"Every oceanographer is a modeller and every modeller should go to sea"

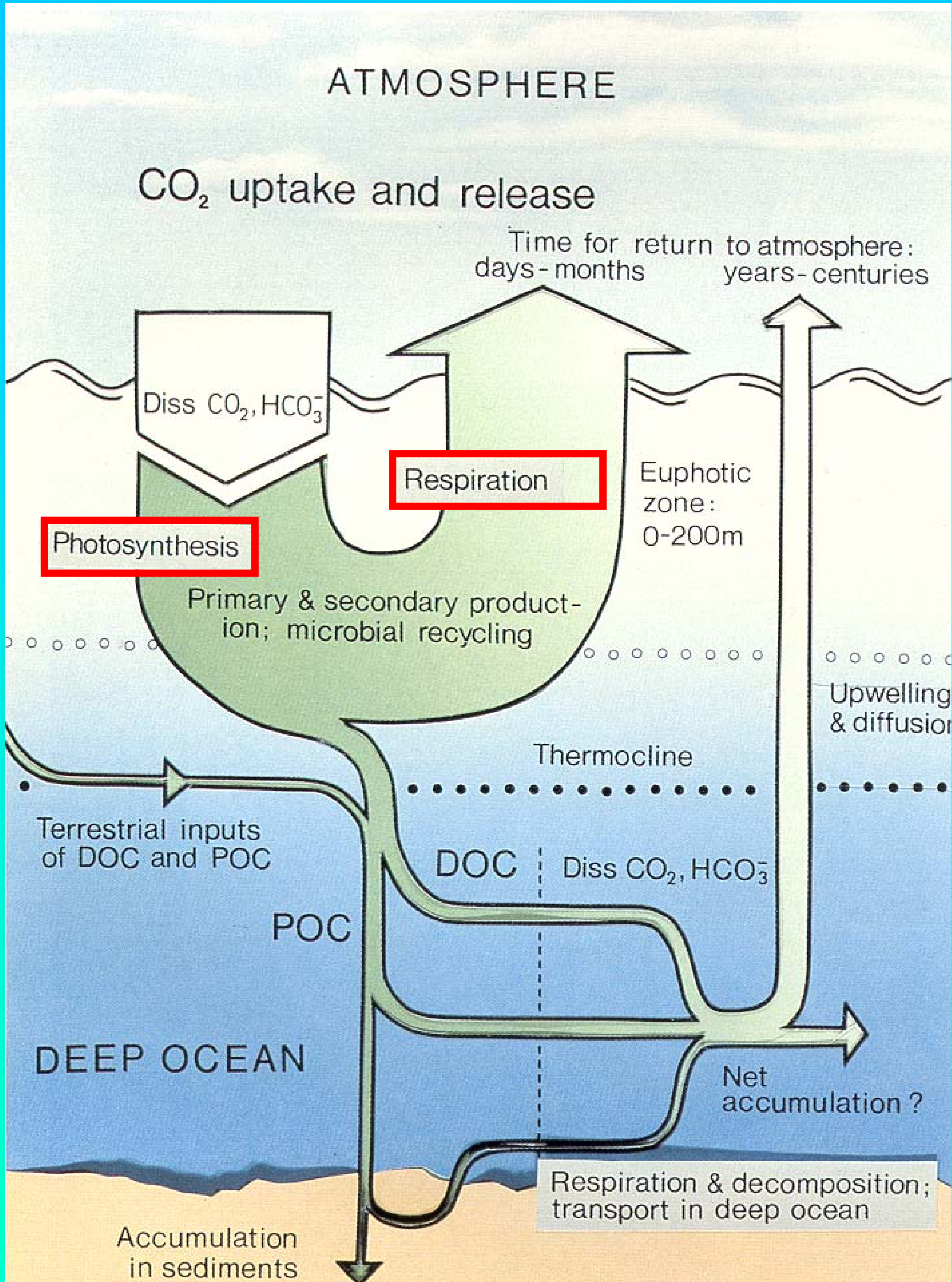
Carol Robinson

School of Environmental Sciences, University of East Anglia

Measuring and modelling marine plankton respiration (1988-2008)

Carol Robinson

School of Environmental Sciences, University of East Anglia
Plymouth Marine Laboratory, The Hoe, Plymouth
University of Wales; Bangor, School of Ocean Sciences, Menai Bridge

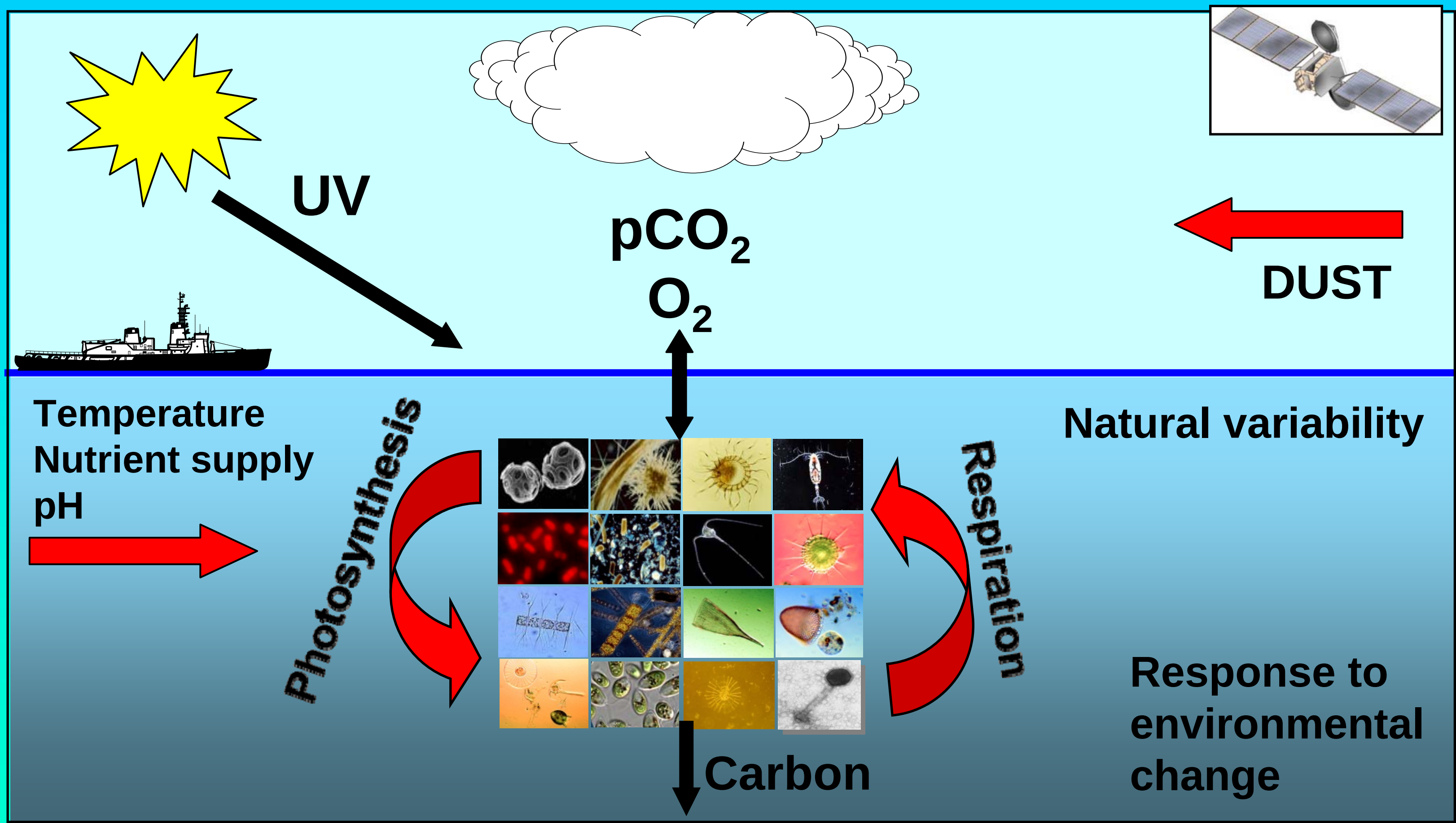


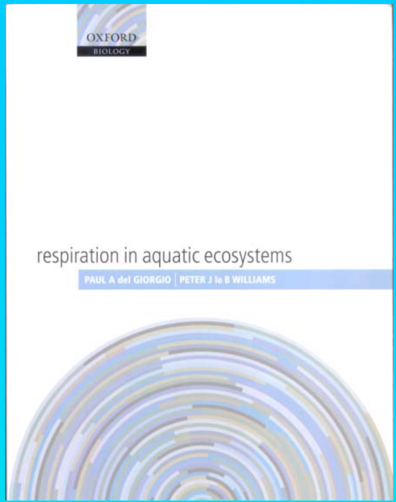
Respiration :

- **Carried out by all marine organisms**
- **Largest sink for organic matter**
- **Constraint on export & net ecosystem production**
- **Determinant of hypoxia**

In an isolated system P>R

Microbial cycling of oxygen and carbon dioxide





"Respiration represents the major area of ignorance in our understanding of the global carbon cycle."

Williams & del Giorgio, 2005

Respiration in the open ocean

Paul A. del Giorgio*† & Carlos M. Duarte†‡

NATURE |VOL 420 | 28 NOVEMBER 2002

"…. the total open ocean respiration is uncertain ….."

"it is probably substantially greater than most current estimates of particulate organic matter production"

"whether the biota act as a net source or sink of carbon remains an open question "

"Respiration remains the least constrained term in most models of metabolism, gas exchange and carbon mass balance in the ocean."

Measuring respiration

dissolved oxygen flux during in vitro incubations

size fractionation, axenic culture

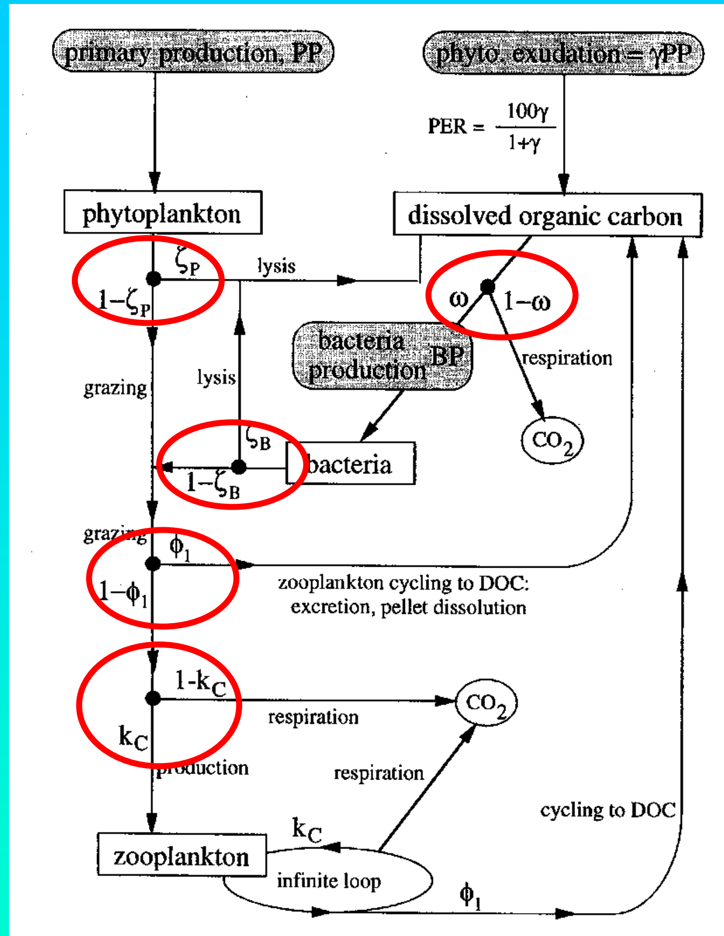
Indirect methods or 'models'

Derivation from biomass
Allometric equations for respiration from weight or size

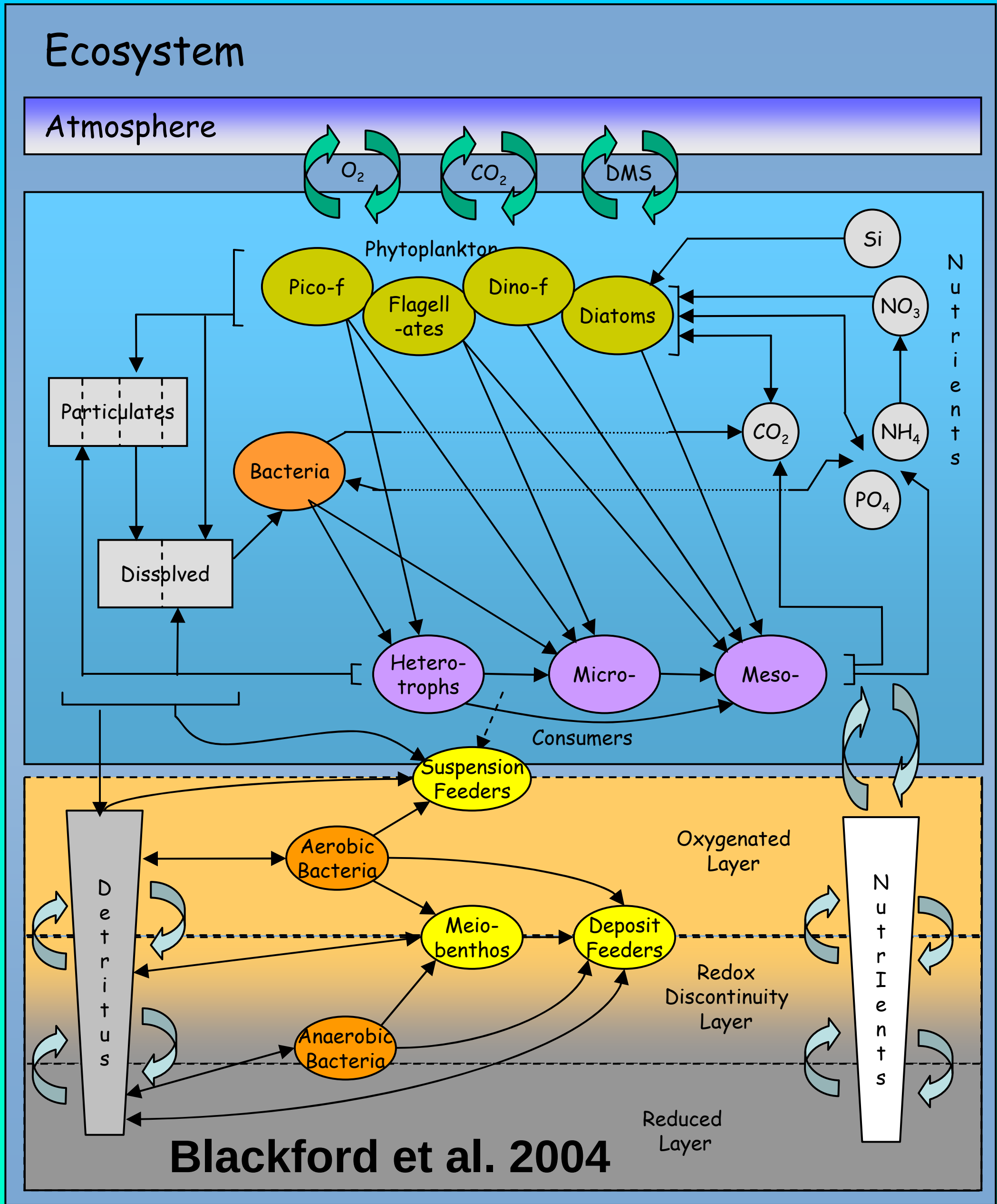
Derivation from activity + growth efficiency
Primary, bacterial or microzoo production together with growth efficiency
Highly variable growth efficiency

Inverse analysis
Steady state microbial loop model
Constrained data set

Ecological models
Phytoplankton, bacteria, zooplankton
Basal, food quality, activity
Standardisation of parameterisation ?



