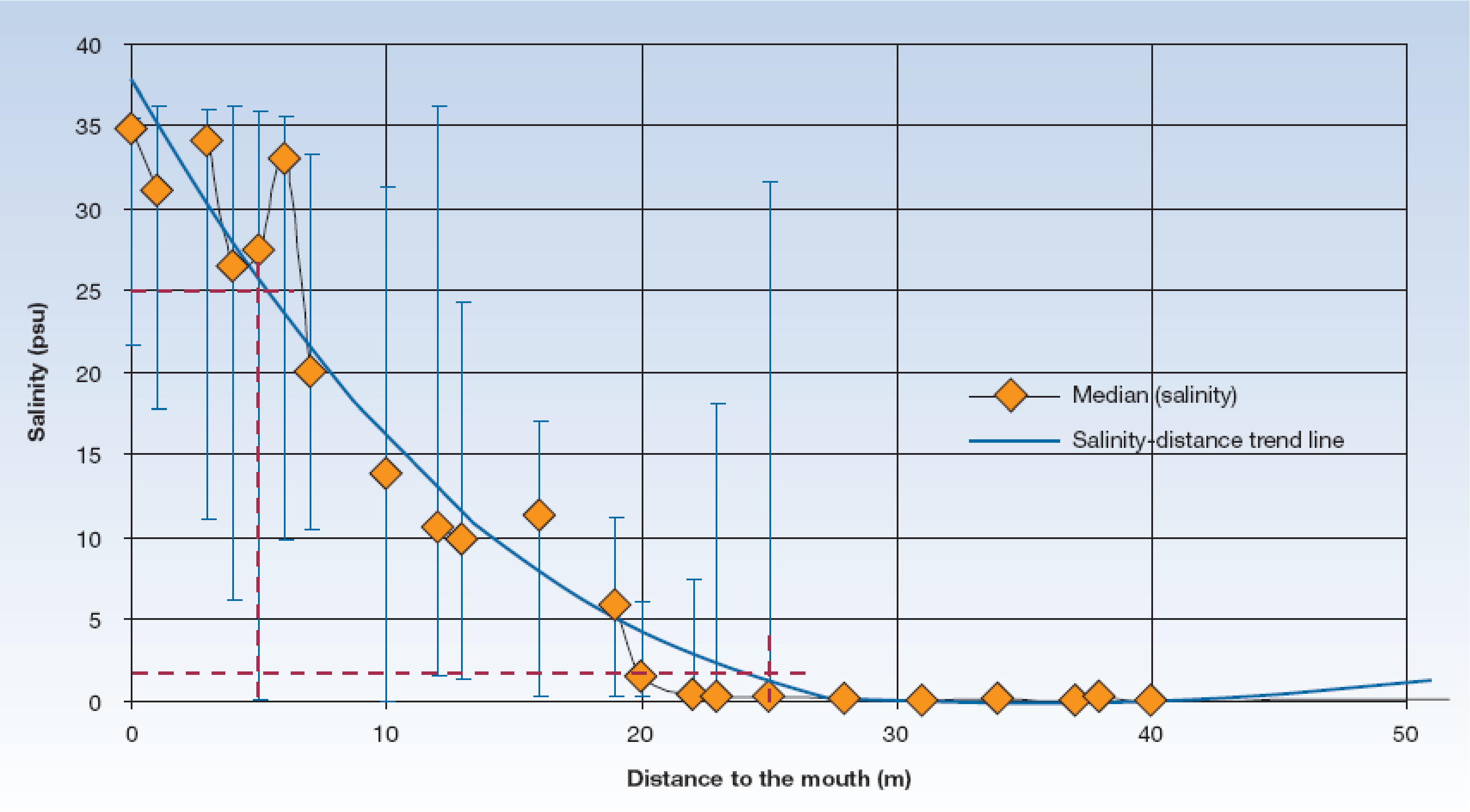
Water column is well-mixed, so there is no significant difference between bottom and surface chlorophyll .

The Guadiana Estuary



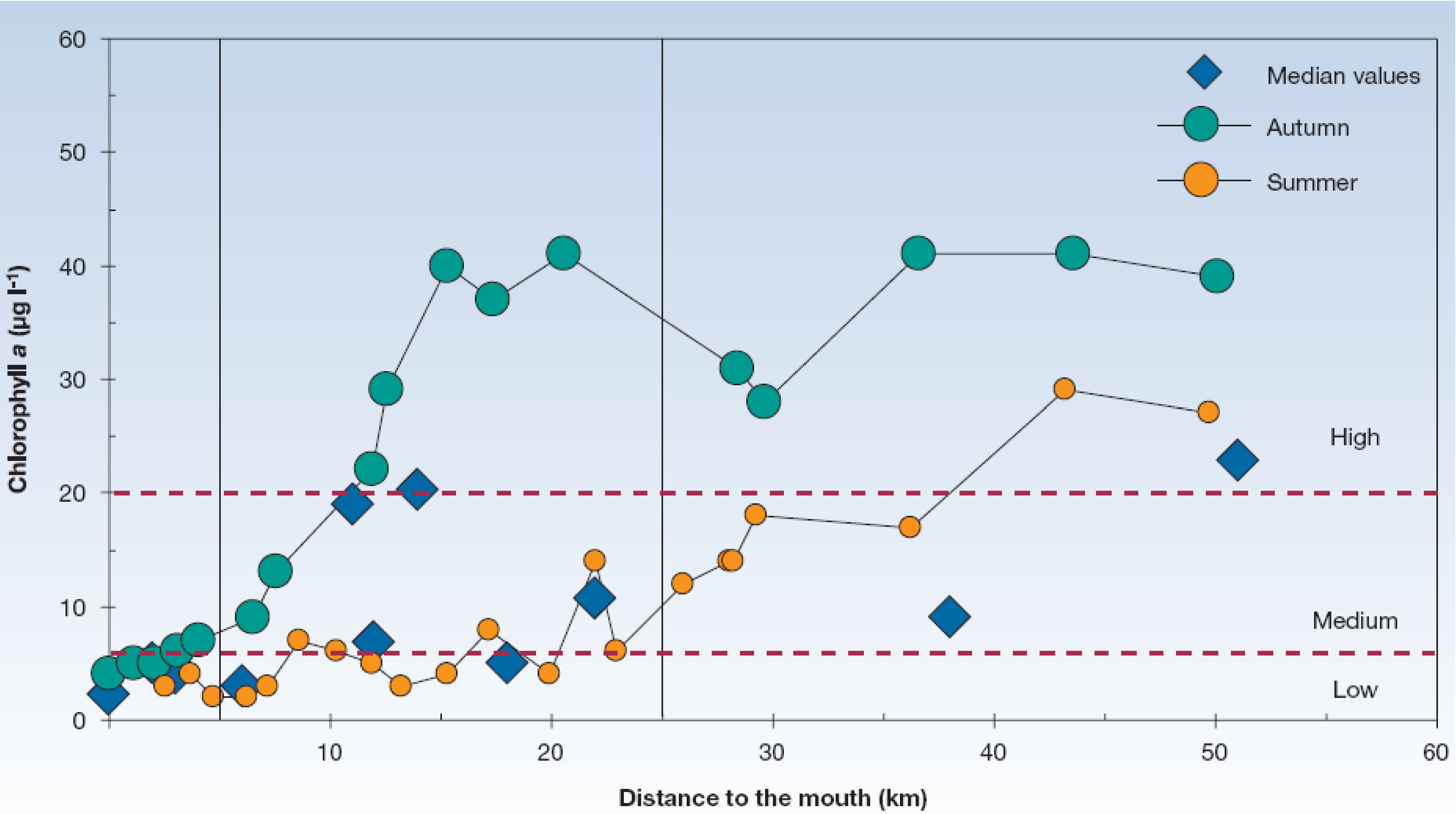
Surce: Ferreira et al., 2003.

