Methane, midges, and maybe some climate change

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NERC SCIENCE OF THE ENVIRONMENT

MAX-PLANCK-GESELLSCHAFT

A potted history of methane

- 1887 chemosynthesis (synthesis of OC using chemical energy derived from the oxidation of simple IC) first observed by Winogradsky

  '*no significant, quantitative role in the carbon cycle'*

- At deep-sea vents and seeps, macroinvertebrates found reliant upon chemosynthetic based nutrition Paull et al 1985; Fisher 1990

- Methanotrophic communities also are found in many terrestrial and freshwater environments Fenchel & Finlay 1995; Hanson & Hanson 1996

- First evidence of billabong, lake and stream food-webs being fuelled by methane-derived carbon via methane oxidising bacteria (MOB)

  See Bunn & Boon 1993; Kiyashko et al 2001; Grey 2002; Kohzu et al 2004

Biogenic CH_4

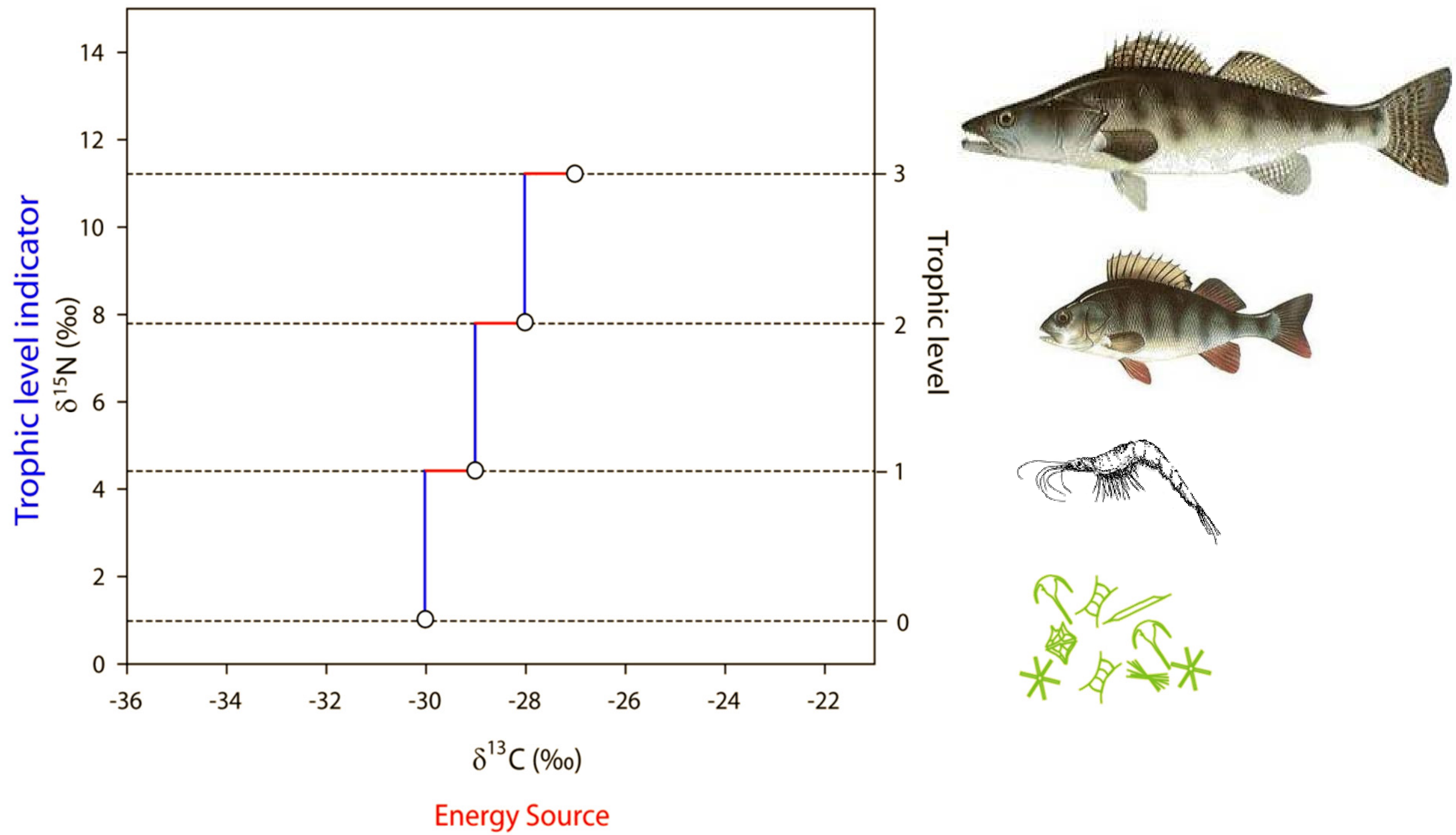
- Reservoirs of CH_4 in oceanic and freshwater sediments all over the world DeLong 2000
- Freshwaters contribute ~20% of annual global CH_4 flux Bastviken et al 2011
- We now have a good understanding of production and flux processes regulated by microbes eg review by Rudd & Taylor 1986

- Methane oxidising bacteria (MOB) are the most important natural mitigative process for emissions of CH_4, accounting for up to 90% of that produced eg Casper 1992; Krüger et al 2001

- Yet few studies have investigated the fuelling of (aquatic) food webs via methanotrophic bacterial biomass

Stable isotopes

- Isotopic signatures are transferred in a relatively dependable way



Biogenic CH_4

- Methanogenesis involves a large Kinetic Isotope Effect (KIE)

  ie the heavy isotope (^{13}C) is discriminated against

- Hence CH_4 $\delta^{13}C$ is markedly different from organic matter substrate

  Whiticar 1999

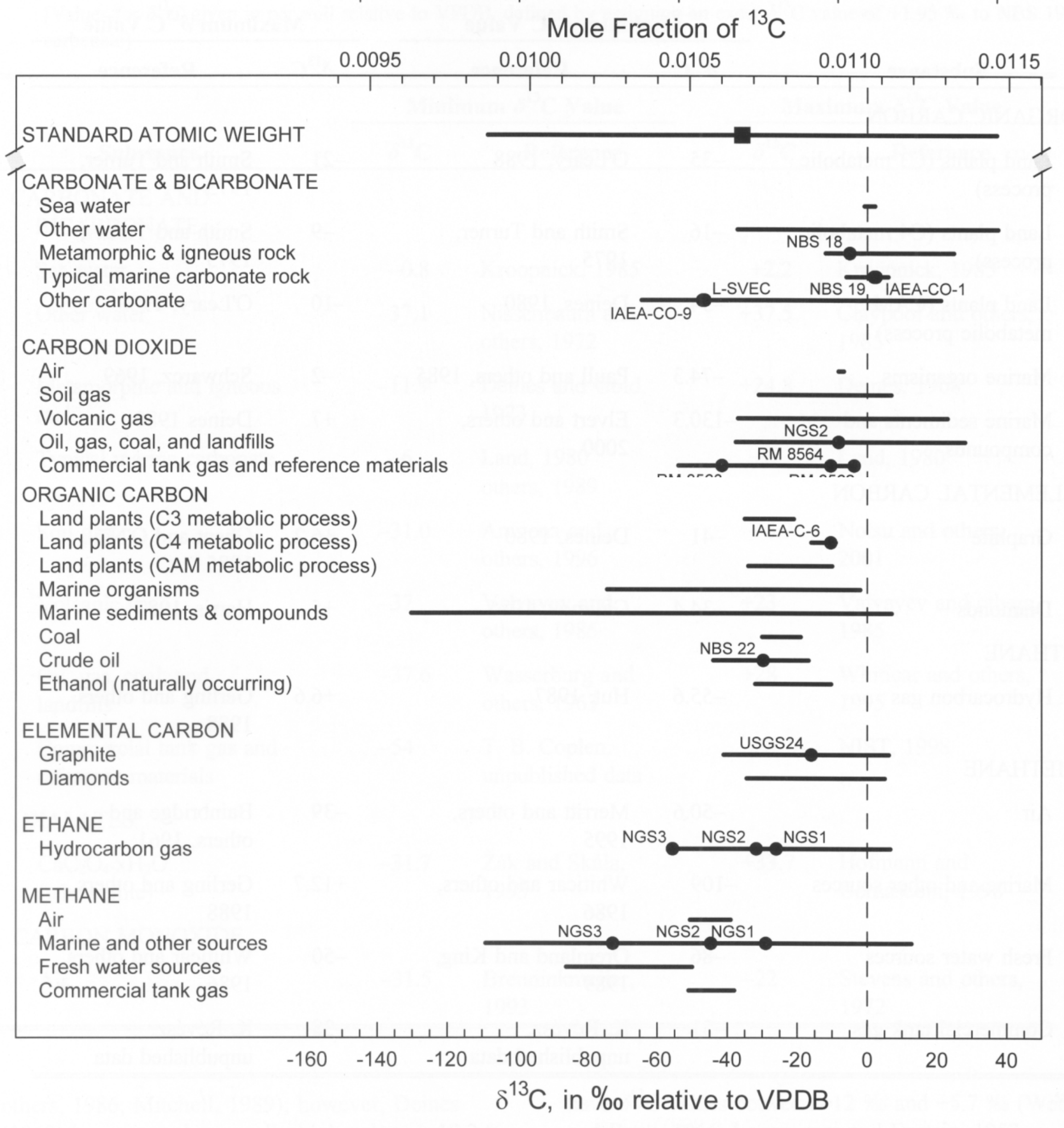
- Methanotrophy (by MOB) also involves KIE, resulting in MOB becoming