POLCOMS-ERSEM Shelf Seas Model



4 primary producers

Basal respiration related to T
Activity respiration as proportion of assimilation

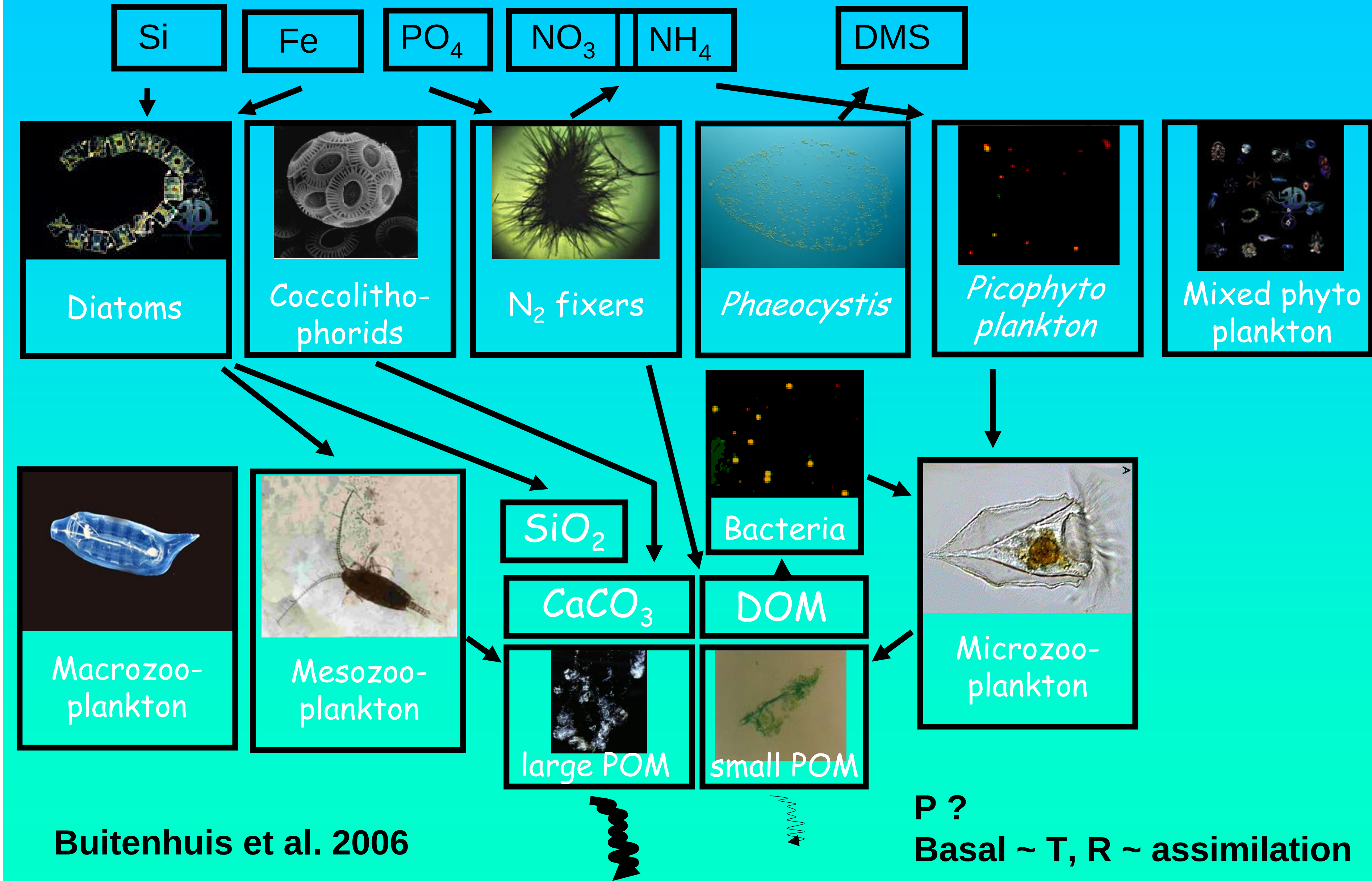
3 consumers

Rest respiration related to T
Activity respiration

1 decomposer

Rest respiration related to T
Activity respiration influenced by ambient oxygen

Plankton Types Ocean Model 10

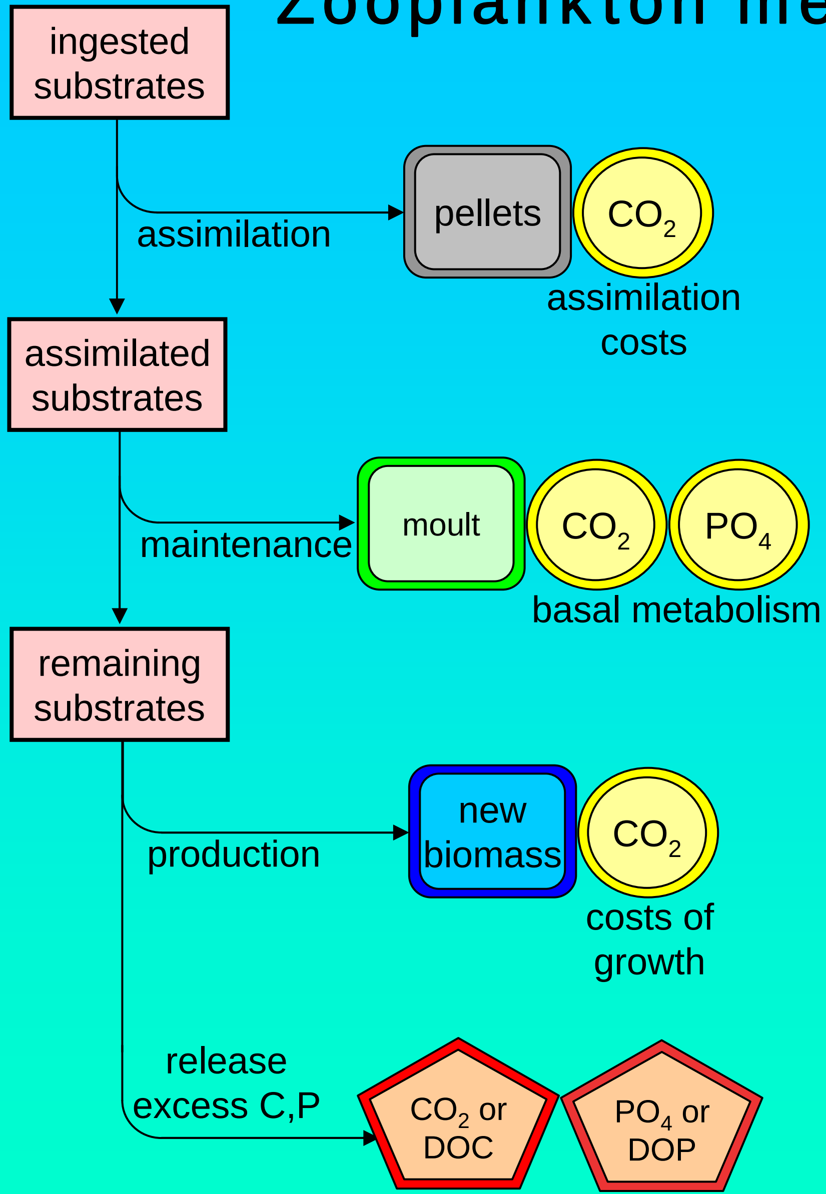


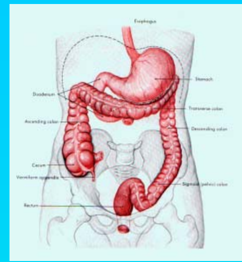
Buitenhuis et al. 2006

P ?

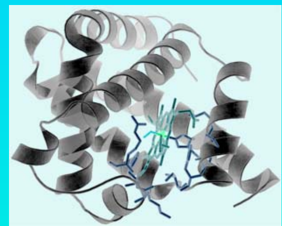
Basal ~ T, R ~ assimilation

Zooplankton metabolic stoichiometry

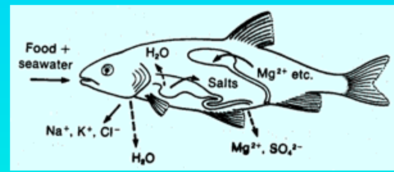




digestion



protein turnover

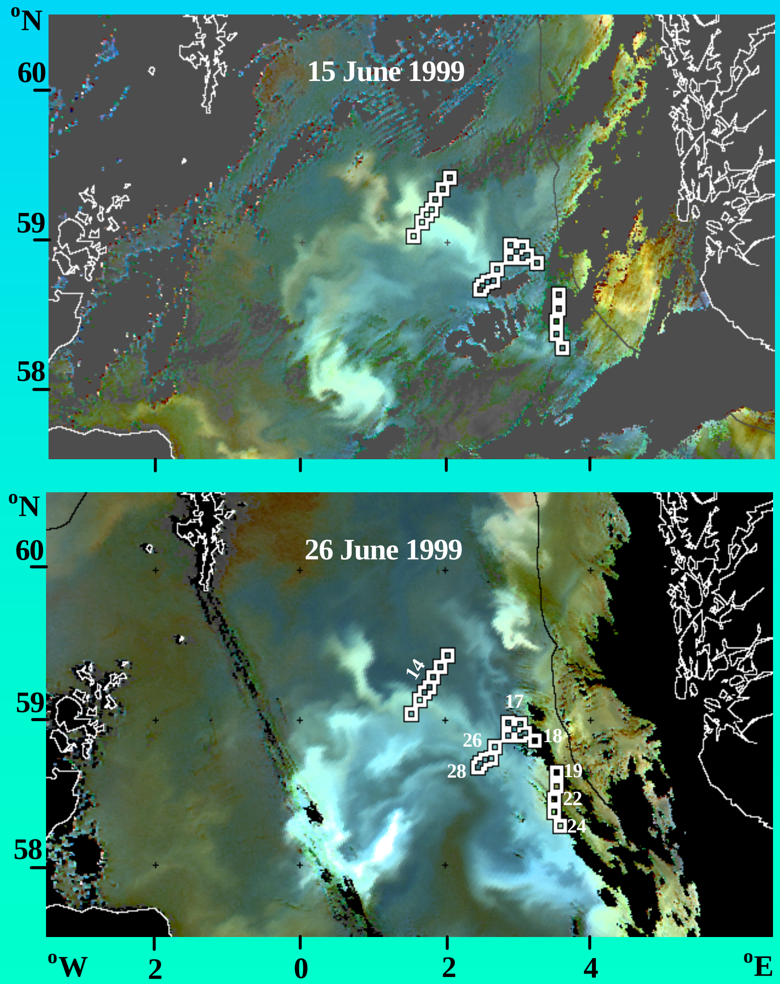


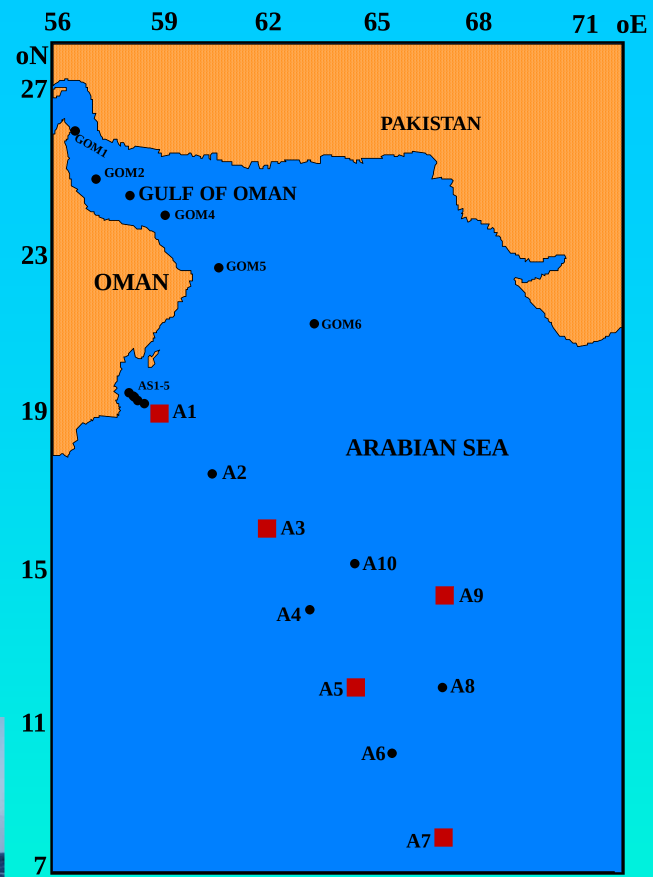
osmoregulation

growth (incl. reproduction)

