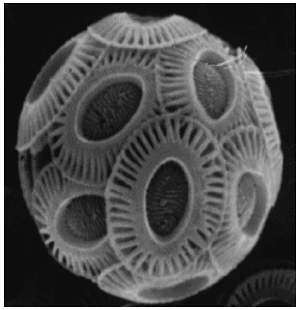
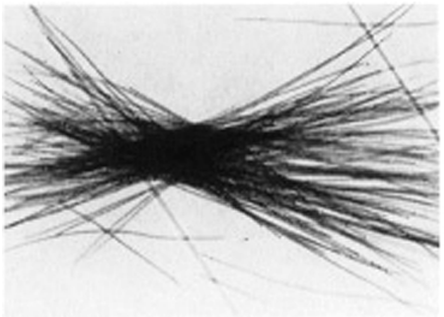
Biological constraints on microalgal production

Richard J Geider
University of Essex



Emiliania huxleyi



Trichodesmium sp

Skeletonema costatum

Contents

- Potential for producing microalgal biomass in East Anglia
- Characterising the light response of photosynthesis
- Challenge & Approach
- Facilities & Current Research at Essex

Algal Bioreactors for Biofuel Production & CO_2 Removal

- What is the surface area of algal bioreactor required to meet the energy demand and offset the carbon footprint of a UK resident?

- Annual per capita energy consumption
  - 170 GJ = 40,000 kW h
  - 12 barrels of oil equivalent
- Annual per capita carbon footprint
  - 9 tonnes CO_2

Potential Biomass Production in East Anglia

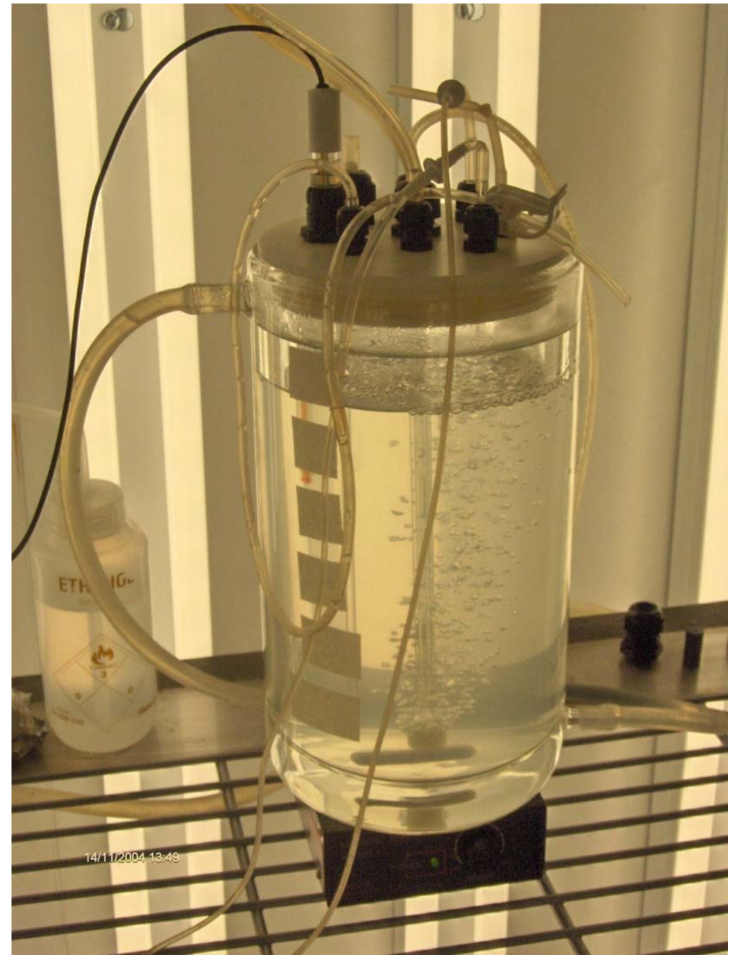
- Annual total solar radiation
  - 1100 kW h m^{-2}
- **Potential** Annual Algal Production
  - 75 kW h m^{-2} bioenergy produced
  - 22 kg m^{-2} CO_2 consumed
  - 11 kg m^{-2} algal biomass produced
- **Absolute upper limit**
  - assumes 7% efficiency of solar energy input converted to energy in biomass
- **Realized** efficiency of biofuel production will be lower
  - energy subsidies (aeration, mixing, fertilizer)
  - inefficiencies in conversion of biomass to biofuel
  - down-time for maintenance
  - sub-optimal biological performance