Guadiana estuary - salinity profile



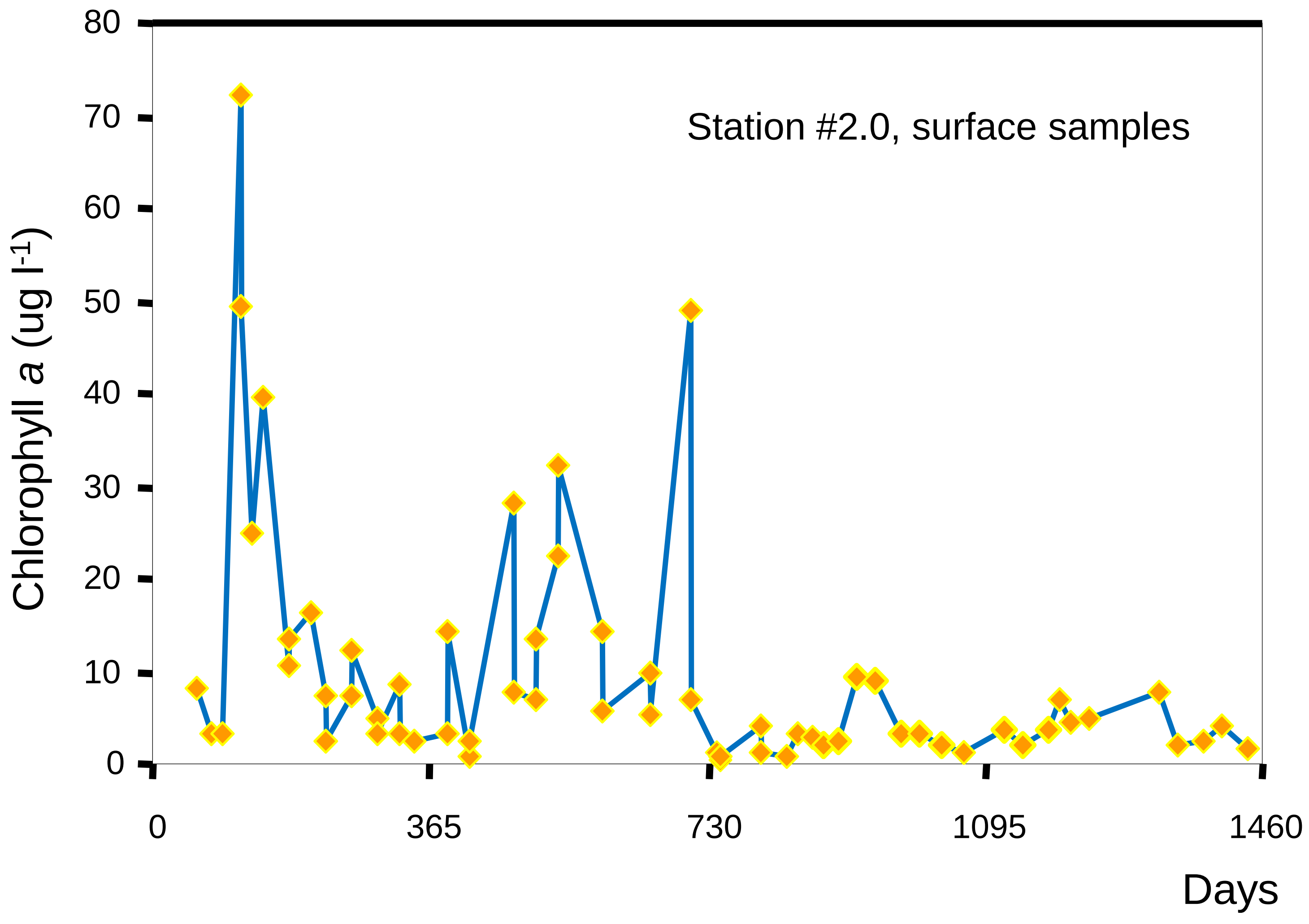
Source: Ferreira et al., 2003.

Guadiana estuary – chlorophyll *a*



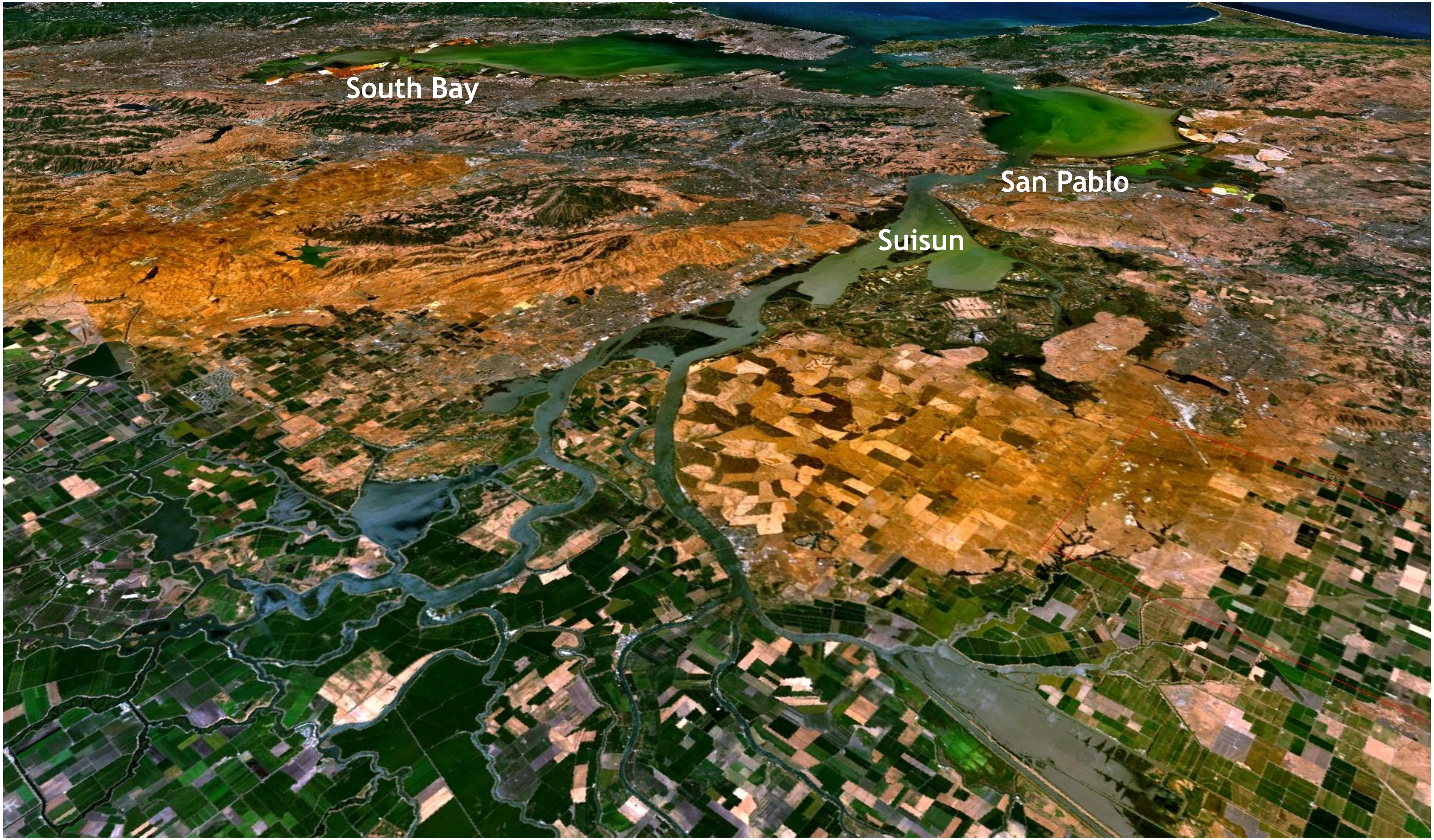
Source: Ferreira et al., 2003.

Interannual variation in chlorophyll *a* over a 4 year period



Why do the last two years show such a marked decrease?

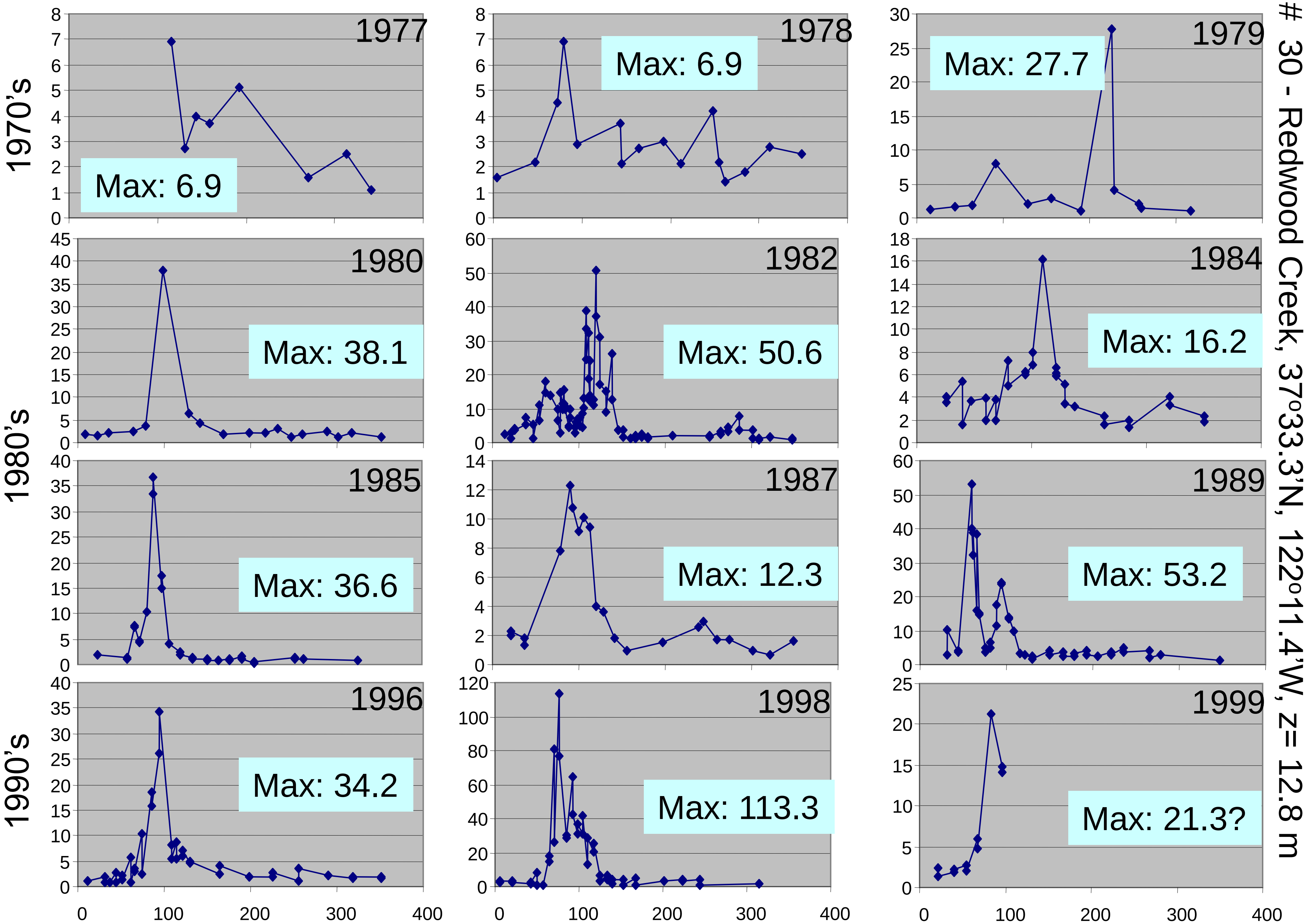
Human impact on San Francisco Bay, U.S.A.