Anderson et al. 2005

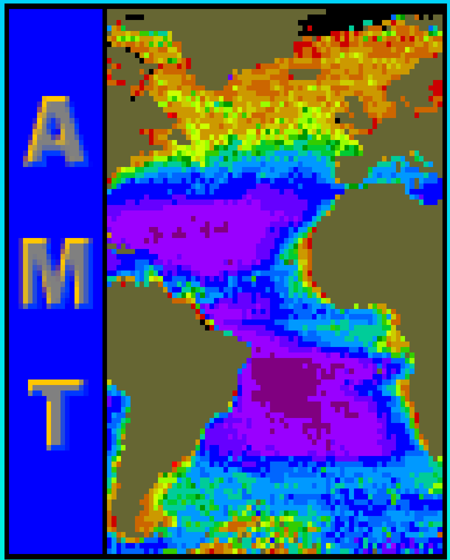
Data collection



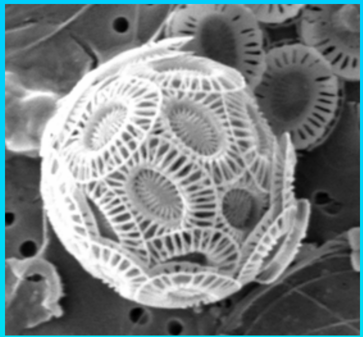


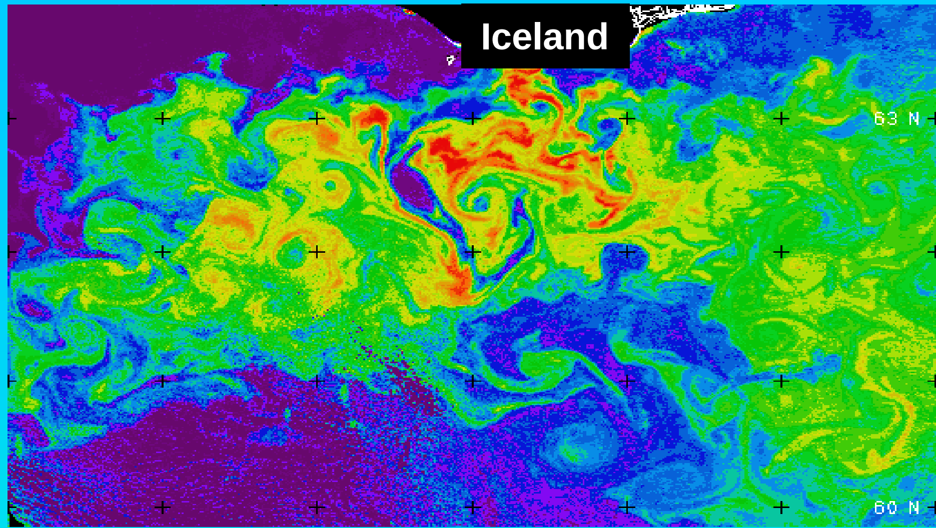
North Atlantic 1989, 1990, 1991
Arabian Sea 1996
North Sea 1999
Mediterranean Sea 1988, 1991, 1992
Southern Ocean 1991, 1992, 1993, 1997

Atlantic Meridional Transect programme
1998, 2003 (twice)
Coastal mesocosms 1994, 1996
Coastal hydrothermal vents 1996, 1997



North Atlantic 1991





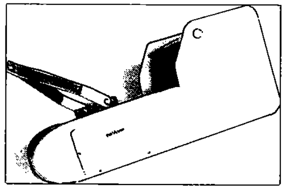
Jim’s ‘model’-ing legacy within PML bio-optical team

SOLAS INSPIRE cruise Nov 2007

Ocean scientist collecting data

Even at the weekend Chelsea Instruments' Aquashuttle is collecting ocean data for this scientist. Aquashuttle is a towed undulating body which collects data on depth, temperature, conductivity, illumination and chlorophyll by fluorescence. It needs no special winch, no onboard computer, no research ship. And no scientist.

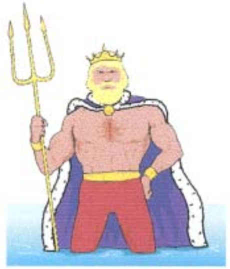
Aquashuttle is deployed from Craft of Opportunity (COOP) and is towed at up to 27 knots, undulating between depths of five and 100 metres over lengths pre-selectable from 800 metres to 4 kilometres.



Aquashuttle is speeding the ocean data gathering programs of leading research laboratories worldwide. Call Chelsea Instruments for case histories and more details of how you can run a multi-parameter ocean data gathering program – and play golf at the same time.

Chelsea Instruments Ltd
2/3 Central Avenue, East Molesey, Surrey KT8 0QX
Tel: 081 941 0044 Fax: 081 941 9319

The Court of KING NEPTUNE in session
on board the RRS James Clark Ross
this 31st day of May 1998



Carol Robinson

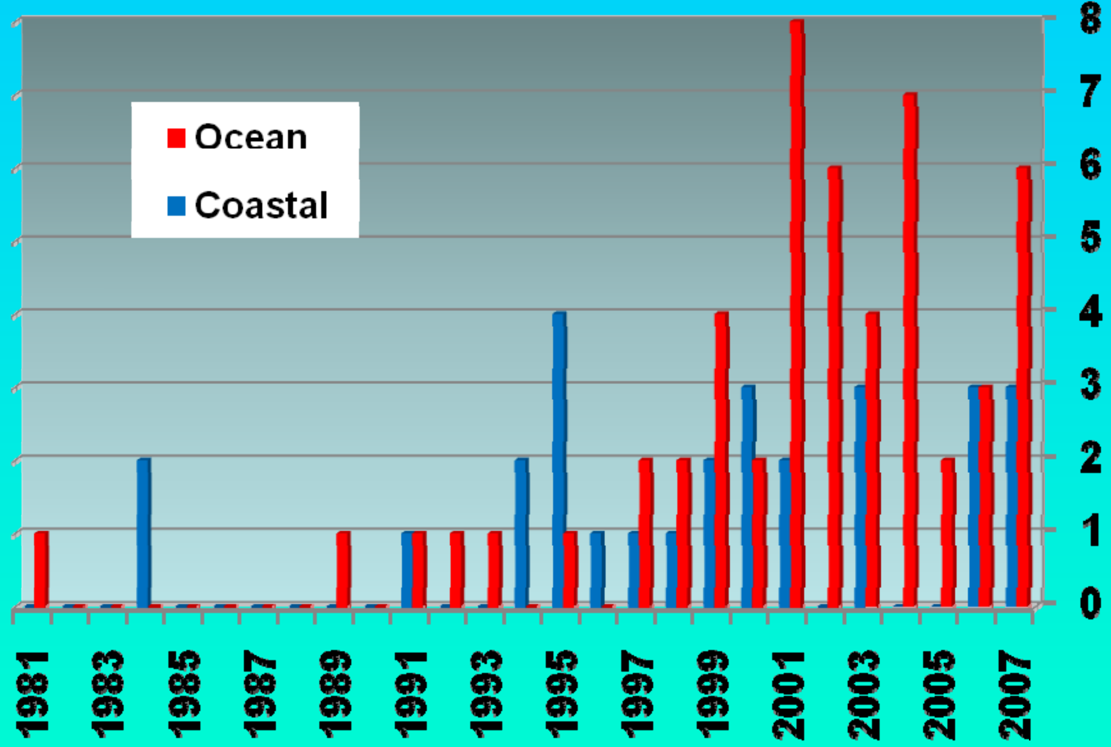
You stand accused of the following offences

1. *For humming too much and being too happy for her own good.*
2. *Glibly crossing the lines to the North and South on many occasions without paying homage to Neptune at his court on the Equator.*
3. *Having a flat on the West Hoe and paying Malc large amounts of money, allowing him to continue his dubious activities.*
4. *Lending Roy soiled hosiery so that he may carry out lewd acts.*
5. *Being No.1 Slave, but not to Neptune.*
6. *Soliciting junk mail to fill her pigeon hole, so forcing HRH "Del" Robins to act as her post boy!*
7. *Calling the Principle Scientist a bastard and accusing him of wearing a skirt.*

OCTOR
DEATH

Database available

80 ISI papers since 1981 report new respiration data



70% open ocean, 30% shelf (water depth < 200m)
~ 90 % derived from *in vitro* oxygen flux
~2700 volumetric ~320 depth integrated

Photosynthesis

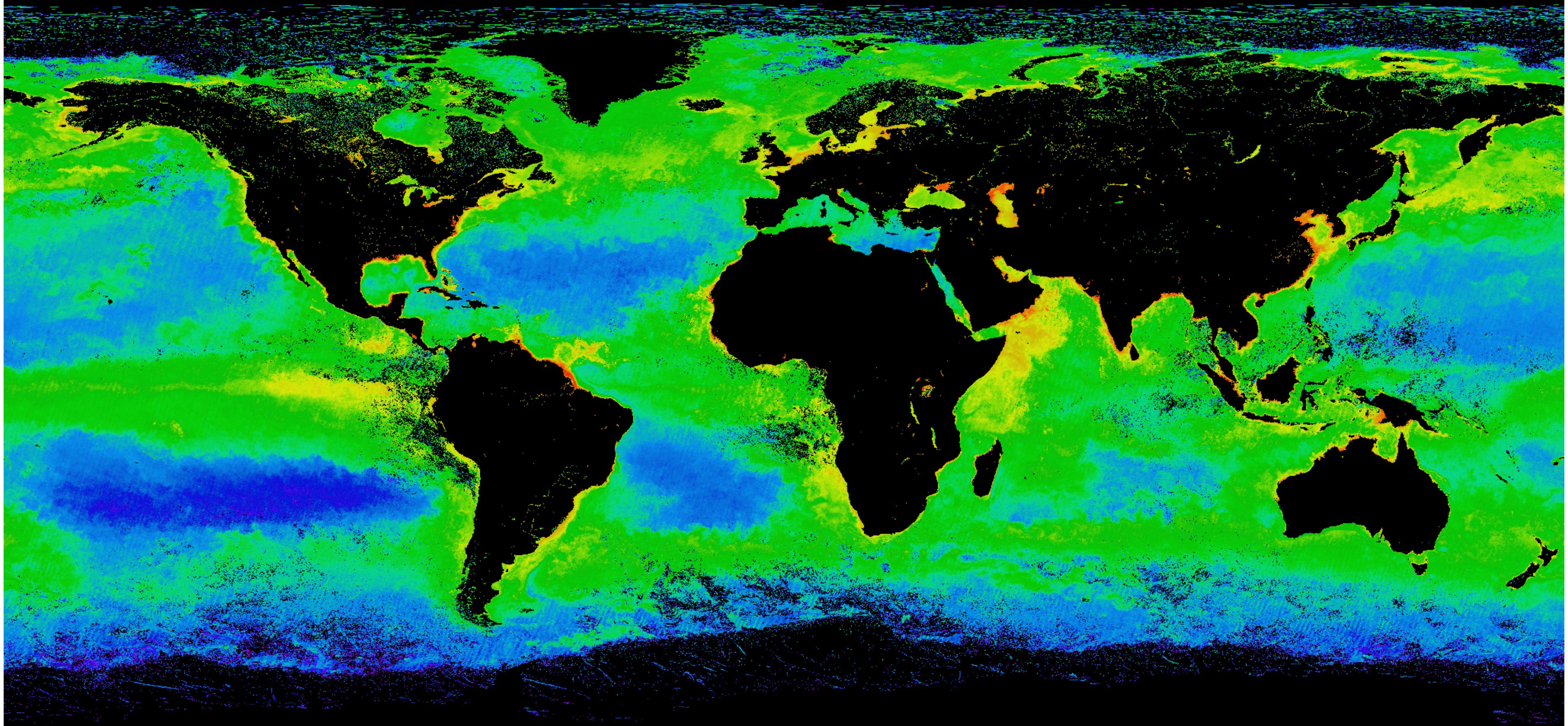
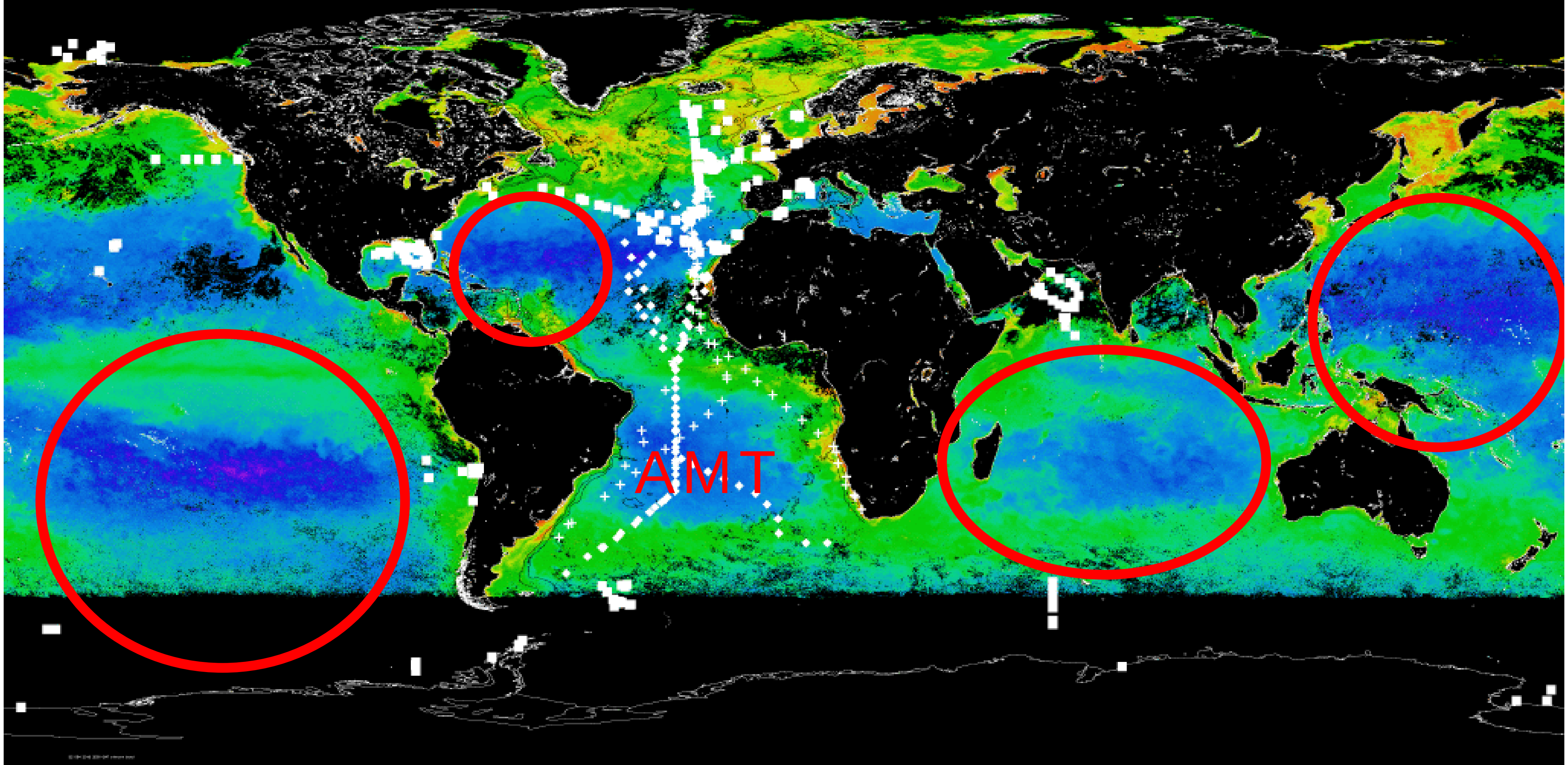


