

Trophic Status and Methanogenesis in Peatlands

Mark E. Hines

University of Massachusetts Lowell

Jeff P. Chanton

Florida State University

Edward A.D. Mitchell

Université de Neuchâtel, Switzerland

Path of CH₄ Formation

Polymers



Monomers

Fermentation

H₂ + CO₂



Other LMW acids/ alcohols

Acetate

Acetogenesis



*2° Fermentation
Acetogenesis*

Acetate

Terminal step

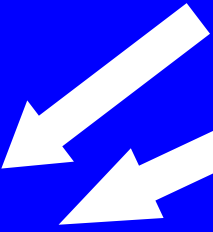
H₂ + CO₂

Acetate

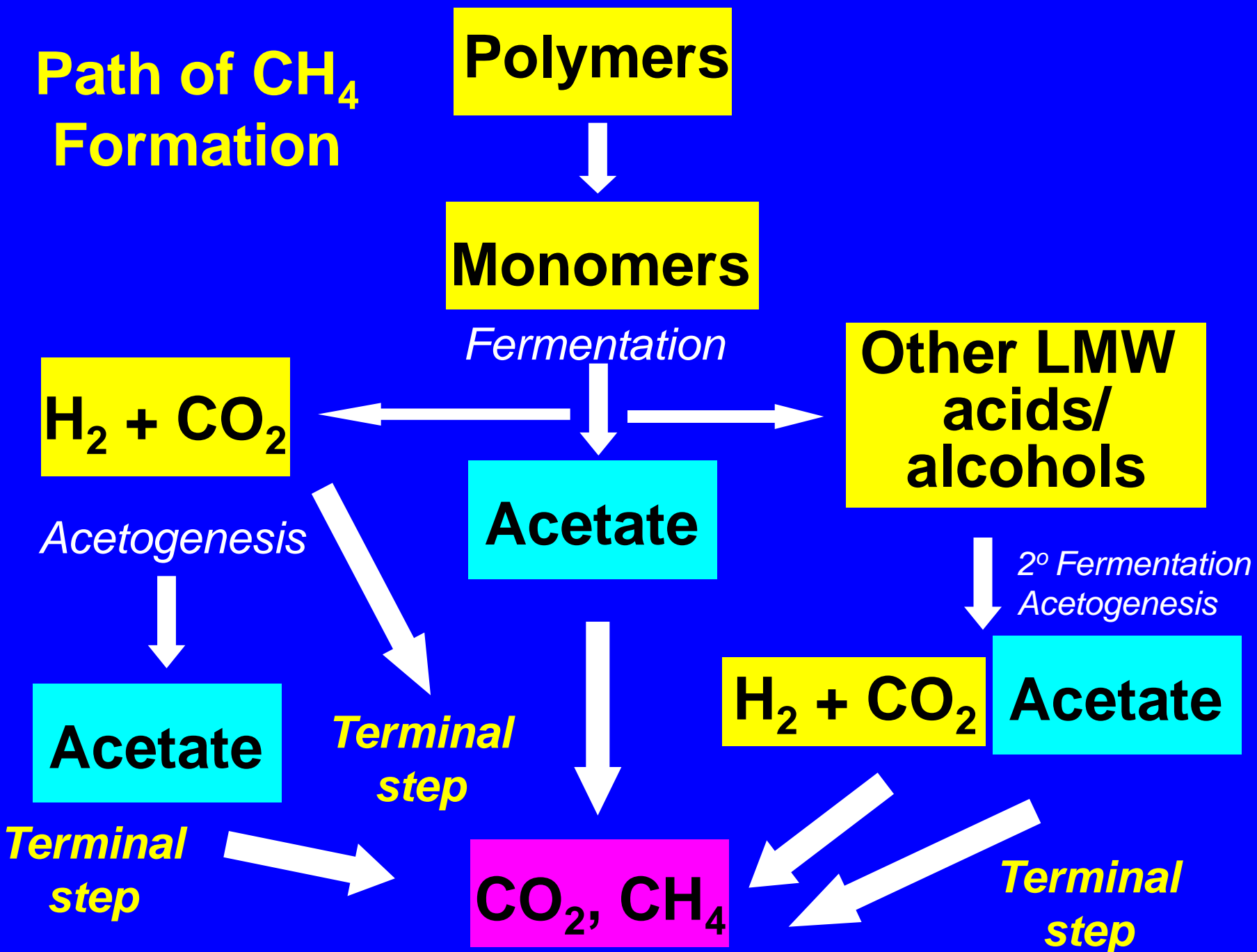
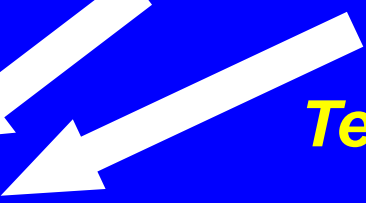
Terminal step



CO₂, CH₄



Terminal step



Which Pathway Matters?

In typical anaerobic systems

e.g., freshwater and marine muds,
sewage sludge, intestinal tracts

2/3 of CH_4 is derived from acetate

1/3 from H_2/CO_2

Ideal conditions: Ratio of $\text{CO}_2:\text{CH}_4 = \sim 1$

In some marine systems, C-one
compounds can be quite important

Uncoupling of Terminal Processes in Peatlands

Polymers

Monomers

Intermediate
Or
End product?