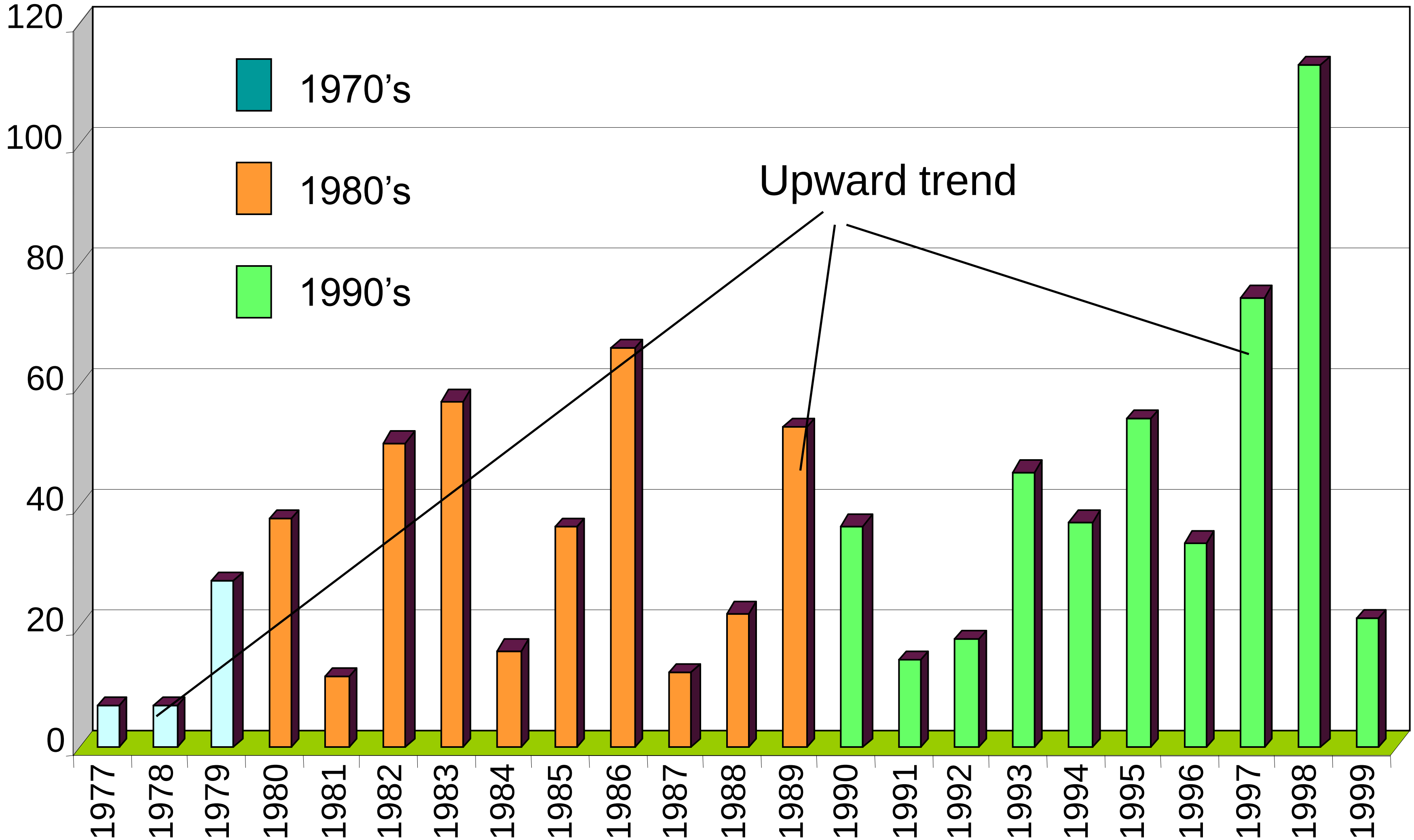
http://ian.umces.edu/neea/

Agricultural and urban nutrient loading in northern California

Chlorophyll *a* in S. Francisco Bay (South Bay)

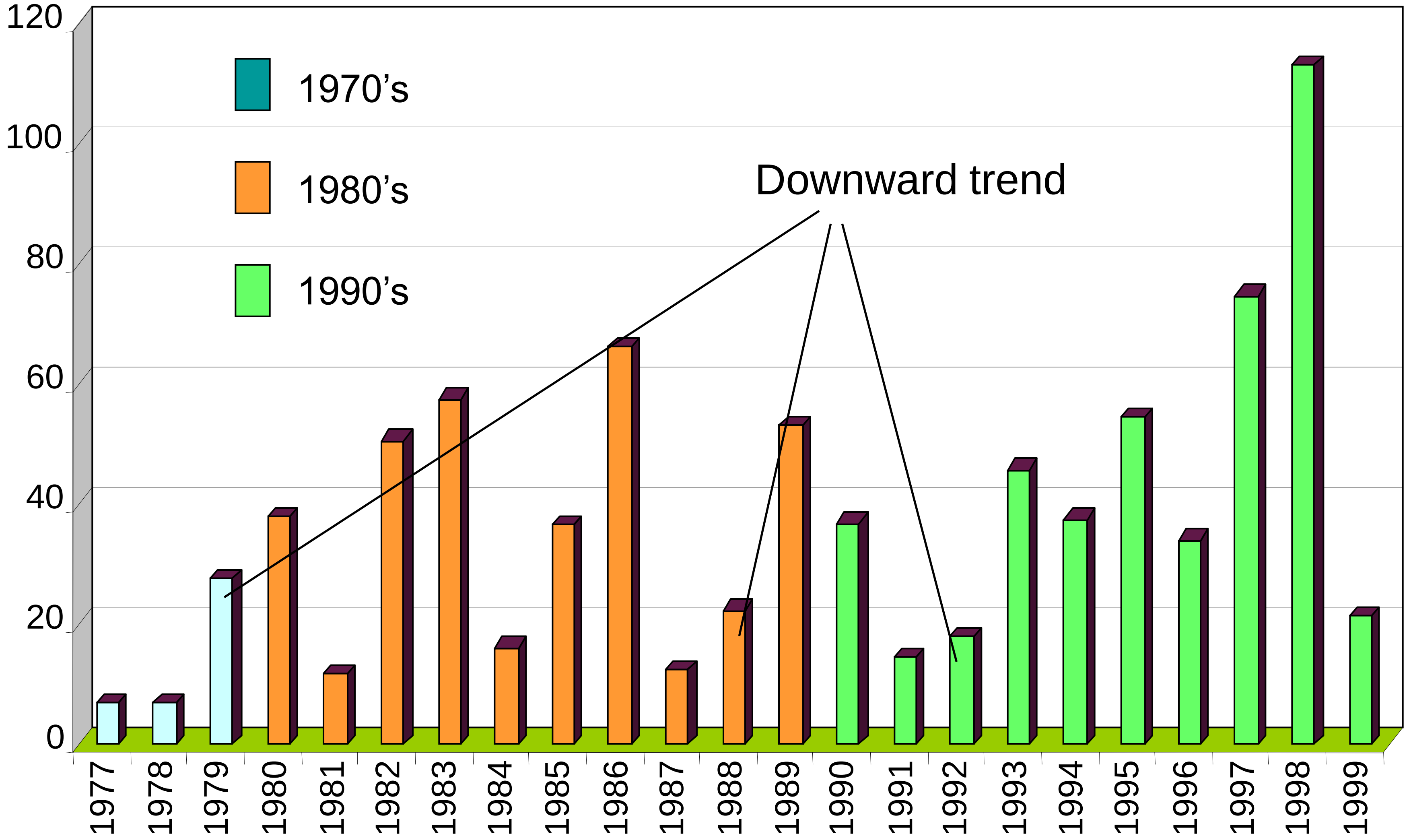


Chlorophyll *a* trends in San Francisco Bay (South Bay) – annual maximum in μg chl *a* L^{-1}