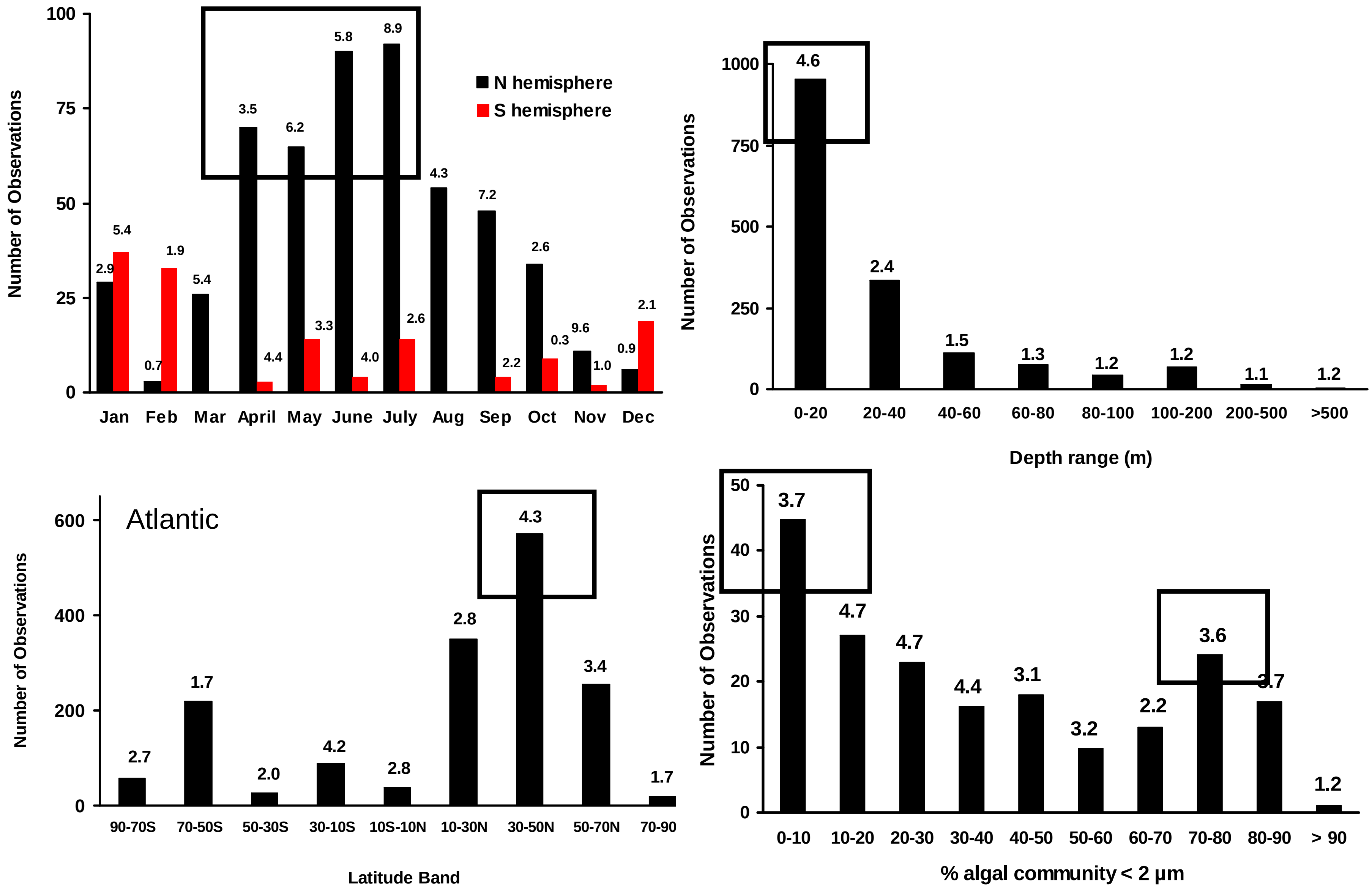
Image prepared by R.Hutson & T.Smyth, PML

Respiration



Robinson & Williams, 2005

Biases: Month, depth, latitude, community structure



Robinson & Williams, 2005

Global estimate of upper ocean respiration

Mean depth integrated - 11.7 Pmol O_2 a^{-1}

Sample bias – times & places of highest production

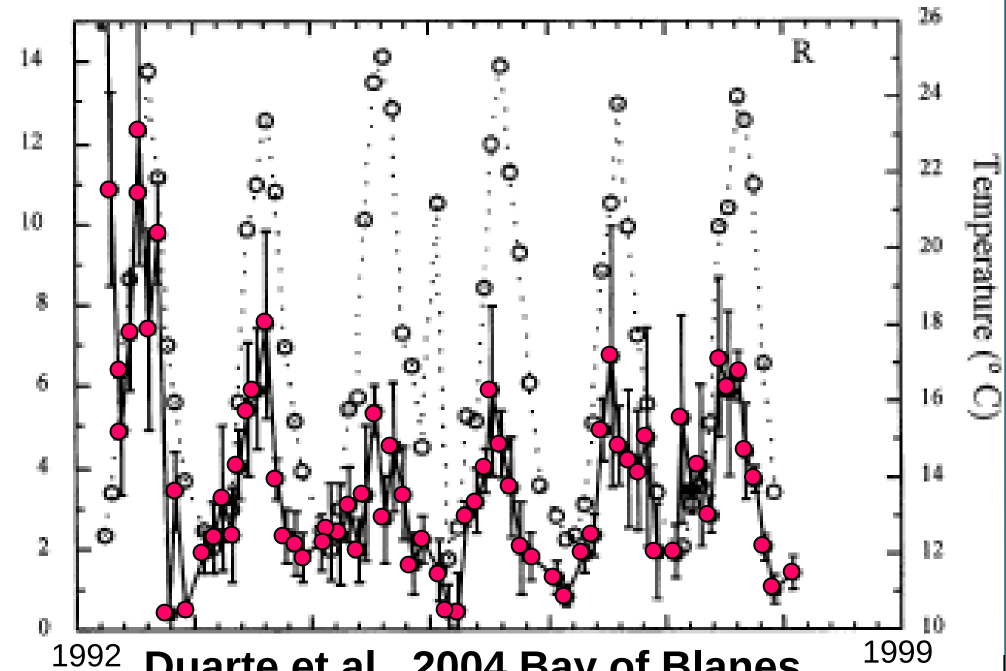
Lowest - Hawaii - 9.9 Pmol O_2 a^{-1}

Upper ocean R : 10 - 12 Pmol O_2 a^{-1}
119-127 Gt C a^{-1}

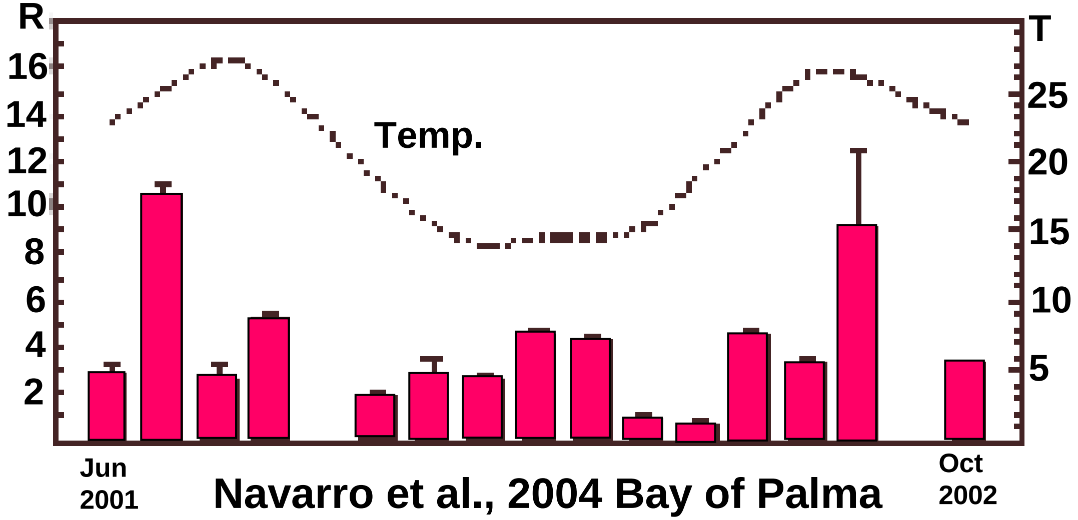
^{14}C (corrected to GP) - 5 to 9 Pmol O_2 a^{-1}

Few biased data

Relationship with temperature



Duarte et al., 2004 Bay of Blanes
Monthly average R $\pm$ SE (mmol O_2 m^{-3} d^{-1})



Navarro et al., 2004 Bay of Palma
R $\pm$ SE (mmol O_2 m^{-3} d^{-1})

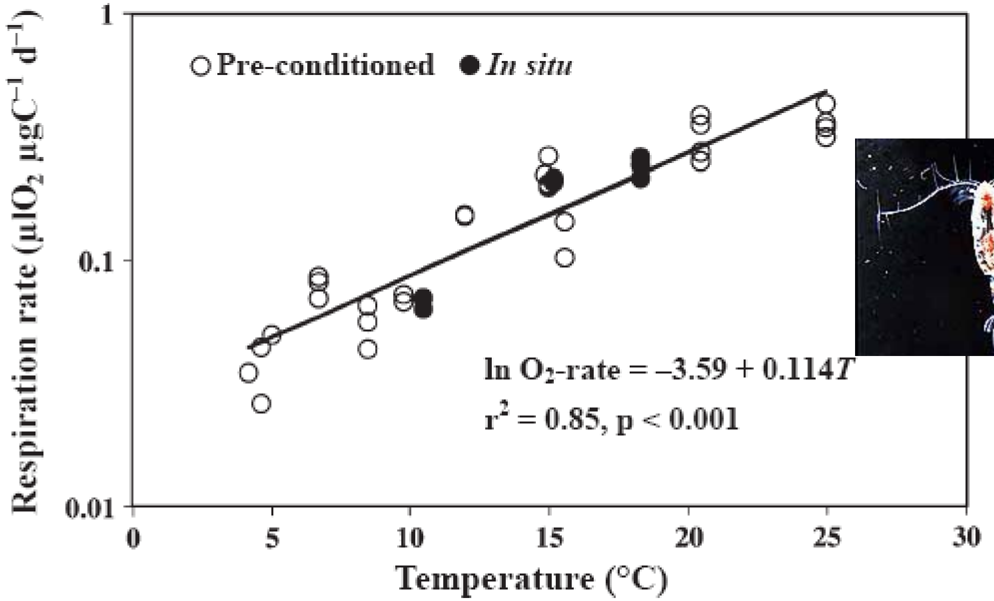
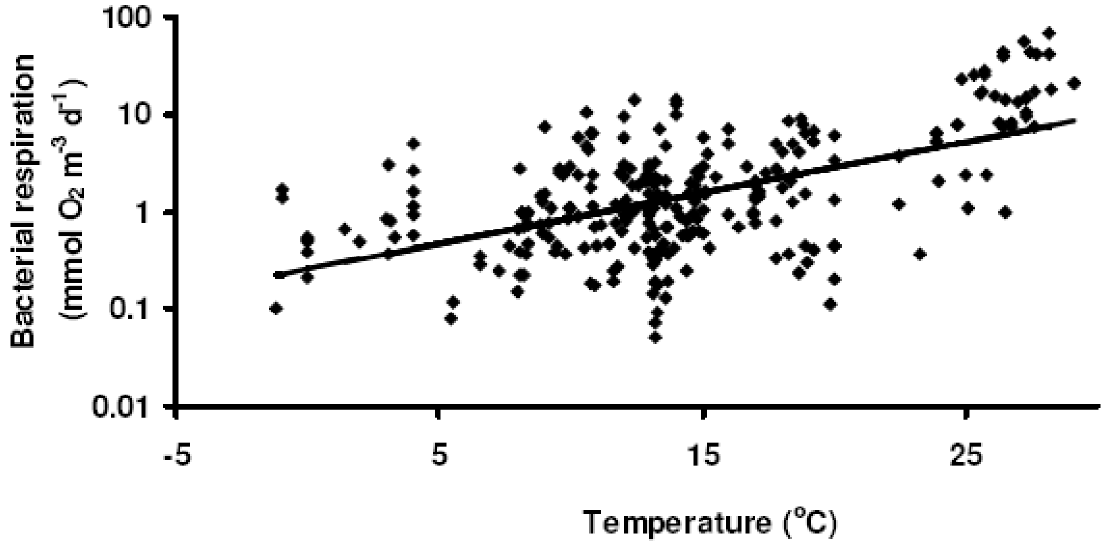


Fig. 2. *Oithona similis.* Weight-specific respiration rate ($\mu l\ O_2$ $\mu g\ C^{-1}\ d^{-1}$) versus temperature (*T*,
temperature (●) or after pre-con
temperature (○). Note log

Castellani, Robinson et al. 2005



Robinson, 2008

Metabolic theory – empirical model

Whole organism metabolic rate (I) scales as the ¾ power of body mass (M)

$$I = I_0 M^{3/4}$$

Metabolic rates increase exponentially with temperature, as described by the Arrhenius relation