Fermentation

$H_2 + CO_2$

LMW acids/
alcohols

Acetate

Acetogenesis

*2° Fermentation
Acetogenesis*

Acetate

*Terminal
step*

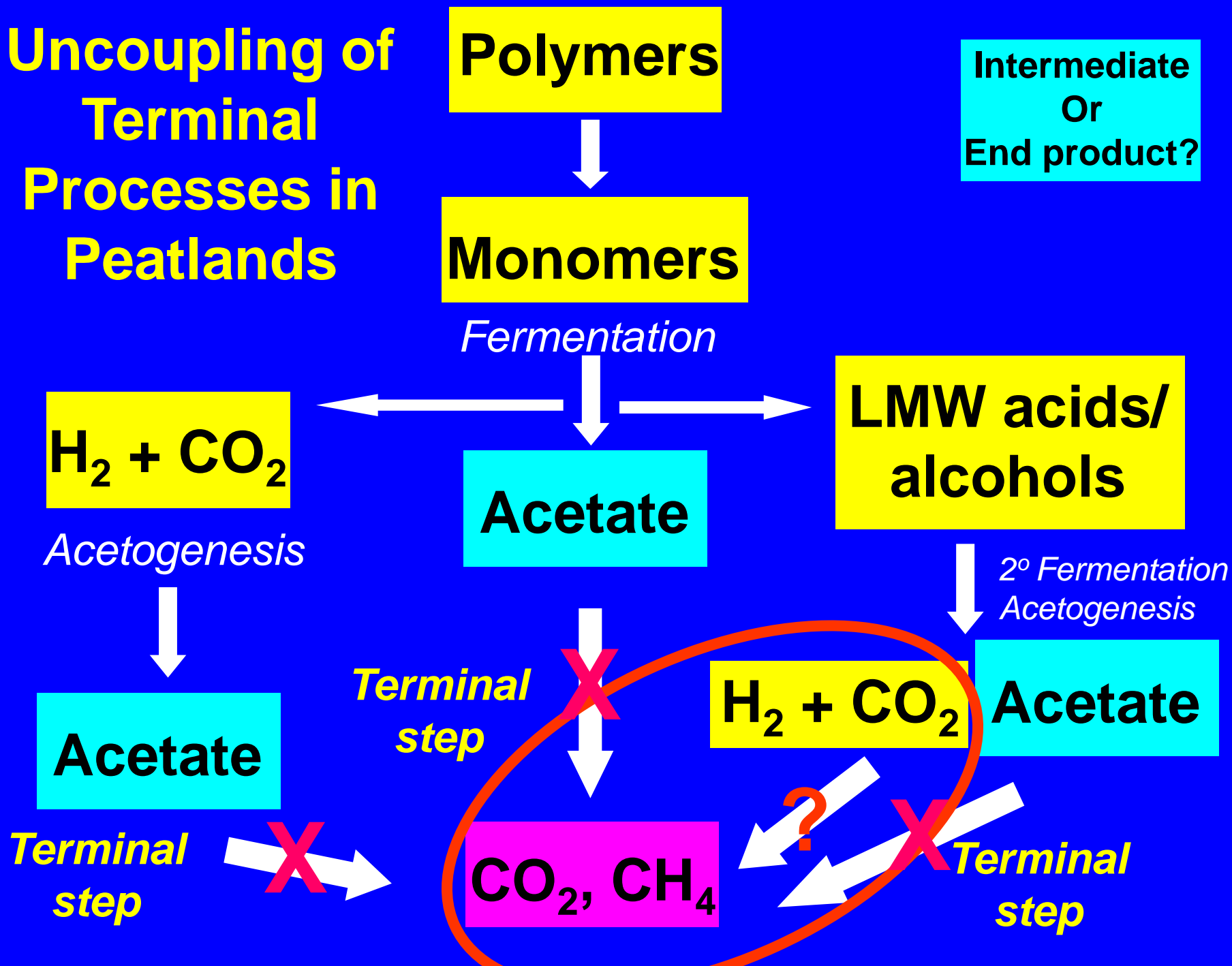
$H_2 + CO_2$

Acetate

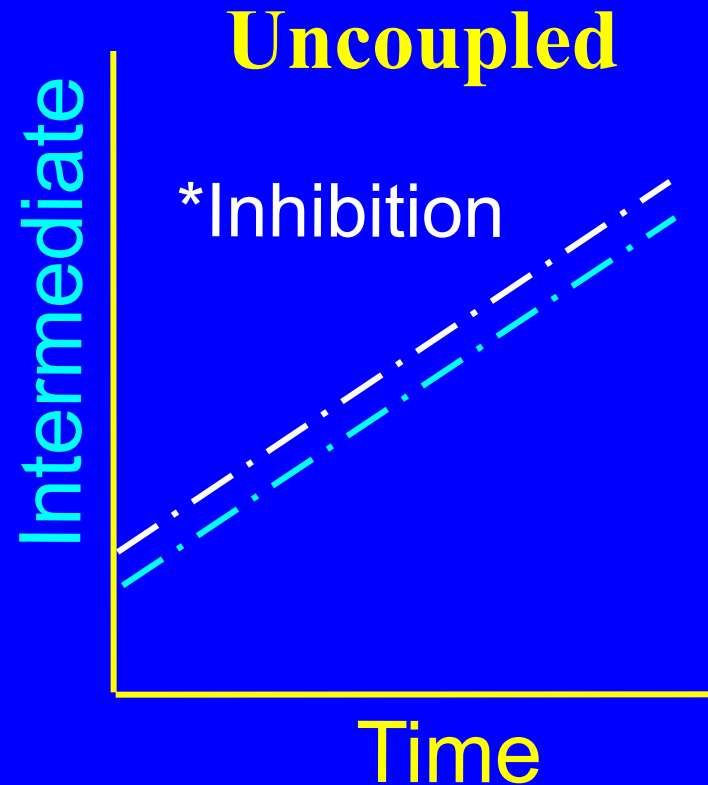
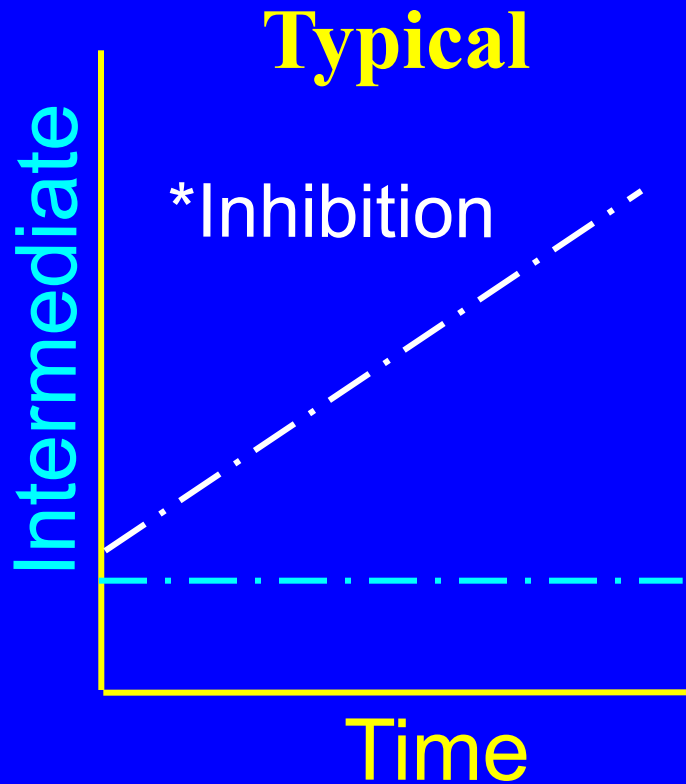
*Terminal
step*

CO_2, CH_4

*Terminal
step*



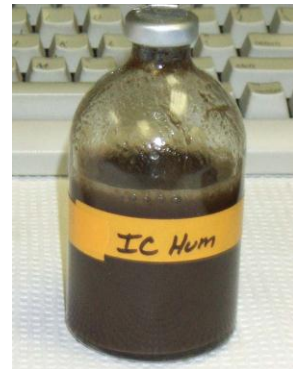
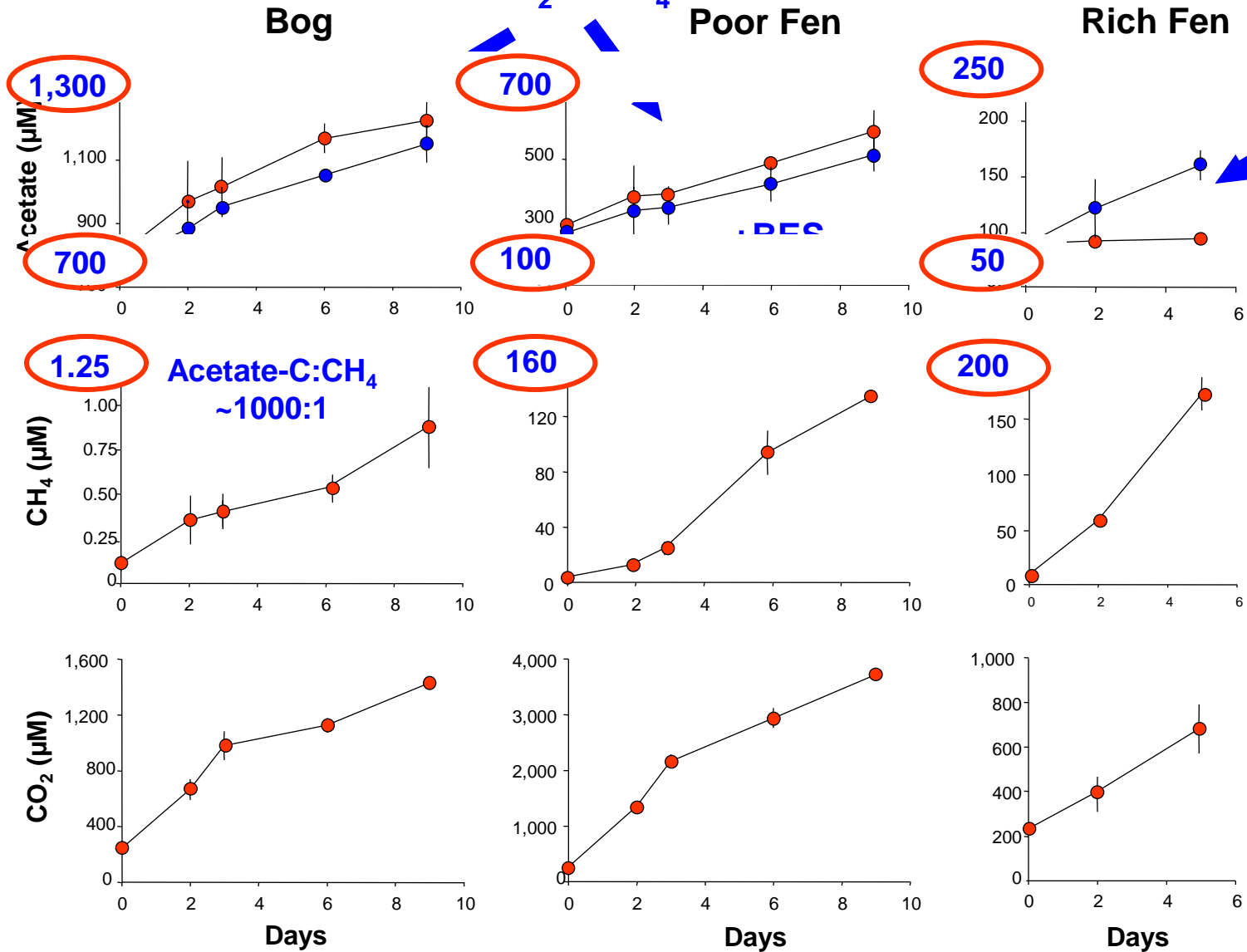
Turnover of *in situ* Intermediates



Trophic Status Affects Pathway

acetate ~~X~~
 $\text{CO}_2 + \text{CH}_4$

acetate \rightarrow
 $\text{CO}_2 + \text{CH}_4$



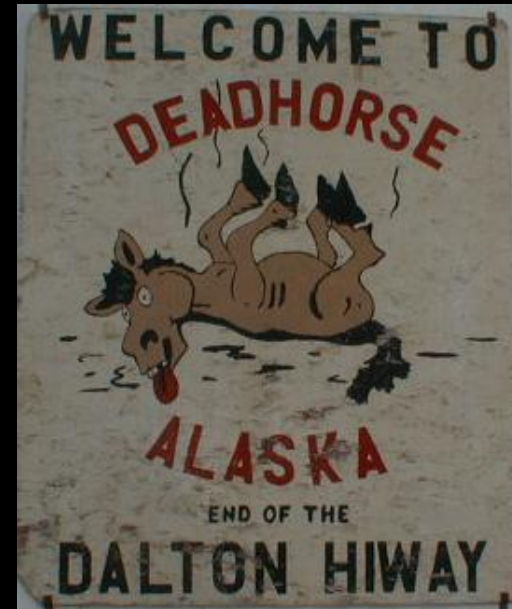
Questions

- **How ubiquitous?**
- Are acetotrophs not present, or not active?
- Does it vary seasonally?
- What happens with alternate electron acceptors?
- What about other organic acids (or alcohols)?
- How might climate change affect decomposition path?
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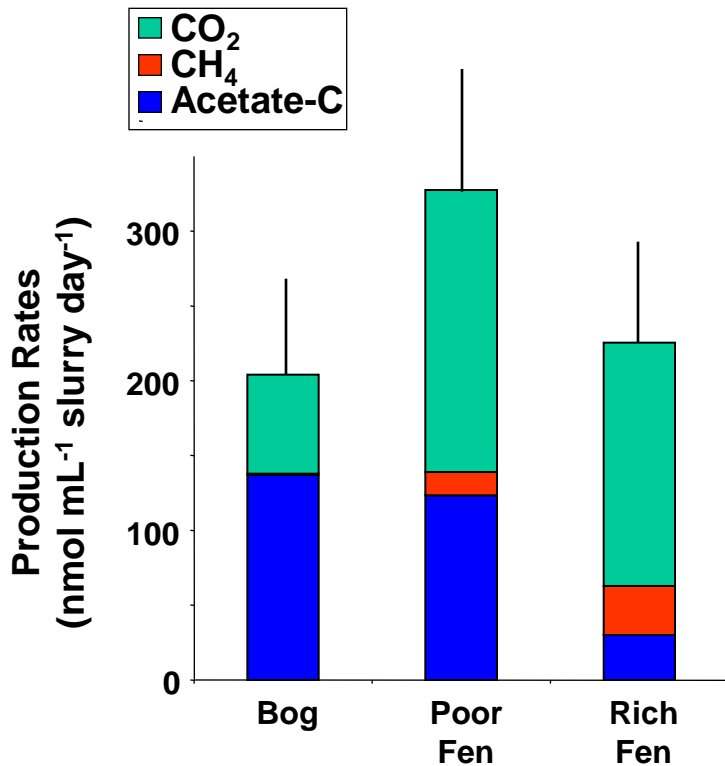