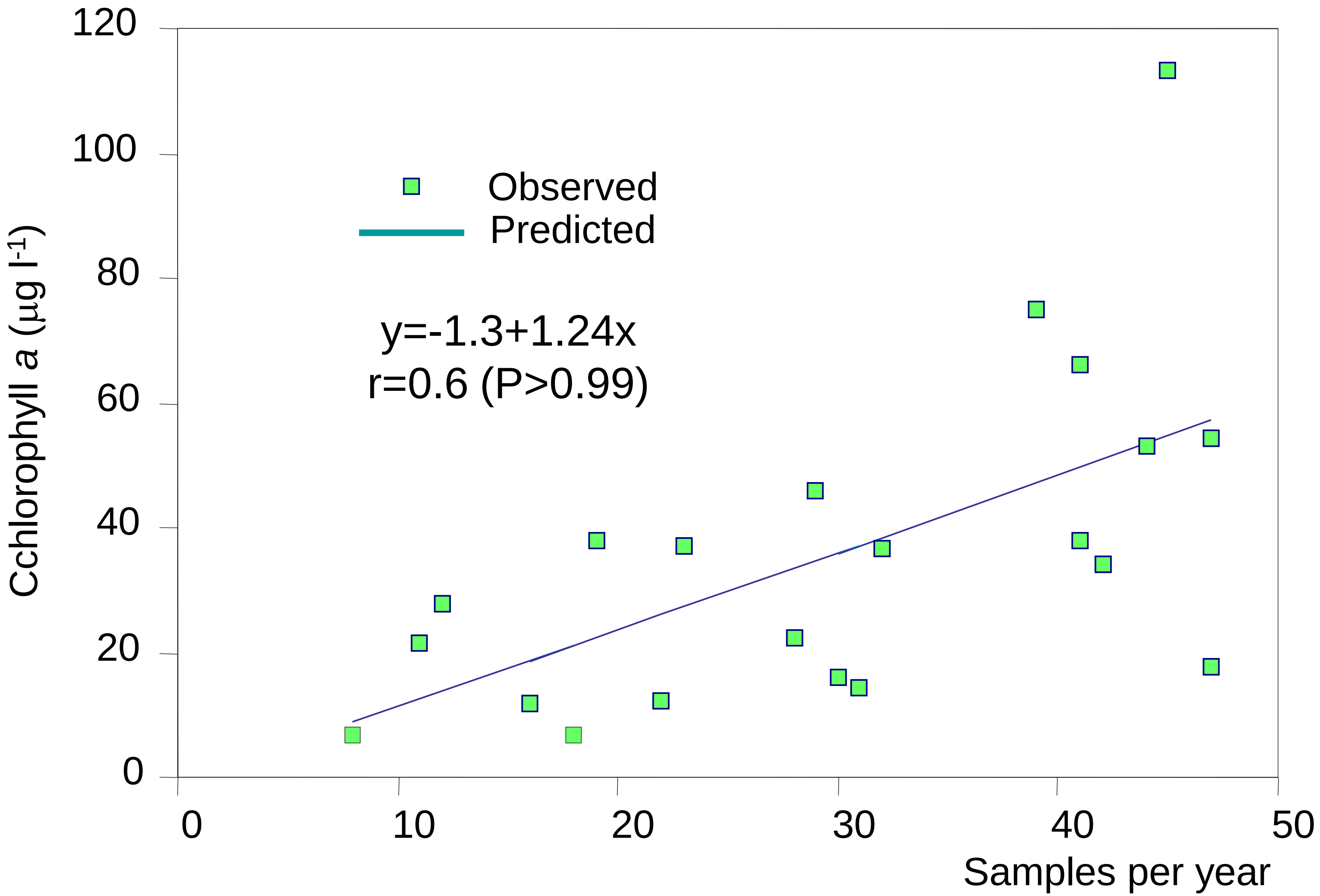
Pick a few years at random, chlorophyll is increasing.

Chlorophyll *a* trends in San Francisco Bay (South Bay) – annual maximum in μg chl *a* L^{-1}



Pick a few years at random, chlorophyll is decreasing.

Chlorophyll *a* maximum in San Francisco Bay (South Bay, μg chl *a* L^{-1}) as a function of number of samples

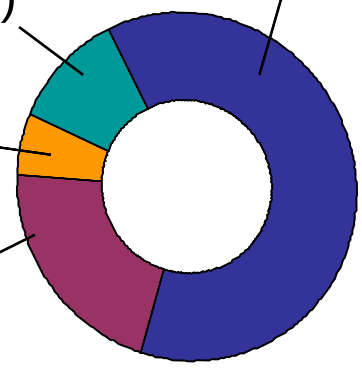


The more you sample, the higher the chlorophyll.

Primary production budget for the Tagus estuary (t C y^{-1})

Pelagic producers			Benthic producers		
Phytoplankton[*1]	41160	-62%	Microphytobenthos[*2]	4265	-6%
			Seaweeds	13770	-21%
			Saltmarsh vegetation[*4]	7700	-11%
Sub-total pelagic	*41160*	*-62%*	*Sub-total benthic*	*25735*	*-38%*

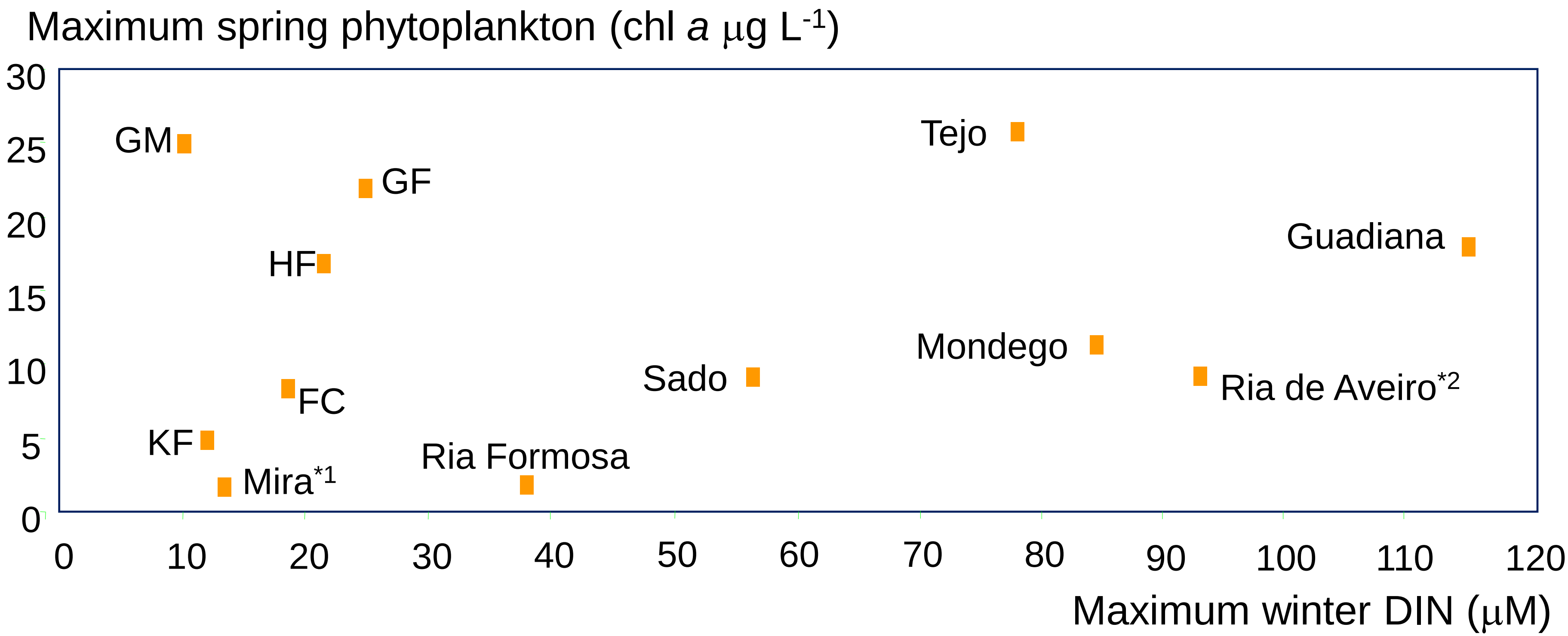
*1 – EcoWin2000 ecological model, Ferreira (2000)
*2 – Modelling and field measurements, Serôdio & Catarino (2000)
*3 – Modelling and field measurements, Alvera-Azcárate et al, (2002)
*4 – Modelling and field measurements, Simas *et al.* (2001)



Benthic production accounts for 38% of total carbon removal.

Alvera-Azcárate, A., Ferreira, J.G. & Nunes, J.P., 2002. Modelling eutrophication in mesotidal and macrotidal estuaries - The role of intertidal seaweeds. Est. Coast. Shelf Sci. 57(4), 715-724

The relationship between chlorophyll *a* and nutrients



Tett, P., Gilpin, L., Svendsen, H., Erlandsson, C.P., Larsson, U., Kratzer, S., Fouilland, E., Janzen, C., Lee, J., Grenz, C., Newton, A., Ferreira, J.G., Fernandes, T., Scory, S., 2003. Eutrophication and some European waters of restricted exchange. Continental Shelf Research, 23, 1635-1671.