  even further ^{13}C-depleted than the CH_4 Whiticar 1999

- Thus MOB have a distinct isotopic signature which can be easily traced

  Boschker et al 1998

CH_4-derived carbon



$\delta^{13}C$ of CH_4 from freshwater sources:

-86 to -50‰

Modified from Coplen et al 2002

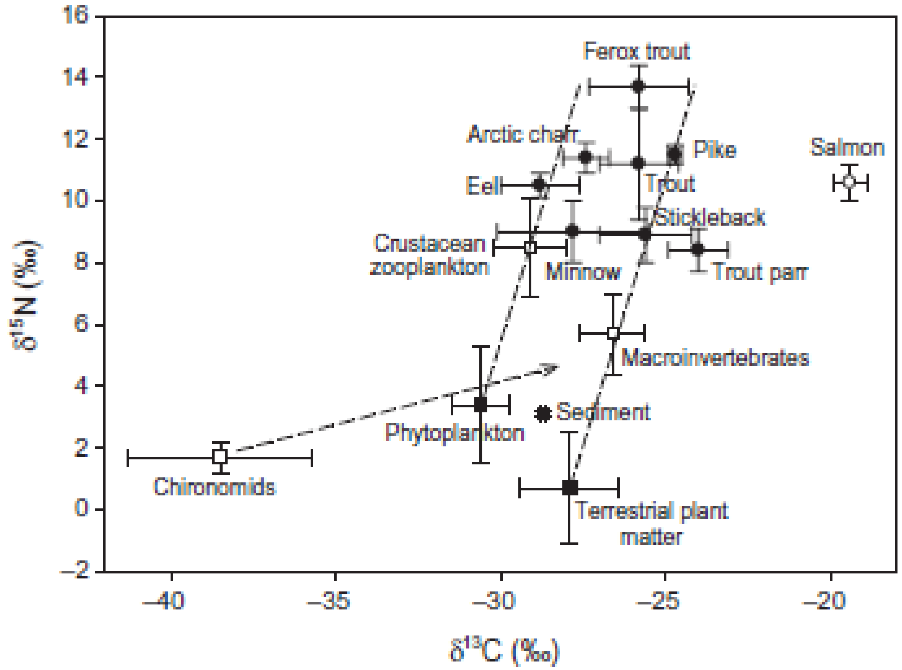
USGS Report 01-4222

$\delta^{13}C$ of typical basal resources in freshwater:

-35 to -20‰

eg Grey et al 2000

Chironomids are key

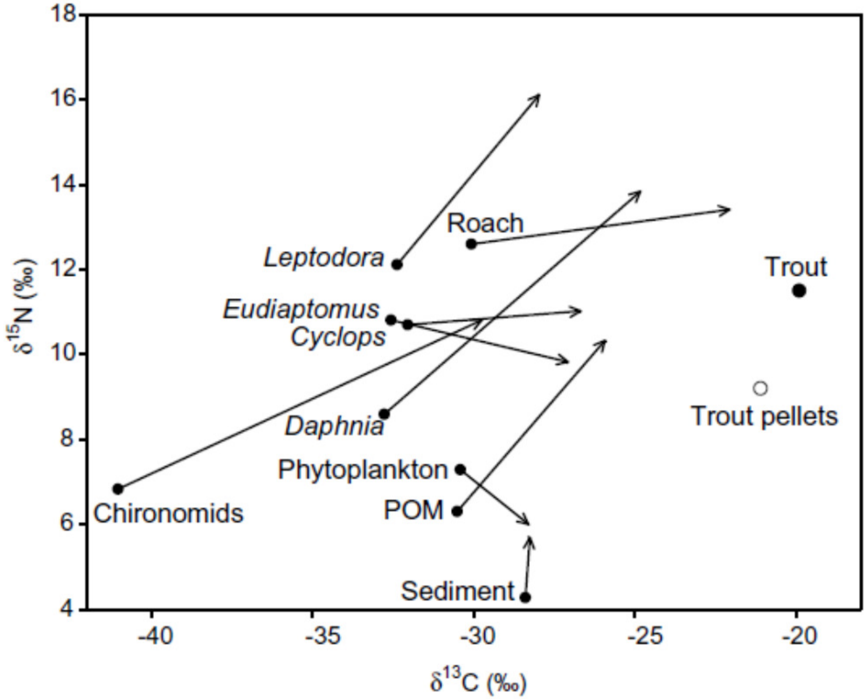


Jones & Grey 2011

Table 1. Some limnological characteristics of Loch Ness, Scotland and Esthwaite Water, Cumbria.

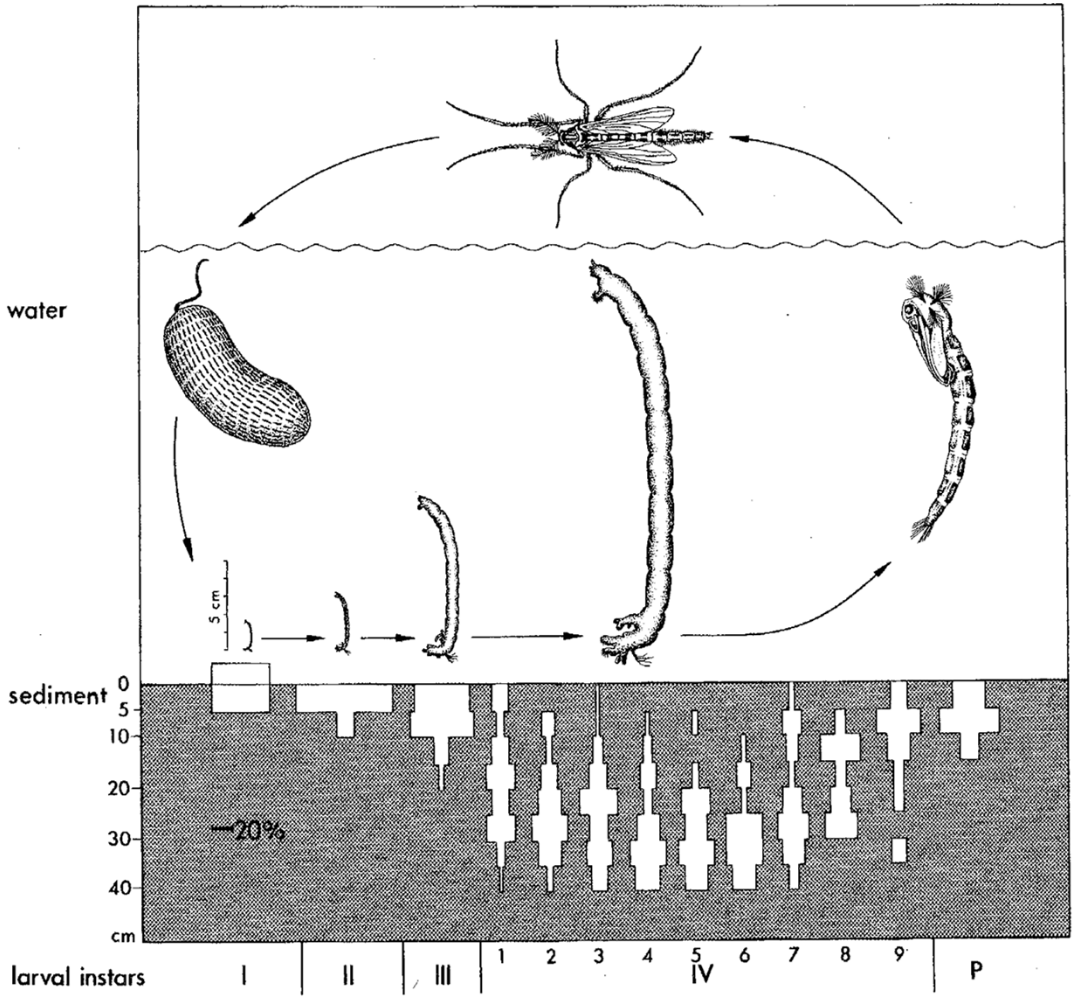
Characteristic	Loch Ness	Esthwaite Water
Area (km^2)	56.4	1.0
Volume (m^3)	7.45×10^9	6.4×10^6
Mean (max.) depth (m)	132 (230)	6.4 (15.5)
[Phosphorus] ($\mu g\ L^{-1}$)	<10	35.7
Peak chlorophyll *a* ($\mu g\ L^{-1}$)	<3	100
Colour (mg Pt L^{-1})	51.0	33.8