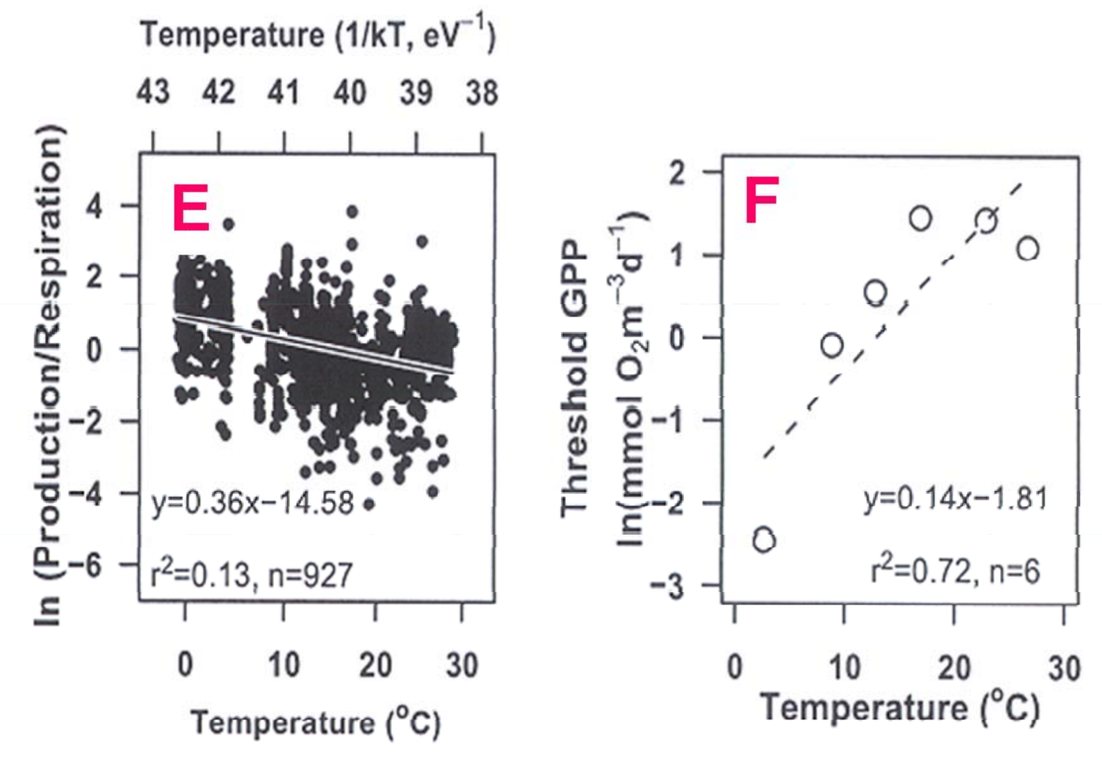
$$I = e^{-E/kT}$$

The metabolic theory of ecology (MTE) combines these

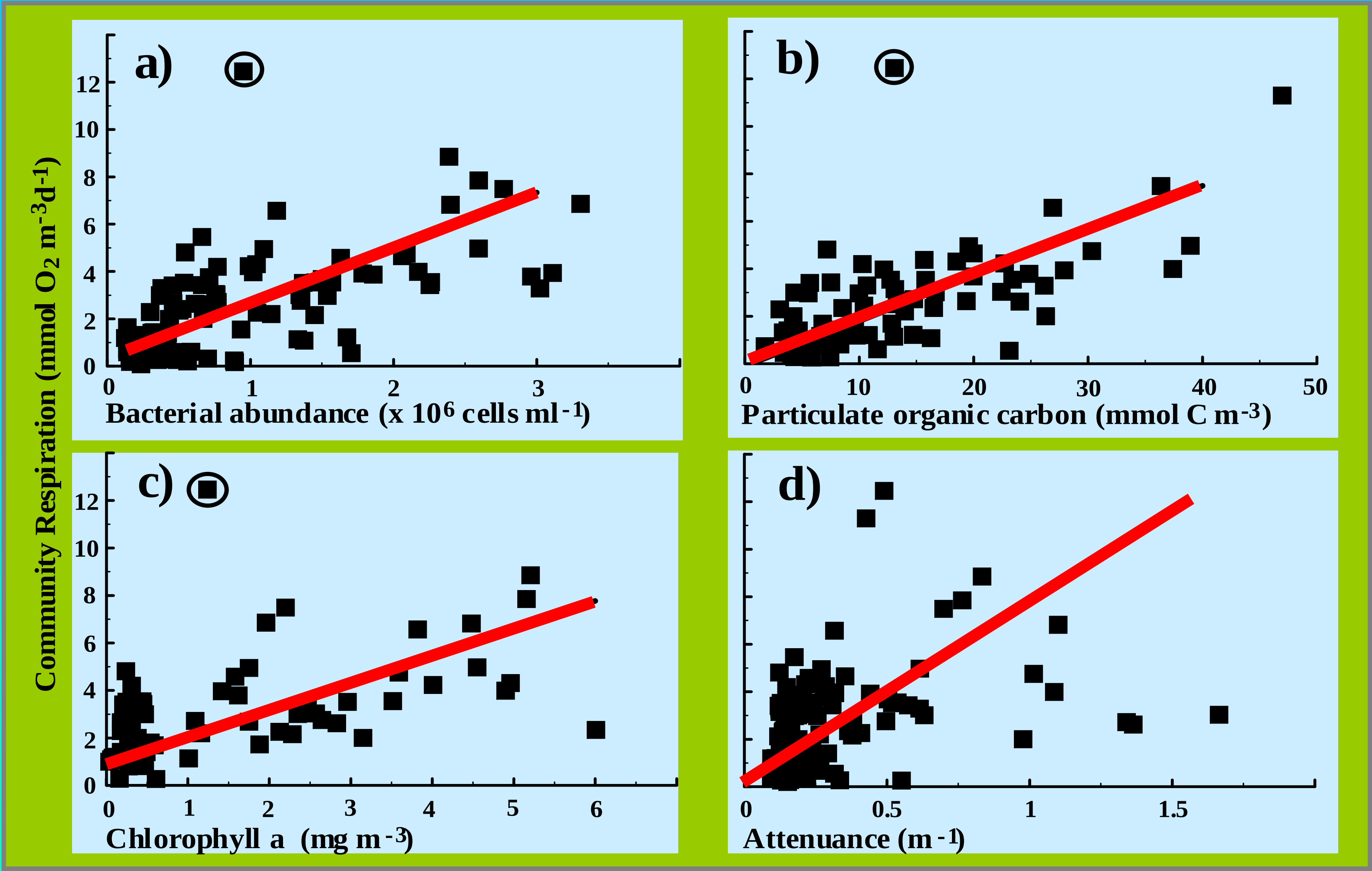
$$I = I_o M^{3/4} e^{-E/kT}$$

Derive respiration and photosynthesis

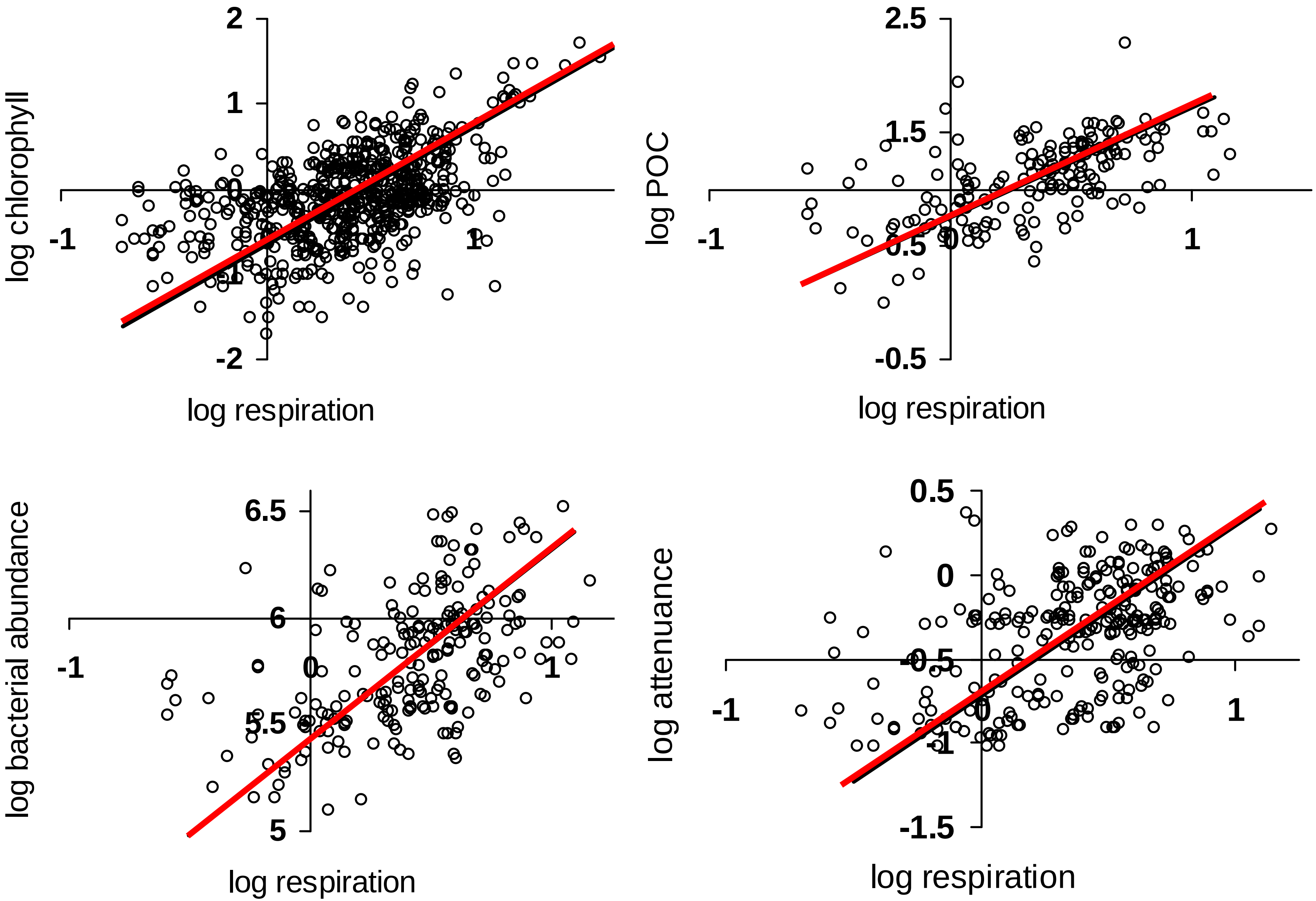
- **Confirm relationship between body size & R and P derived from T & PAR**
- **Compare estimates of P and R with concurrently measured P & R (A,B,C)**
- **Derive P and R from body size & abundance during AMT1-6 (D)**
  - **Predict increasing T decreases P:R & increases threshold P**
  - **Confirmed with global database (Robinson & Williams, 2005) (E,F)**
  - **Predict with increasing T, by 2100, 21% less uptake CO_2**