Potential Biomass Production in East Anglia

- 1 ha (10,000 m^2) of bioreactor operating at maximum potential yield could
  - offset domestic energy demand of 19 UK residents
  - offset the domestic carbon footprint of 24 UK residents
- Does not offset carbon footprint imported with goods manufactured abroad.
- Does not account for inefficiencies in photosynthesis, growing & harvesting biomass, or converting biomass to biofuel.

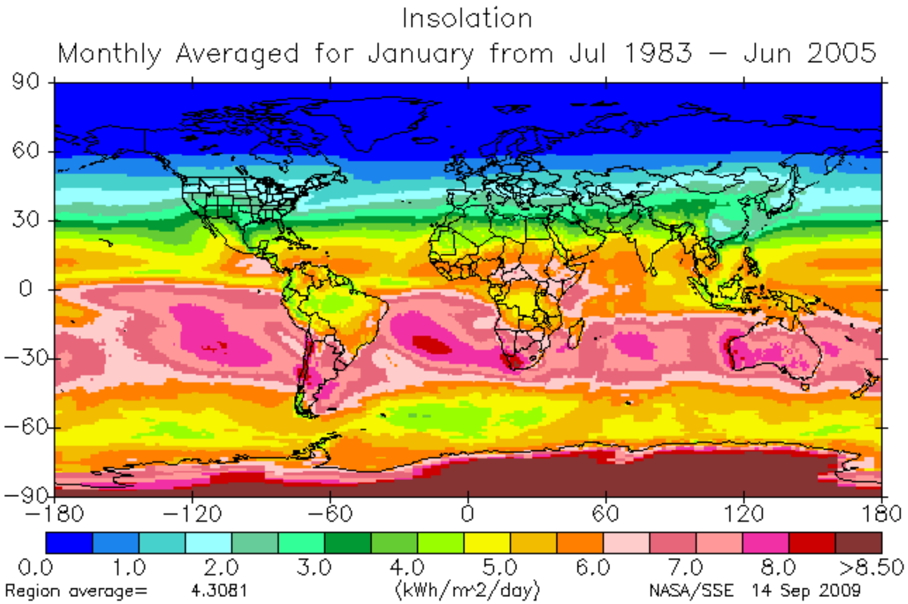
Resource Requirements for Algal Biomass Production

- Light
- Temperature
- CO_2
  - 50% C by weight
- Nutrients
  - 2-8% N by weight
  - 0.5-1% P by weight
- Land
- Water
- Mechanical energy for aeration and mixing