Grey 2002



Grey et al 2004

Chironomid (midge) life



Life-cycle of *C. plumosus* in Federsee,

copied from Frank 1982

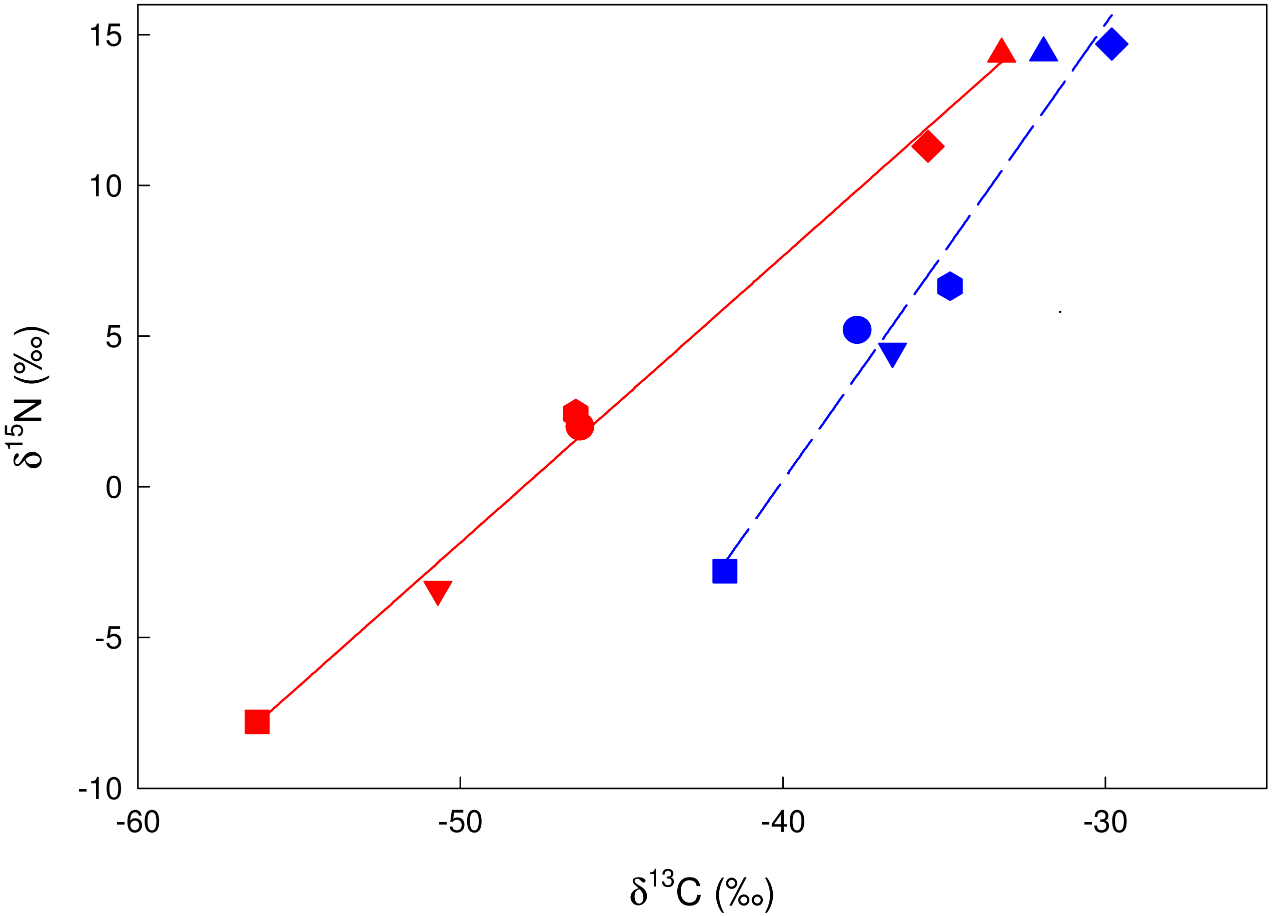
Chironomid life

- Tubicolous species bioturbate sediments creating micro-niche

Interspecific variability

Chironomus plumosus & *C. anthracinus*

Interaction between species and $\delta^{15}N$ ($F_{1,11}$ = 16.09; p = 0.0039)

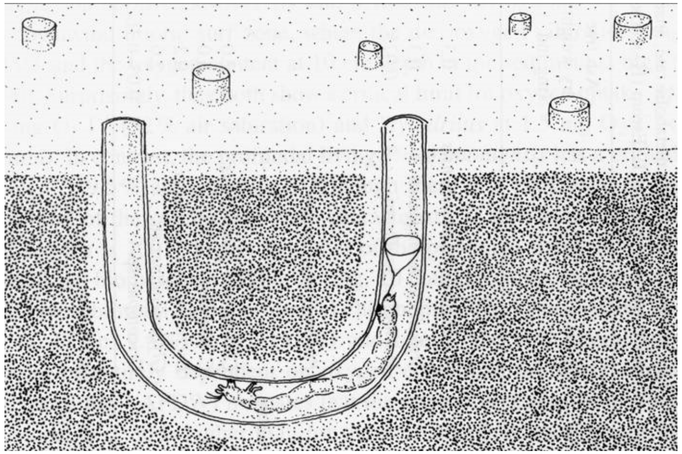


Data derived from six lakes represented by differing symbols

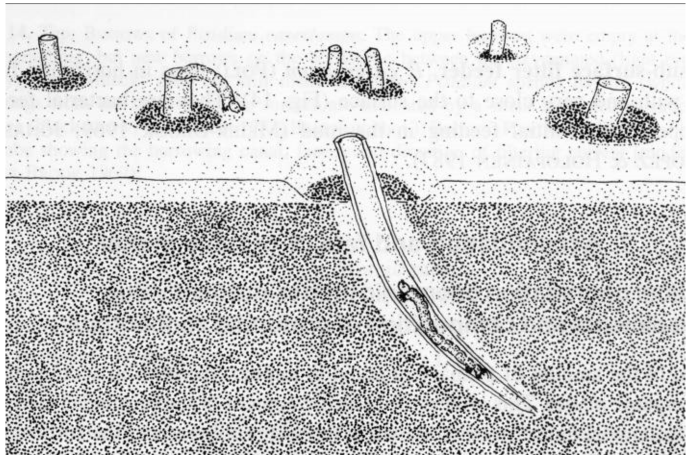
C. plumosus generally ^{13}C and ^{15}N-depleted relative to congener