[*1] – Chlorophyll determined from graphical data

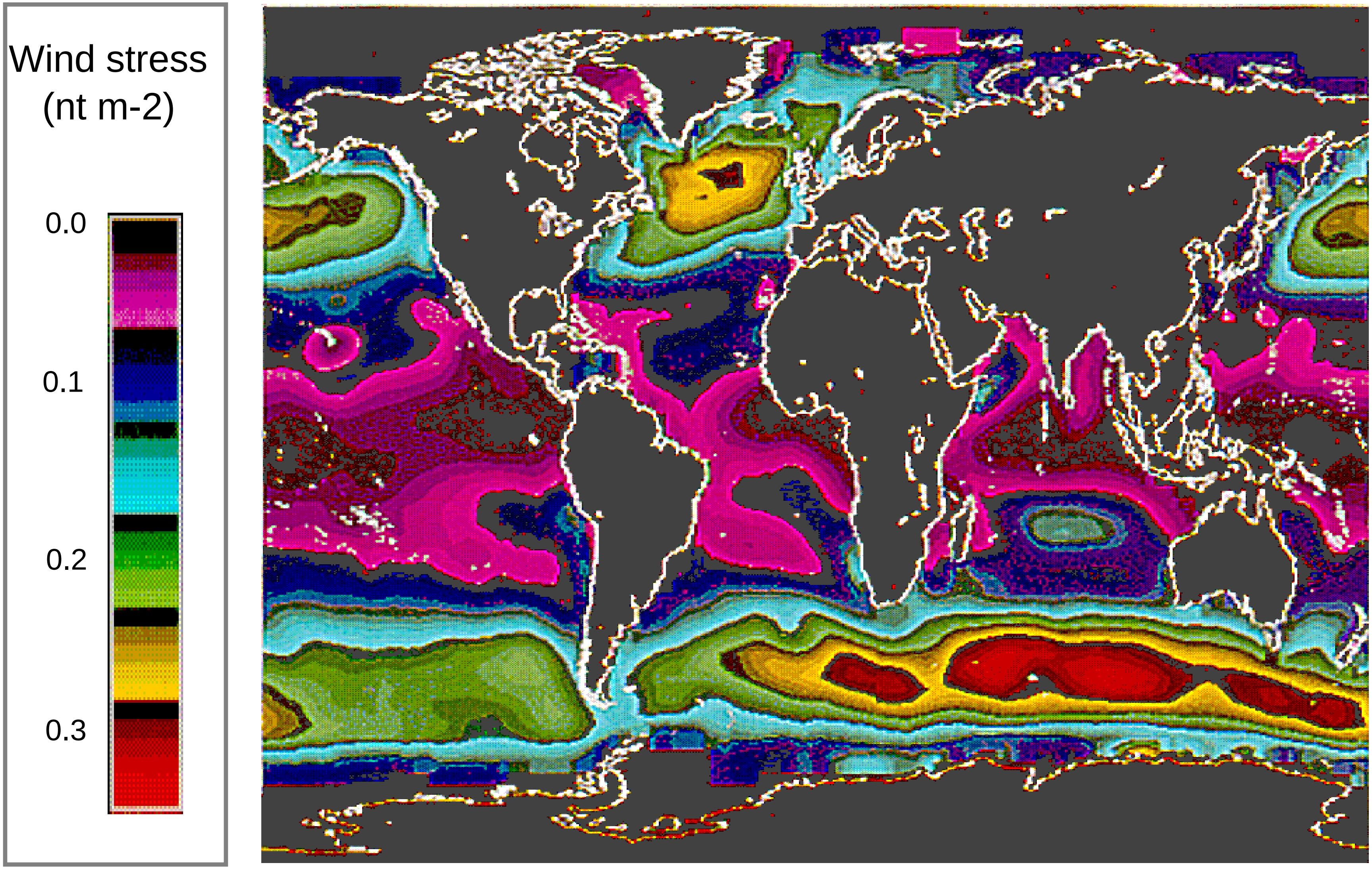
[*2] – Nitrate, not DIN

Why is there no relationship?

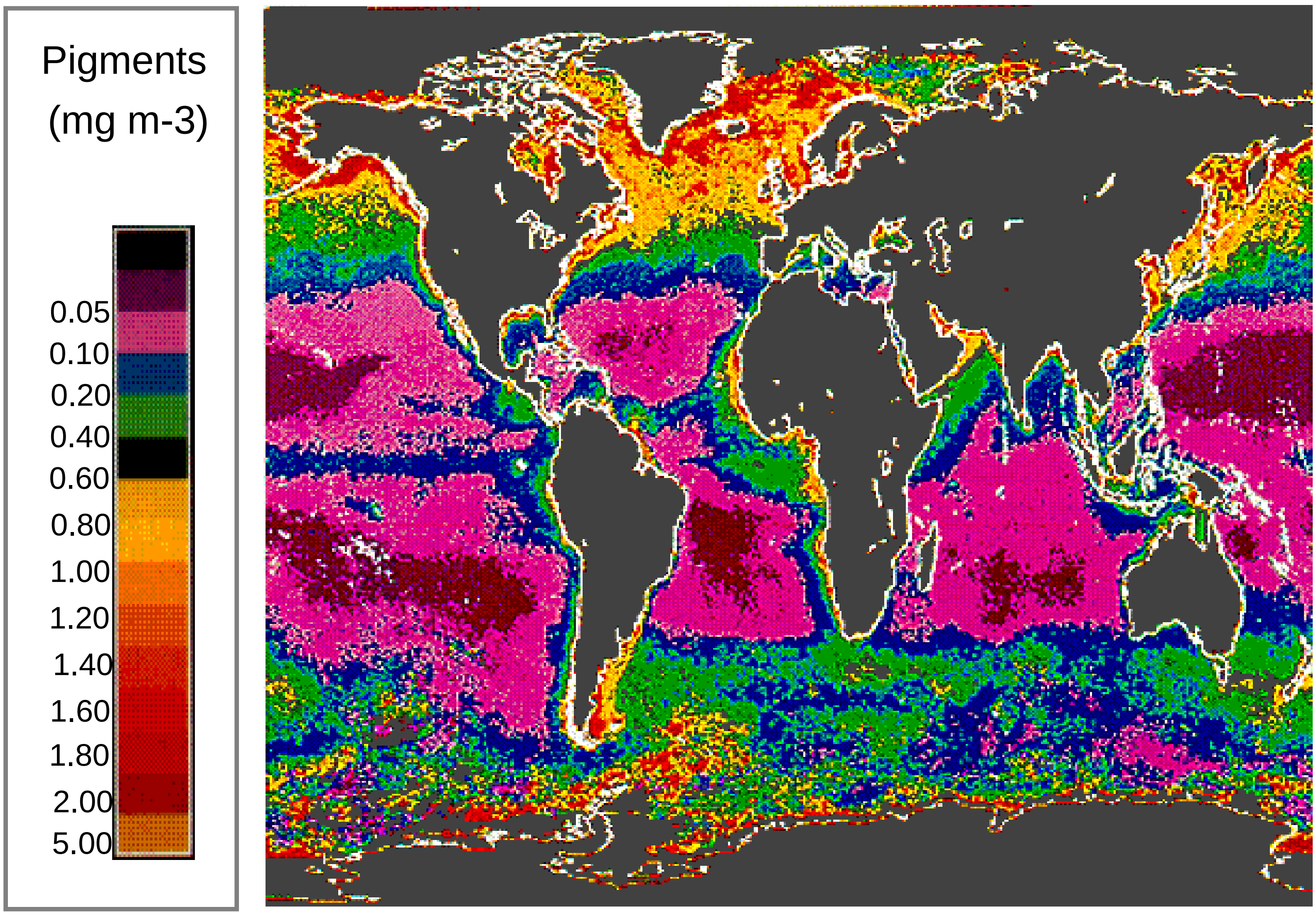
- Estuaries are not lakes
- Differences in residence time
- Range of turbidity
- Top-down pressure from filter-feeders such as clams
- Limiting factors vary
- Phytoplankton chlorophyll may not be the best, and is certainly not the only, indicator
- Nevertheless, ‘old’ thinking still defines the OSPAR COMPP approach to eutrophication assessment

Climate change, primary production, and micronutrients

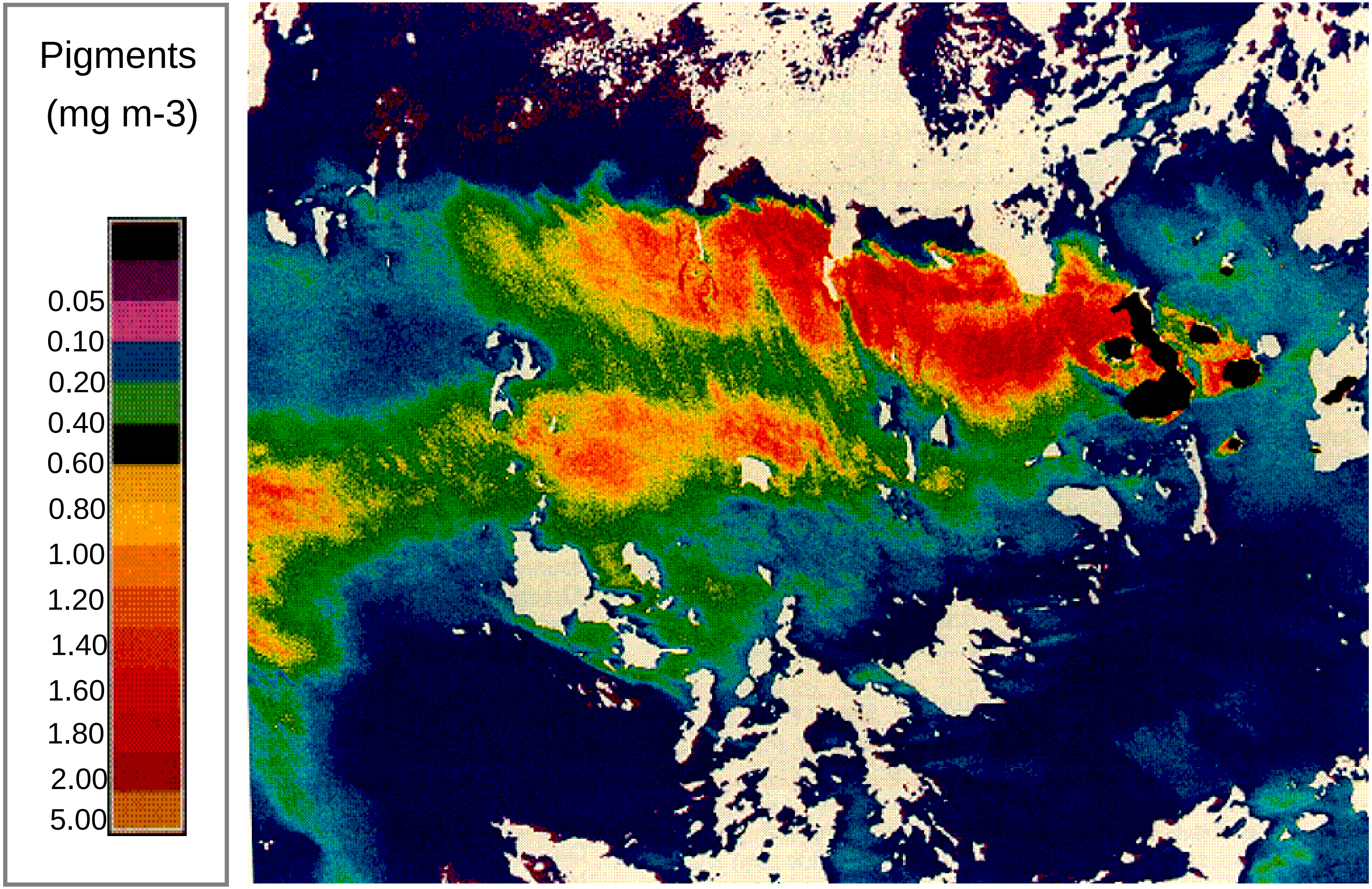
Global climatology of mean annual wind stress



