Sistemas de Informação e Modelação em Ambiente

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Primary production modelling

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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
- 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

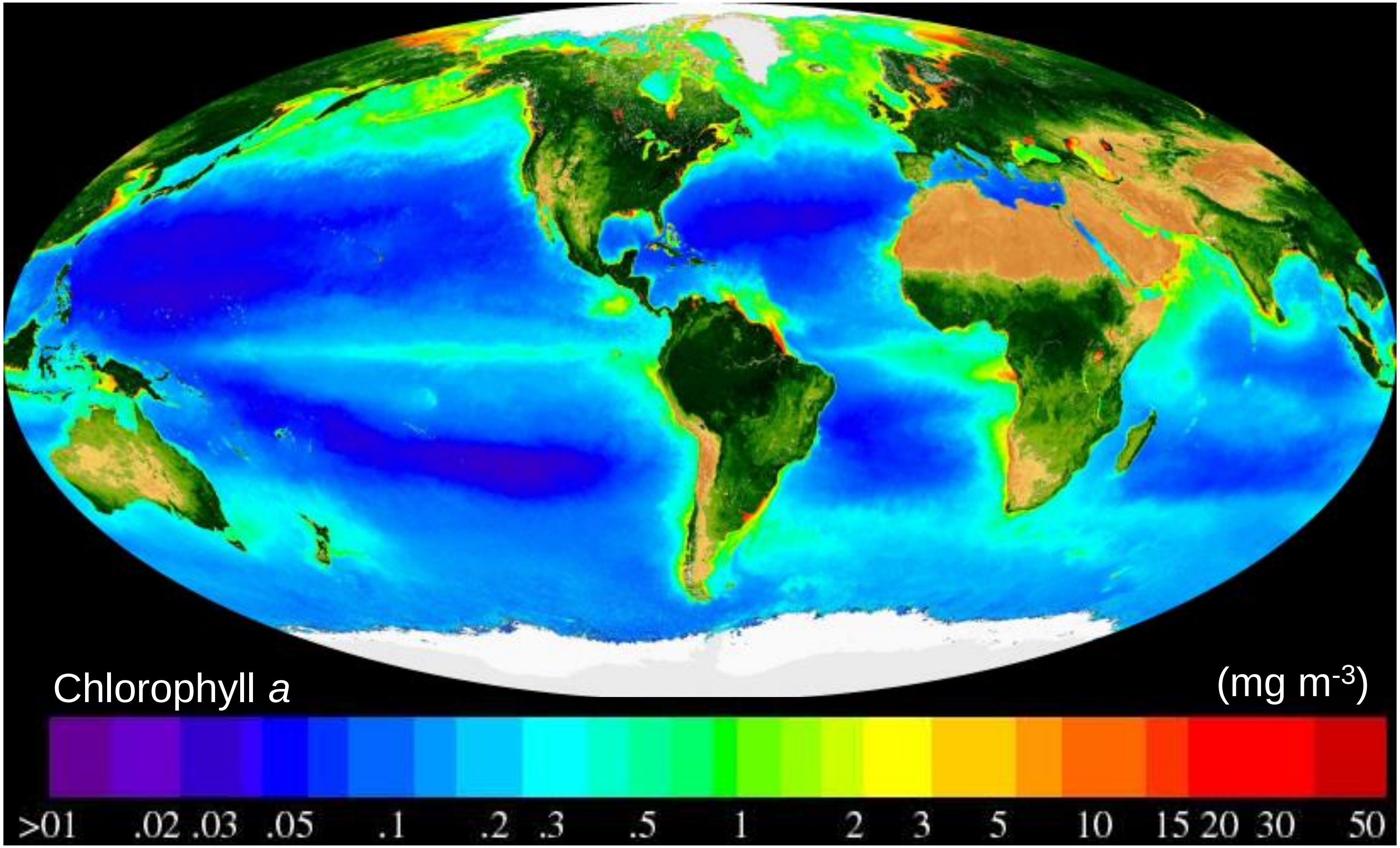
Producer	Nutrient source	Examples
Phytoplankton	Water column	Diatoms/dinoflagellates
Microphytobenthos	Water column, sediment pore water	Penate diatoms
Macroalgae (seaweeds)	Water column	*Fucus, Laminaria, Ulva*
Saltmarsh plants	Sediment	*Spartina*
Seagrasses (SAV)	Sediment and water	*Zostera, Posidonia*

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

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

Ecosystem relevance

Global distribution of chlorophyll from satellite data

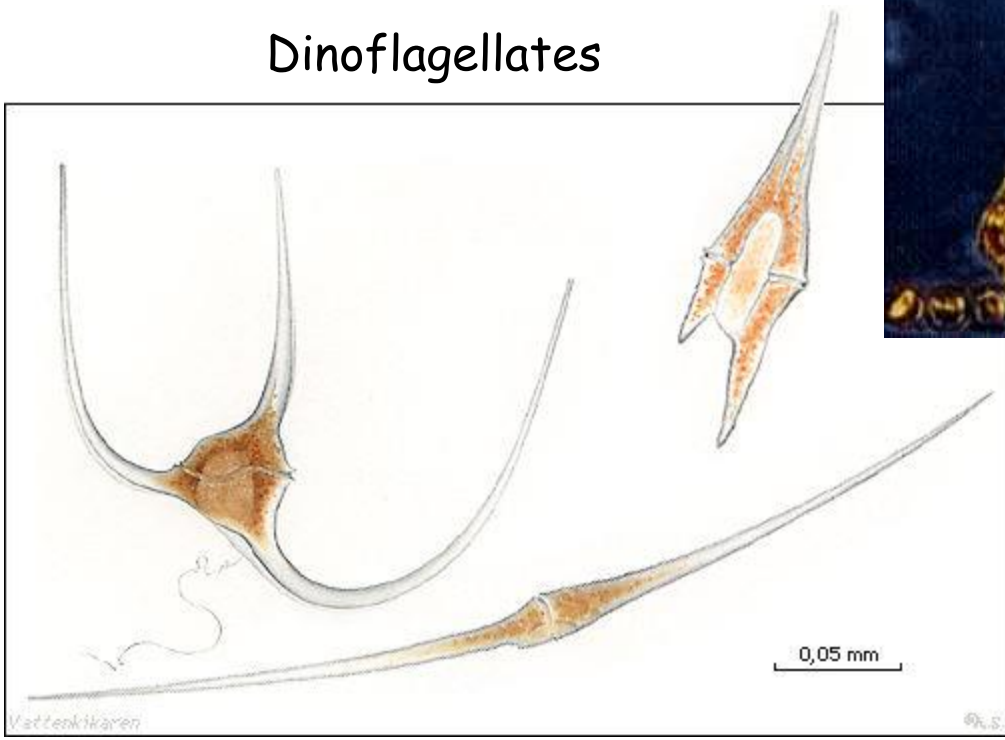


Data fromSEAWIFS, summer in the northern hemisphere (1998-2001)

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

Phytoplankton
Some examples

Dinoflagellates



Coccoliths

Management relevance
Harmful Algal Bloom (HAB) events

This (non-toxic) *Noctiluca* bloom (California) led to coastal resource impairment.

Management relevance

Harmful Algal Bloom (HAB) events

Cyanobacteria bloom in the Potomac estuary, near Washington D.C.