Alaskan Study Sites

Grouped sites by trophic status (vegetation cover)

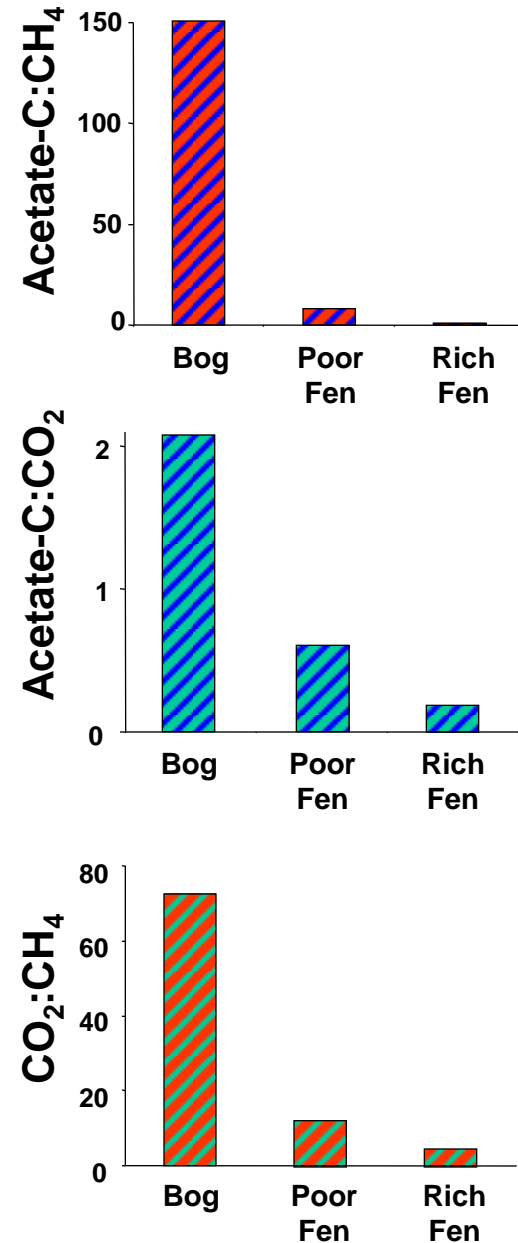


Path of Anaerobic C Flow Varies with Vegetation Cover



CH₄ production increases with trophic status, but total C flow does not vary greatly (acetate remains important)

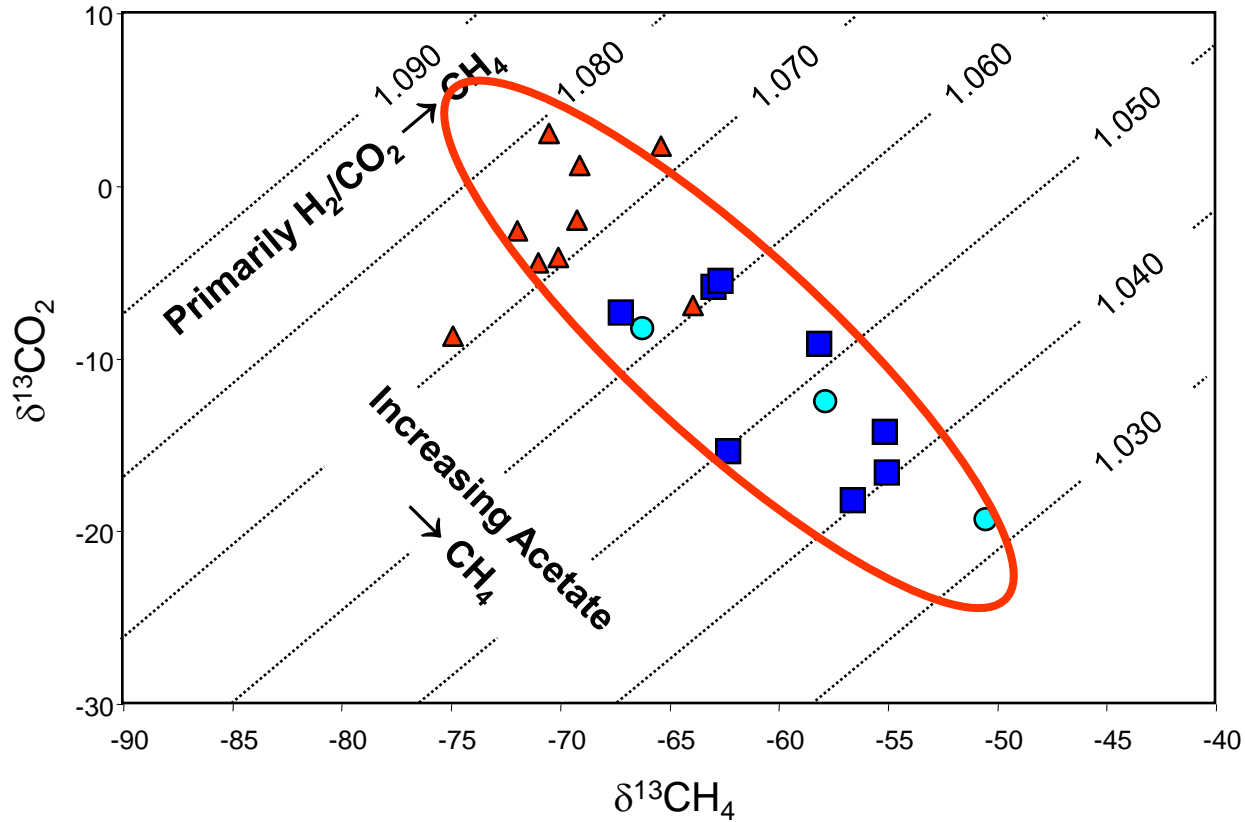
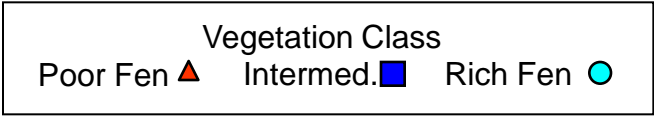
Ratios



Stable C Isotopes and CH₄ Production Path

$$\alpha = \frac{\delta^{13}\text{CO}_2 + 1000}{\delta^{13}\text{CH}_4 + 1000}$$

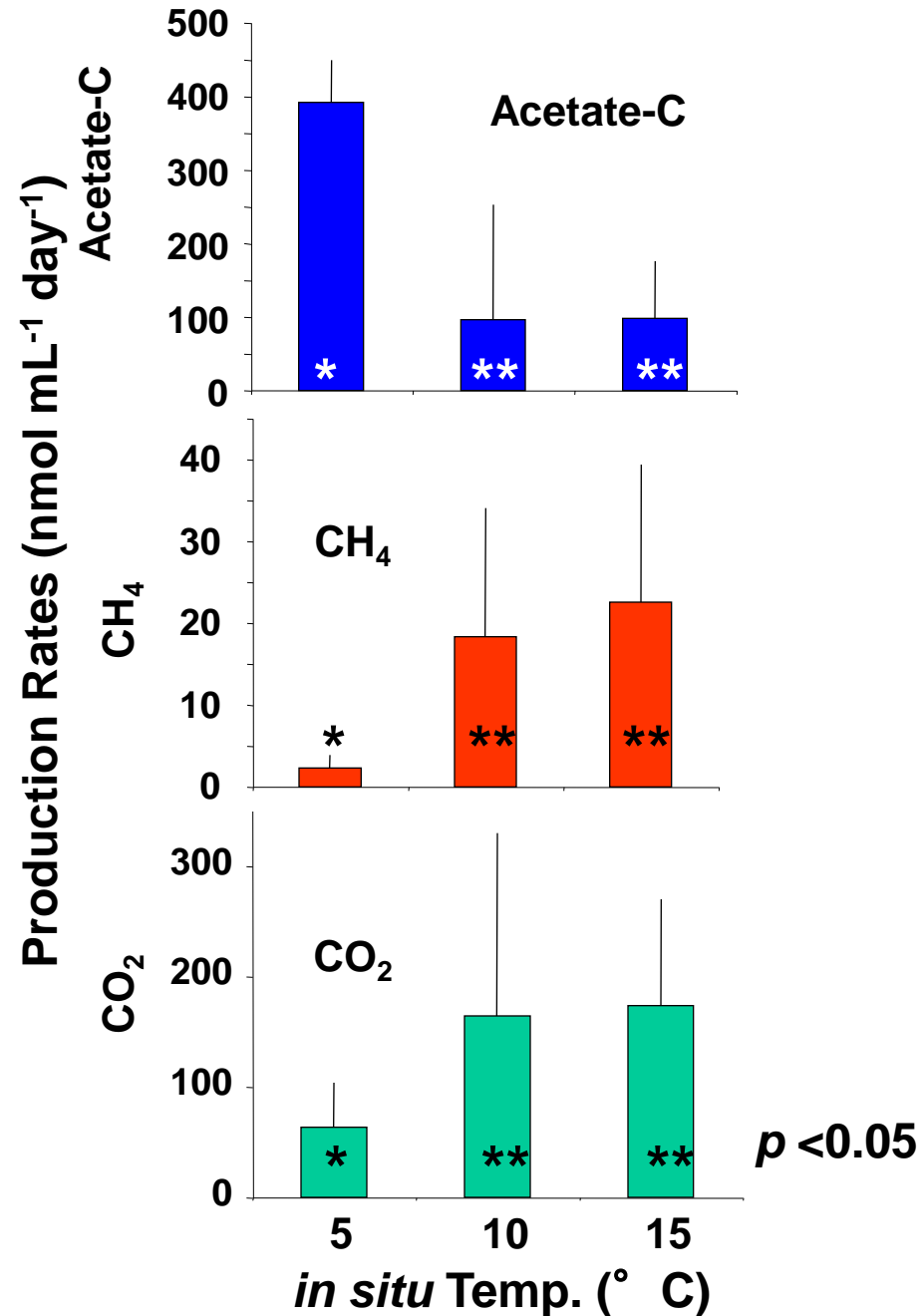
Sphagnum → *Carex*



Temperature Affects Pathway

Temperature increases CH_4 and CO_2 , but acetate production is highest at low temperature