Global seven year mean pigment fields

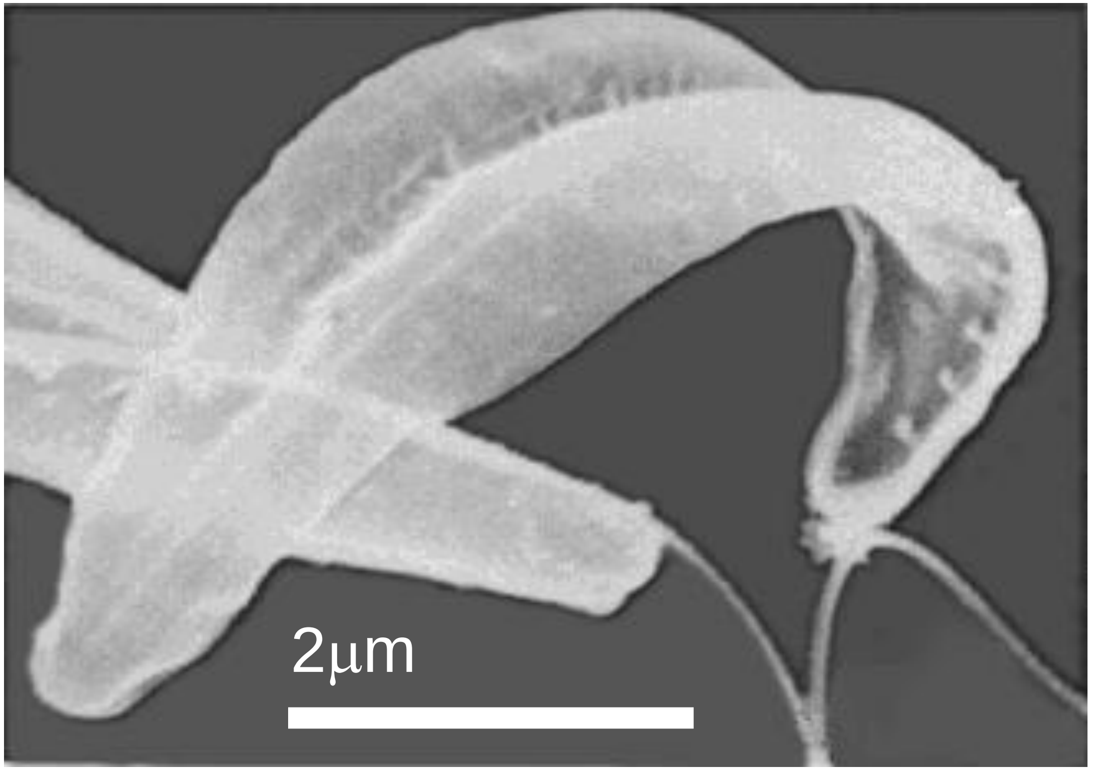


High nutrient low chlorophyll paradox



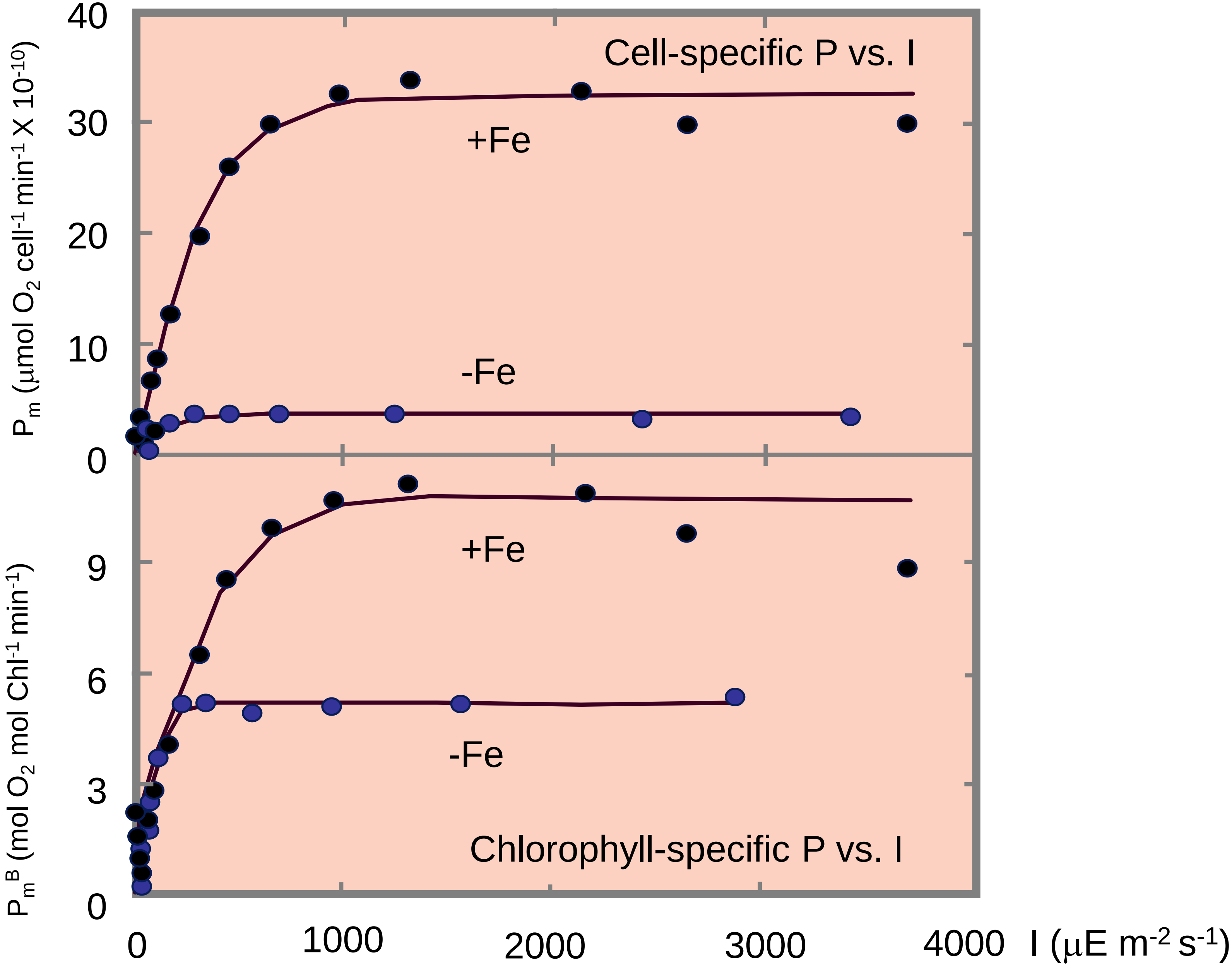
Phytoplankton from 40m Fe enrichment incubations

Nitschia sp.