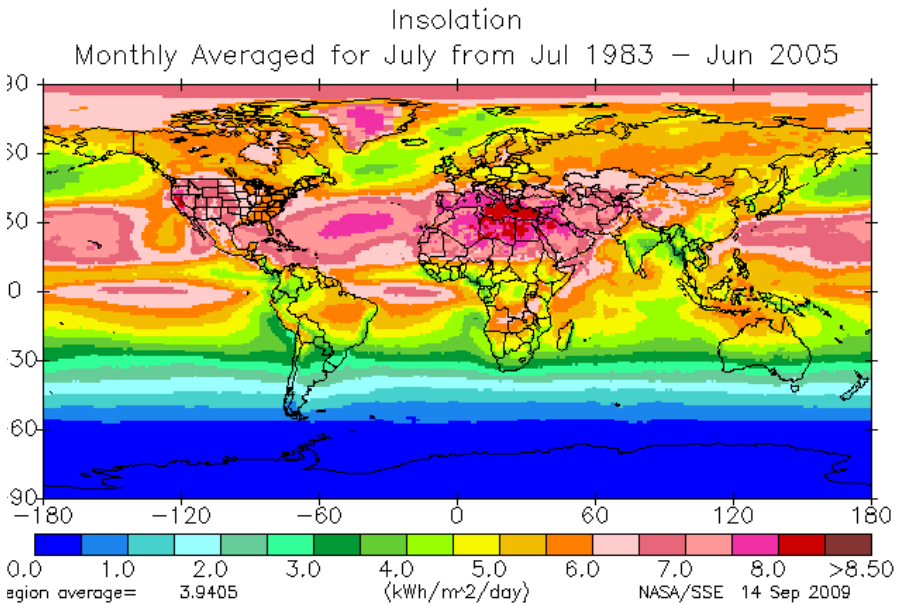


Seasonal variability of solar energy incident on a horizontal surface

January

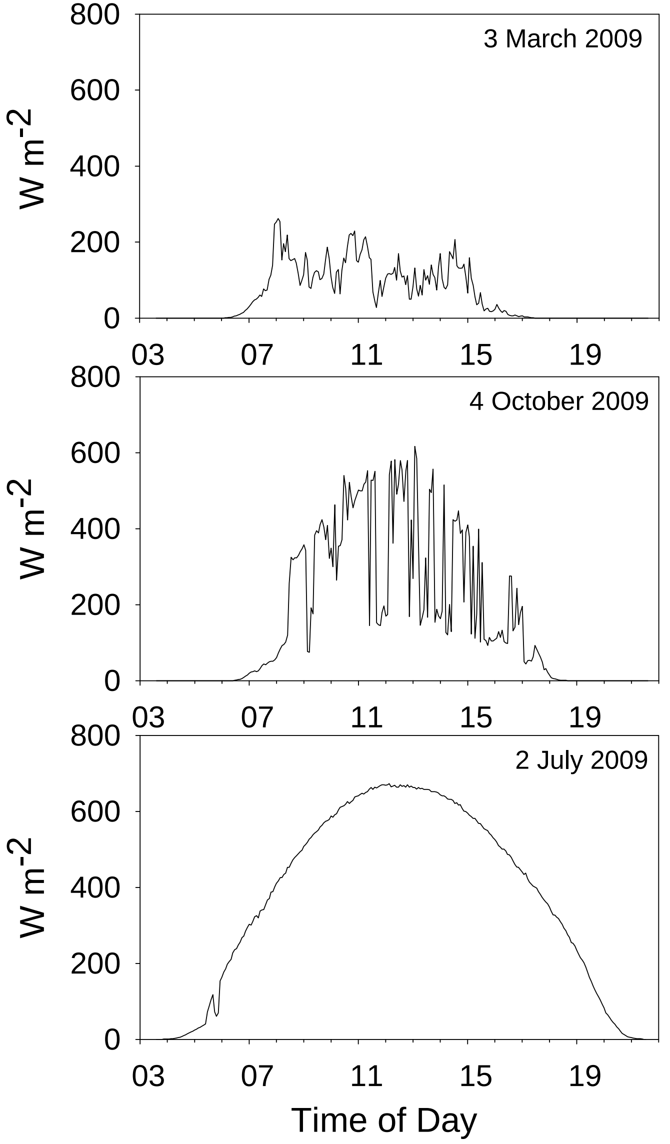