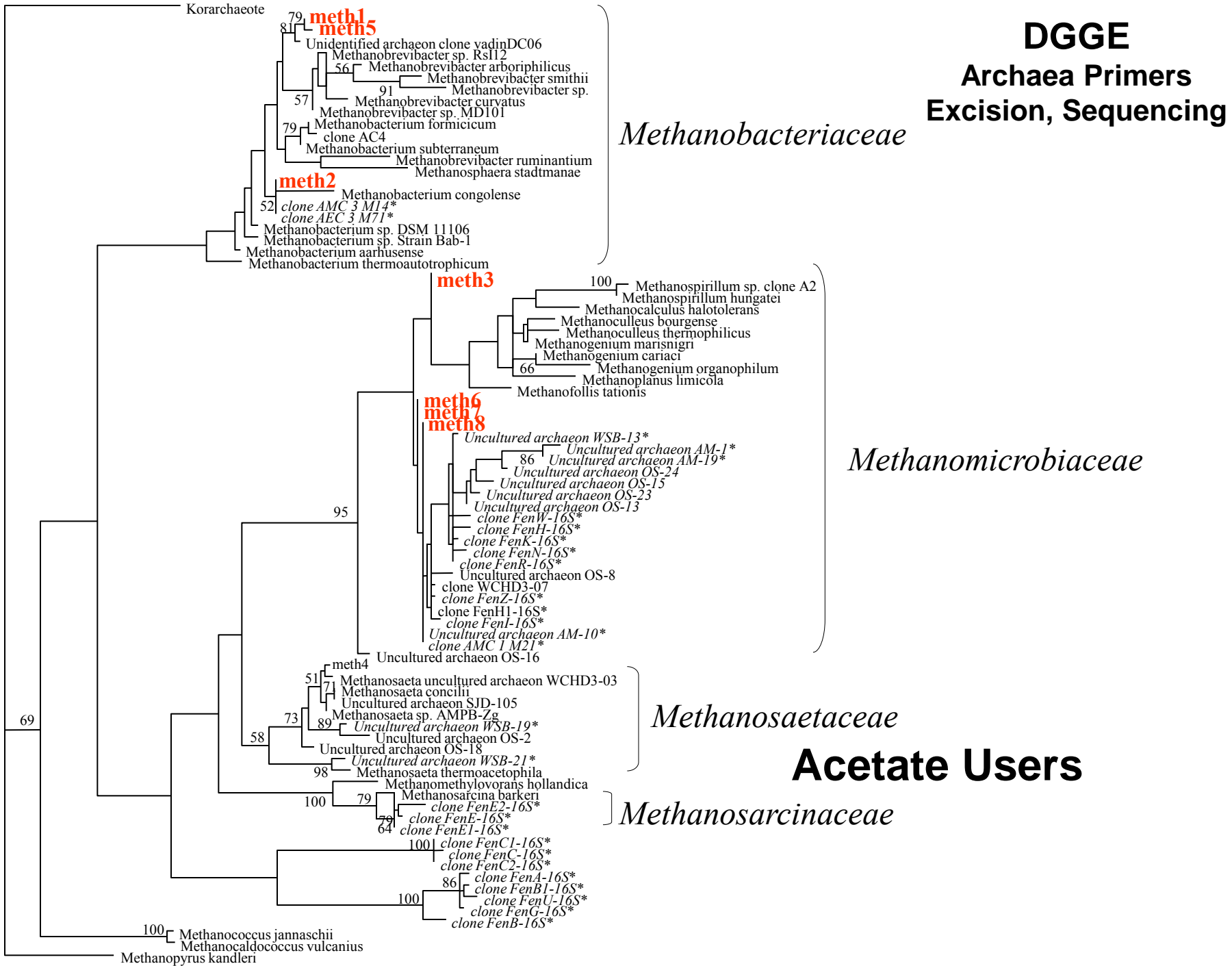
Incubation temperature similar to in situ temperature



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Korarchaeote

79 **meth1**
 81 **meth5**
 Unidentified archaeon clone yadinDC06
 Methanobrevibacter sp. Rsl12
 56 Methanobrevibacter arboriphilicus
 Methanobrevibacter smithii
 Methanobrevibacter sp.
 57 Methanobrevibacter curvatus
 Methanobrevibacter sp. MD101
 79 Methanobacterium formicicum
 clone AC4
 Methanobacterium subterraneum
 Methanobrevibacter ruminantium
 Methanosphaera stadtmanae
meth2
 Methanobacterium congolense
 52 clone AMC 3 M14*
 clone AEC 3 M71*
 Methanobacterium sp. DSM 11106
 Methanobacterium sp. Strain Bab-1
 Methanobacterium aarhusense
 Methanobacterium thermoautotrophicum

Methanobacteriaceae

meth3
 100 Methanospirillum sp. clone A2
 Methanospirillum hungatei
 Methanocalculus halotolerans
 Methanoculleus bourgense
 Methanoculleus thermophilicus
 Methanogenium marisnigri
 Methanogenium cariaci
 66 Methanogenium organophilum
 Methanoplanus limicola
 Methanofollis tationis

meth6
meth7
meth8

Methanomicrobiaceae

Uncultured archaeon WSB-13*
 Uncultured archaeon AM-1*
 86 Uncultured archaeon AM-19*
 Uncultured archaeon OS-24
 Uncultured archaeon OS-15
 Uncultured archaeon OS-23
 Uncultured archaeon OS-13
 clone FenW-16S*
 clone FenH-16S*
 clone FenK-16S*
 clone FenN-16S*
 clone FenR-16S*
 Uncultured archaeon OS-8
 clone WCHD3-07
 clone FenZ-16S*
 clone FenH1-16S*
 clone FenI-16S*
 Uncultured archaeon AM-10*
 clone AMC 1 M21*
 Uncultured archaeon OS-16

Methanosaetaceae

meth4
 51 Methanosaeta uncultured archaeon WCHD3-03
 Methanosaeta concilii
 Uncultured archaeon SJD-105
 Methanosaeta sp. AMPB-Zg
 73 89 Uncultured archaeon WSB-19*
 Uncultured archaeon OS-2
 Uncultured archaeon OS-18
 58 98 Uncultured archaeon WSB-21*
 Methanosaeta thermoacetophila
 Methanomethylivorans hollandica

Acetate Users

Methanosarcinaceae

100 79 Methanosarcina barkeri
 clone FenE2-16S*
 79 clone FenE-16S*
 64 clone FenE1-16S*
 100 clone FenC1-16S*
 clone FenC-16S*
 clone FenC2-16S*
 100 clone FenA-16S*
 86 clone FenB1-16S*
 clone FenU-16S*
 clone FenG-16S*
 clone FenB-16S*

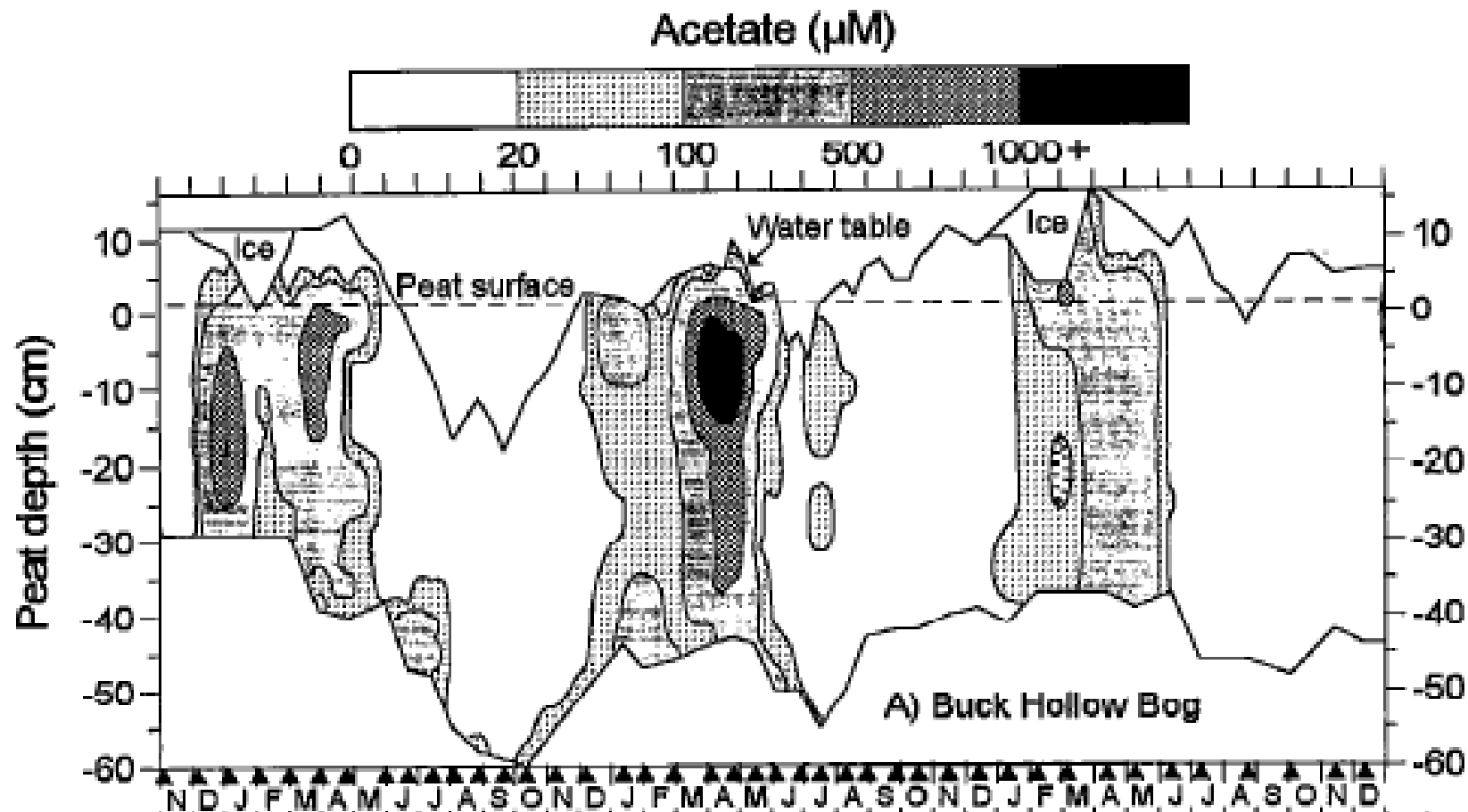
100 Methanococcus jannaschii
 Methanocaldococcus vulcanius
 Methanopyrus kandleri