Lopez-Urrutia et al., 2006

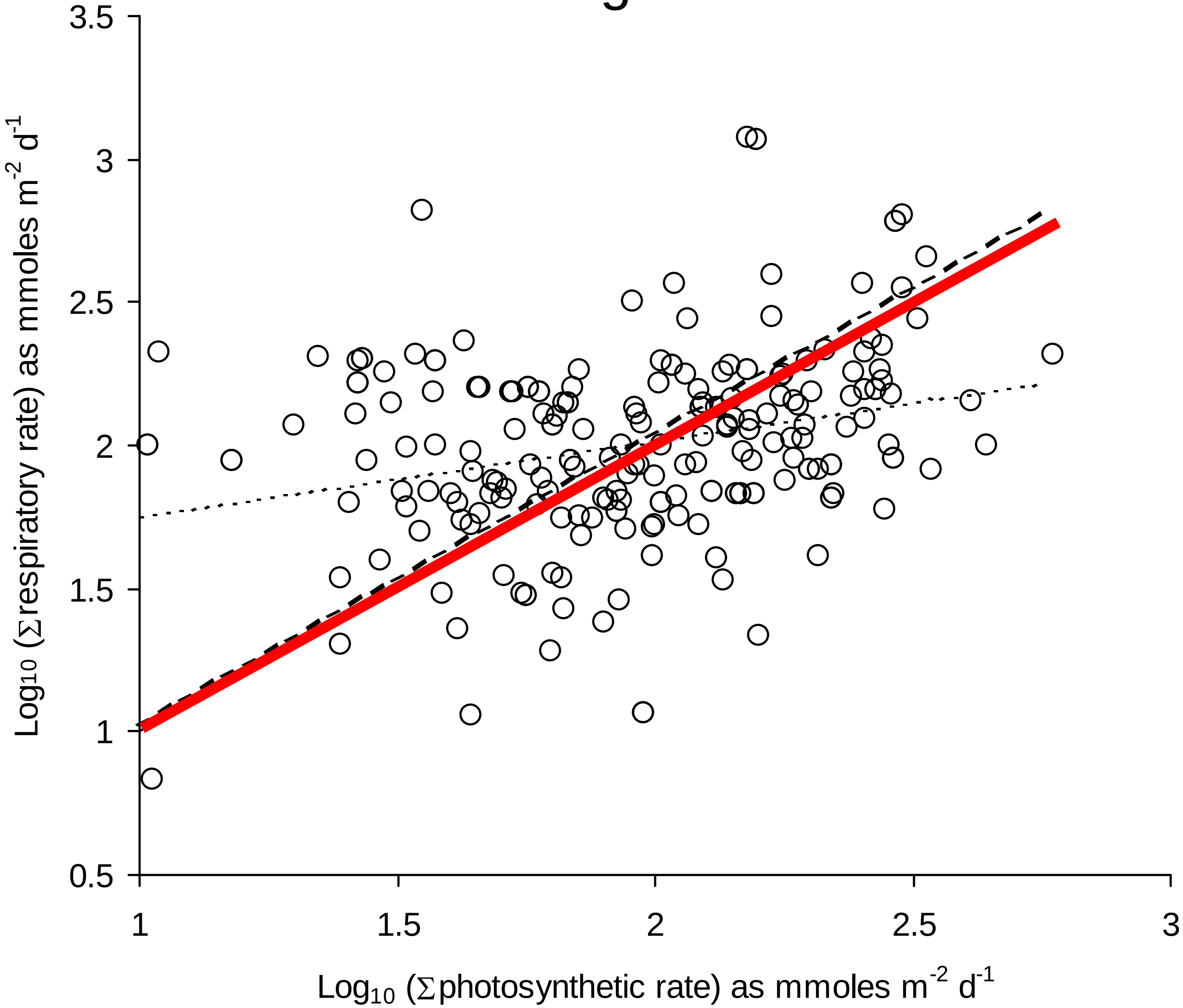


AMT6, Robinson et al., 2002a



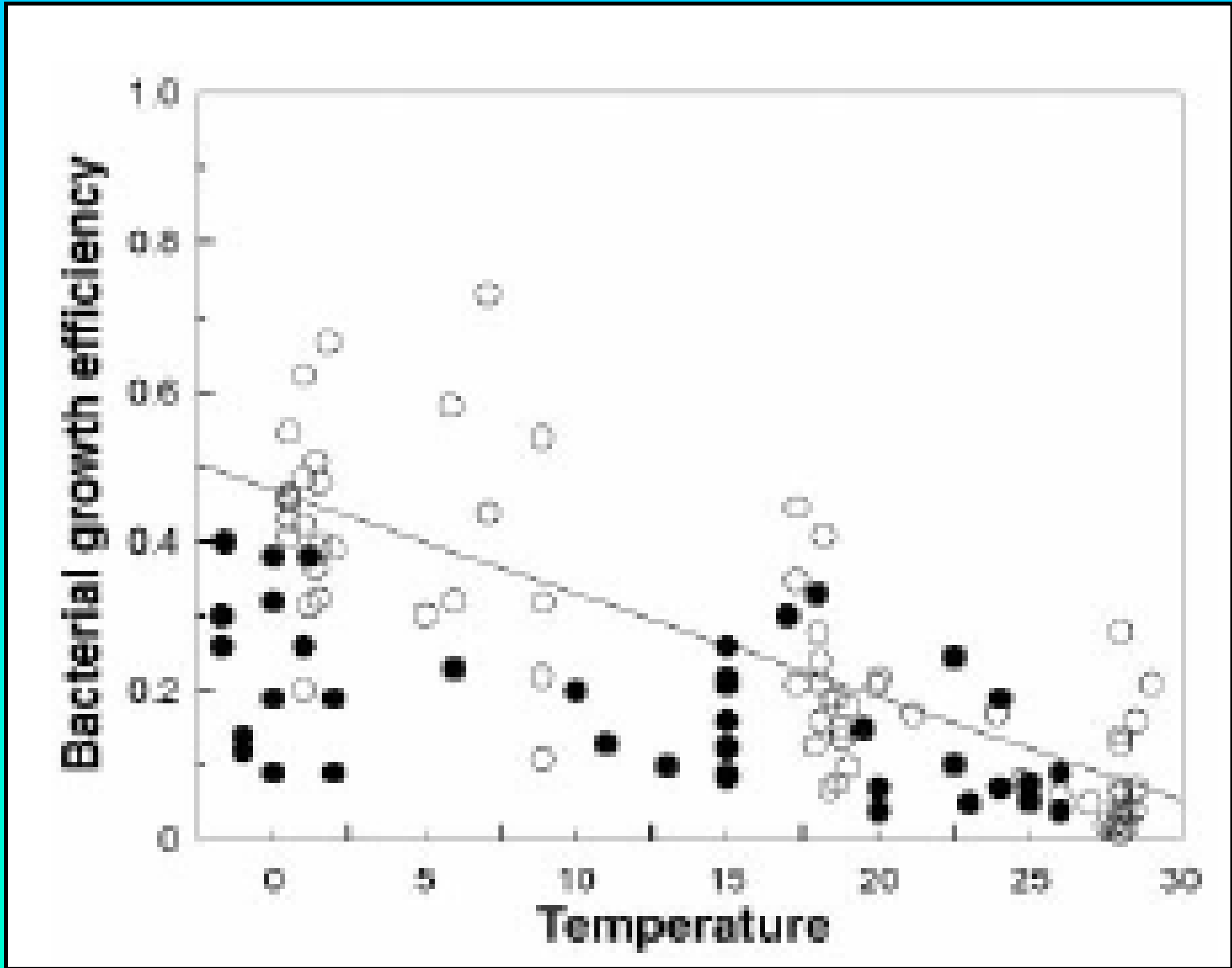
Robinson & Williams, 2005

Relationship between depth integrated P and R



Robinson & Williams, 2005

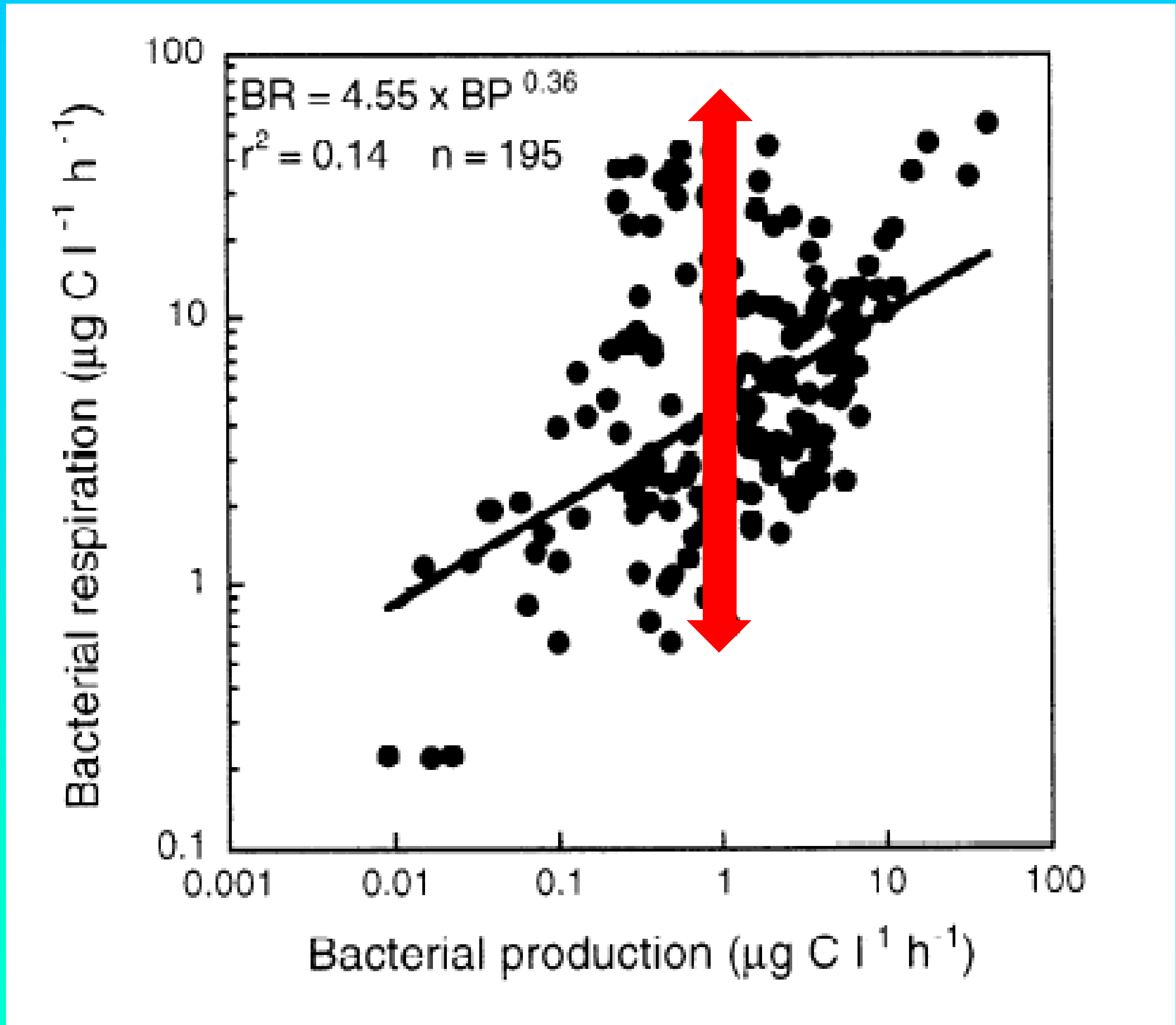
Derive bacterial respiration



Bacterial production, temperature and size fractionated oxygen uptake

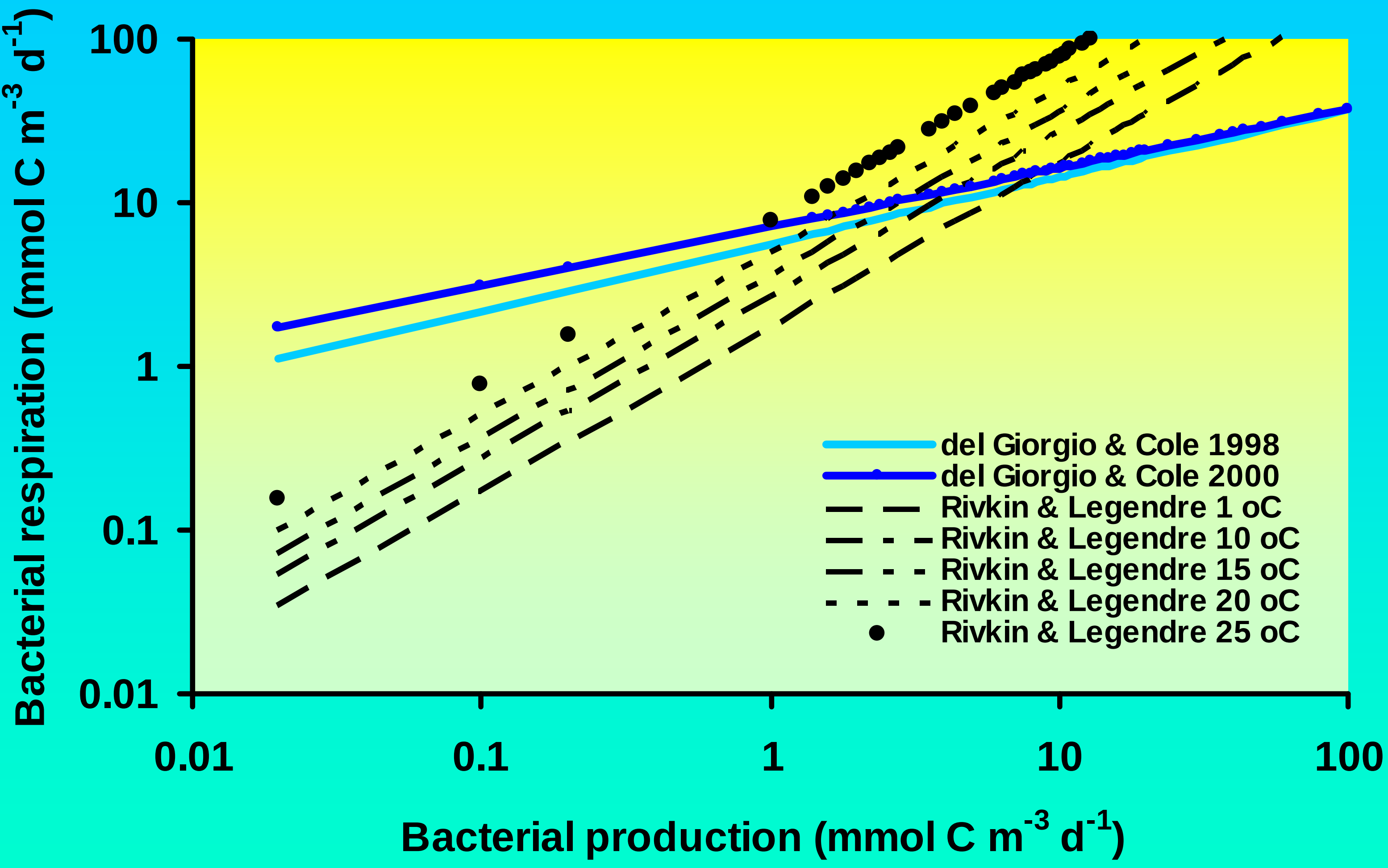
Rivkin and Legendre 2001

Derive bacterial respiration



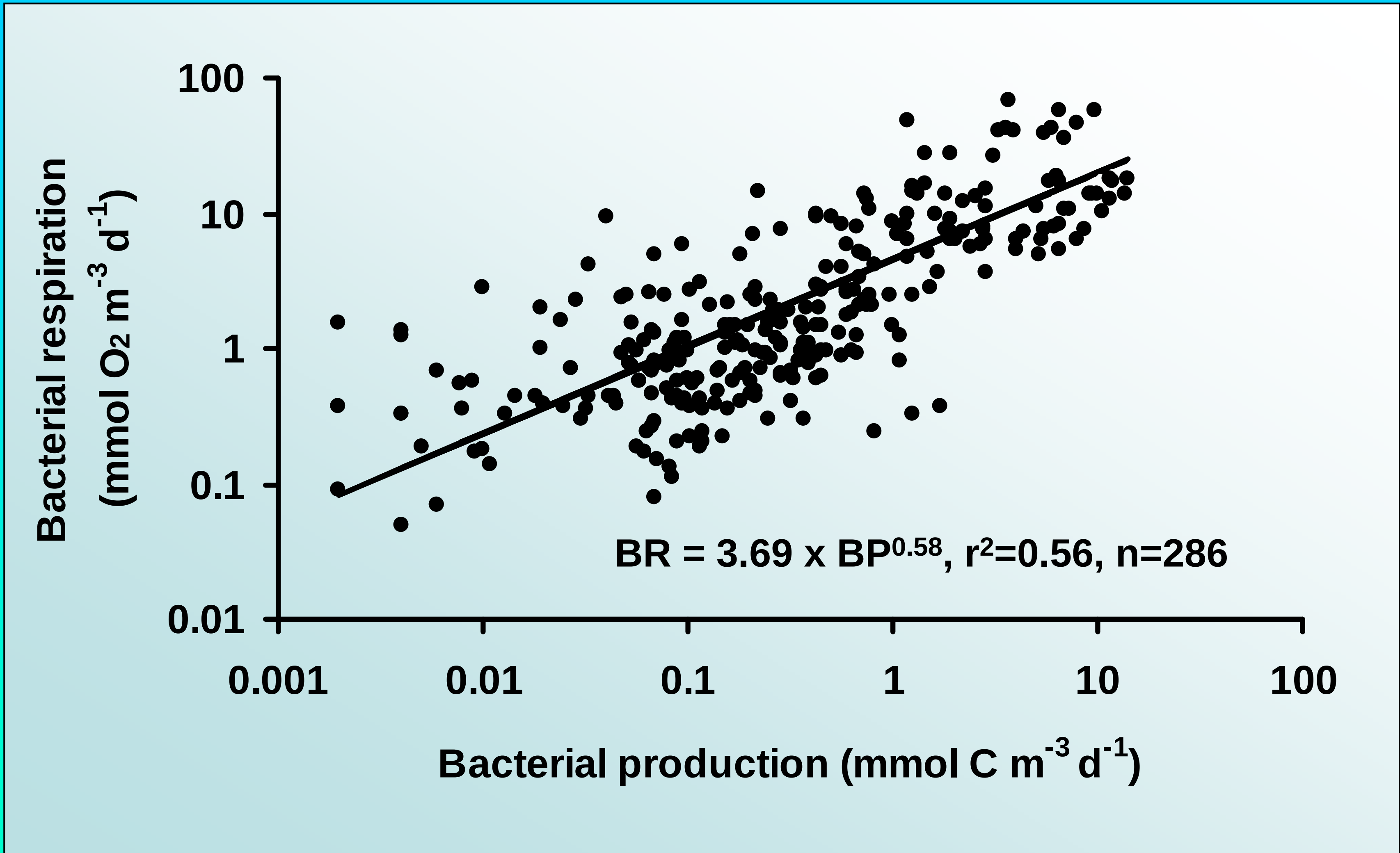
del Giorgio and Cole, 1998, 2000

Derive bacterial respiration



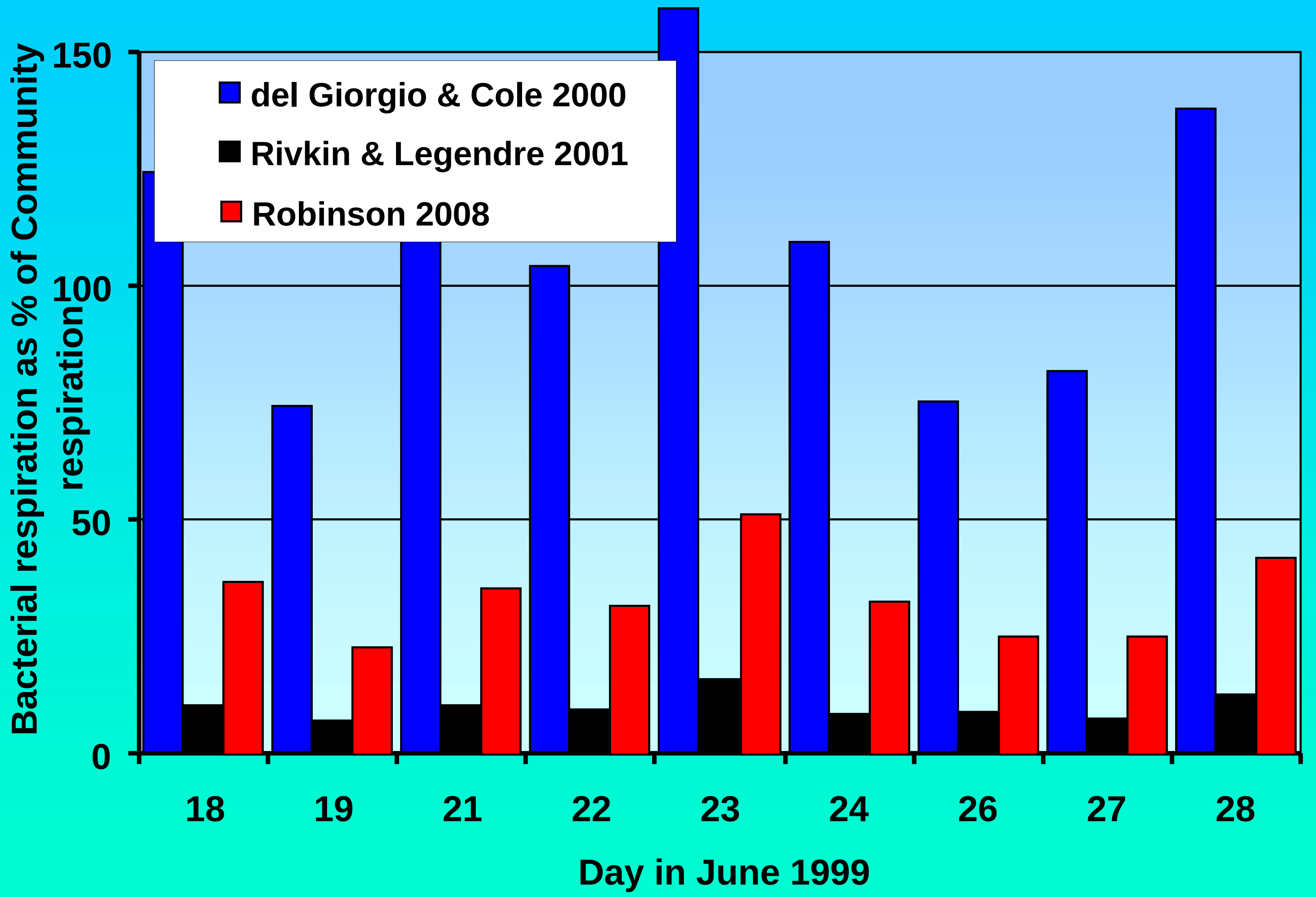
Robinson, 2008

Derive bacterial respiration – empirical model



Robinson, 2008

Predict bacterial respiration



Robinson, 2008

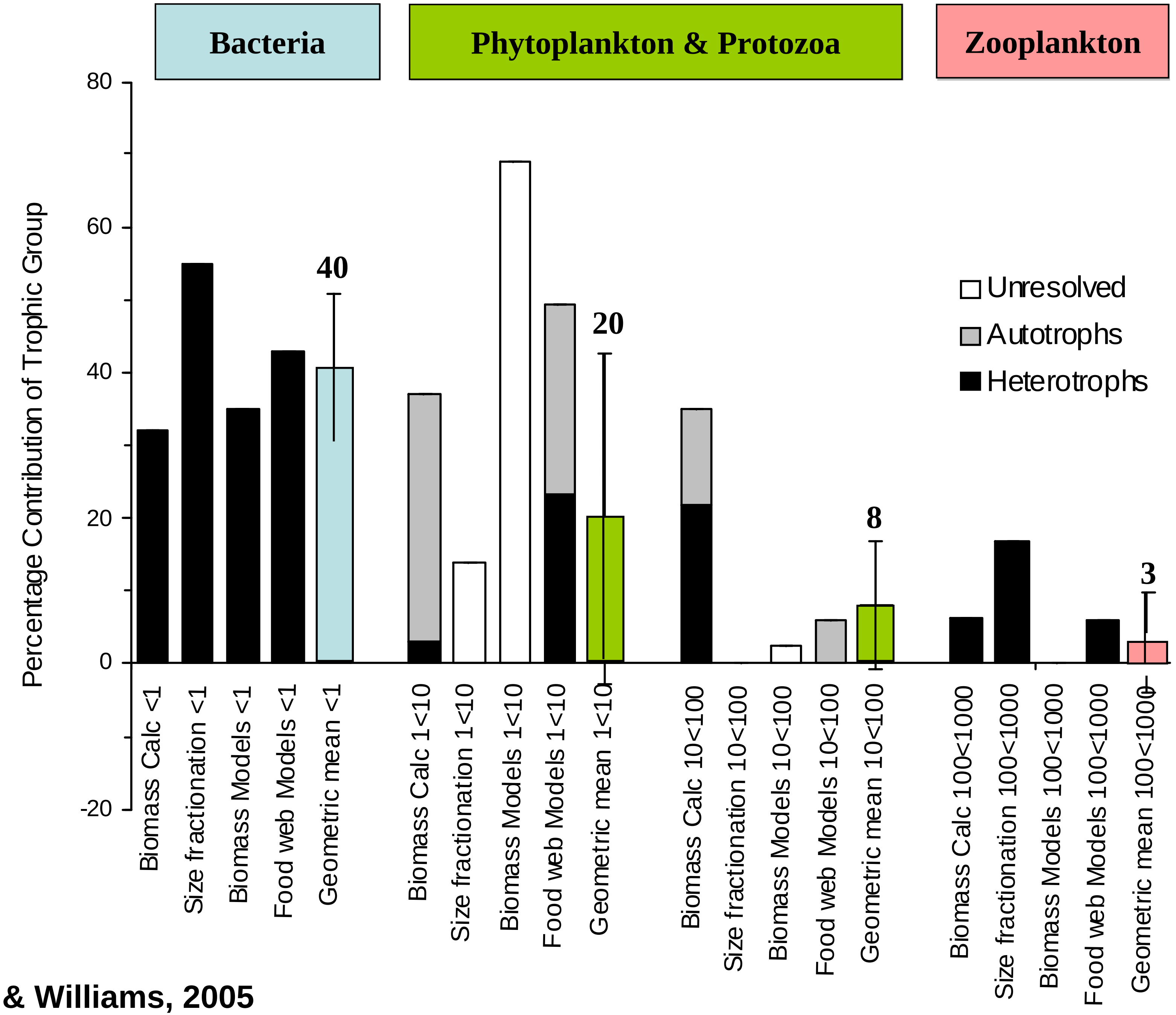
Apportion to trophic group

		Bacteria	Protozoa				Phytoplankton				Zooplankton			
		TOTAL	Nanoflag.	Hetero. dinos.	Cilliates	TOTAL	Pico	Nano	Micro	TOTAL	Larval	Adults	Others	TOTAL
Calculation from Biomass Determinations														
Williams (1981) (n=3; geometric mean)	Mesocosm (Canada)	52	*not included in estimate*		1		←	40	→	40	3	1	1	5
Holligan *et al*. (1984)	English Channel	←		83	→		←	7.8	→	7.8				9.4
Robinson *et al*. (1999) (n=7; geometric mean)	E. Antarctic	12	3	11	1.4	15	←	69	→	69	*not included in estimate*			
Robinson & Williams (1999) (n=6; geometric mean)	Arabian Sea	11				20				13				
Sondegaard *et al.* (2000) (n=3; geometric mean)	Mesocosm (Norway)	51	←	35	→	35	←	12	→	12	*not included in estimate*			
Robinson *et al*. (2002b) (n=6 & 8; geometric mean)	N. Sea	58 (18*)		21	5	28				21				
Summary Statistics														
Arithmetic mean of all observations		32	3	18	4	24				34	3	1	1	6
Standard deviation of all observations		22	1	12	4	16				28	1	1	1	3
Total number of observations		26	7	13	13	26				27	3	3	3	4