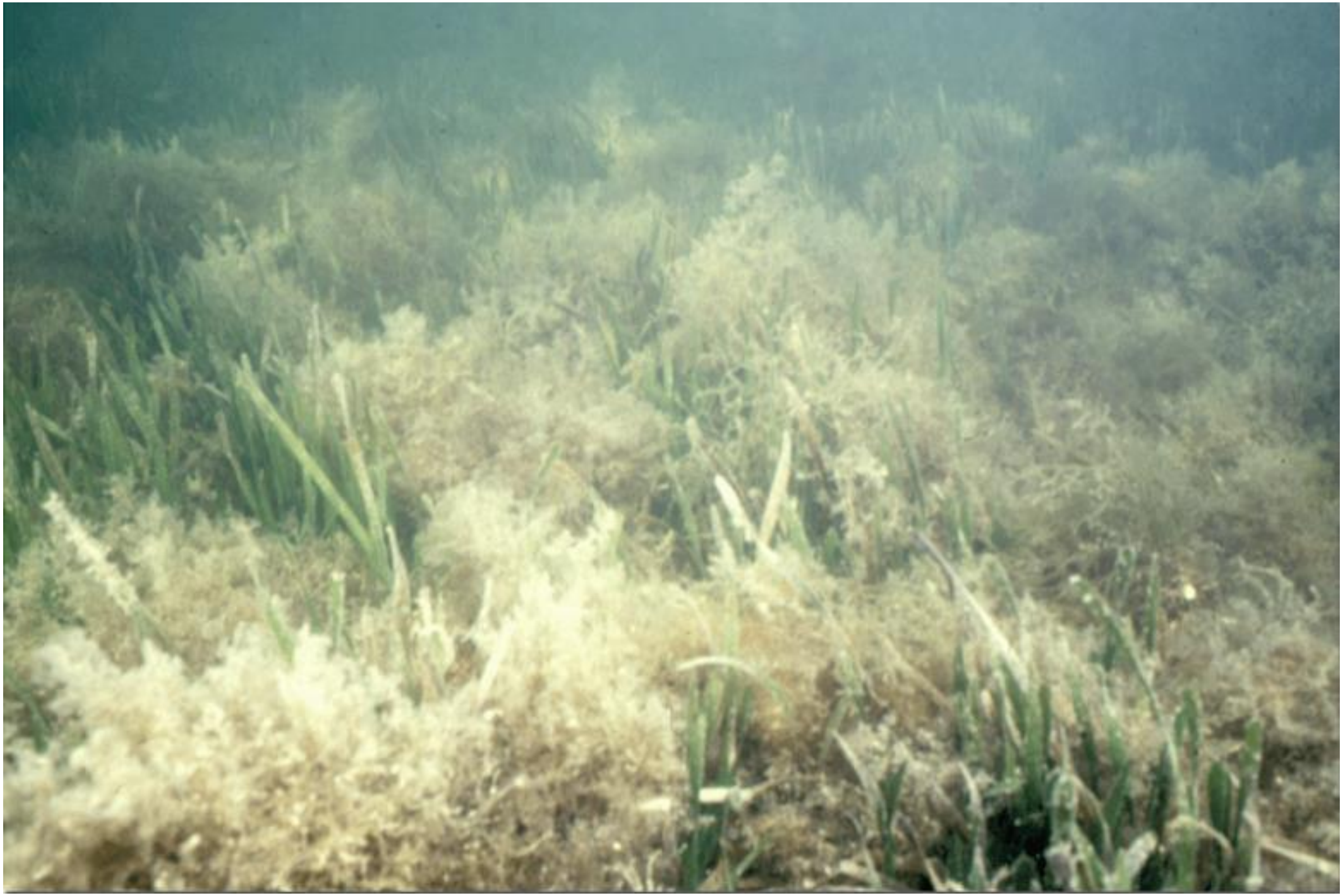
Management relevance

Harmful Algal Bloom (HAB) events

Toxic algae killed 26 million salmon in Chilean aquaculture, 2016.

Management relevance

Macroalgal bloom in Florida Bay, USA



Courtesy Brian Lapointe, Harbor Branch Oceanographic Institute.

Impact of eutrophication on submerged aquatic vegetation (SAV) and fisheries.

