If you have an extra electron where do you put it?

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Systems Ecological Perspectives on Sustainability Conference
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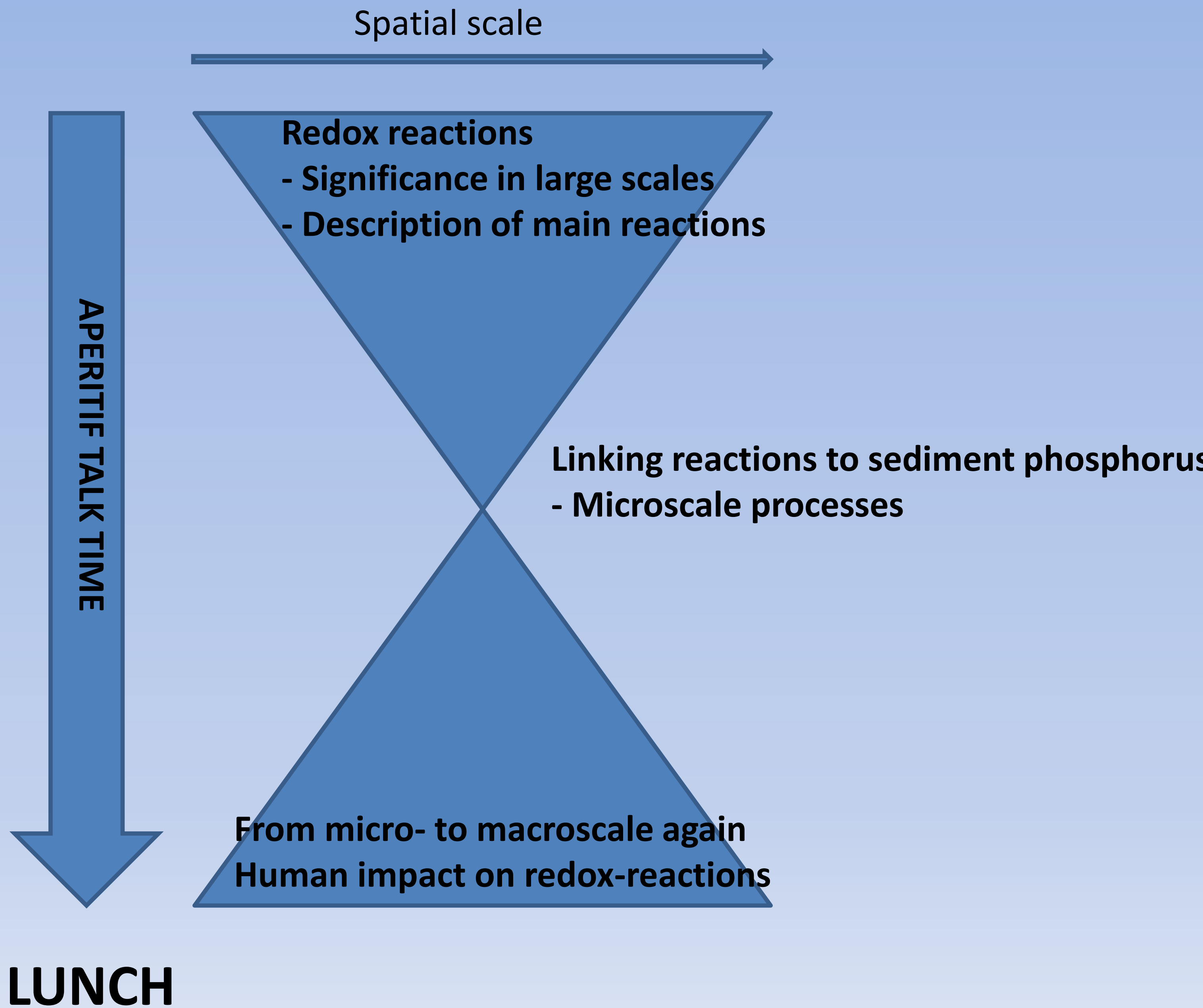
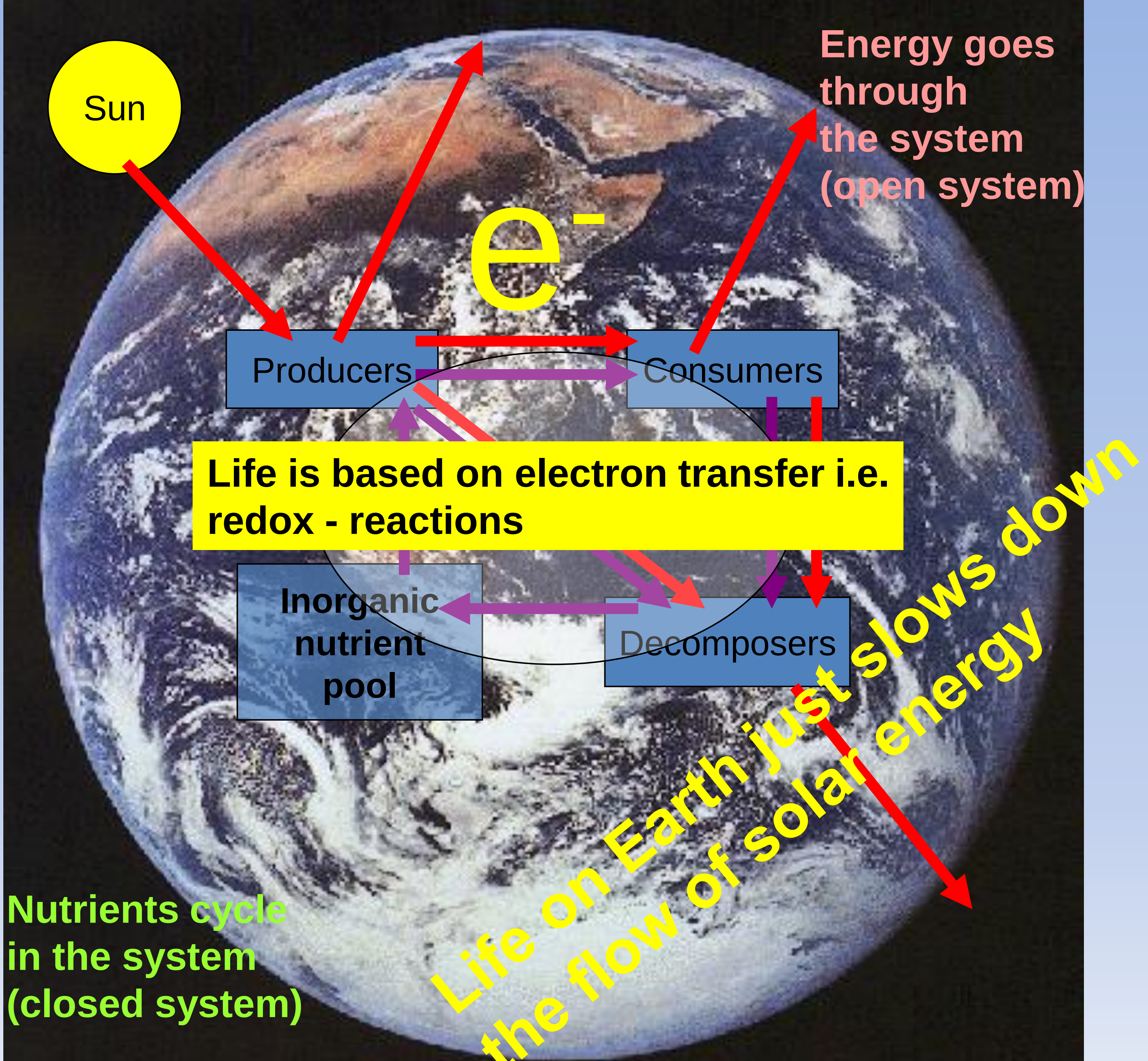
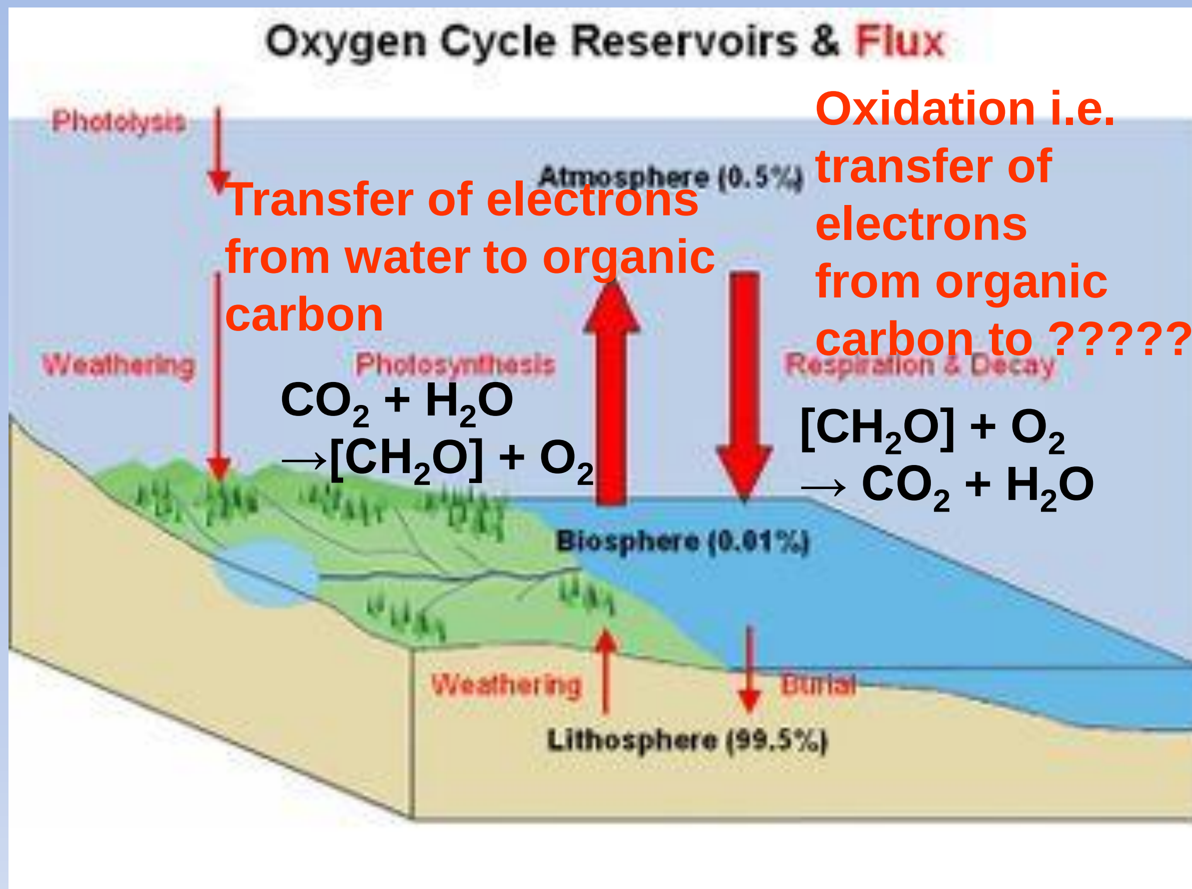