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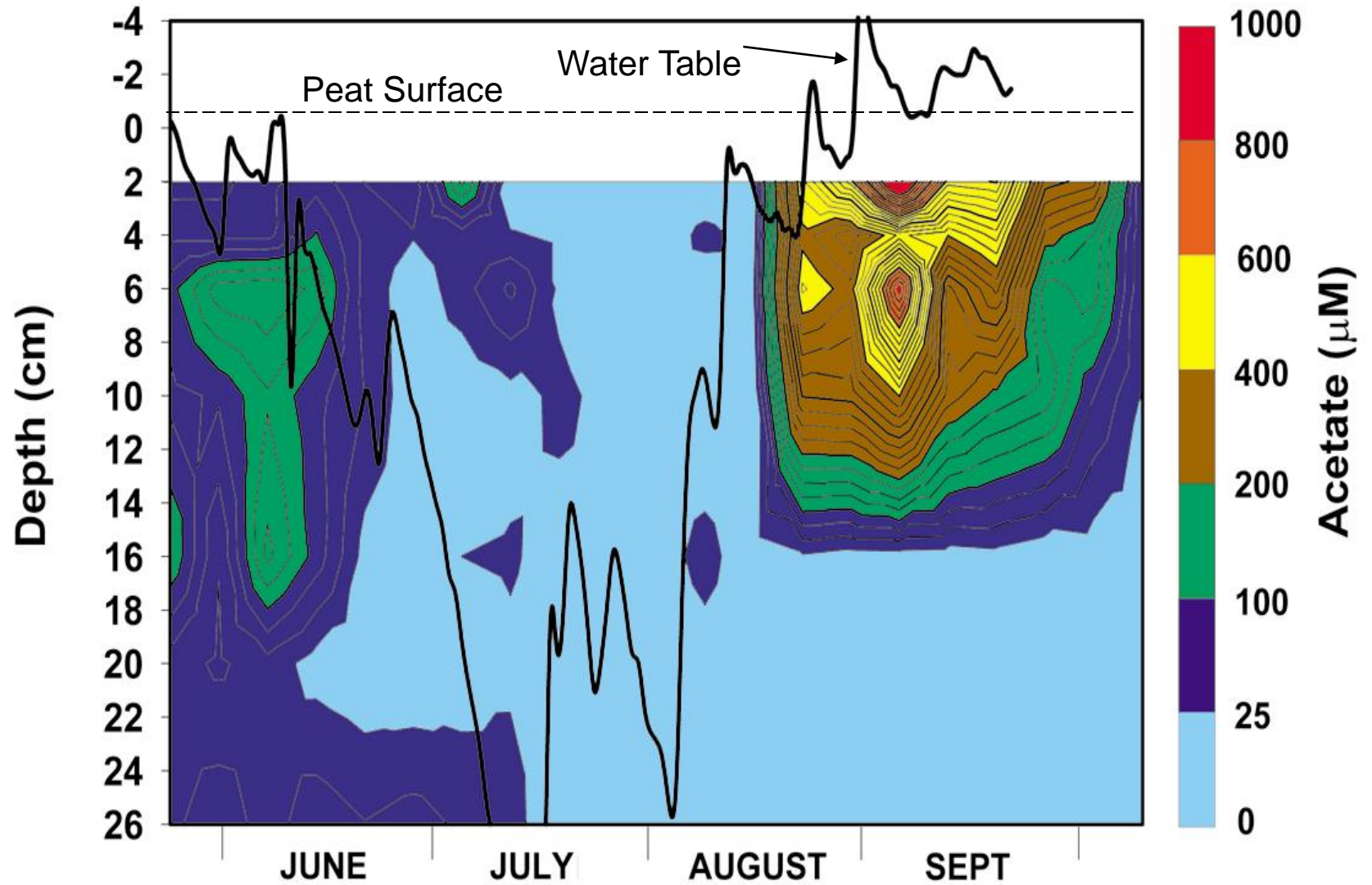


In Temperate Bogs, Acetate Becomes a Source of CH₄ After a Spring Lag (“Acetotrophic Switch”)

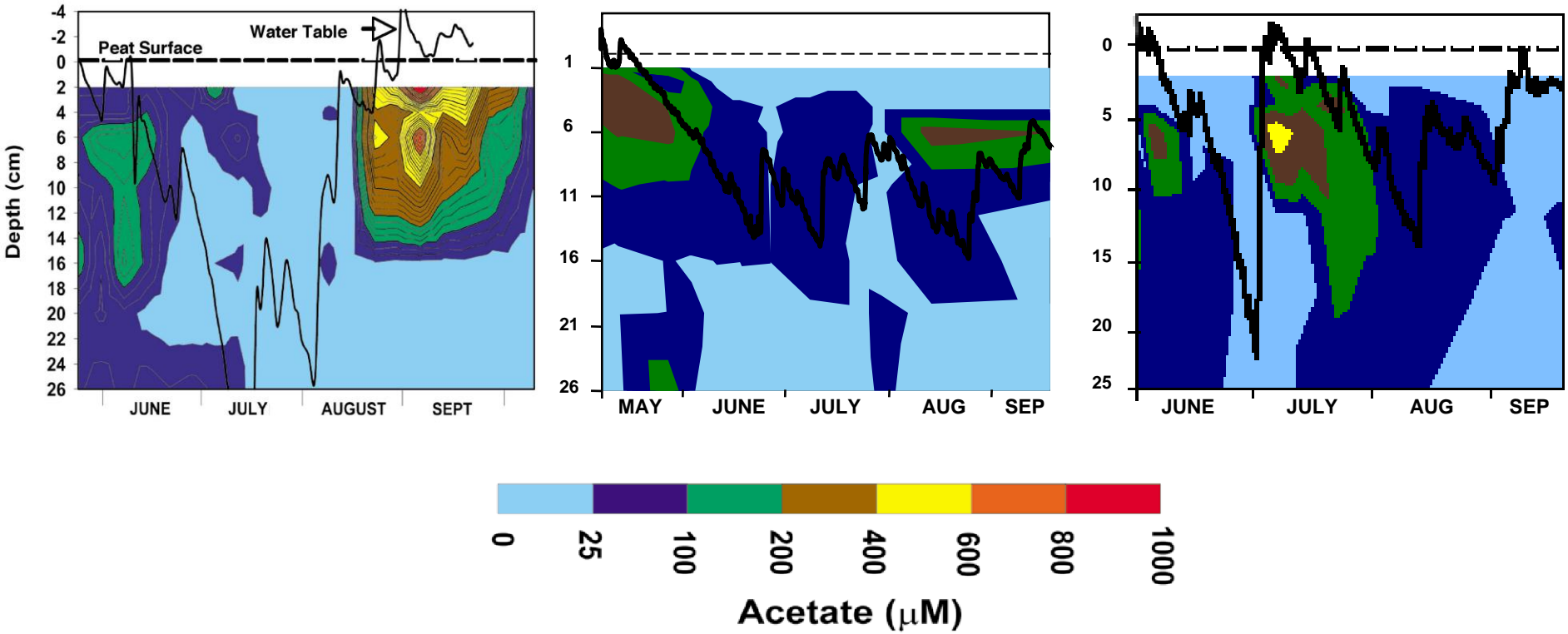


Shannon and White (1996)