Eutrophication in the Yellow Sea

Ulva prolifera in Jiaozhou Bay, NE China, 2008

These macroalgal blooms have occurred annually for the last few years

Eutrophication in the Yellow Sea

Ulva prolifera in Jiaozhou Bay, NE China, 2013

These macroalgal blooms have occurred annually for the last few years

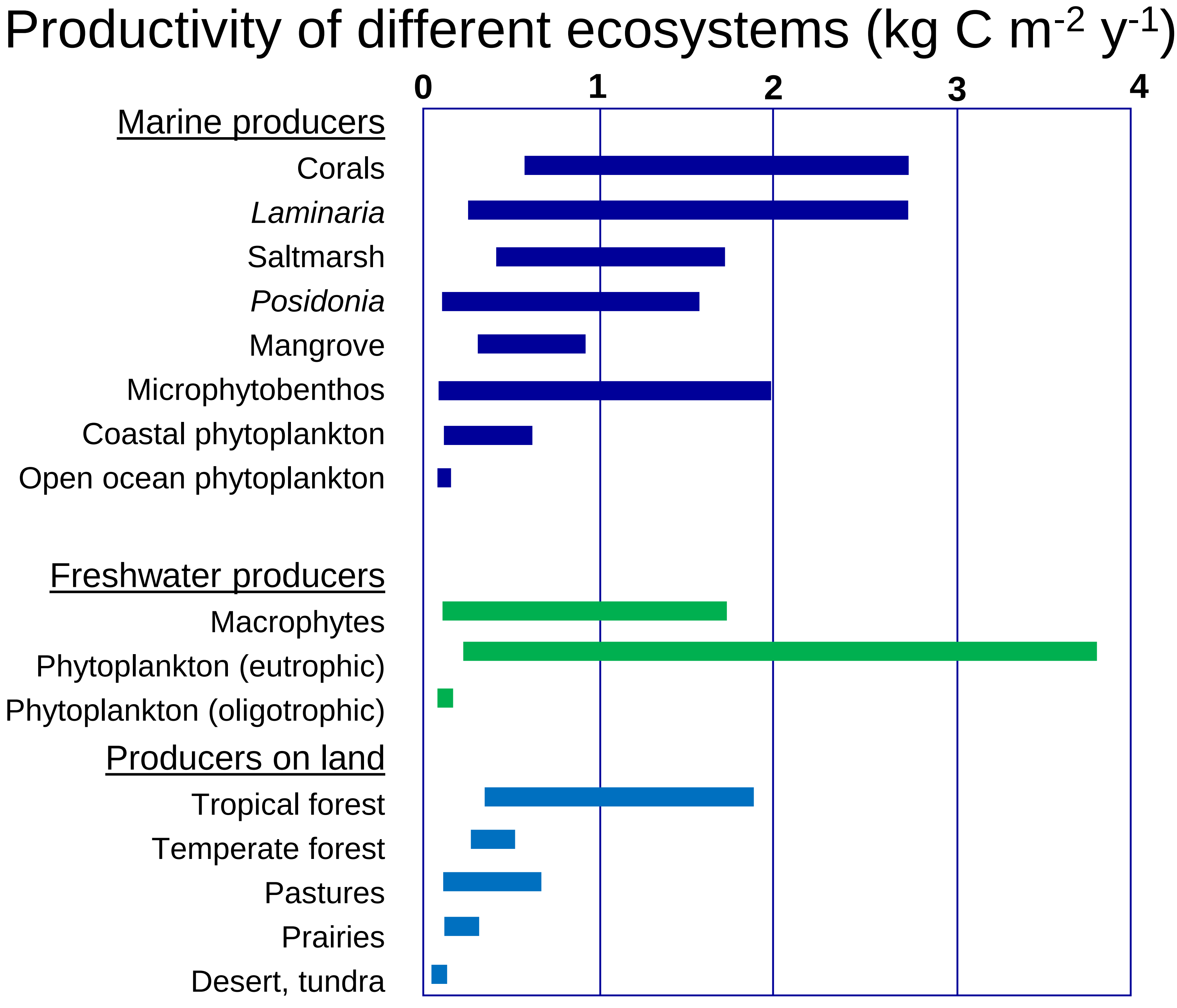
Eutrophication in the Yellow Sea

Ulva prolifera in Rizhao, NE China, 2015

These macroalgal blooms have occurred annually for the last few years

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

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



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.

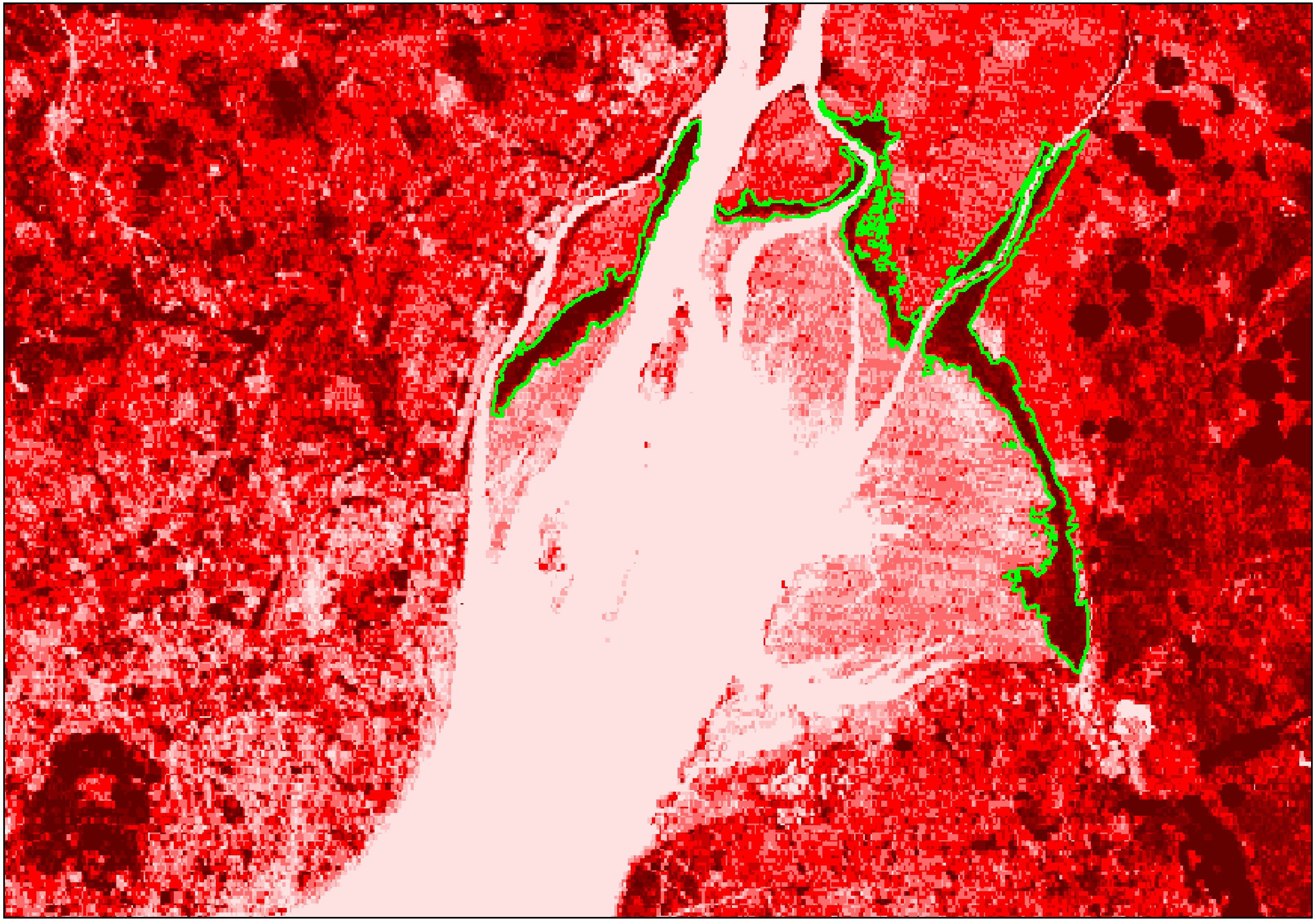
Whittaker & Likens, 1975. The Biosphere and Man. Primary productivity of the biosphere. Springer-Verlag.

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	$g\ C\ m^{-2}\ d^{-1}$

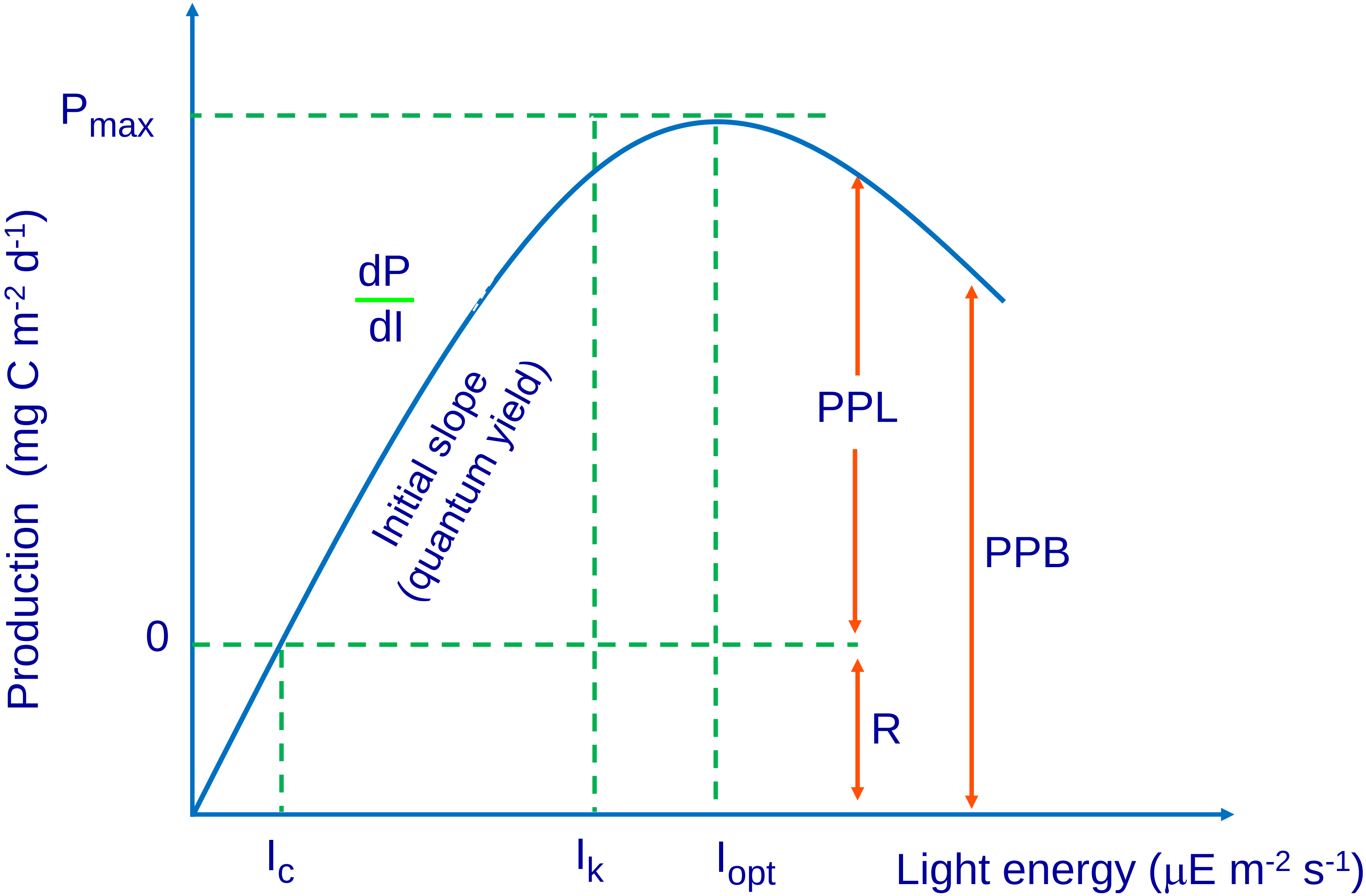
Different methods are used for different producers. Upscaling may be done using models, including GIS, remote sensing, and dynamic simulation.