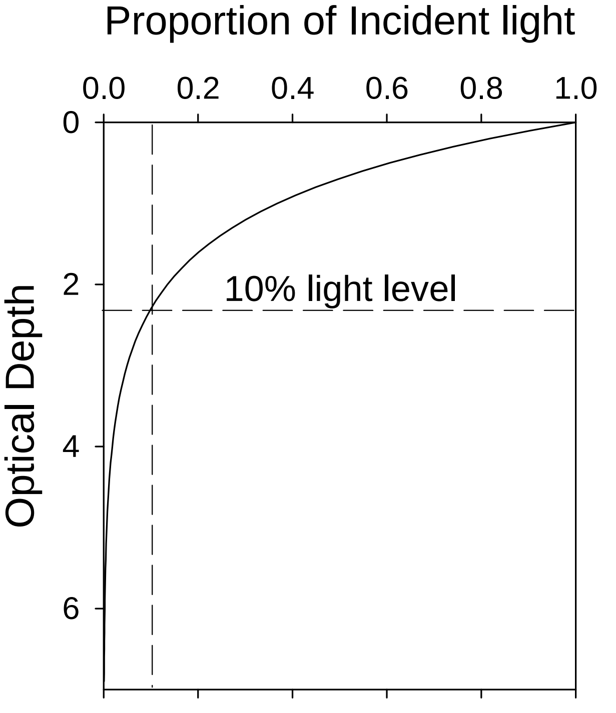
July



http://eosweb.larc.nasa.gov/cgi-bin/sse/

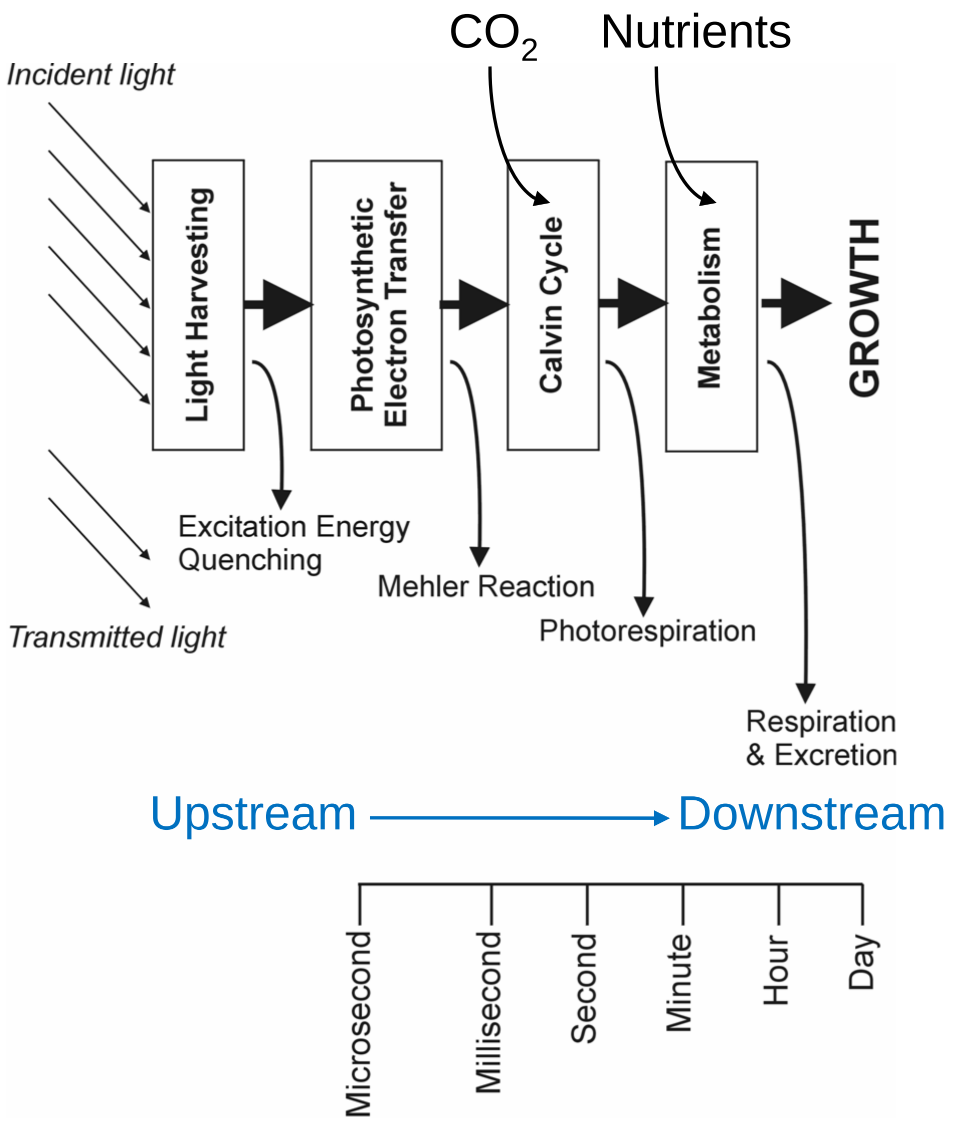
Between day and within day variability of solar radiation