Modified from Kelly, Jones & Grey 2004

Interspecific variability



C. plumosus



C. anthracinus

Suggested roles of tube morphology and larval physiology

affecting larval ability to irrigate tubes

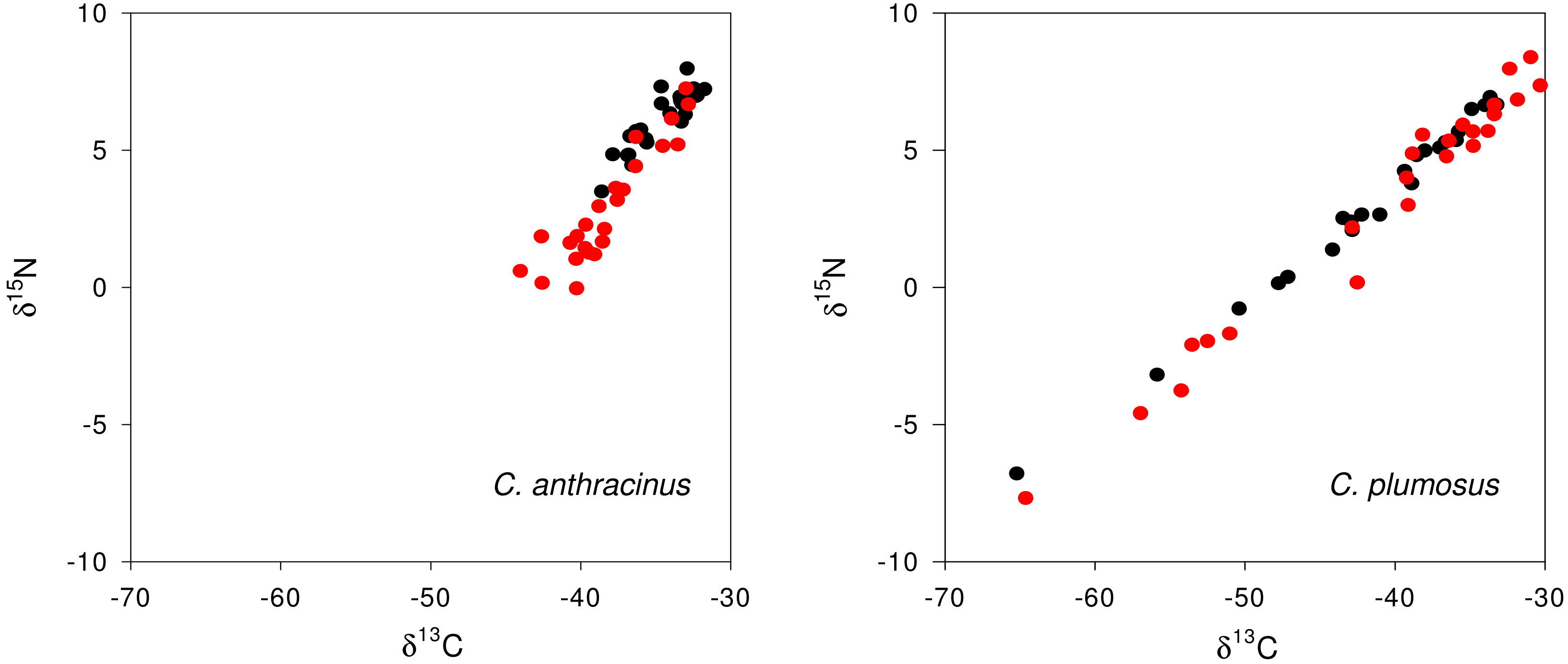
AND feeding mode assimilating bacteria from different sediment layers

in Kelly, Jones & Grey 2004

Grey & Deines 2005

Tube pictures courtesy of P.M. Jónasson

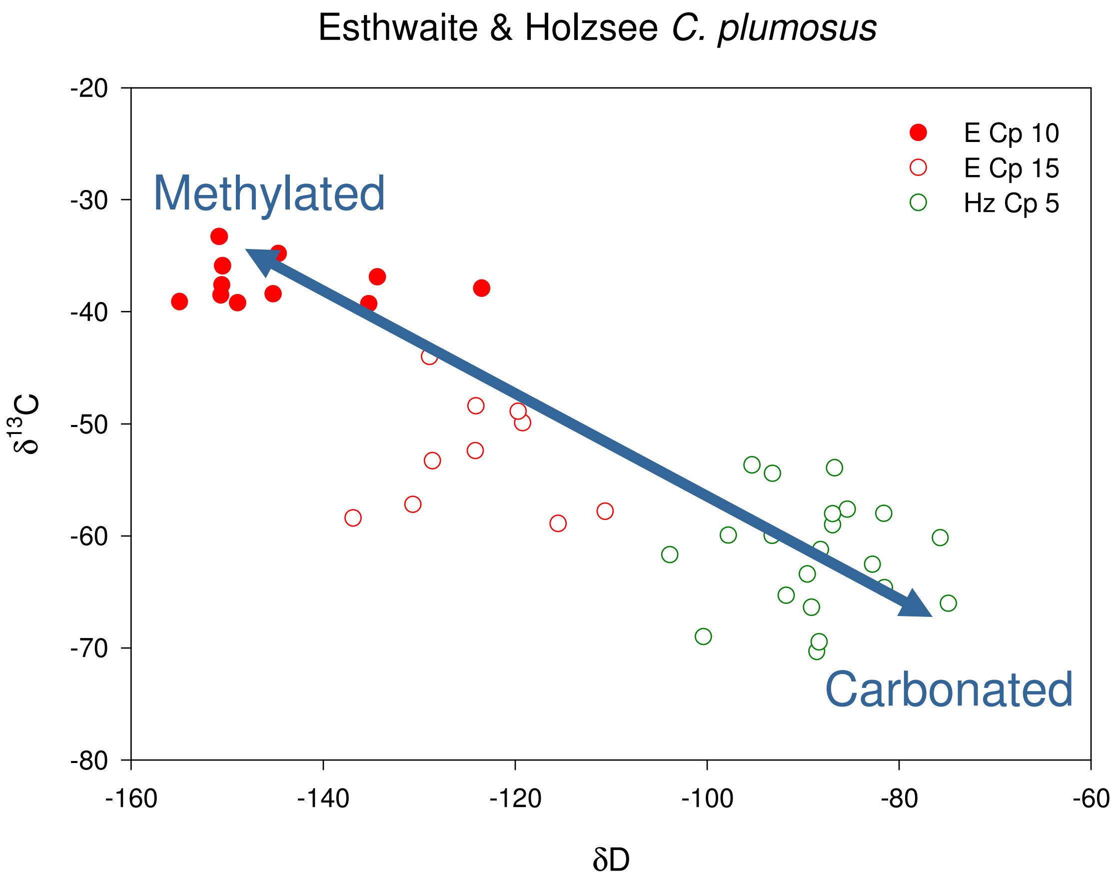
Intraspecific variability



- Individual 4th instar larvae, same depth, same date
- $\delta^{15}N$ range over 15‰ = 5 trophic levels (!)
- $\delta^{13}C$ range over 35‰

Grey, Kelly & Jones 2004

Stable hydrogen isotopes



Bacterial reduction of CO_2 to CH_4 gives rise to CH_4 $\delta^{13}C$ to –110‰

Fermentation of methylated substrates gives rise to CH_4 $\delta^{13}C$ to –50 to –60‰

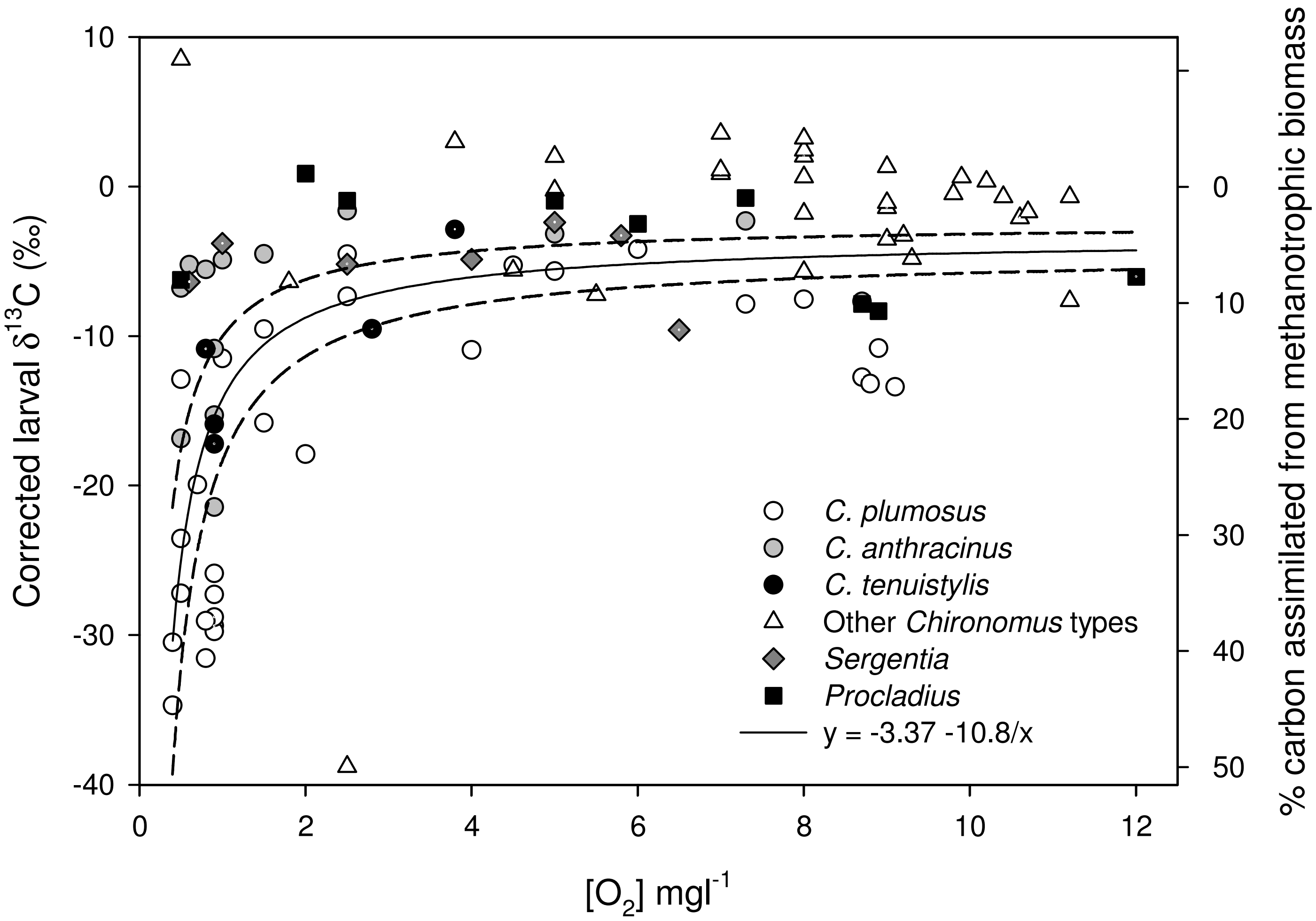
Bacterial D/H discrimination during CO_2 reduction is less than during methanogenesis of methylated substrates