Saltmarsh production estimated by cropping, NDVI, and bathymetry



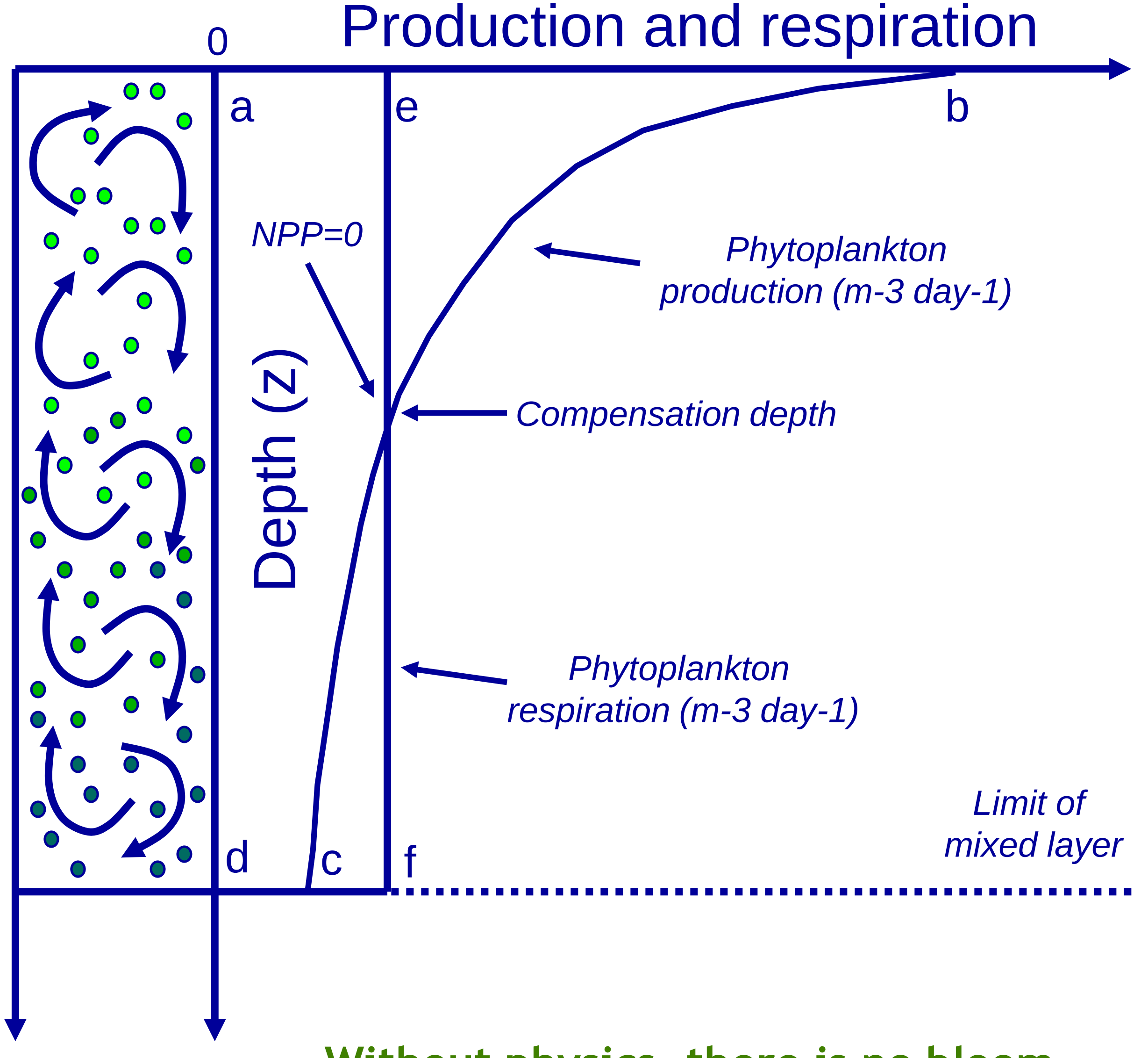
NDVI = (Near_Infrared - Red) / (Near_Infrared + Red) Near_Infrared and Red are two satellite image bands. NDVI ranges between -1 and 1. Pigments absorb lots of energy in R, but barely any in NIR. Other objects absorb both spectra identically.

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



Some producers display photosaturation, others display photoinhibition.