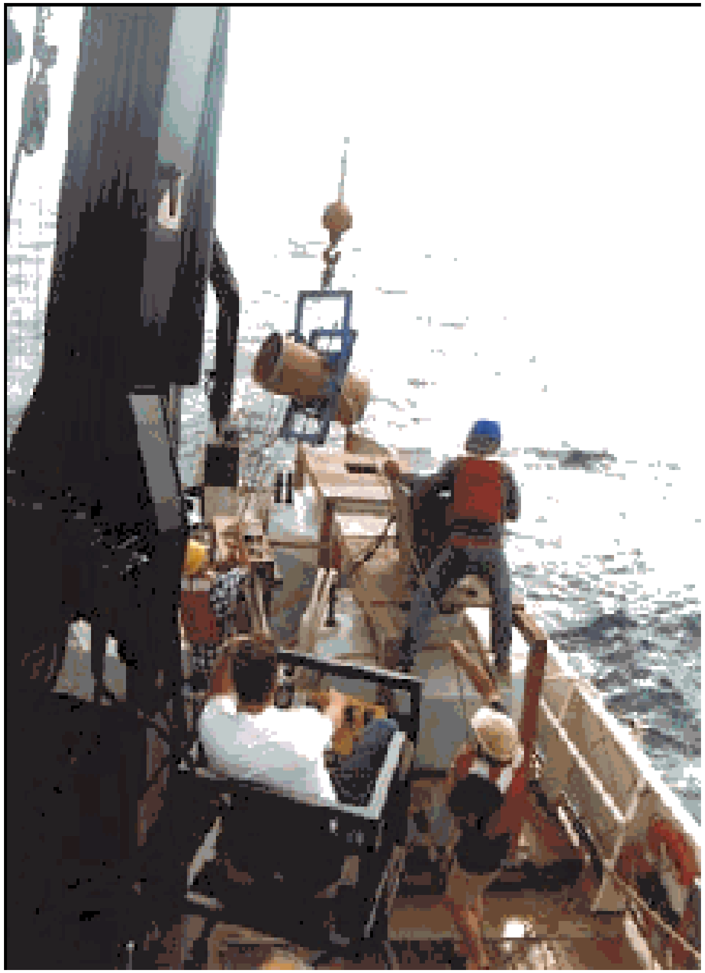
Chavez *et al*., 1991 - Limnol. & Oceanog. 36, p. 1816-33

Effect of iron on P-I curves for *Phaeodactylum tricornutum*



Greene et al., 1991. Limnol. & Oceanog. 36, 8, 1772-1782

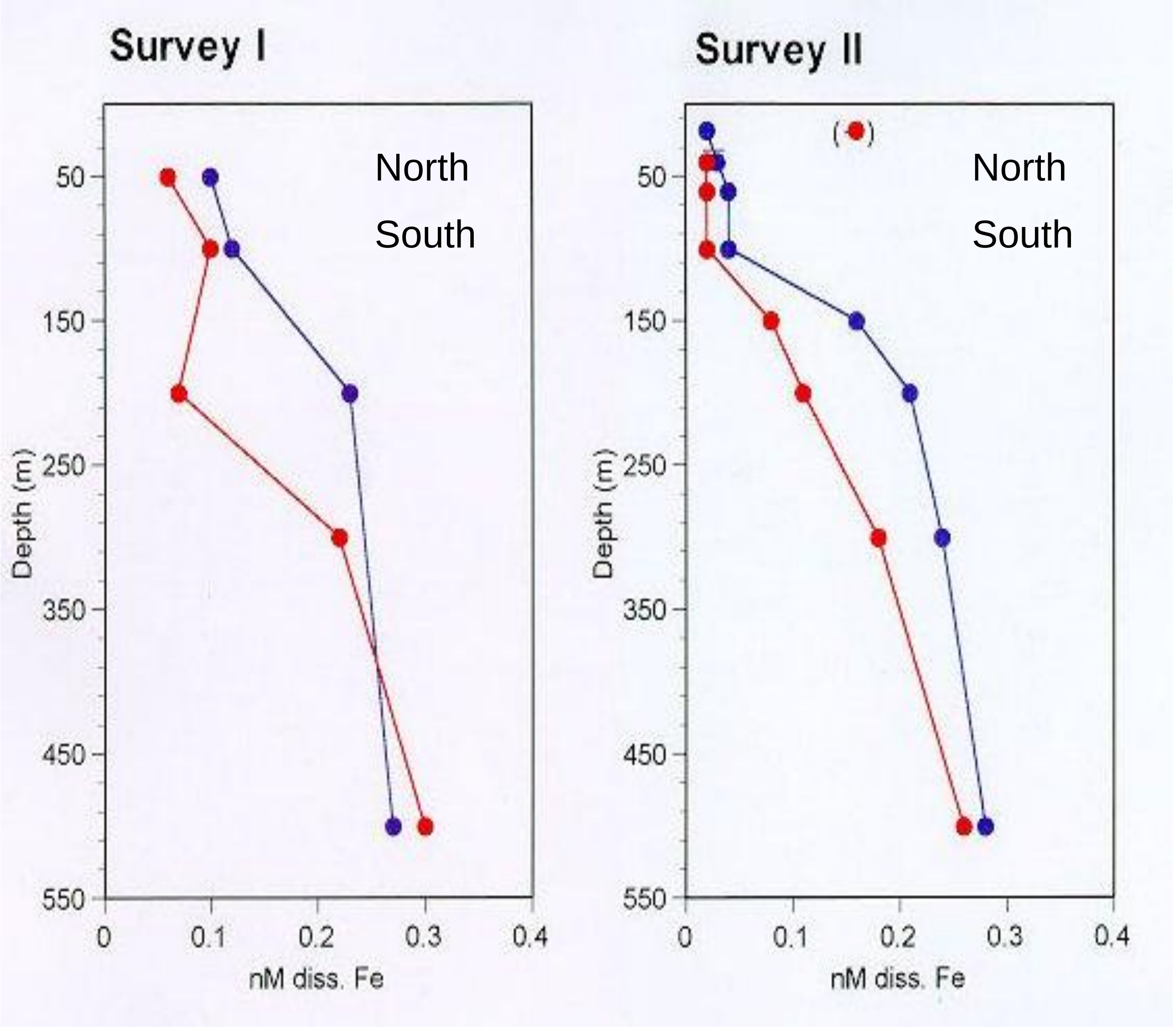
IronEx I - Large-scale patch experiment in 1993



Mixing Fe and SF_6 (artificial tracer) in the equatorial Pacific Ocean.

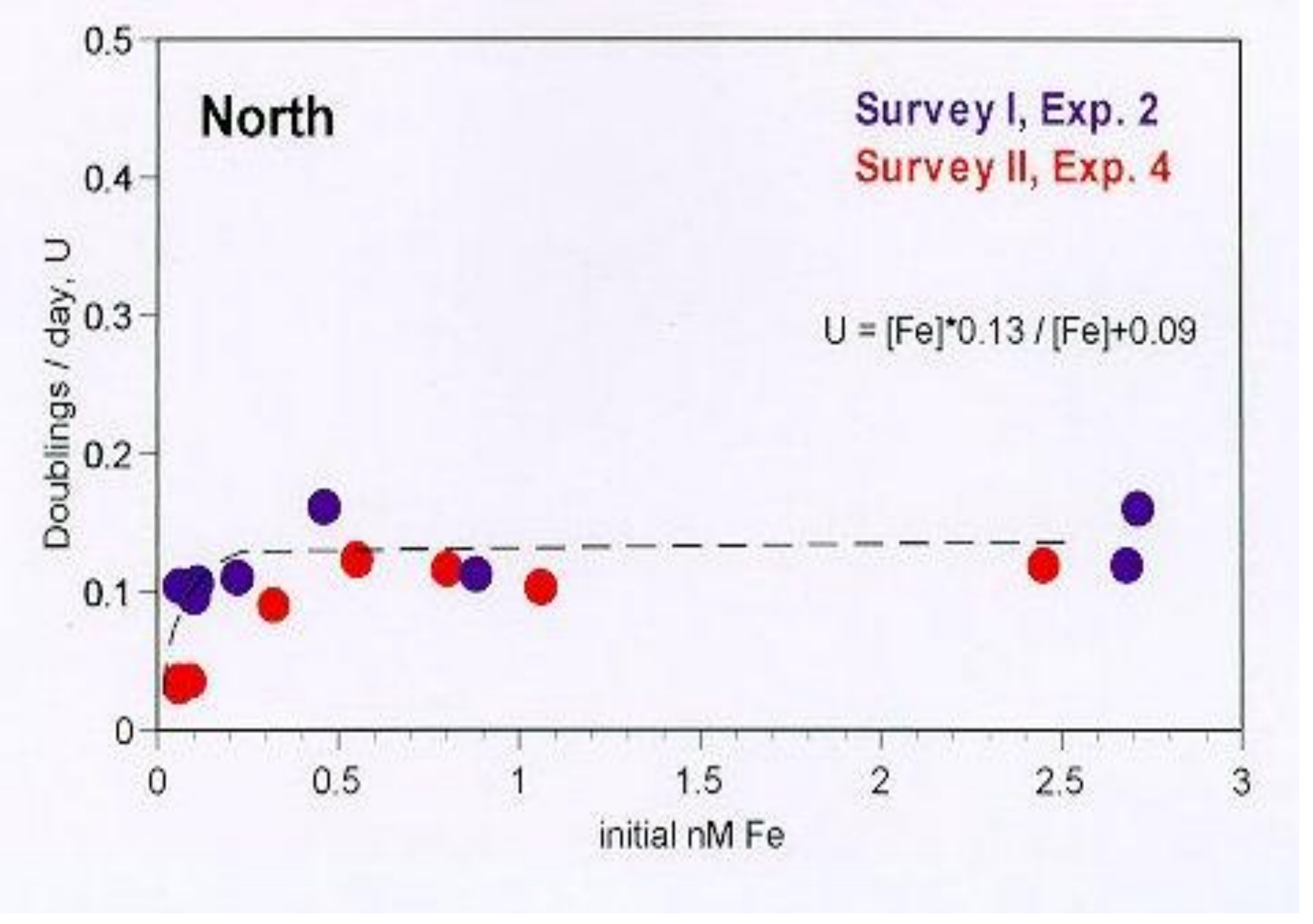
IronEx I was followed by IronEx II in 1995, which showed conclusively that phytoplankton production may be limited by Fe.