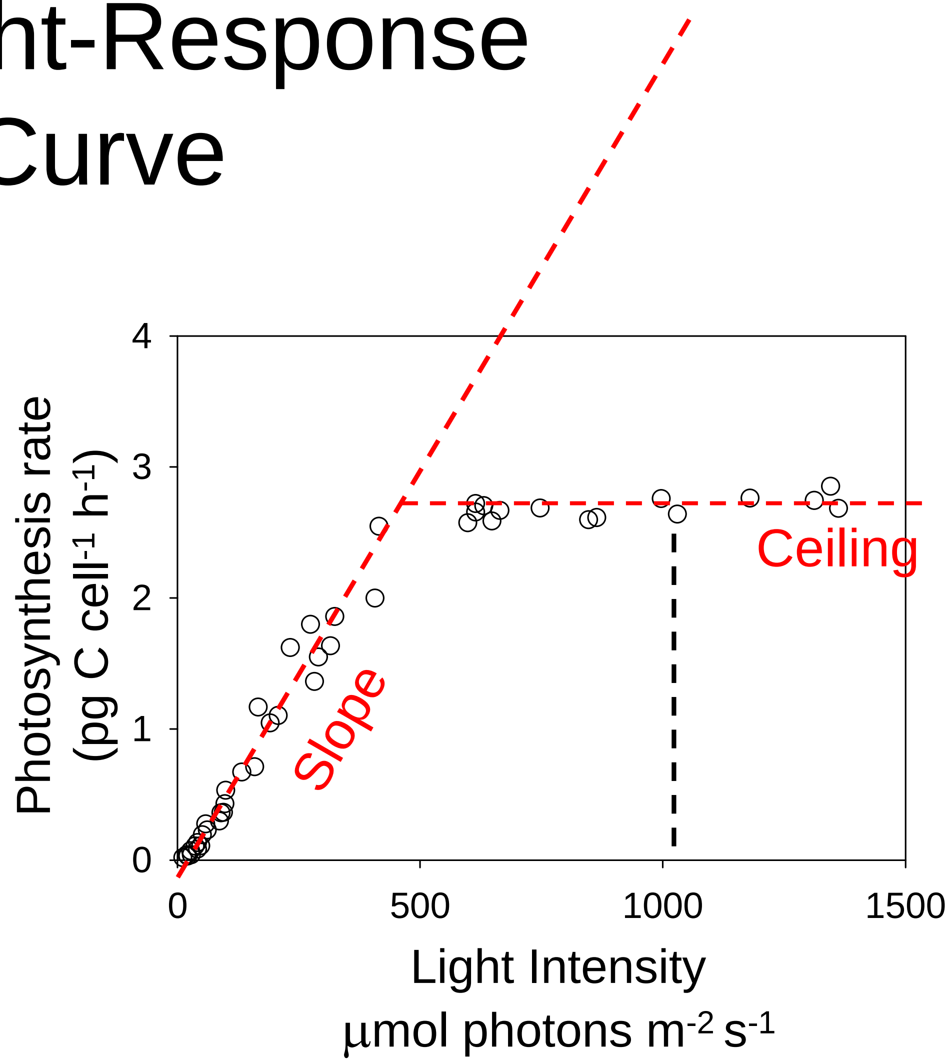
Mixing through a light gradient

Energy conversion from Light to Biomass



The Light-Response Curve

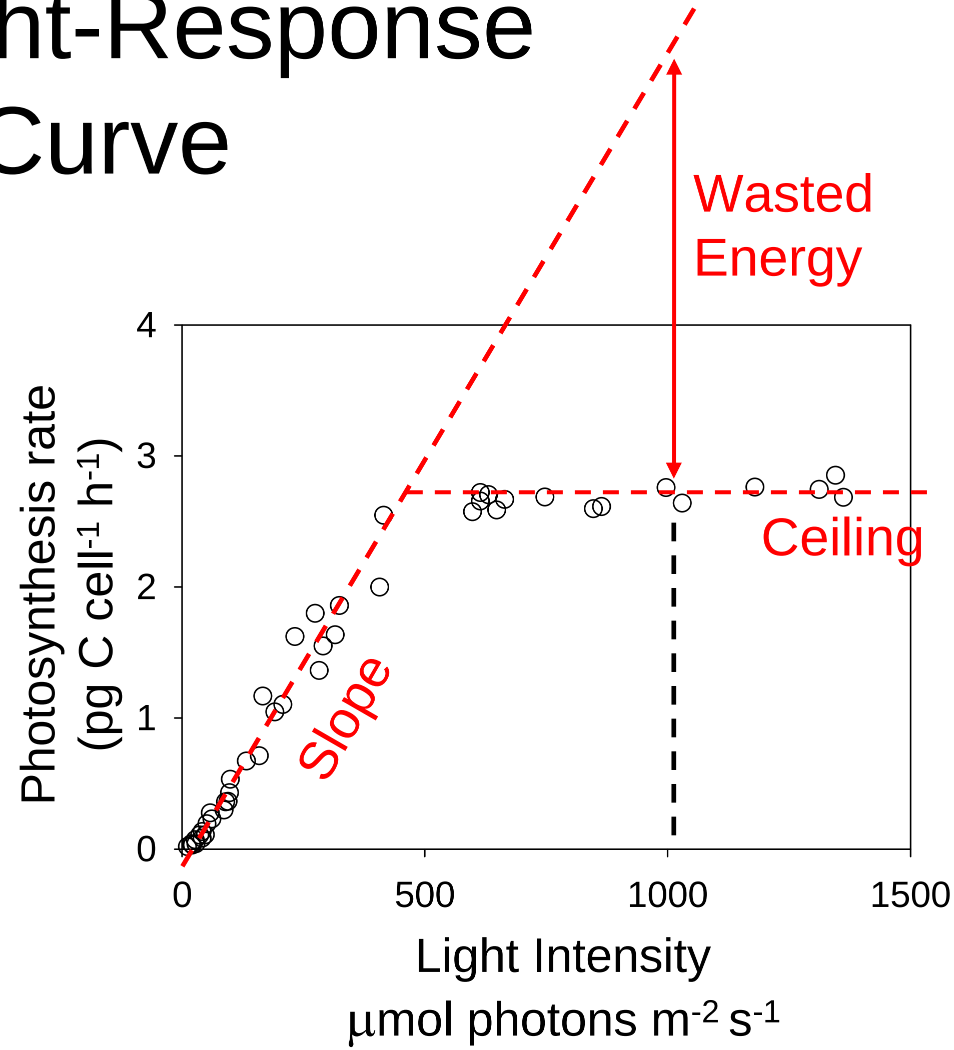
- Efficiency of photosynthesis is maximal at low light
  - rate limited by light absorption
- Efficiency declines at high light due to a ceiling that may be regulated by "downstream" rate(s) of
  - CO_2 fixation
  - protein synthesis
  - cell division



Data for high-light acclimated *Skeletonema costatum*. Anning et al. (2000) Limnology & Oceanography 45: 1807-1817

The Light-Response Curve

- How can we increase the rate & efficiency at high light?
- Engineer the growth environment by
  - raising the ceiling (increase temperature) or
  - lowering the mean light (flashing light effect).
- Genetically engineer the cells to be high-light light adapted.



Data for high-light acclimated *Skeletonema costatum*. Anning et al. (2000) Limnology & Oceanography 45: 1807-1817

Disconnect between the lab and the field.

"An important lesson from the outdoor testing of algae production systems is the inability to maintain laboratory organisms in the field. **Algal species that looked very promising when tested in the laboratory were not robust under conditions encountered in the field.** In fact, the best approach for successful cultivation of a consistent species of algae was to allow a contaminant native to the area to take over the ponds."

A Look Back at the U.S. Department of Energy's Aquatic Species Program—Biodiesel from Algae

July 1998

U.S. Department of Energy's
Office of Fuels Development

Contract No. DE-AC36-83CH10093

Challenge

- How can the operation of complex metabolic networks linking light harvesting to biomass production be reconfigured to meet the demands of biotechnology?

- high energy efficiency
- high production of desired product
- resilience to environmental variability & stress
- suitability for industrial scale processing

The essential principle & challenge of algal physiology.