Phytoplankton blooms and vertical mixing



Integrated production(GPP)
abcd

Integrated respiration
aefd

Conditions for blooming
abcd > aefd

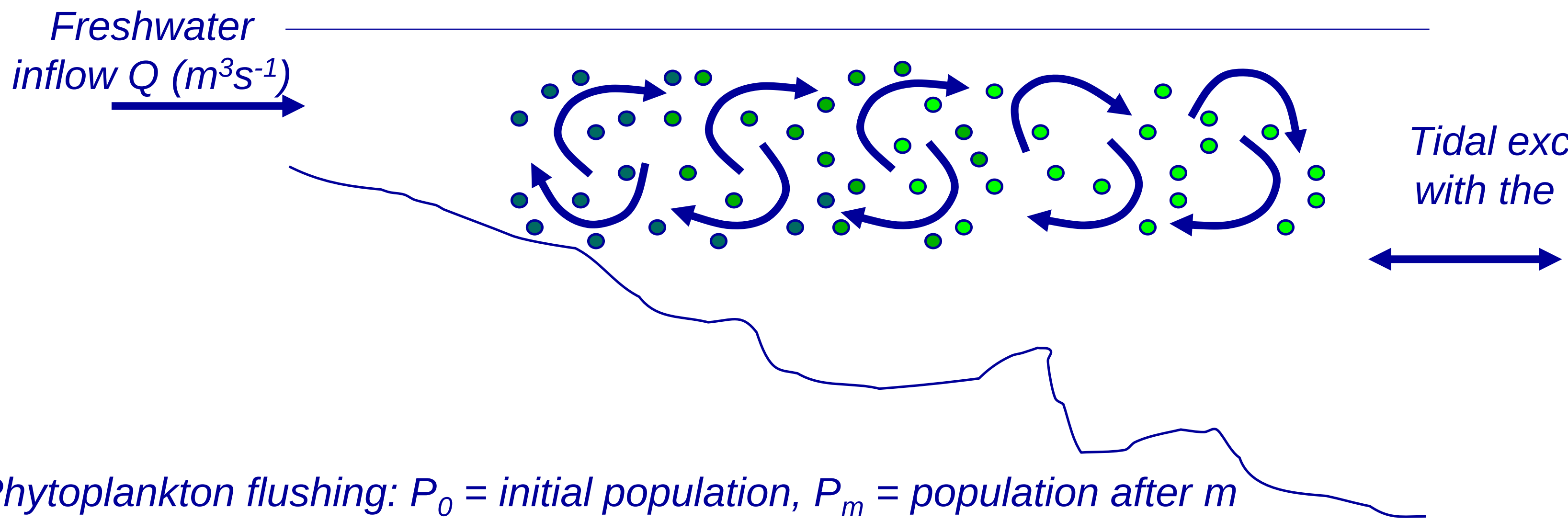
Without physics, there is no bloom.

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

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)