Dissolved Fe profiles - Antarctic Polar Front



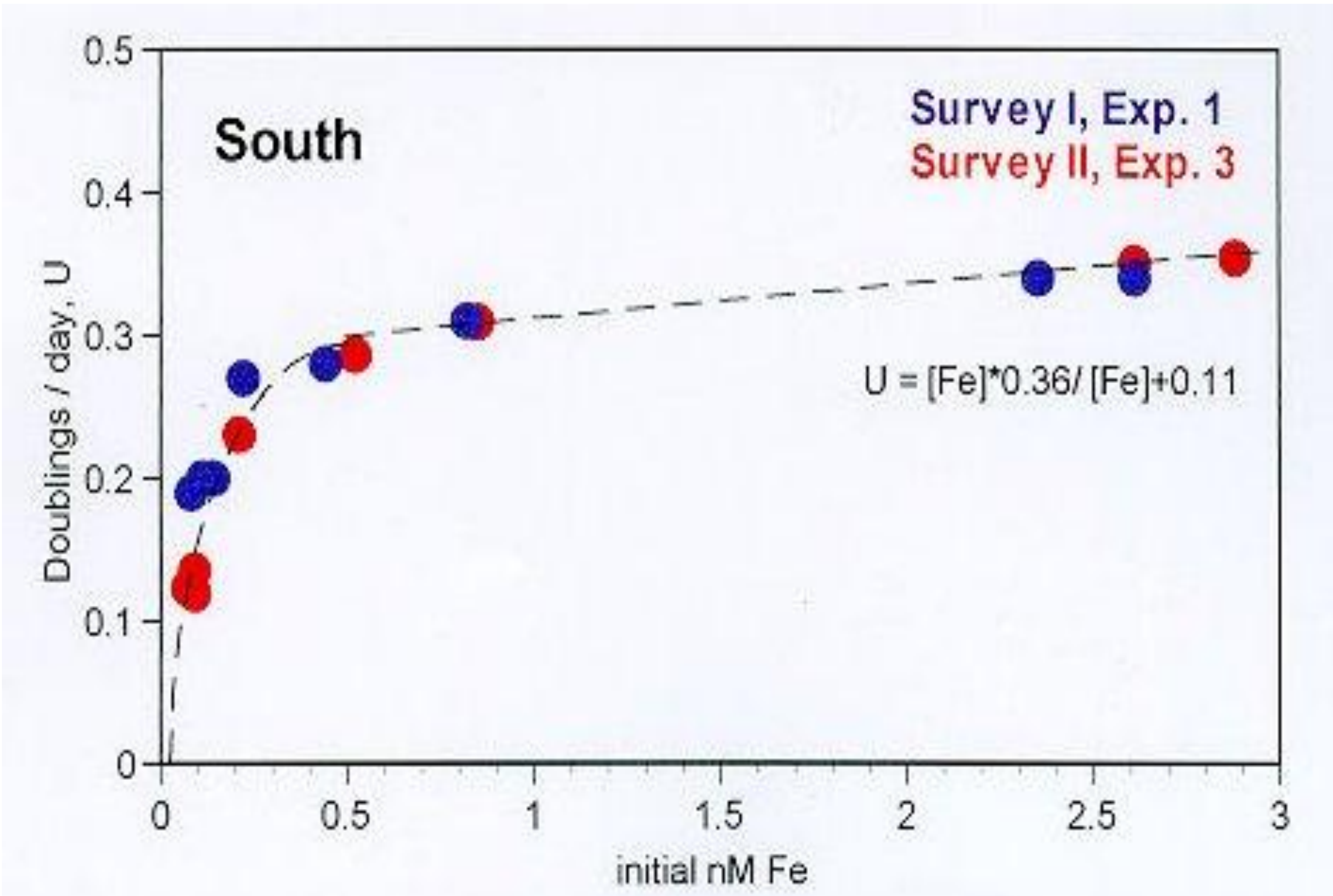
Dissolved Fe profiles North (red) and South (blue) of the Polar Front during JGOFS experiment in the late 1990's

Phytoplankton growth rates versus initial Fe concentration



Phytoplankton incubation experiments North and South of Polar Front during Survey I (blue) and Survey II (red)

Phytoplankton growth rates versus initial Fe concentration



Phytoplankton incubation experiments North and South of Polar Front during Survey I (blue) and Survey II (red)

Phytoplankton growth rates versus initial Fe concentration

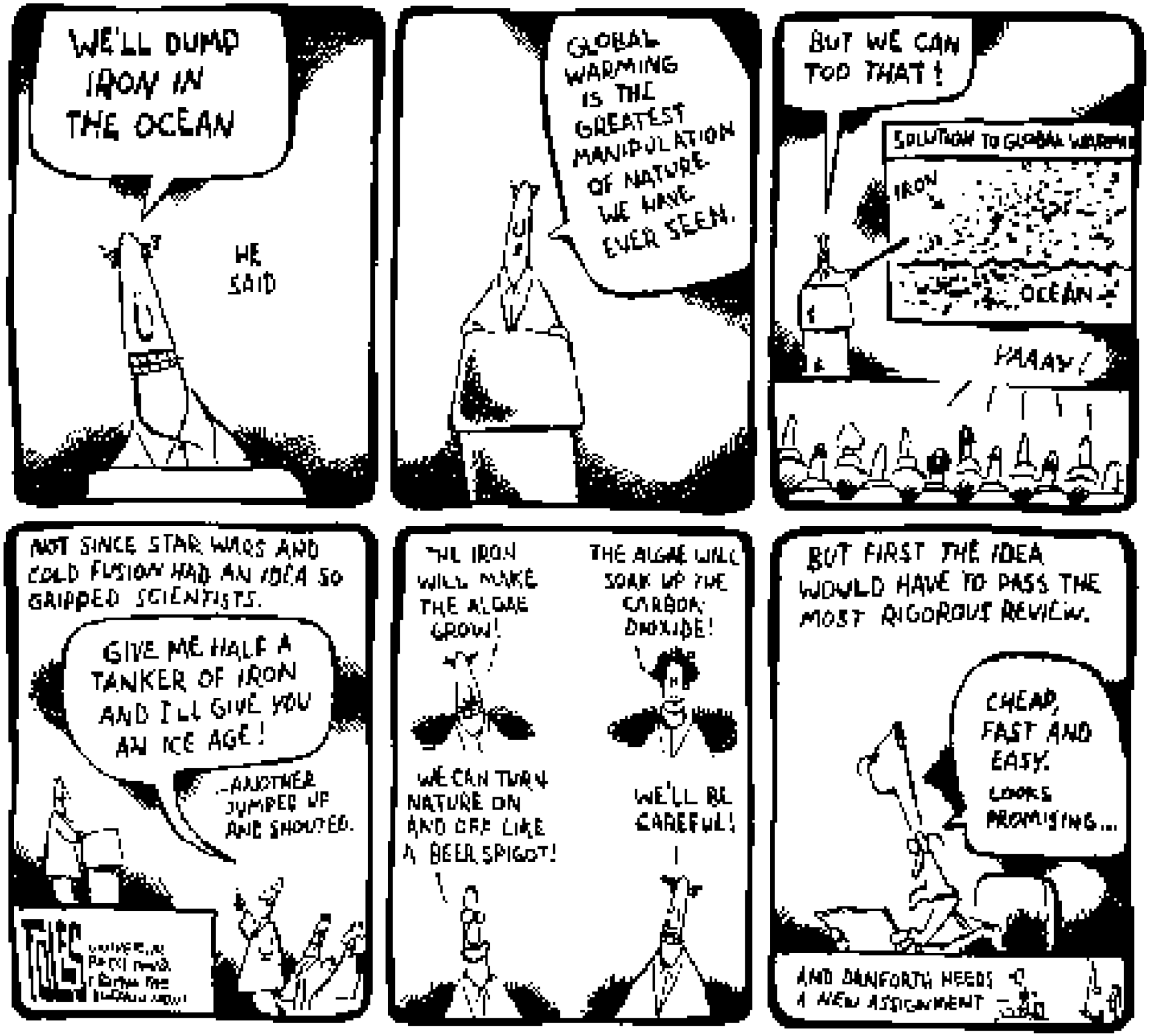
<u>Comparison between North and South results</u>

"The pseudo-Michaelis Menten response to added iron in deckboard enrichment experiments differs north of the APFZ relative to south of the APFZ, indicating:

- All dissolved iron concentrations are below half saturation constants, indicating limiting conditions persist throughout the entire Southern Ocean.
- Waters to the North may be limited by something in addition to iron (silicate).
- Similar saturation values are consistent with other observations from other oceans."

http://color.mlml.calstate.edu/www/news/workshp2.htm

High Nutrient Low Chlorophyll Paradox



Synthesis

- Different kinds of primary producers in the sea
- Rates of primary production (and therefore carbon fixation) are difficult to measure and very difficult to scale
- An excess of primary production in coastal zones is now common in many parts of the world
- The study of primary production is important for understanding world food supply, coastal eutrophication, and climate change

All slides

http://ecowin.org/aulas/mega/pce