Spatial scale
APERITIF TALK TIME
Redox reactions
- Significance in large scales
- Description of main reactions
Linking reactions to sediment phosphorus
- Microscale processes
From micro- to macroscale again
Human impact on redox-reactions
LUNCH


Sun
Energy goes through the system (open system)
e-
Producers
Consumers
Life is based on electron transfer i.e. redox - reactions
Inorganic nutrient pool
Decomposers
Life on Earth just slows down the flow of solar energy
Nutrients cycle in the system (closed system)

Nasa

Transfer of electrons



Pathways of organic matter oxidation

i.e. transfer of electrons

	Reduction r	E	Depth in sediment
oxic	Aerobic res		mm
anoxic	Denitrificat	$2N_2 + 7H_2O$	mm
anoxic	Manganese	$Mn^{2+} + 3H_2O$	cm
anoxic	Iron reducti	$+ 4Fe^{2+} + 7H_2O$	cm
anoxic	Sulfate redu	$H_2S + 2H_2O$	m
anoxic	Methanoge	O	m

Anaerobic r ly O_2 consumption (reoxidatio $_4$)

→O_2 is the released during mineralization

→ In long run oxygen production = oxygen consumption (1:1)

Not true in geological timescales: Long term burial of organic carbon and formation of FeS_2 (iron oxidizes sulphur) we have free O_2 in athmosphere

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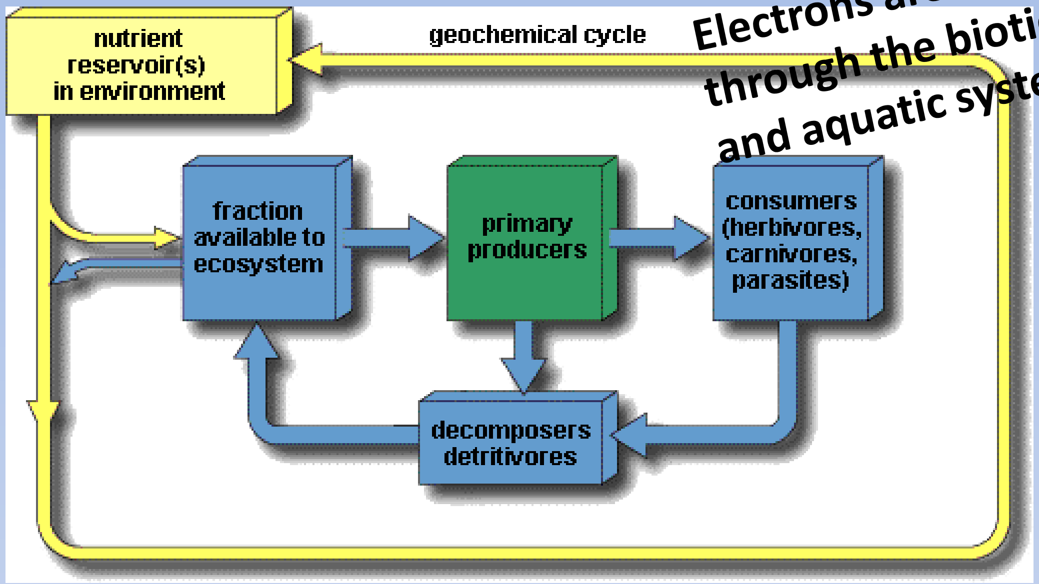
Biogeochemical cycles (closed system)