Acetate in Bog Pore Water at Turnagain Bog



Controlled by hydrology without a temporal shift

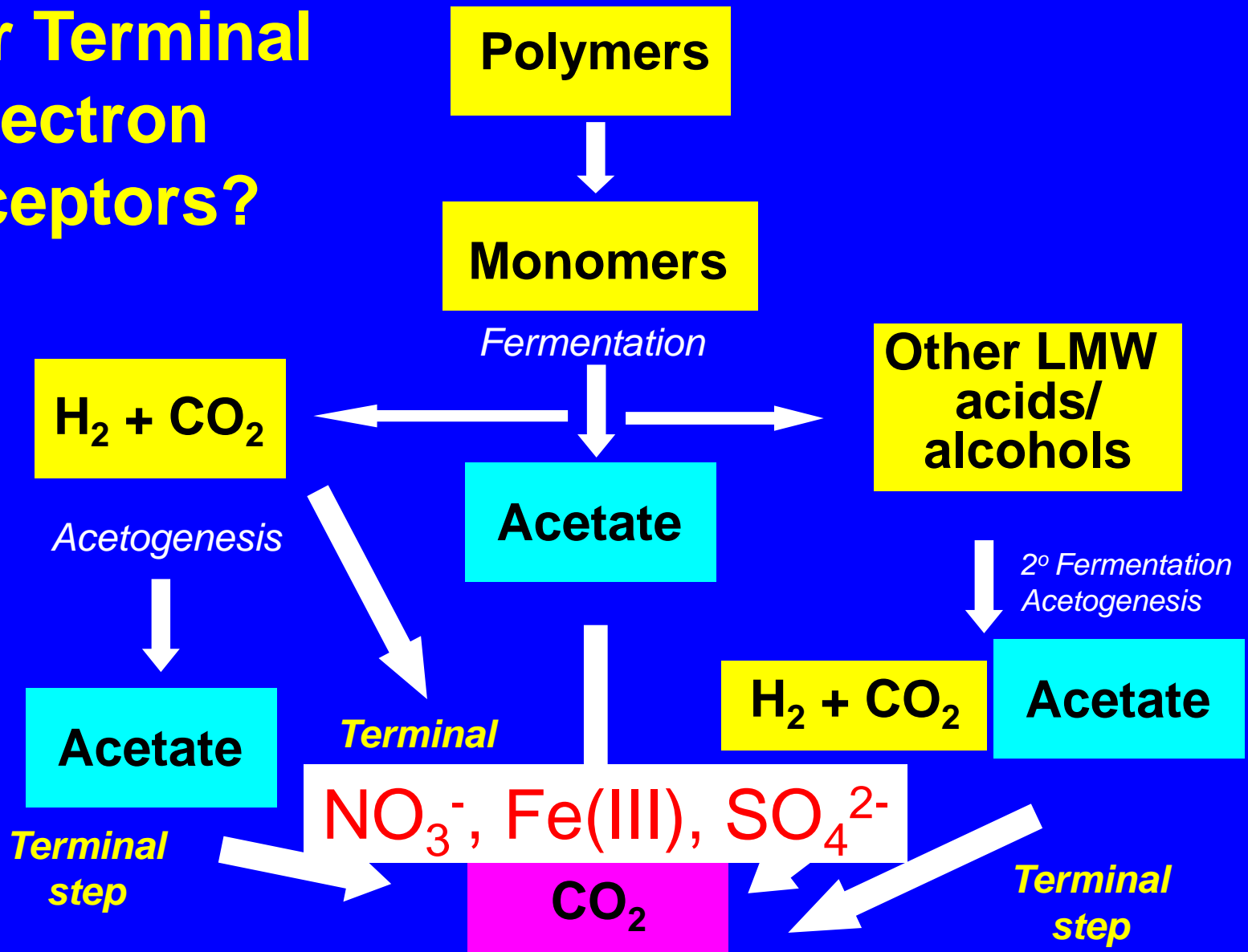


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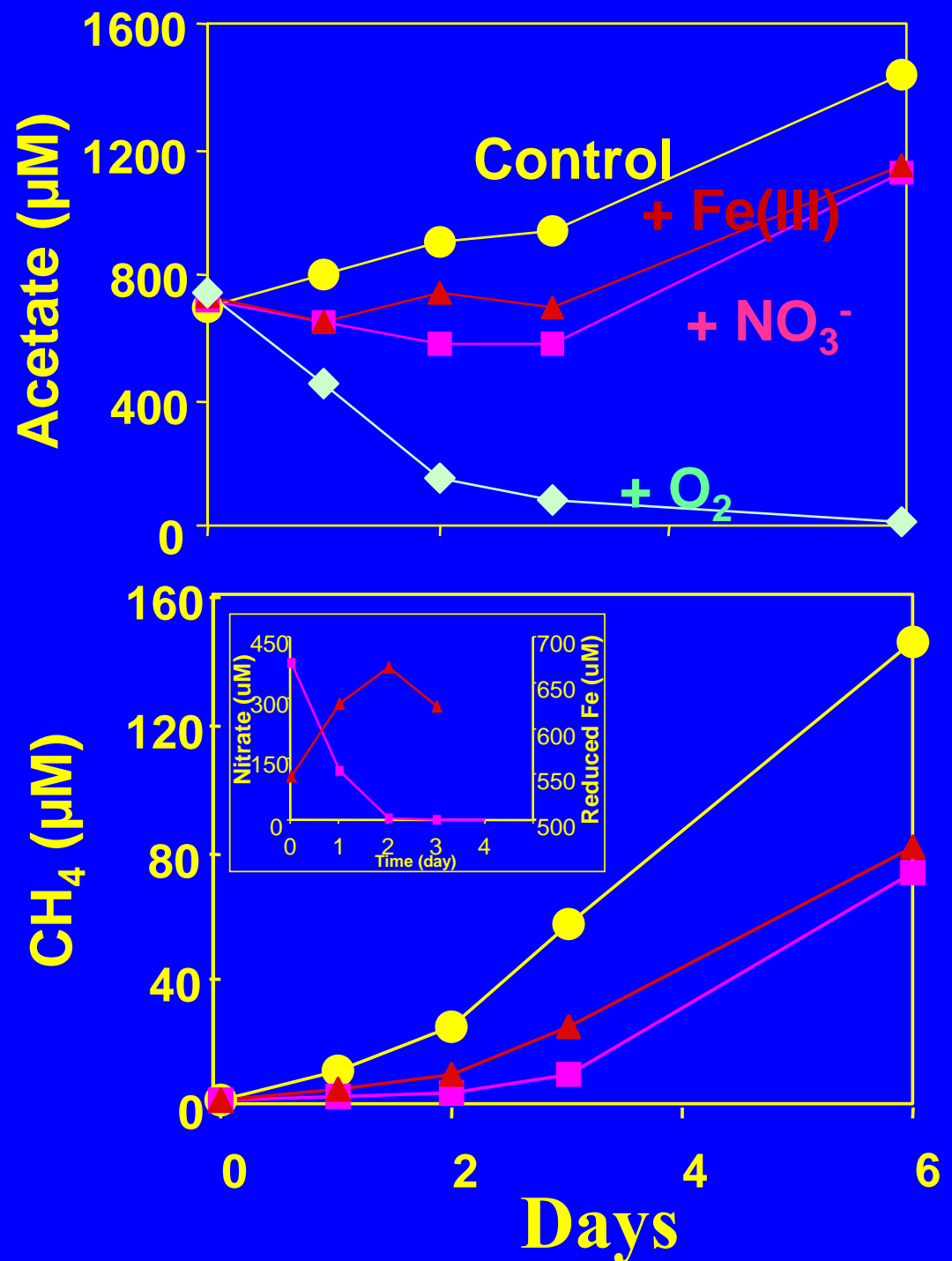
What About Other Terminal Electron Acceptors?



What happens to acetate that is produced in anaerobic environments?

Acetate is consumed by all other processes (Uncoupling only during CH_4 production)