$$P_m = P_0 \, (1\text{-}r)^m$$

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

$P_t = P_0 e^{kt}$

Flushing

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

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

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

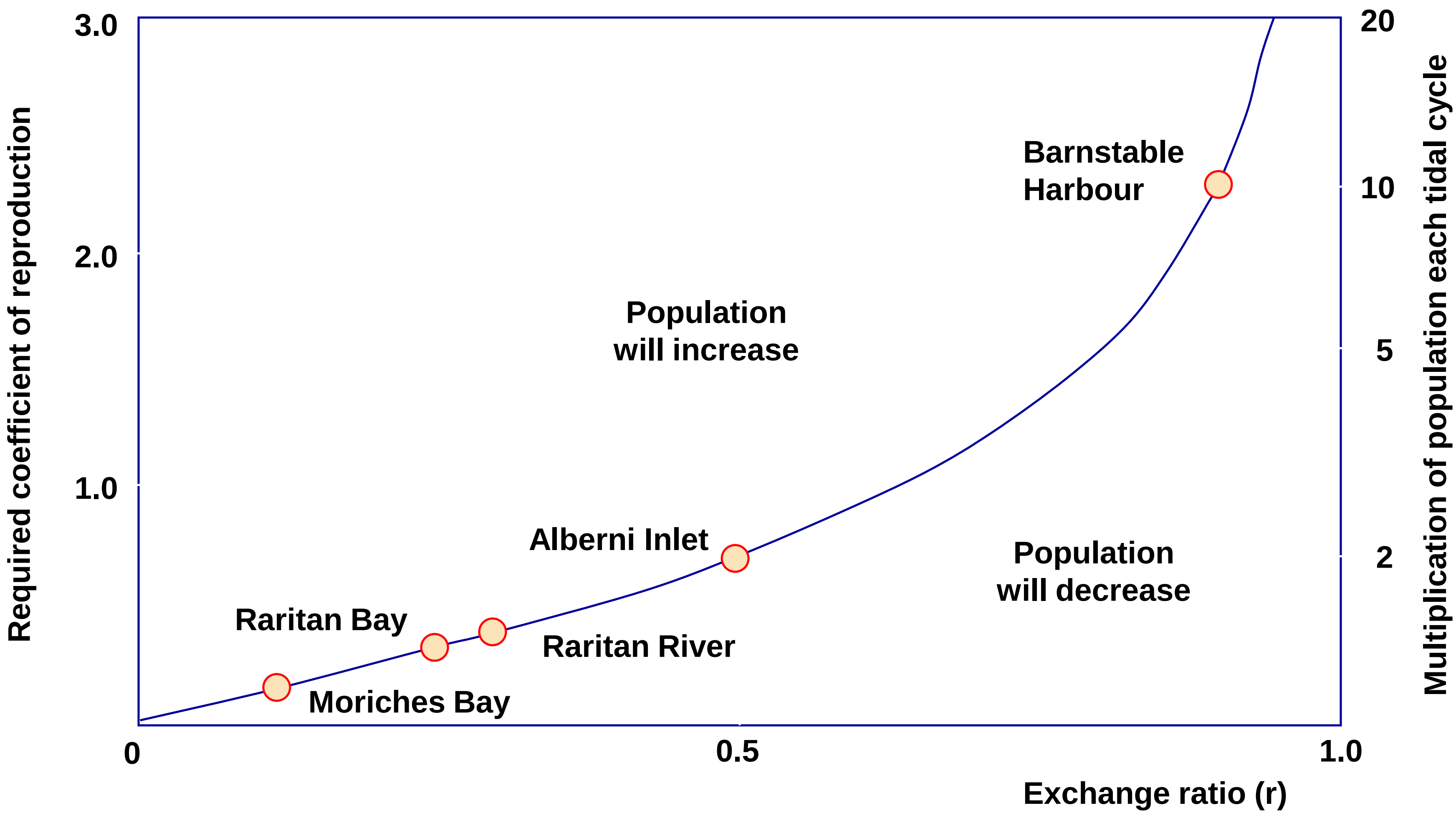
$$\frac{1}{(1-r)^m} = e^{mk}$$

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

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

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

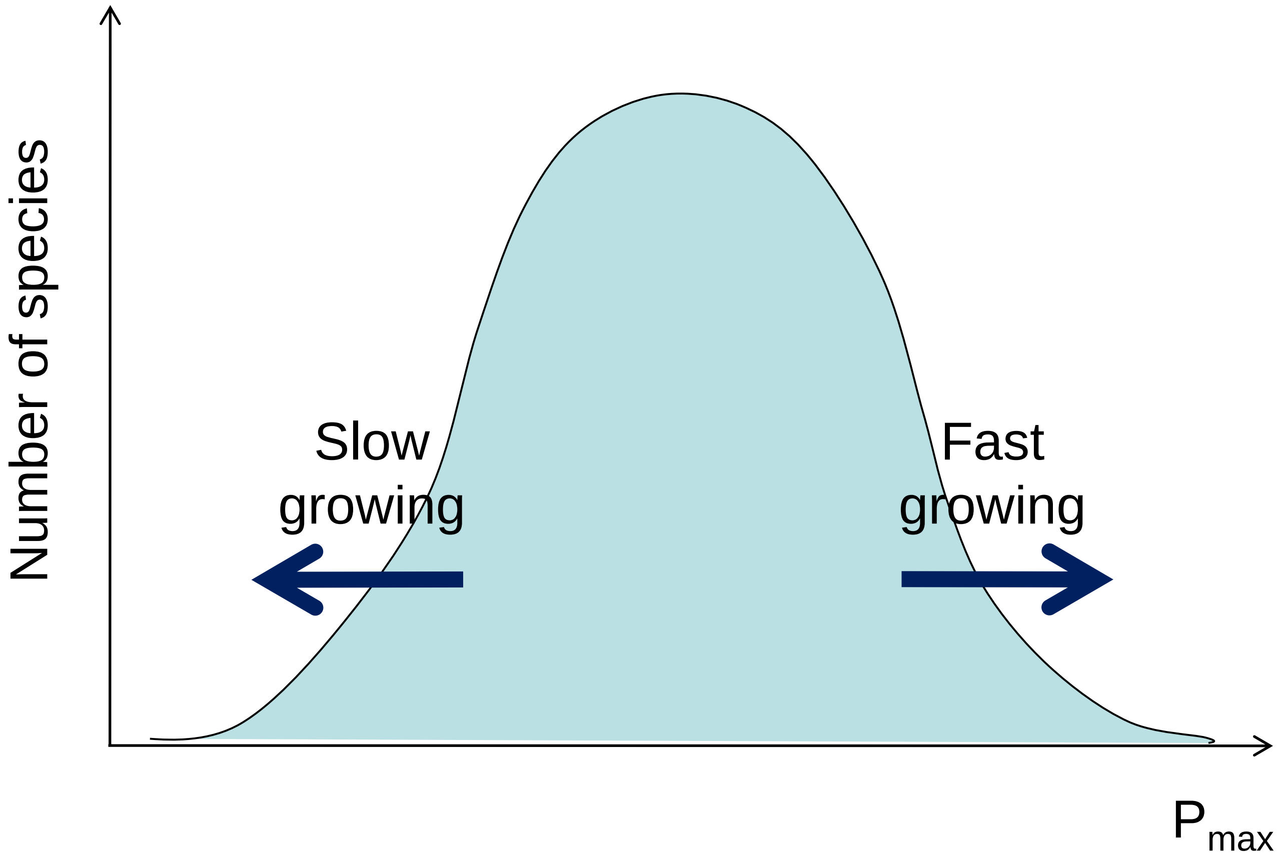
Phytoplankton blooms and tidal mixing in estuaries



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

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

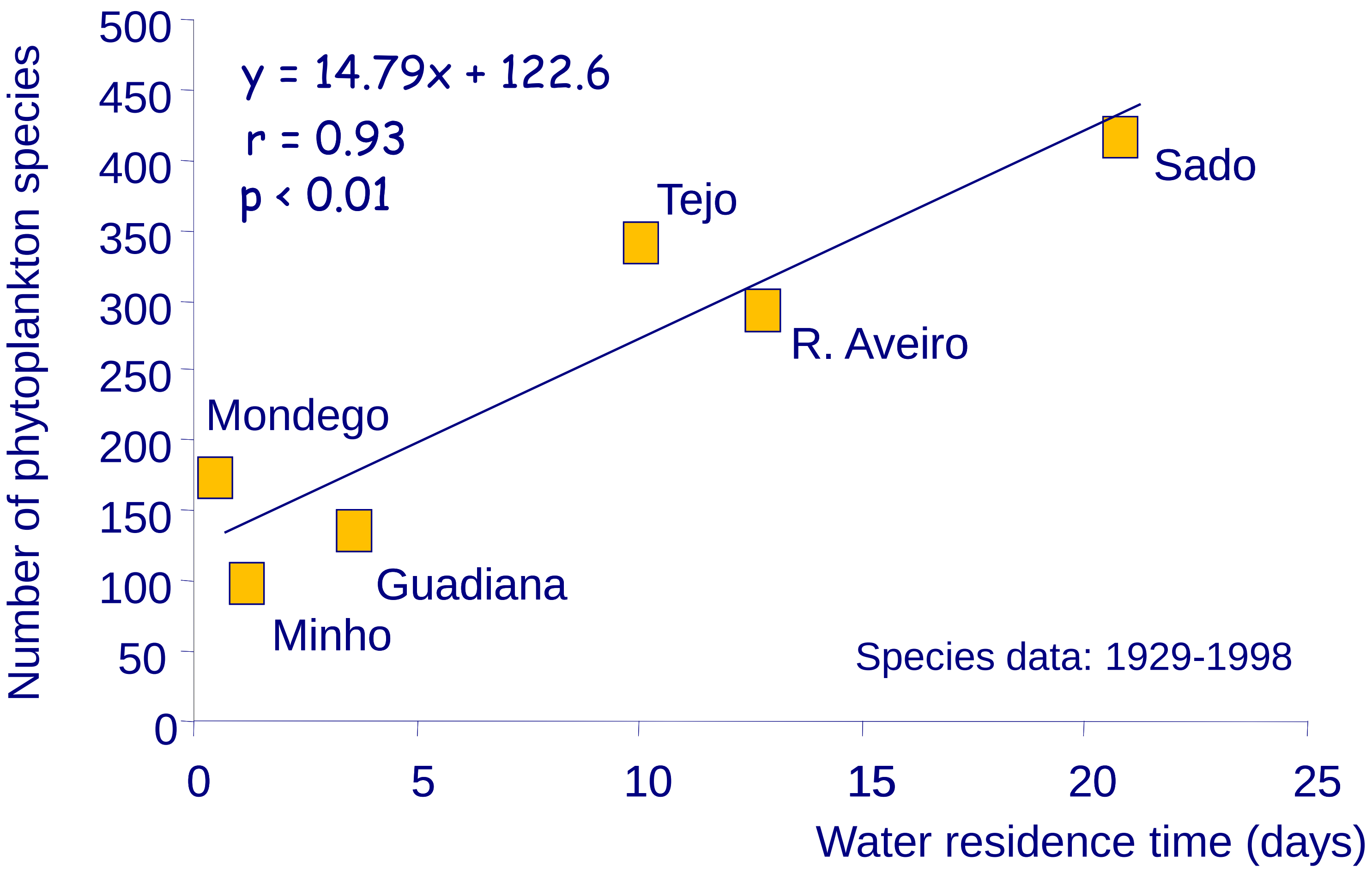
Biodiversity of phytoplankton in estuaries



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.