Whiticar 1999

- Further evidence of bacterial substrate usage: methylated substrates appear more prevalent at shallower depths in Esthwaite

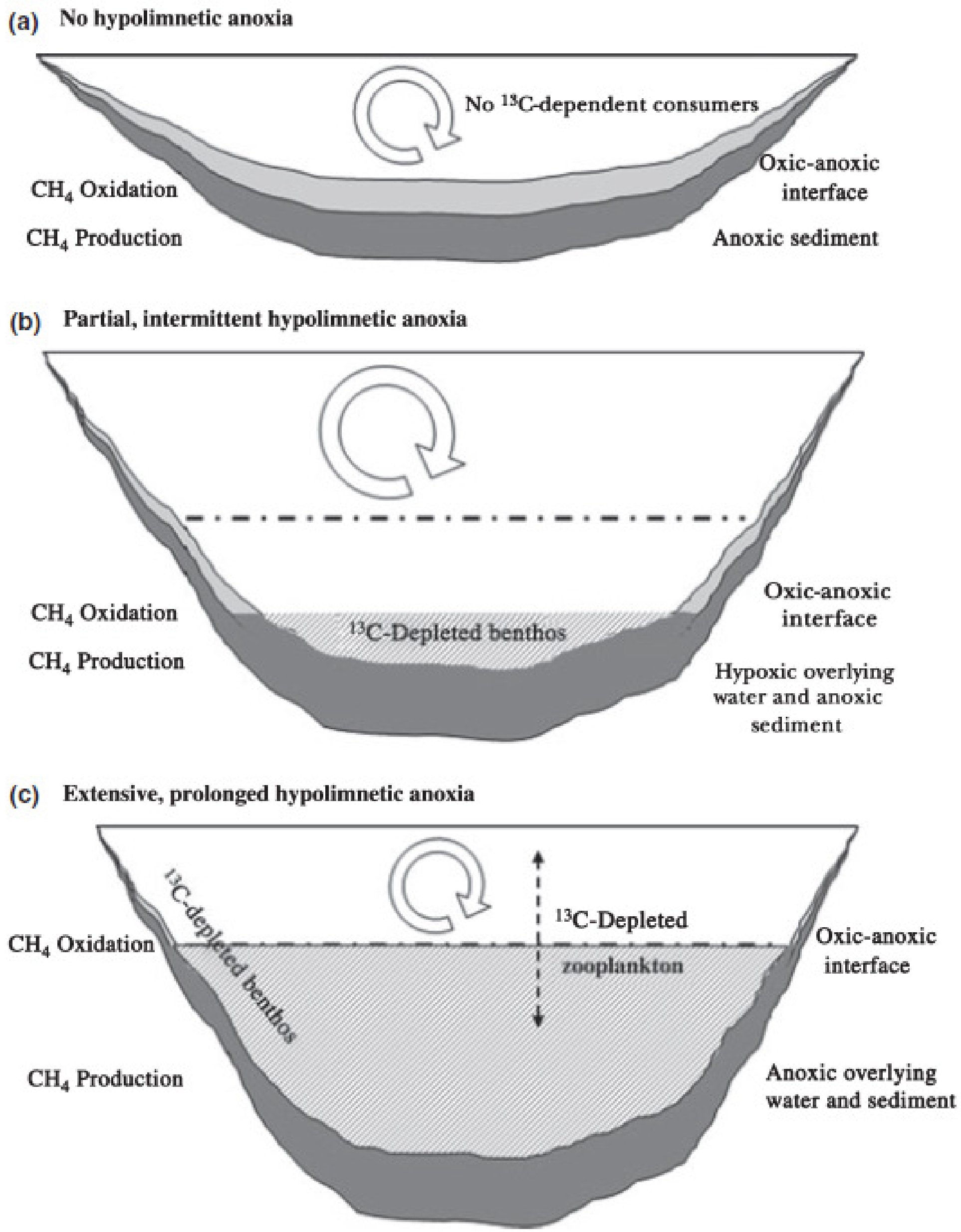
Deines, Wooller & Grey 2009

How common a phenomenon?



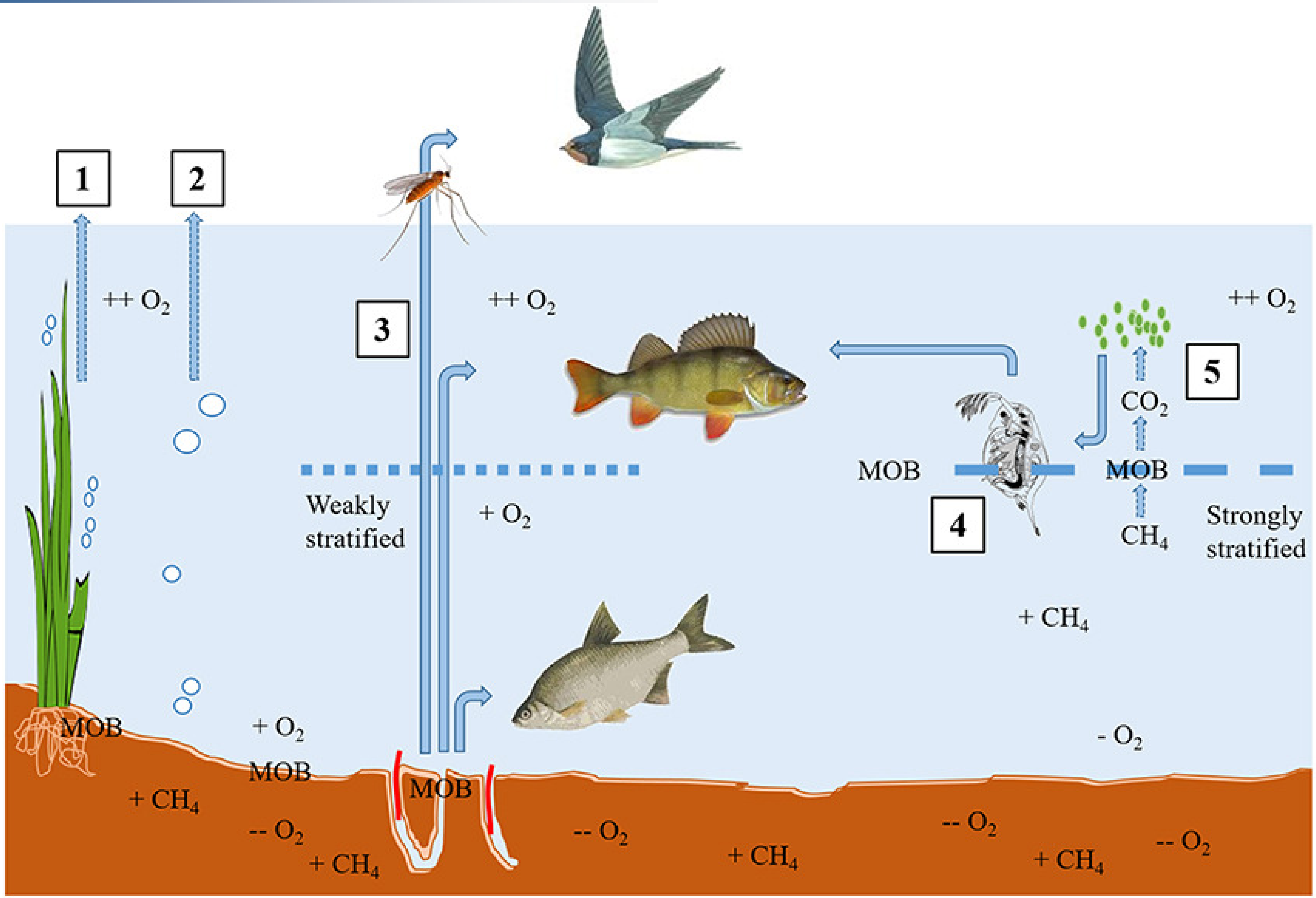
Jones et al 2008

Related to lake 'structure'