Acetate C destined for CH_4 in methanogenic habitats is converted to CO_2

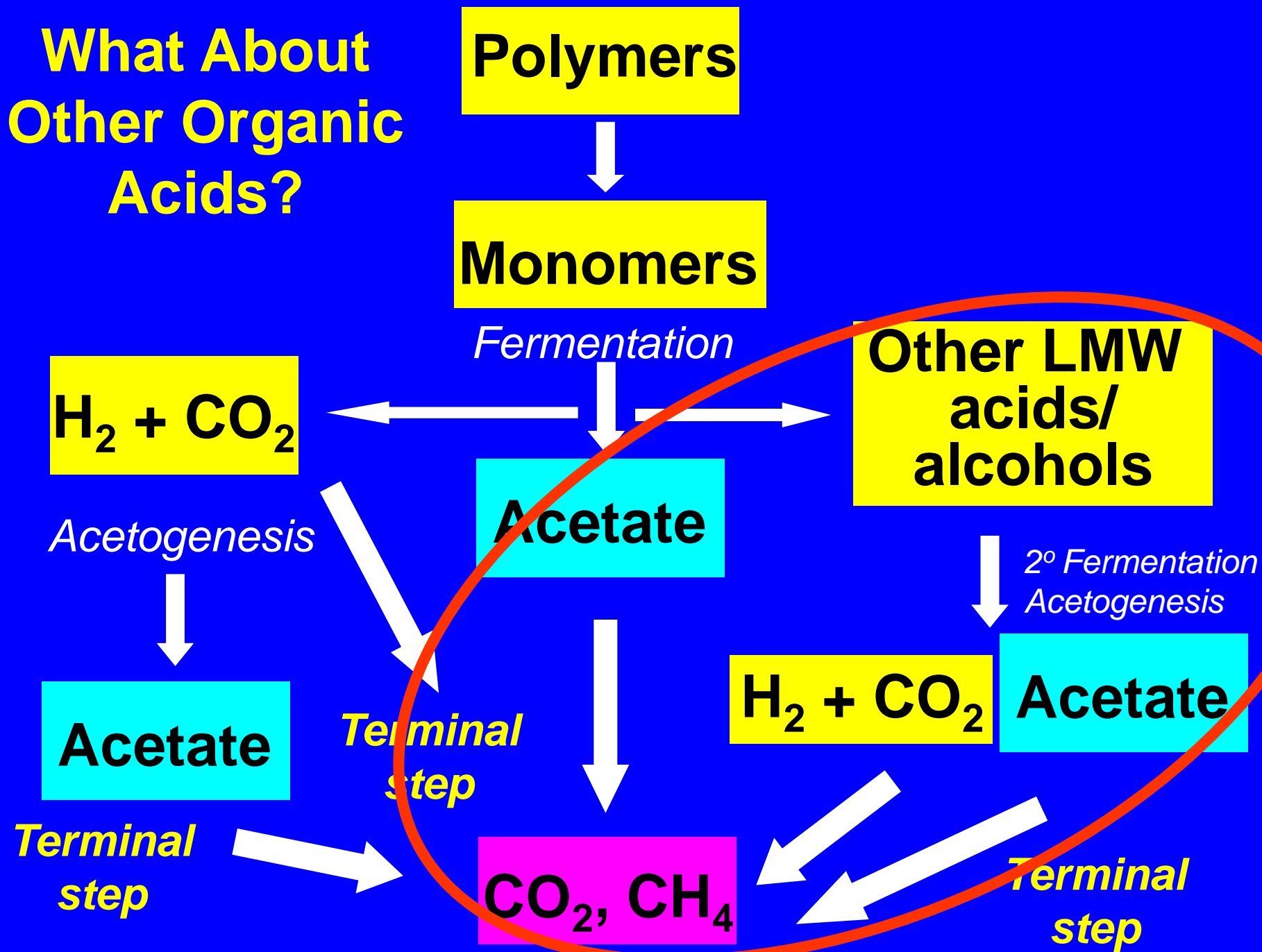


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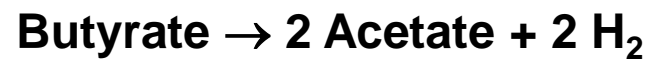
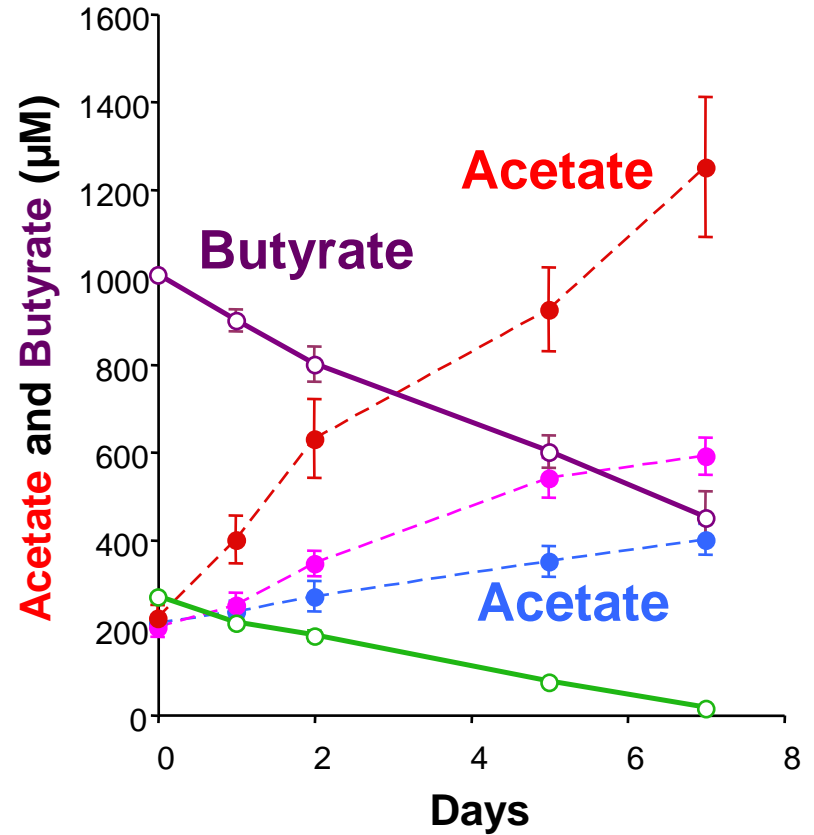
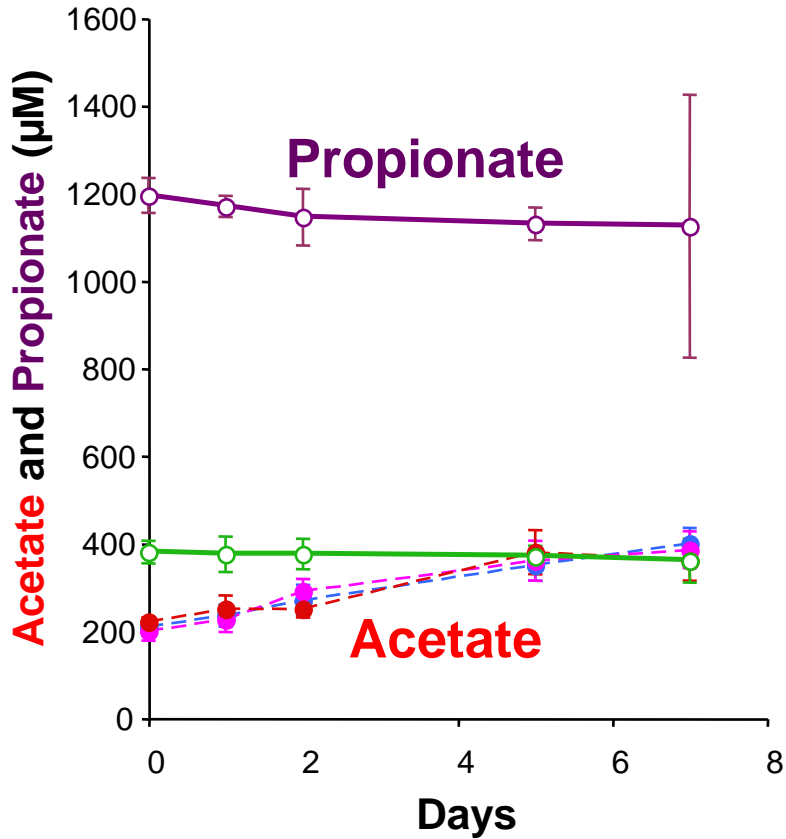
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What About Other Organic Acids?



Other Organic Acids

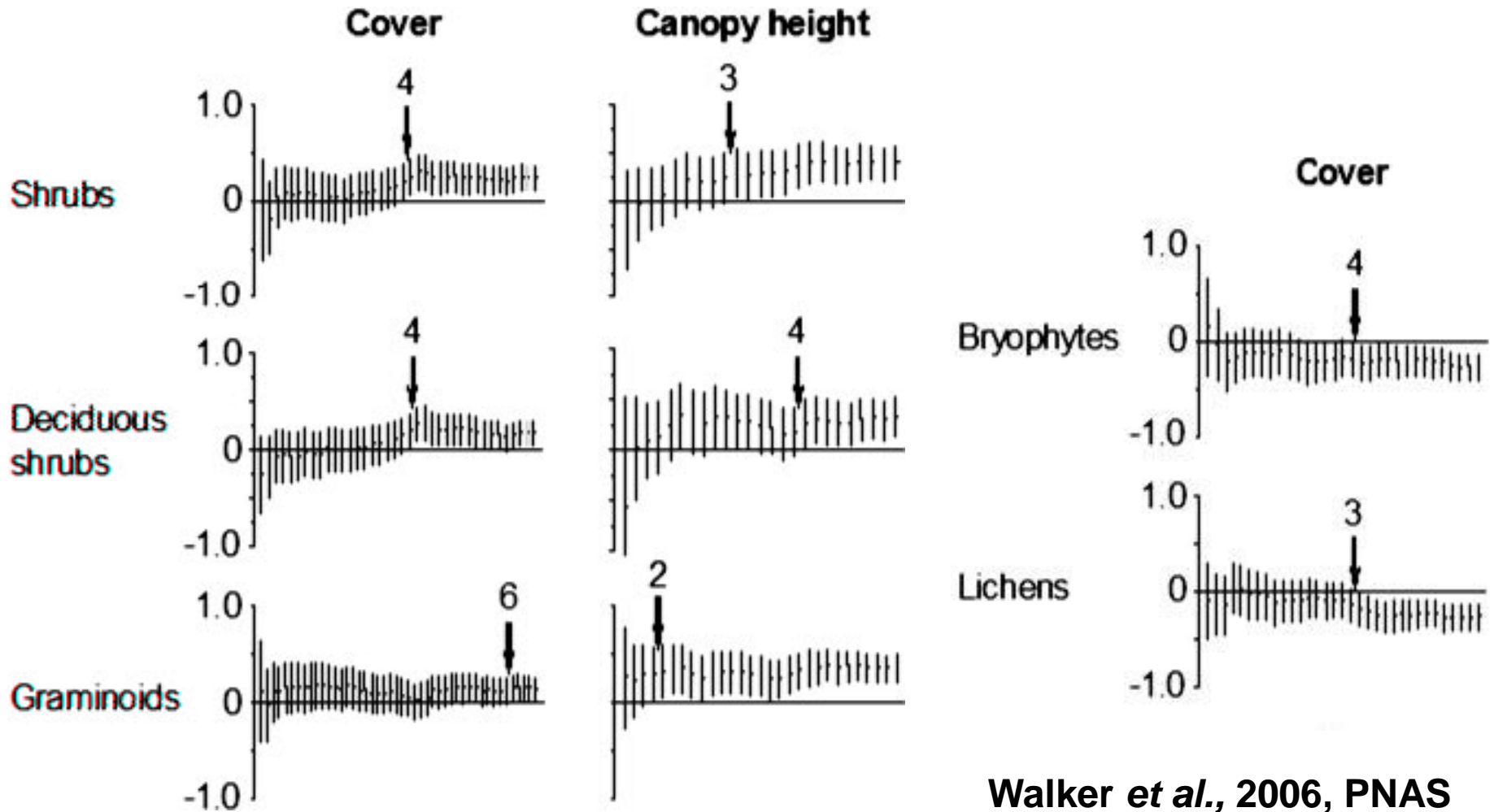


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Plant response to 1-3° C warming



Replacement of mosses by vascular plants may lead to severe increases in CH₄ production

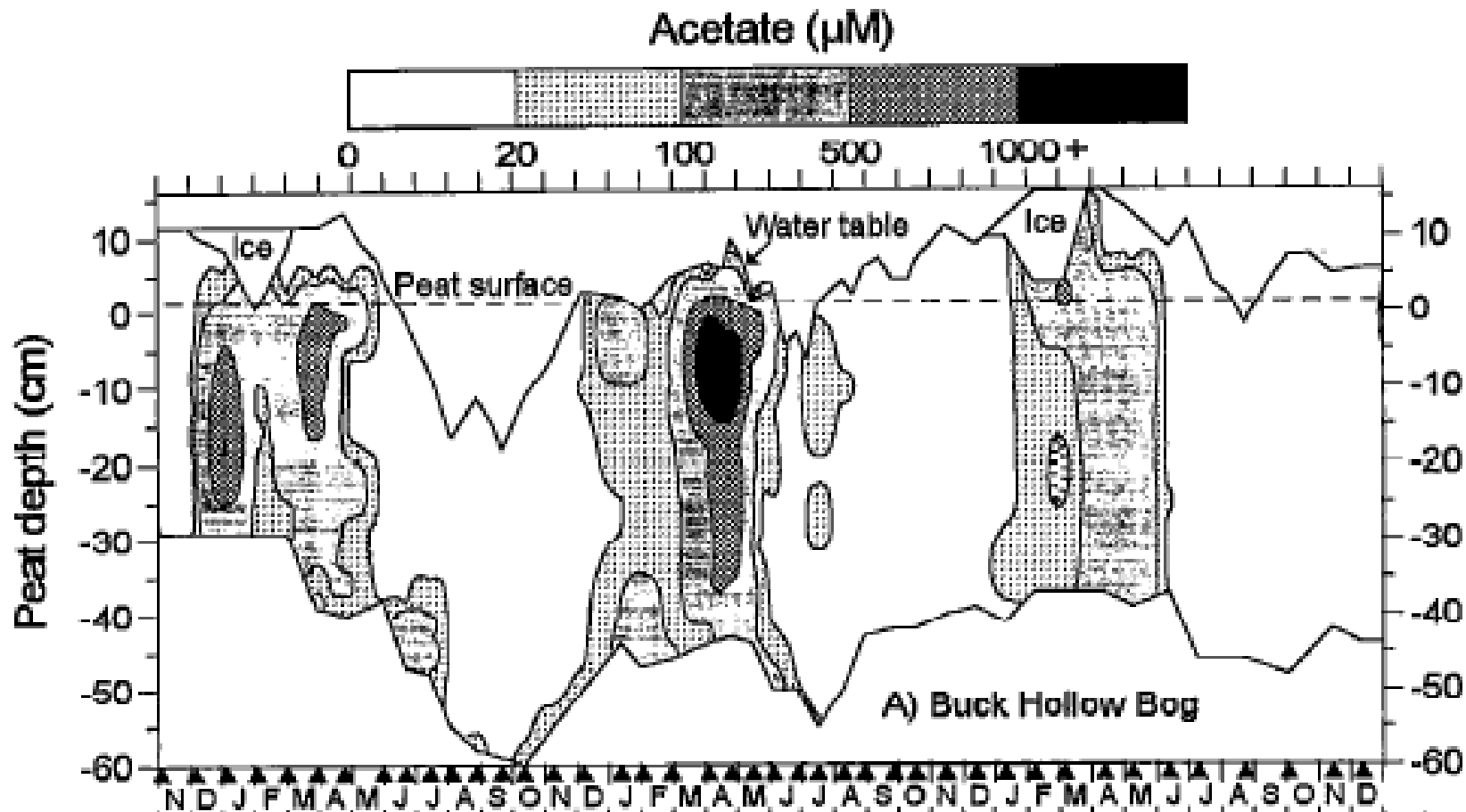
“Sites with small increases in sedges use much more acetate”