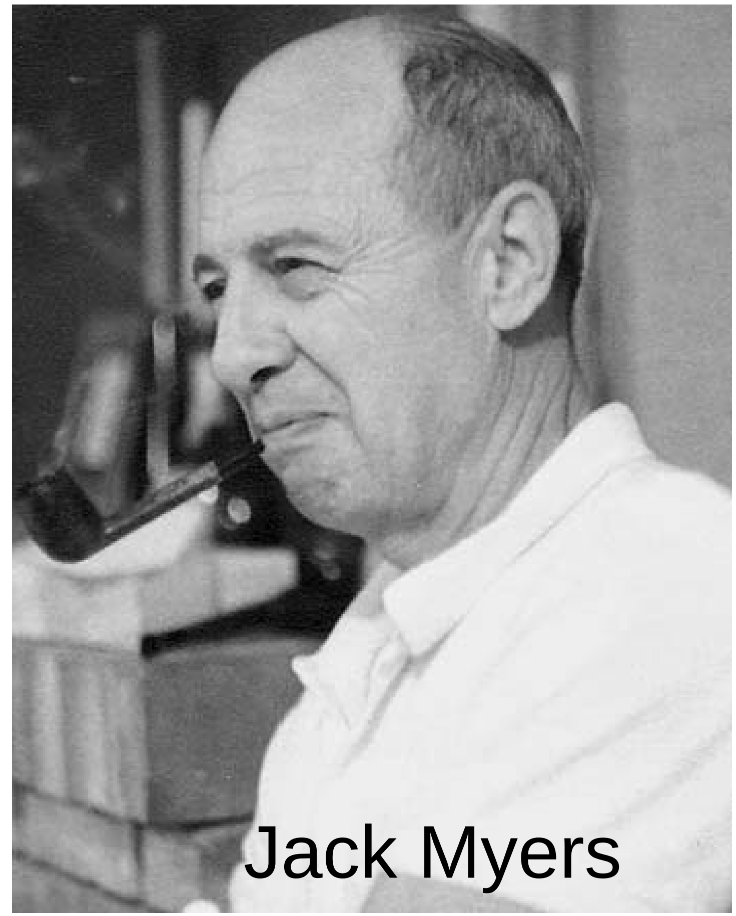
"The **essential principle** is that the algae are microbes, powered by a photosynthetic metabolism ...

they are highly adaptive …

response to an environmental factor depends on past history for that factor ...

there is no fixed or static machinery….

this is the **particular challenge** of algal physiology"



(Myers 1980) page 4 in "Primary Productivity in the Sea." Plenum Press.

Approach

- Systems biology approach to metabolism of the target species.
  - from light harvesting to cell division
- New data on the
  - changes of gene expression (transcription and remodelling of the proteome) and
  - changes in metabolite and macromolecule pools and synthesis rates
  - within the context of responses of photosynthesis, biosynthesis and the cell cycle to growth conditions.
- Natural variability (clones in culture collection)
- Transformation system

Current NERC funded microalgal research @ Essex

- Effect of CO_2 on growth, photosynthesis and gene expression (*Emiliania huxleyi*)
- Remodelling of proteome in response to light and nutrient limitation (*Emiliania huxleyi*)
- Effects of pH/pCO_2 and temperature on calcification and growth of corals and their symbiotic algae (*Symbiodinium*)
- Photosynthesis and nitrogen fixation in cyanobacteria (*Trichodesmium, Crocosphaera*)
- Exopolyer production (benthic diatoms)

Facilities @ Essex

- algal and microbiological culture facilities (controlled environment cabinets, anaerobic culture facilities, glasshouse)
- environmental control for algal culturing (pH-stat, chemostat)
- photosynthetic rate & efficiency (fluorometers, membrane inlet mass spectrometer, spectrophotometers, flash yield systems)
- bioimaging (FACSCalibur flow cytometer, confocal microscope)
- dissolved nutrients, particulate and dissolved organic carbon and nitrogen, trace gases
- gene expression (microarray readers)
- proteomics (GC-MS/MS)

Plant and Marine Science Groups

Prof. Neil Baker
Prof. Richard Geider
Dr Tracy Lawson
Prof. Phil Mullineaux
Prof. Christine Raines
Dr Michael Steinke
Dr David Suggett
Prof. Graham Underwood


Biological
Sciences
at the University of Essex