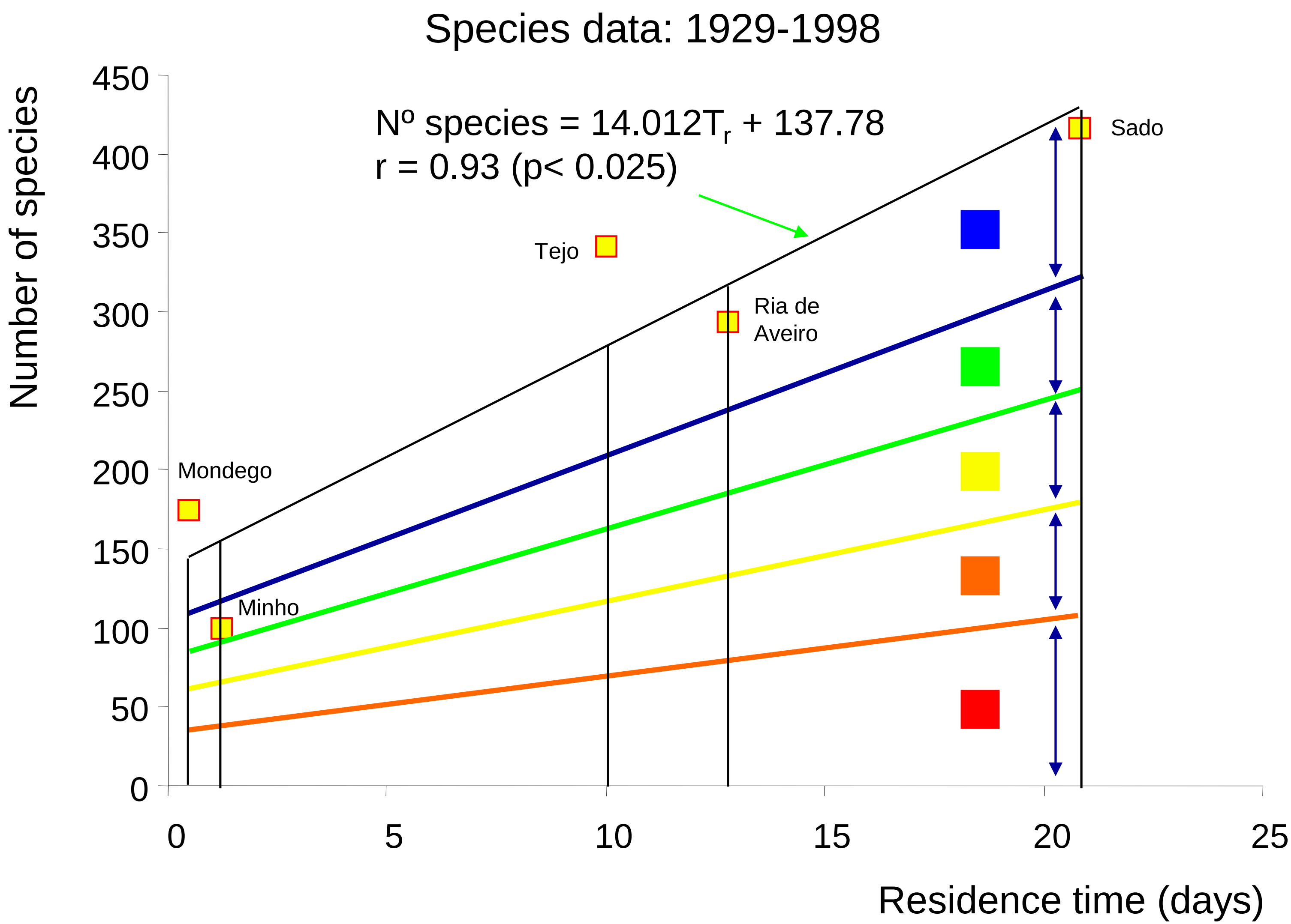
Number of phytoplankton species as a function of water residence time



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.

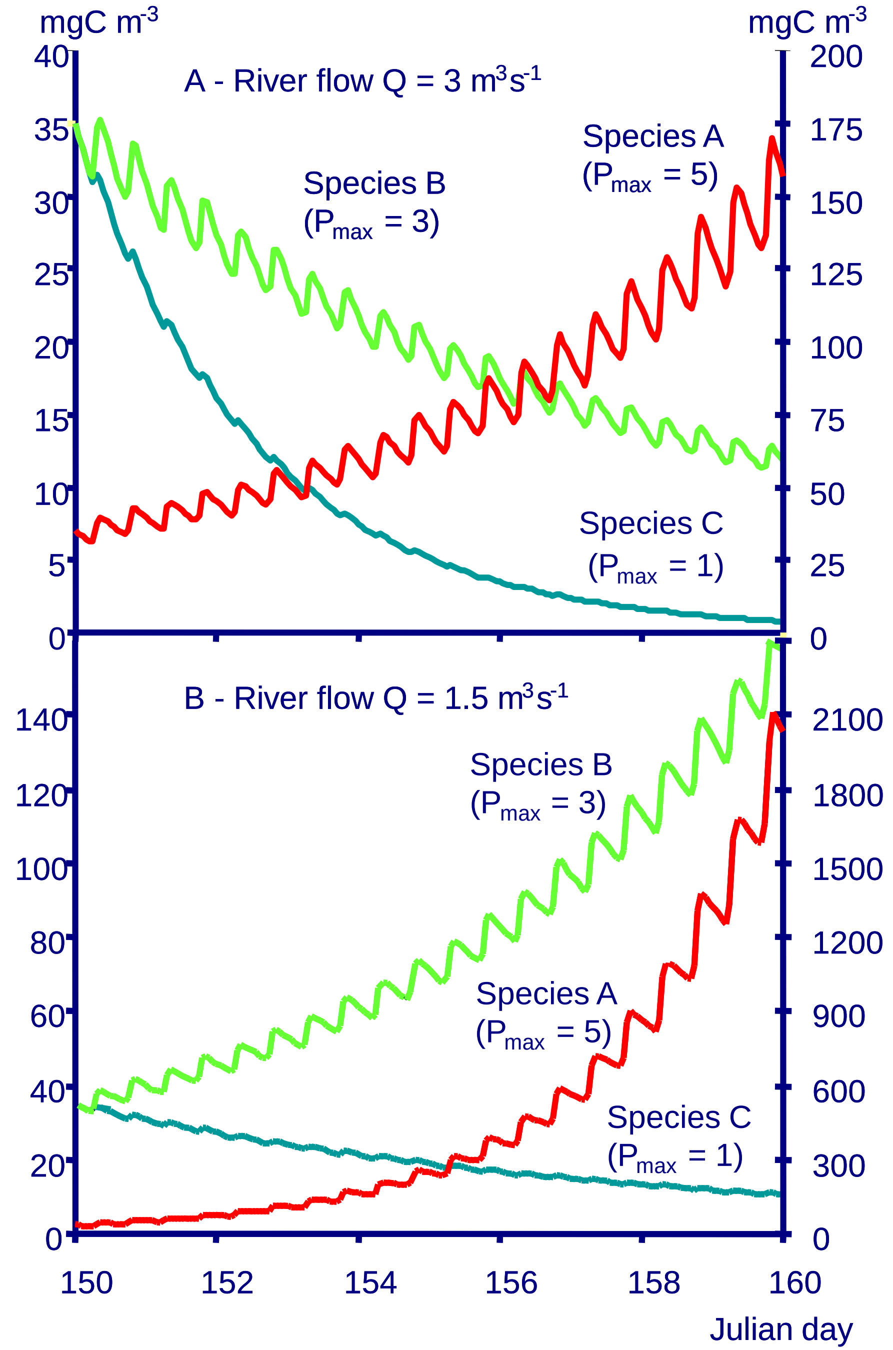
Ferreira et al., 2005. Ecological Modelling, 187(4) 513-523.