* two calculation methods for bacterial respiration

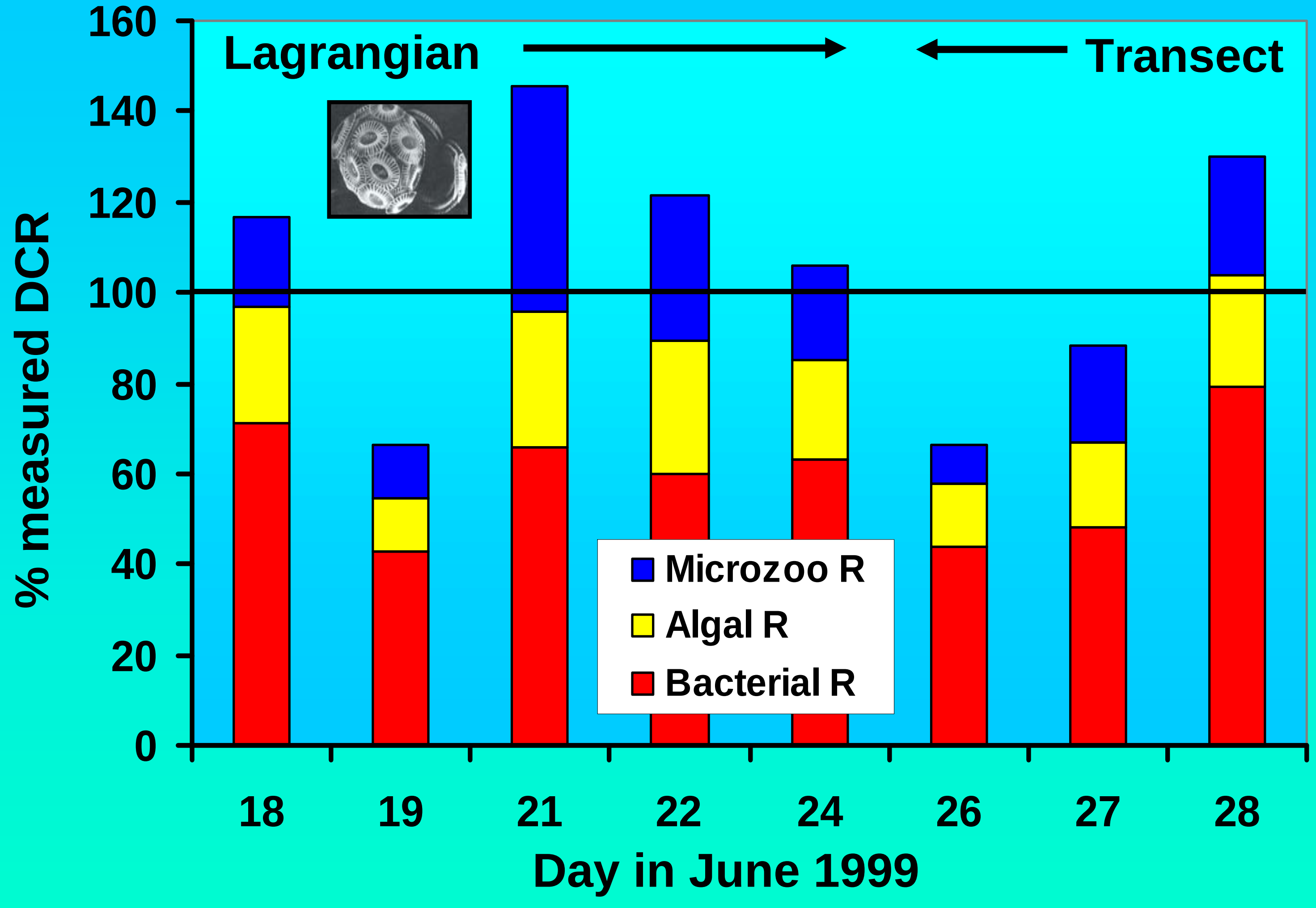
Robinson & Williams, 2005

Size / trophic distribution of respiration



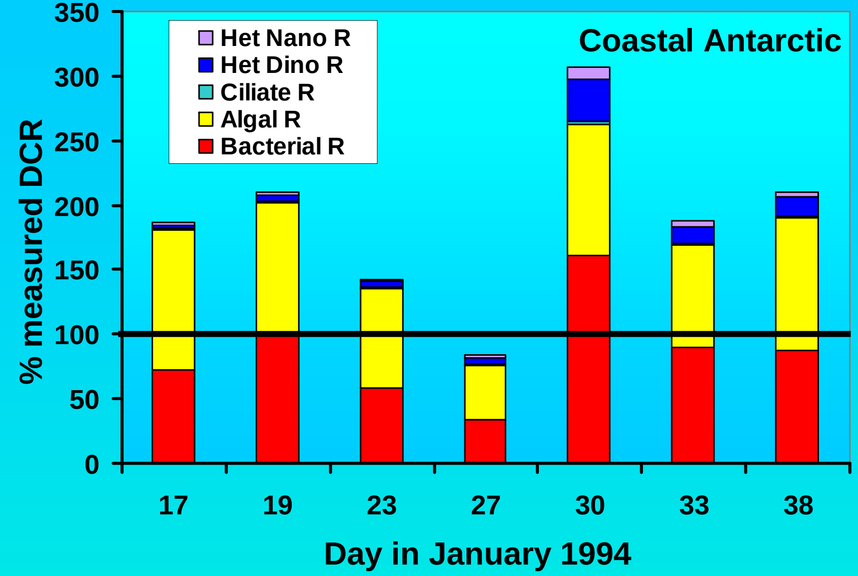
Robinson & Williams, 2005

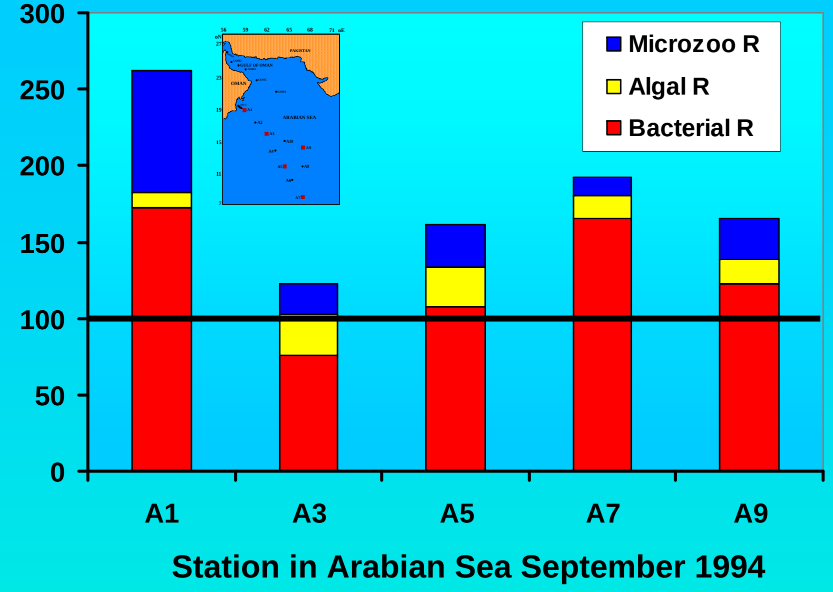
Apportion to plankton trophic group

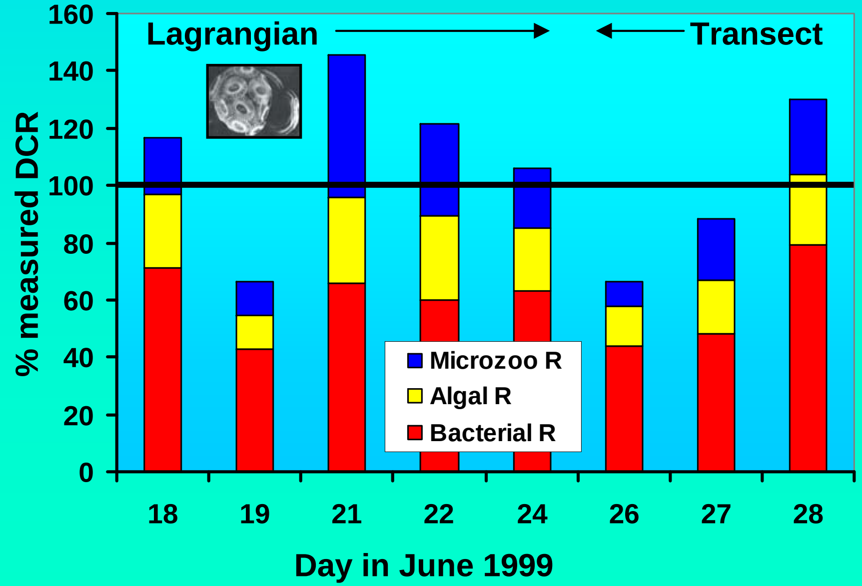


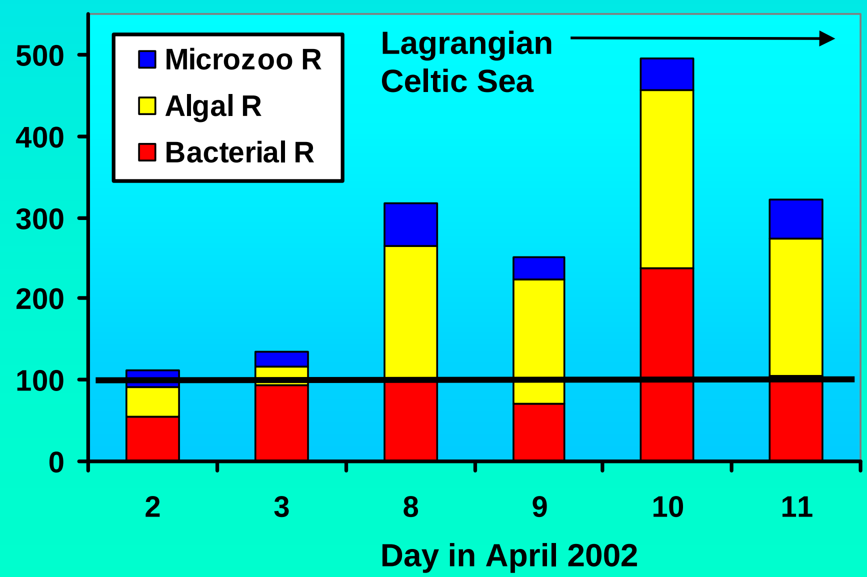
Robinson et al., 2002a

Apportion to plankton trophic group



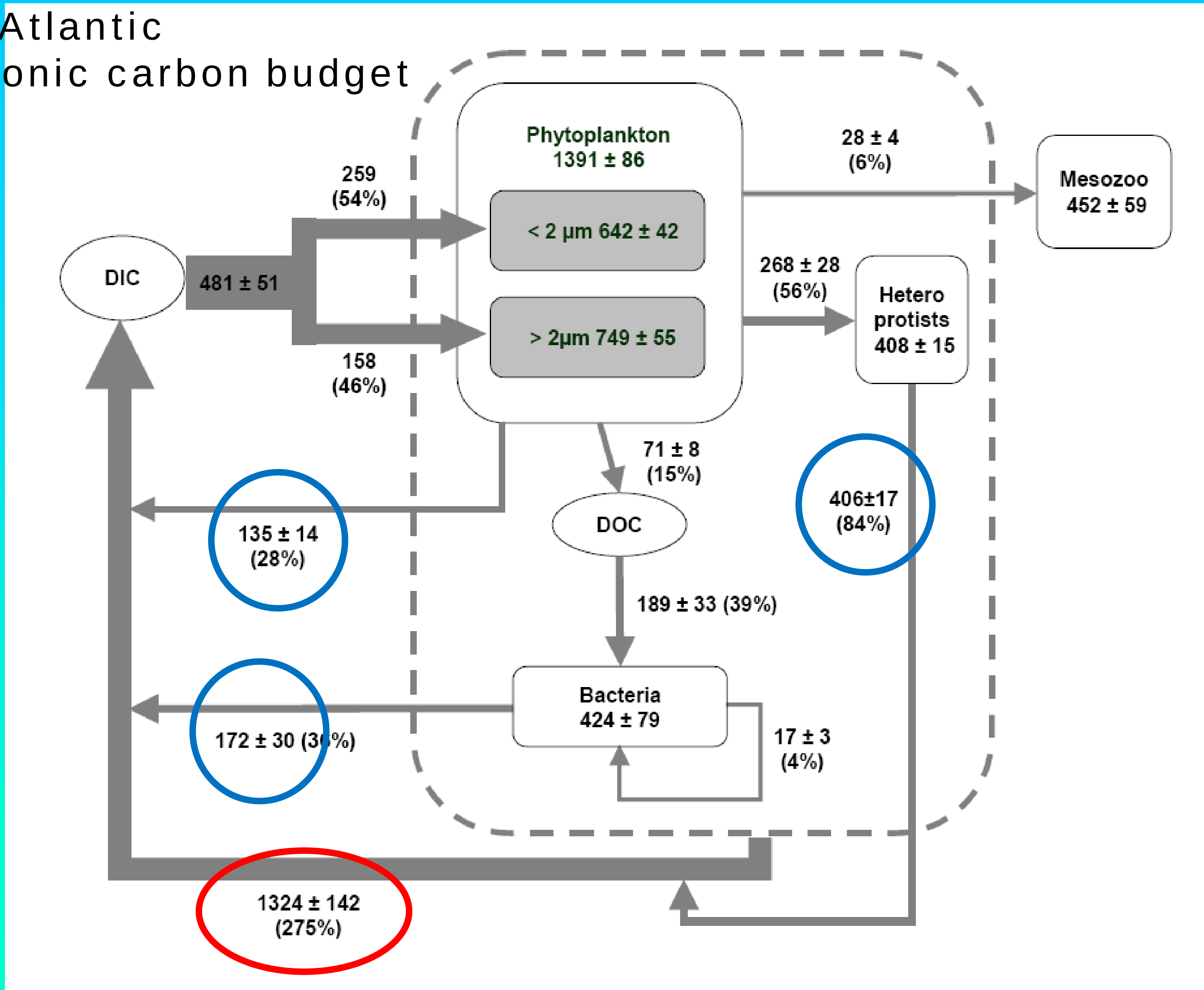






Robinson & Williams, 1999; Robinson et al., 1999; 2002; Robinson et al., unpubl.

North Atlantic
Planktonic carbon budget

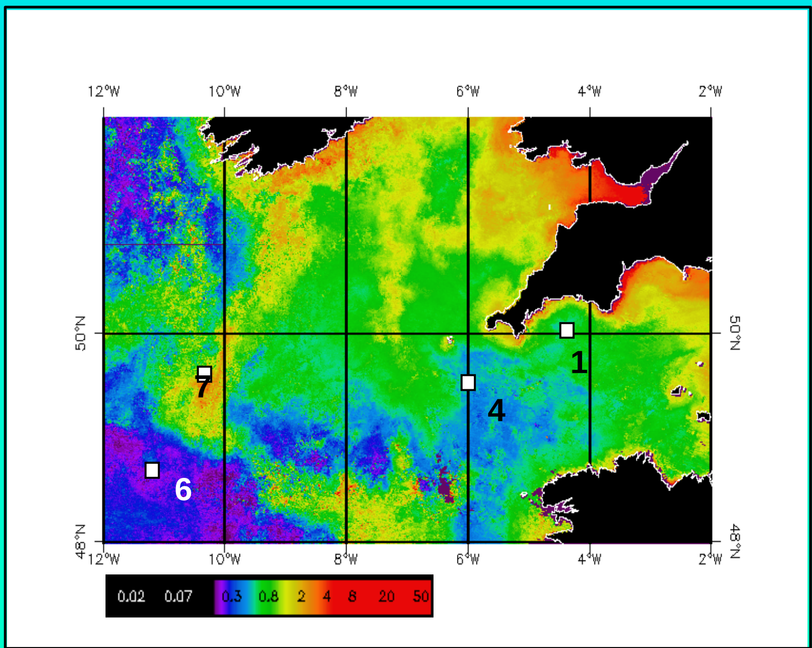


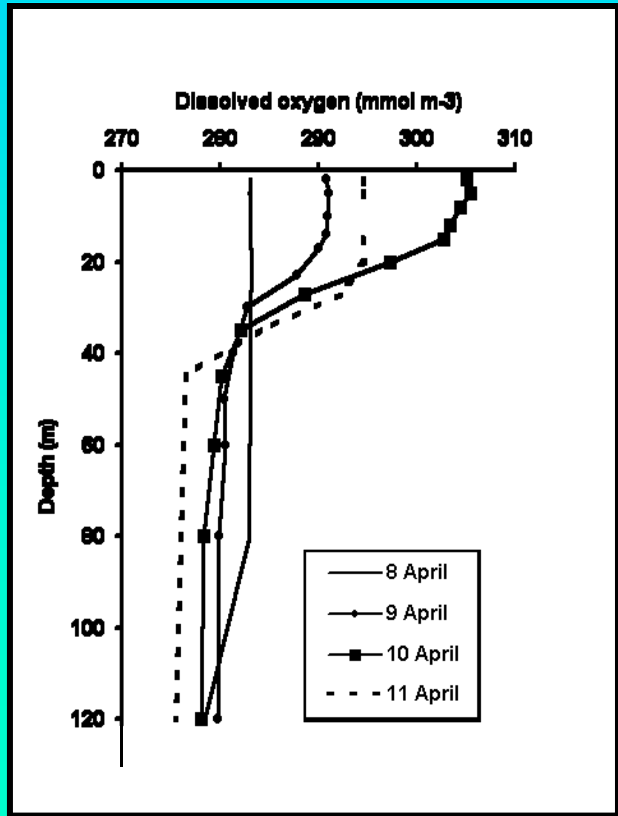
10 years, 60 stns (mg C m^{-2} d^{-1})

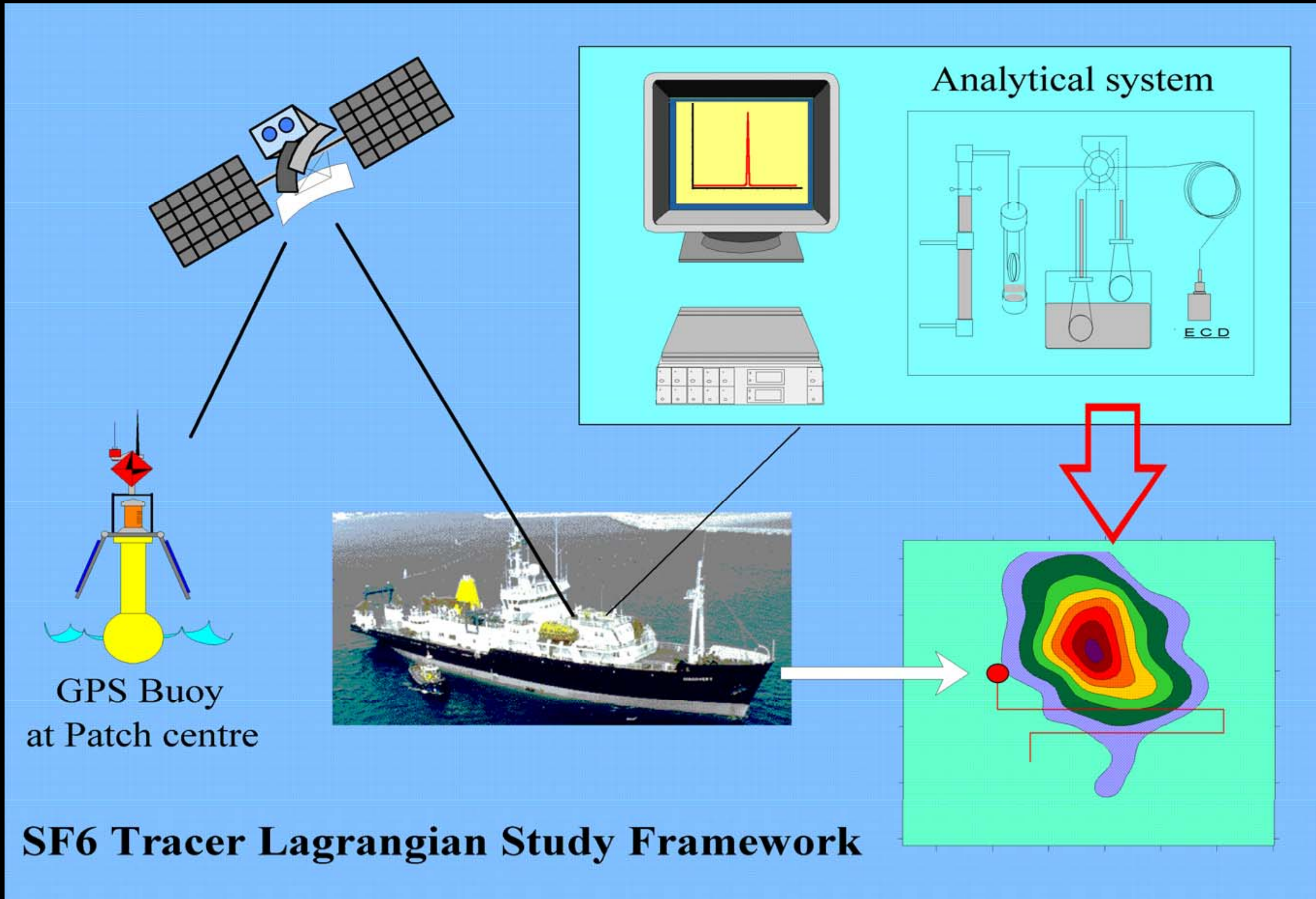
Maranon et al., 2007

Are *in vitro* changes representative ?

In vitro NCP (ΔO_2)	In situ NCP (ΔO_2)	Site	Reference
1	1-3	MERL mesocosms	Bender et al., 1987
1	1.6	N Atlantic	Bender et al., 1992 & Kiddon et al., 1995
1	0.9	Ross Sea	Bender et al., 2000
1	0.6	Antarctic Polar Front	Dickson and Orchardo, 2001
1	6	N Pacific Gyre	Williams and Purdie, 1991
1	0.5 - 2	UK shelf sea	This study







Phil Nightingale, PML

SUMMARY

- Respiration is weak link in understanding C cycle
- Database is small but increasing, link to biotic and abiotic factors, no long time series
- web.pml.ac.uk/amt/data/Respiration.xls
- Quantification at large temporal and spatial scales only achievable through ‘model’ - empirical
- Ecological models require ‘functional group’ information
- Need to quantify changes in response to a changing environment – temperature, nutrients, pH, light

Every oceanographer is a modeller

Do we want more 'model' ers at sea ?


Aiken Meridional Transect
Thank you Jim