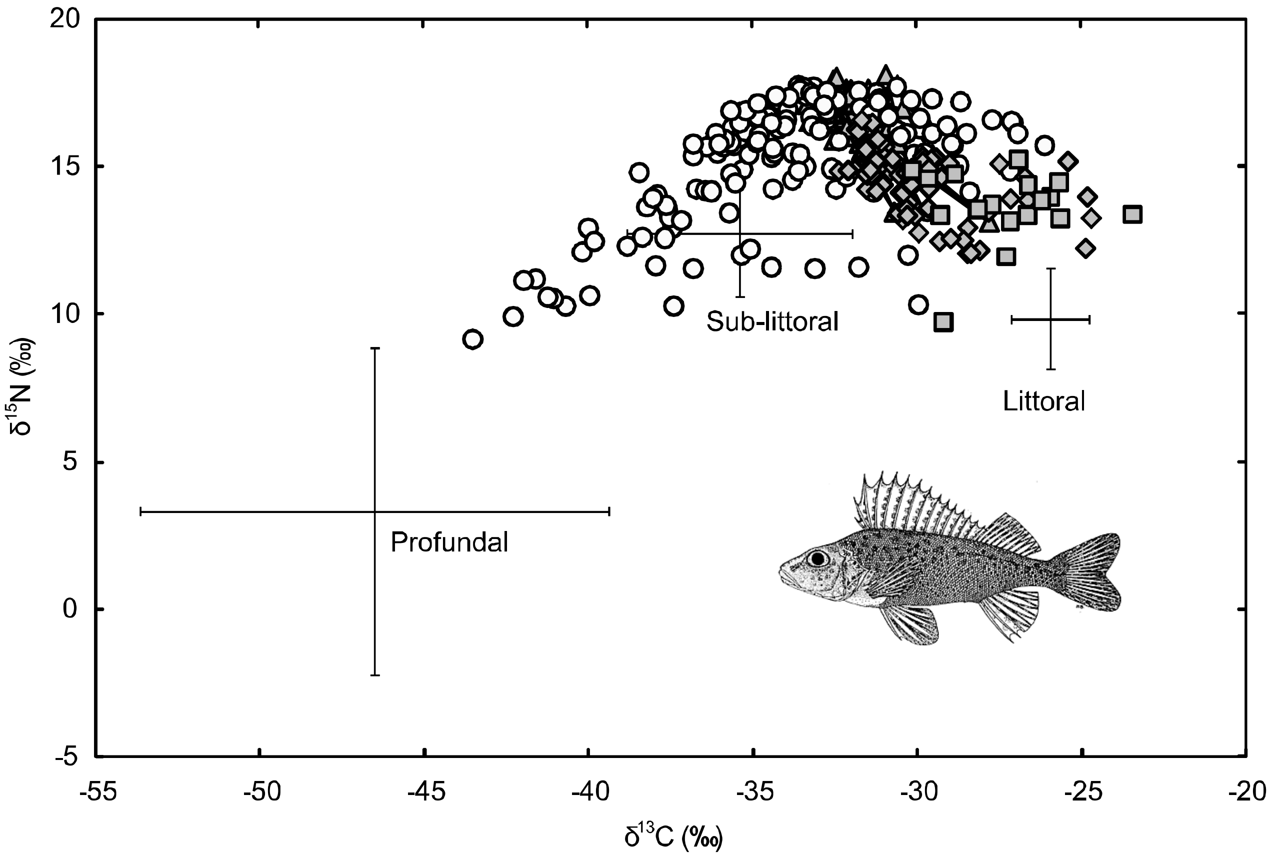
Jones & Grey 2011

Routing of methane?



Grey 2016

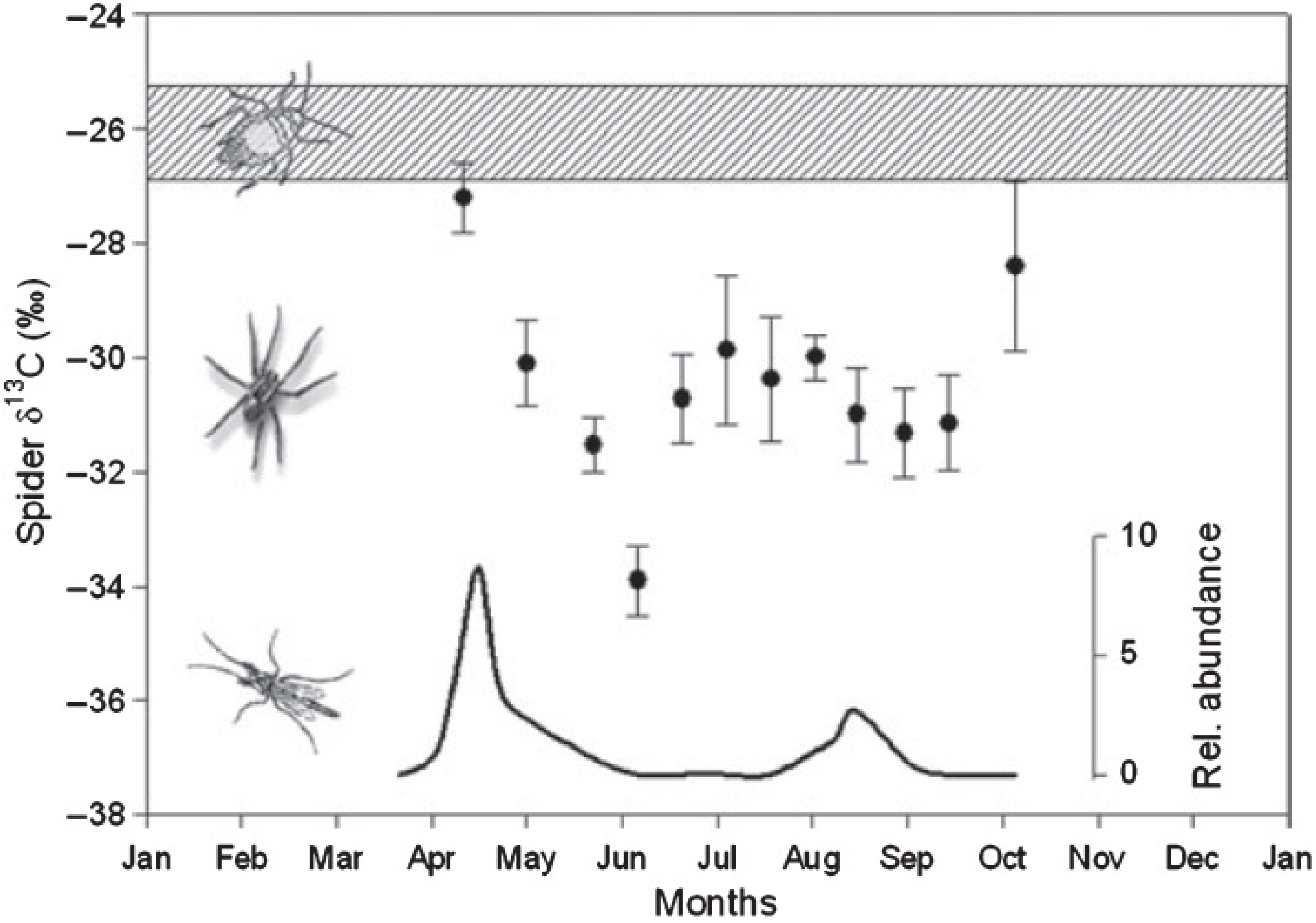
Methane and higher trophic levels



Mean profundal, sub-littoral and littoral chironomid SI values as likely prey sources for fish species such as ruffe

Ravinet et al 2010

Wider use of methane?