Simulation of growth for three hypothetical phytoplankton species

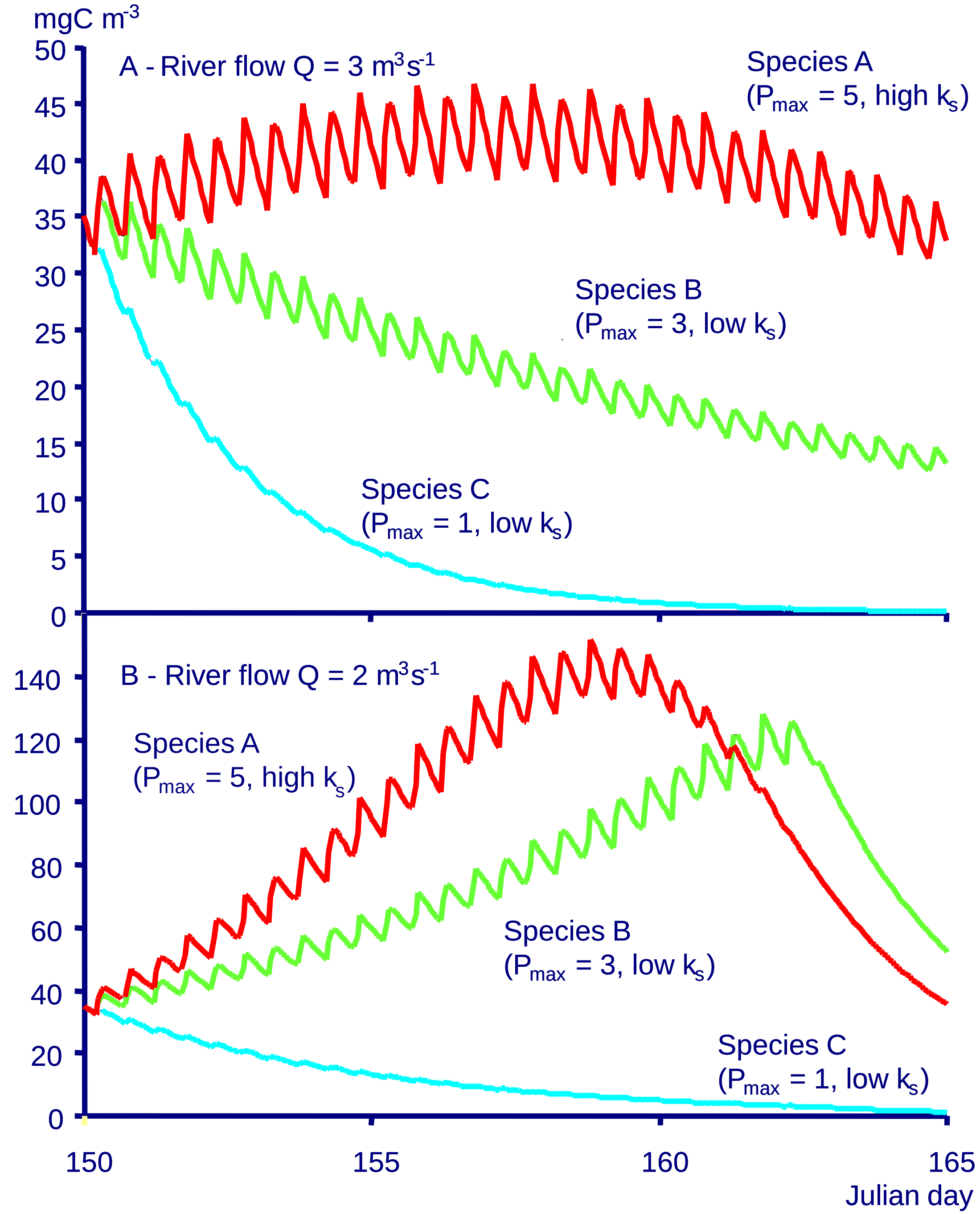
(species A on right axis)

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.



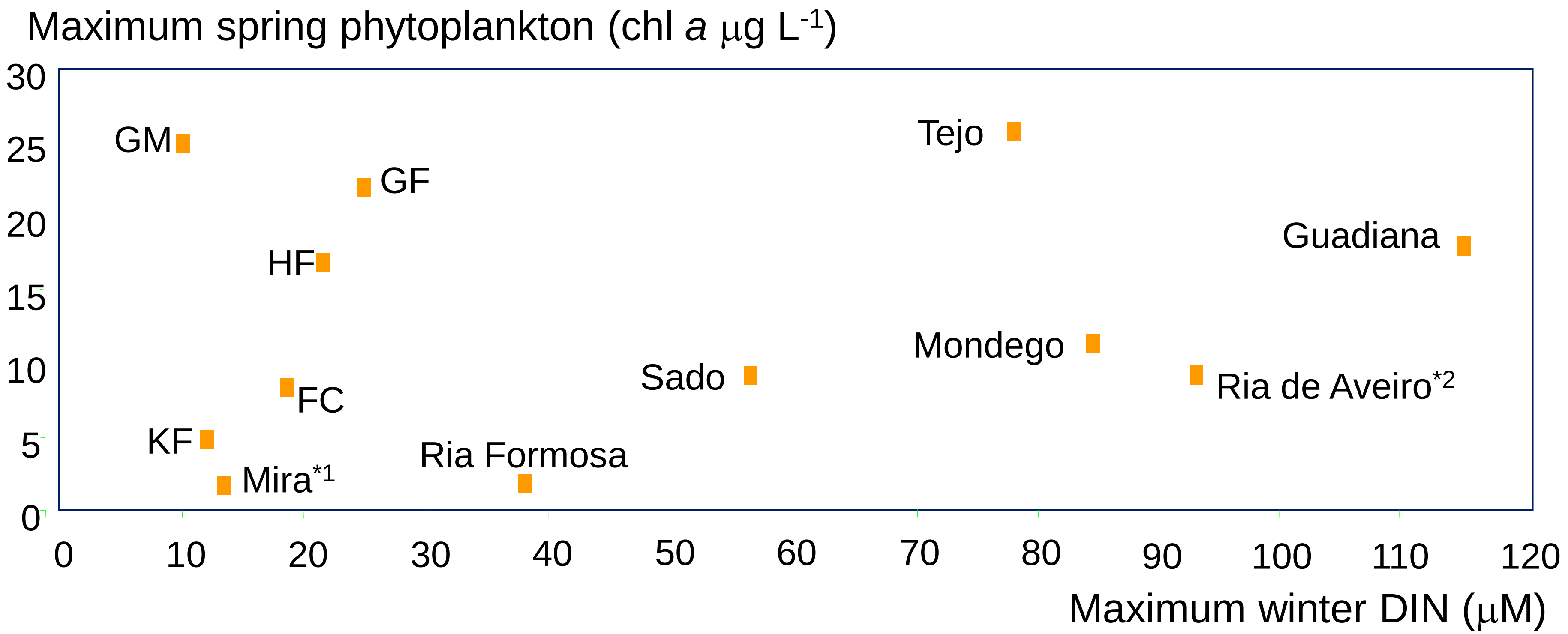
Simulation of nutrient limited growth for three hypothetical phytoplankton species



Nutrient limitation

- 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

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

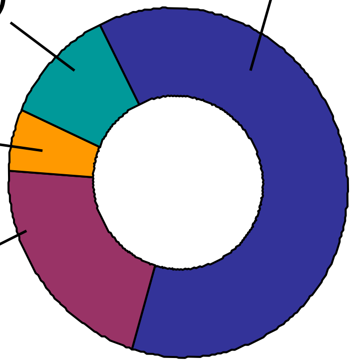
Why is there no relationship?

- 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

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

Synthesis

- Primary producers in the sea occur in many forms
- An understanding of primary production is critical for studies of food webs, aquaculture, and eutrophication
- Dynamic models relate primary production to light availability, underwater light climate, hydrodynamics, nutrients, and top-down control;
- Mass balance simulations of primary production help to understand how coastal systems function.

All slides

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