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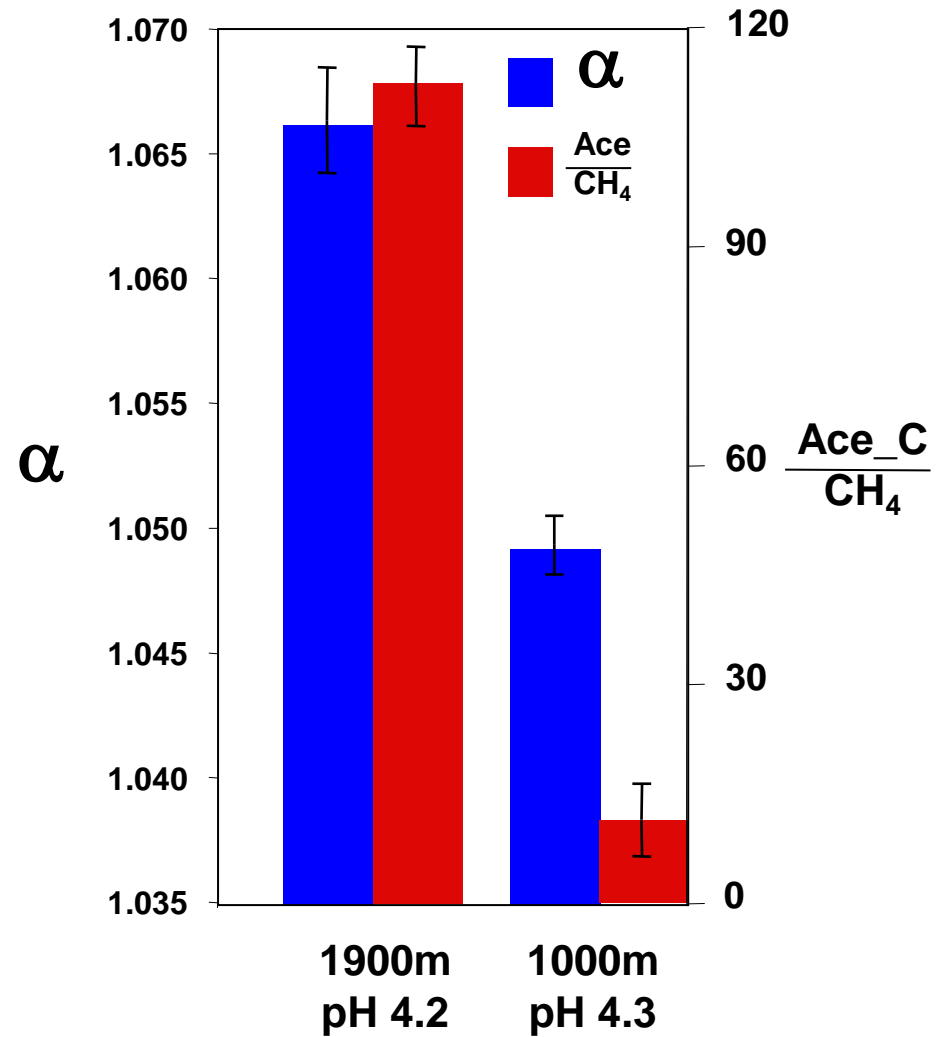
Shannon and White (1996)

Since higher latitude sites often accumulate acetate all season, this suggests that temperature may influence whether a shift occurs and when

Poor fen at 1000 m experienced an acetotrophic shift in May, but at ~1900 m, this had not occurred, even in September



September

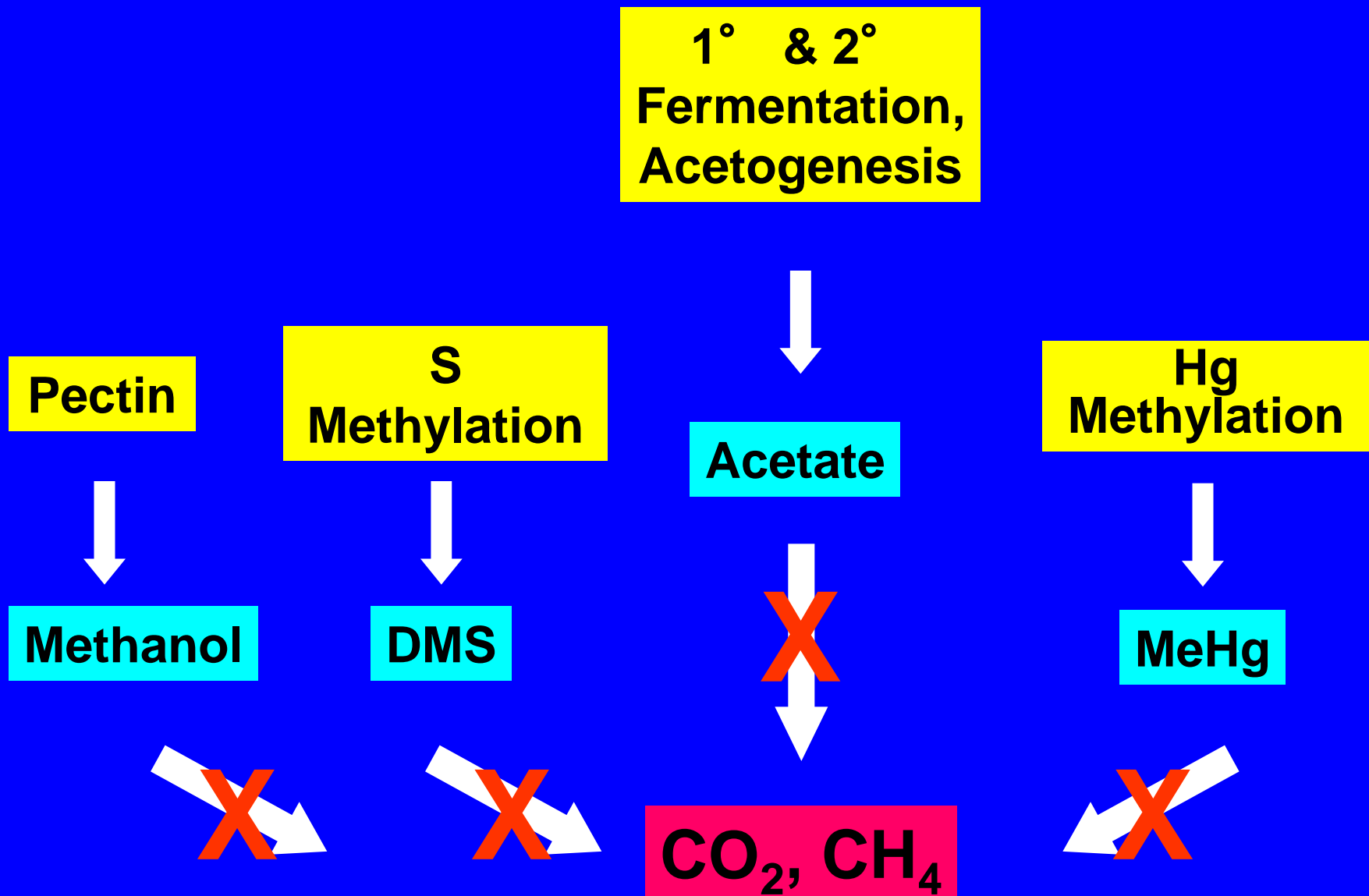


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Uncoupling of Methanogenesis Affects Other Compounds



Implications

- The uncoupling of methanogenesis is a common phenomenon in the north that is linked to trophic status and temperature.
- Temperature seems to create a latitude and elevation gradient, in which seasonal effects observed in temperate bogs are postponed, sometimes indefinitely, as active seasons become colder and shorter.
- Uncoupling only occurs during methanogenesis, i.e., intermediates are consumed during respiration of other electron acceptors.
- Compounds similar to acetate are also not degraded to methane.
- Uncoupling appears to be an inhibition in which acetate use is more sensitive than CO₂ reduction.

Implications, con' t

- **Local consequences of uncoupling of decomposition:**
 - 1) enhanced importance of fermentation and acetogenesis;
 - 2) C flow to acetate that is degraded to CO₂ (fuels stream and other bacteria);
 - 3) unique microbial population;
 - 4) “recycling of C to mosses”
- **Global consequences of decoupling:**
 - 1) slight increases in vascular plants (sedges) may lead to sharp increases in methane formation
- **Worst case scenario:** Climate warming leads to methanogenic use of acetate at current production rates (temp alone: 2° ↑ → ~15%↑; path change: 100x)

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