Jones & Grey 2011

Wider use of methane?

…and maybe some climate change?

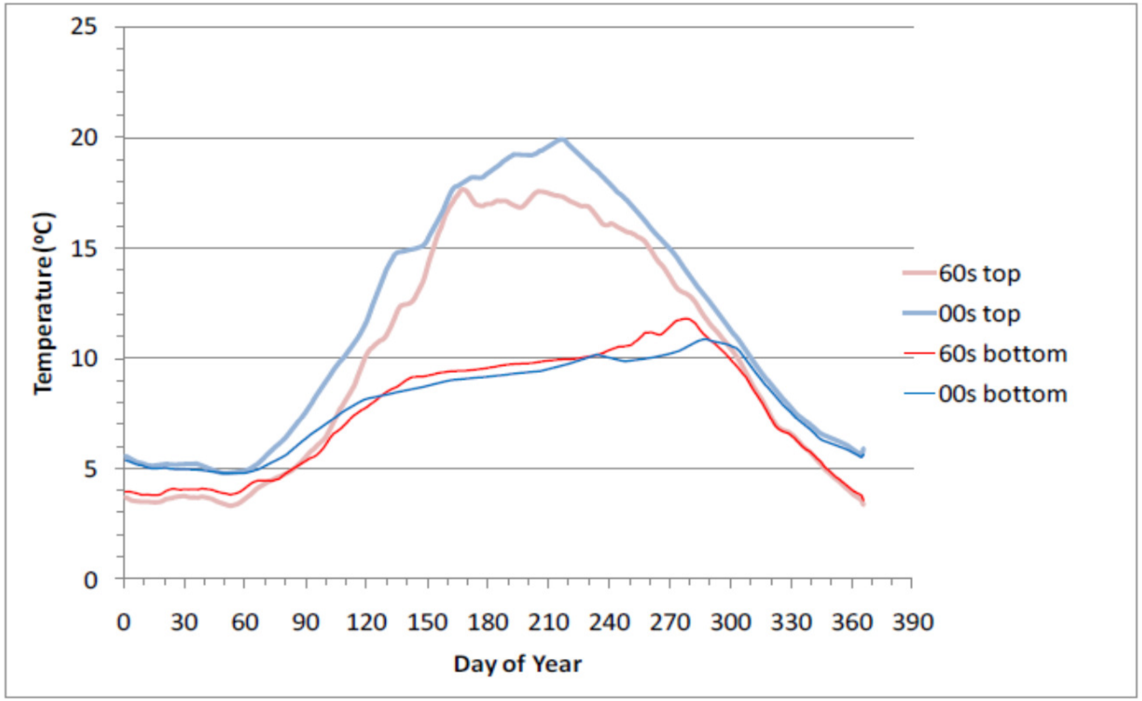
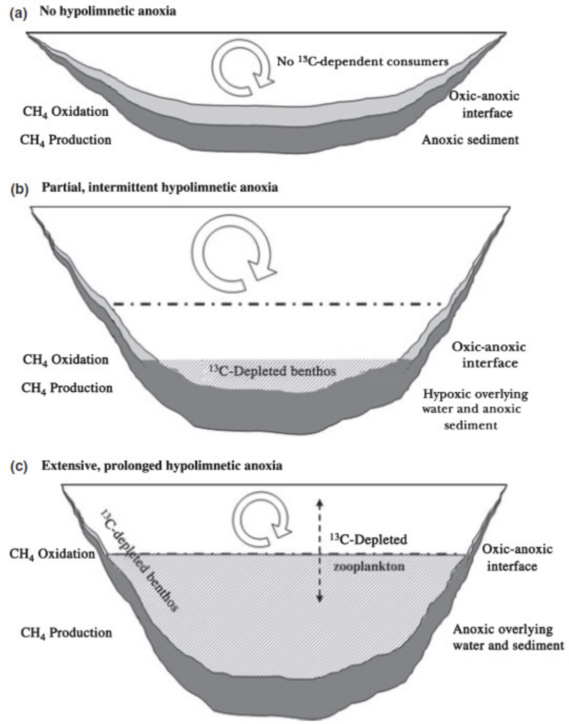
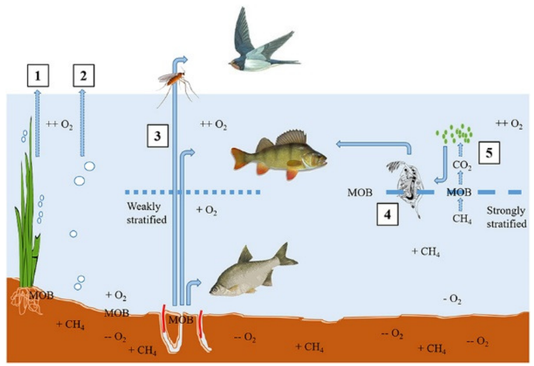


Figure 7.4. Average daily surface (thick lines) temperature and bottom (thin lines) temperature for the 1960s (red lines) and 2000s (blue lines) for Esthwaite Water.

From Maberly et al 2011





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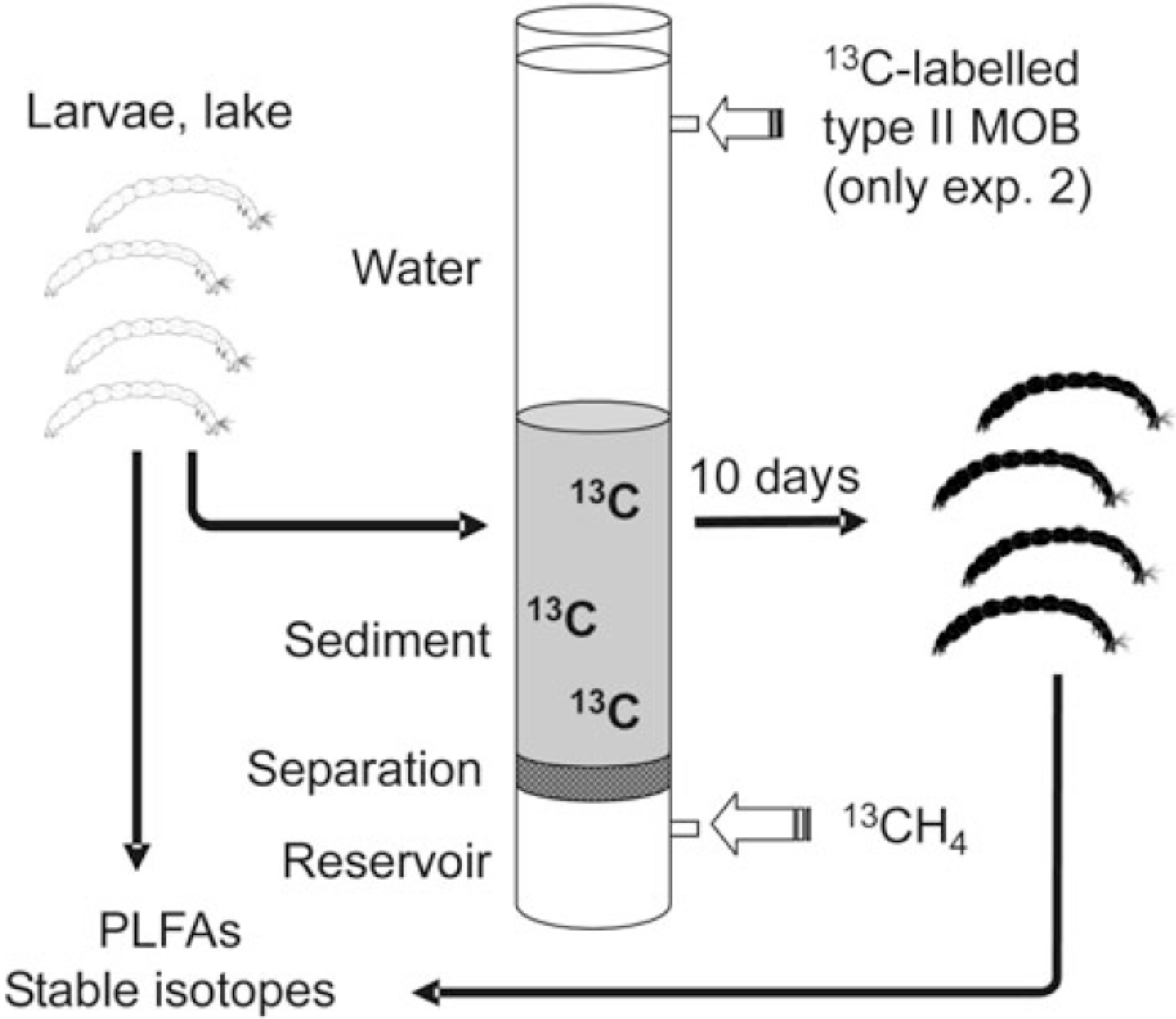
MDC in river food webs too….

Methane and river food webs?

Typical $\delta^{13}C$ values researchers are associating with some degree of methane-derived carbon assimilation

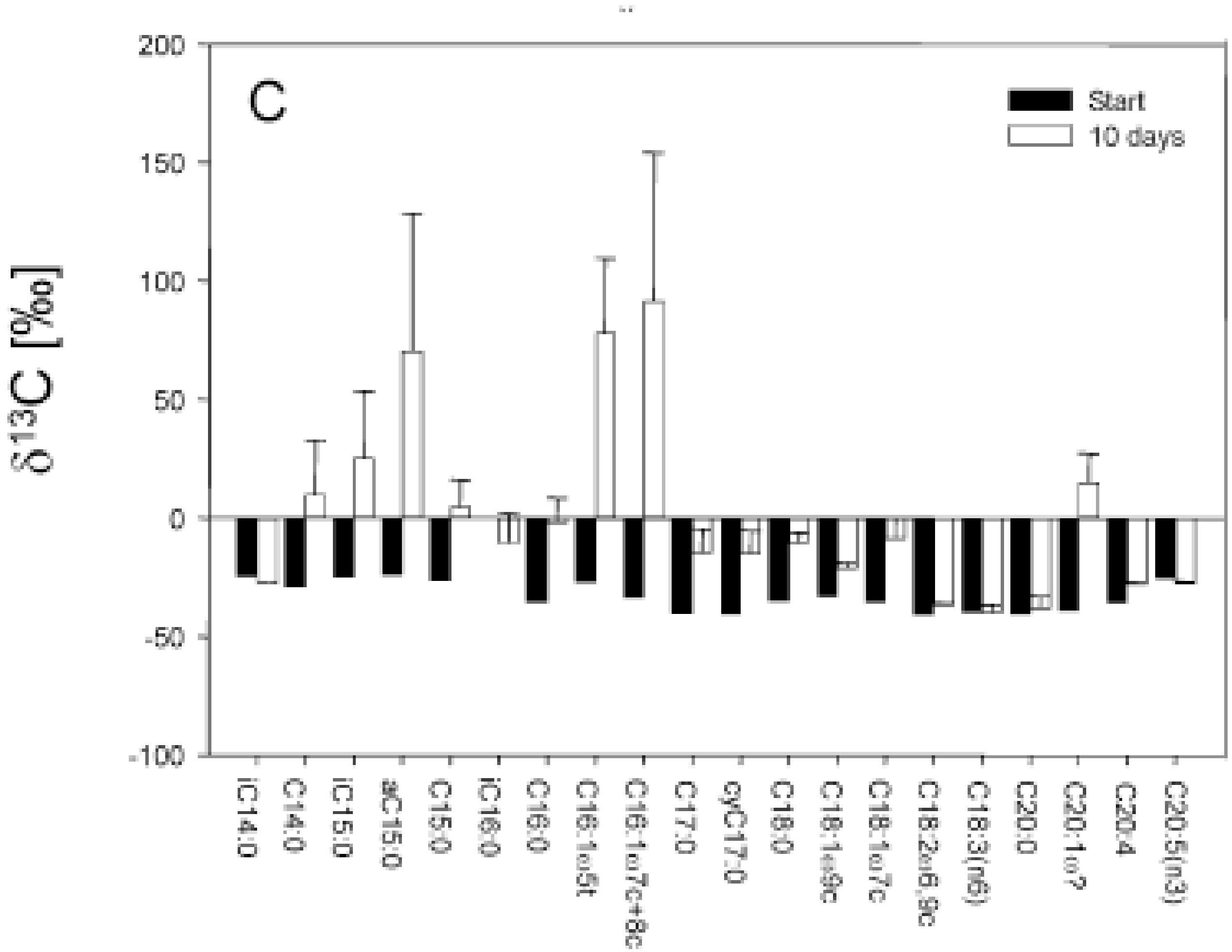
-82 to -32‰ in lakes	chiros	Grey 2002; Grey et al 2004; Deines & Grey 2006; Jones et al 2008
-68‰ in stream backwaters	beetles	Kohzu et al 2004
-31‰ in a headwater stream	snails	Doi et al 2006 (chemoautotrophy)
~-40‰ in a stream	caddis	McNeely et al 2006
-46 to -44‰ in a stream	caddis	Graham 2010 (pers. comm.)
-74‰ in the Lawrence River	caddis	Marty 2011 (pers. comm.)

^{13}C-addition experiment



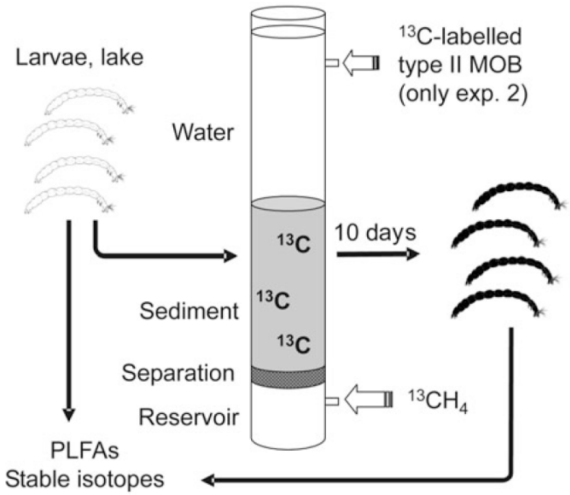
Deines et al 2007

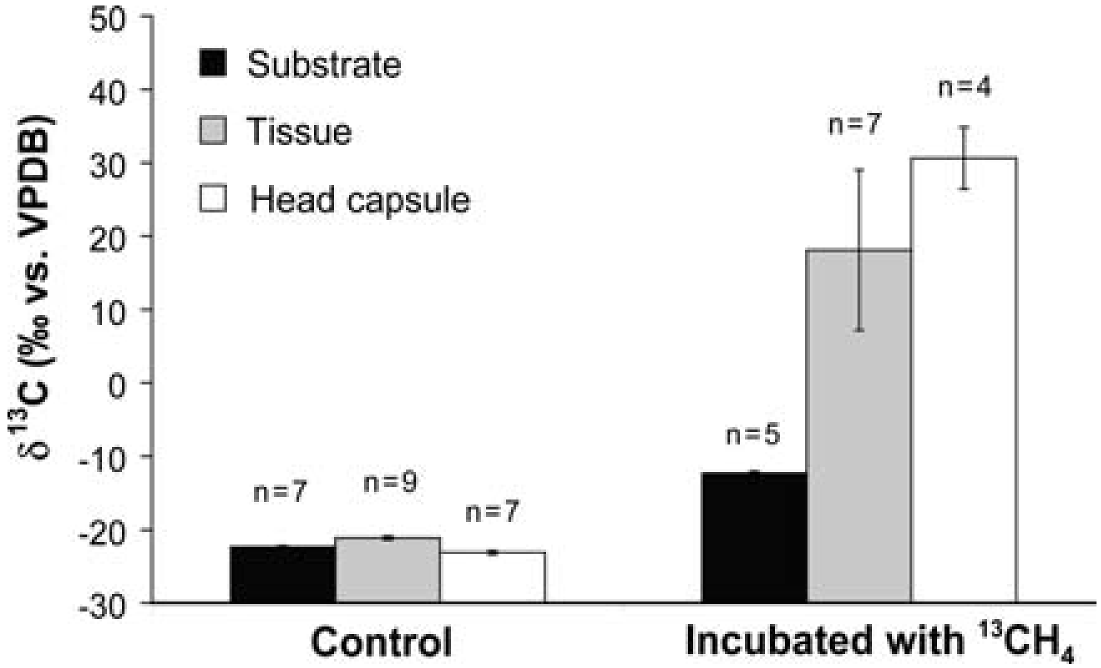
^{13}C-addition experiment



Deines et al 2007

Hindcasting potential





van Hardenbroek et al 2010