Electrons are carried by organic carbon through the biotic compartments in terrestrial and aquatic systems



Reservoir
chemical is held for long periods of time in one place (coal and apatite deposits)

Exchange pool
chemical is held for only short period of time.
Generally reservoirs are abiotic factors and exchange pools are biotic

Residence
the amount of time that a chemical is held in one place

Abiotic compartments
Water = hydrosphere
Land = lithosphere
Air = atmosphere

However, there exists also abiotic electron carriers

Terrestrial and aquatic systems
Differences in reservoirs and exchange pools

	Terrestrial	Lake
Nutrient pools		
a) Reactive sites	Minerals, org. horizons, rhizosphere	Particles, sedim.-water
b) Sites of nutrient storage	Soils, vegetation	Sediment, fish
Biota		
a) Lifespan of primary producers	Long	Short
b) C:N, C:P of primary producers	High	Low
c) N-fixers	Symbiotic with long-lived organisms	Free living
d) Ratio consumers:producers	Lower	Higher
Prevalence of anoxia	Rare, microsites only	Sediments, hypolimnion

P-pools in marine and terrestrial living organisms

- P-pool (50 to 70 x 10^{12} g) in marine plankton is only 2 % of that in terrestrial living biomass
- However, the marine primary production incorporates 1200 x 10^{12} g P yr^{-1}
  - is 3 to 4 times higher than the terrestrial incorporation rate

Turnover times (’residence’)

- The turnover time of living oceanic biomass is short:
  - few days for prokaryotes
  - week for phytoplankton
  - few months for zooplankton
- In terrestrial systems the P is mainly bound to long-lived forests
  - average turnover time for terrestrial living biomass is at least 10 years

Resting cells

What does this mean?

- Phosphorus cycles much faster in aquatic than terrestrial systems
- With a same amount of phosphorus we get more organic carbon (i.e. electron packages) into aquatic than terrestrial system

Primary production

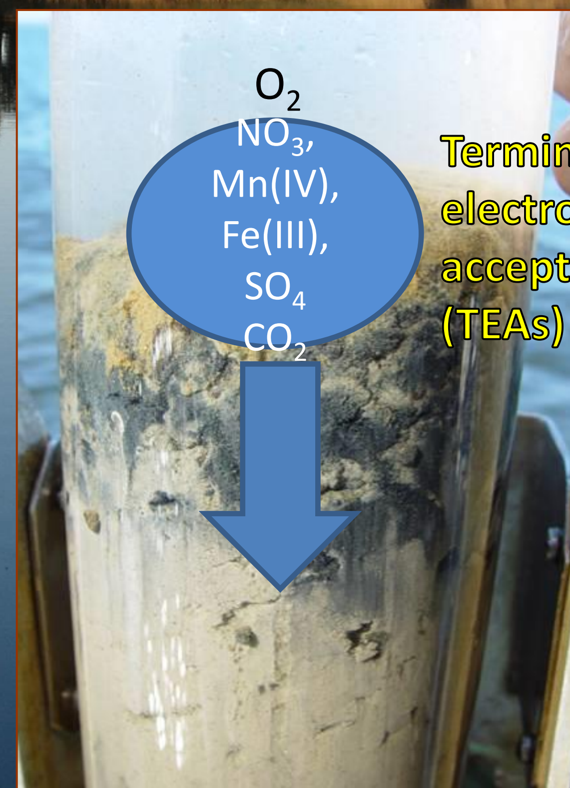
$$CO_2 + H_2O \rightarrow [CH_2O] + O_2$$

Mineralization

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$$

Problem: Nutrient loading increases primary production

Seija Hällfors

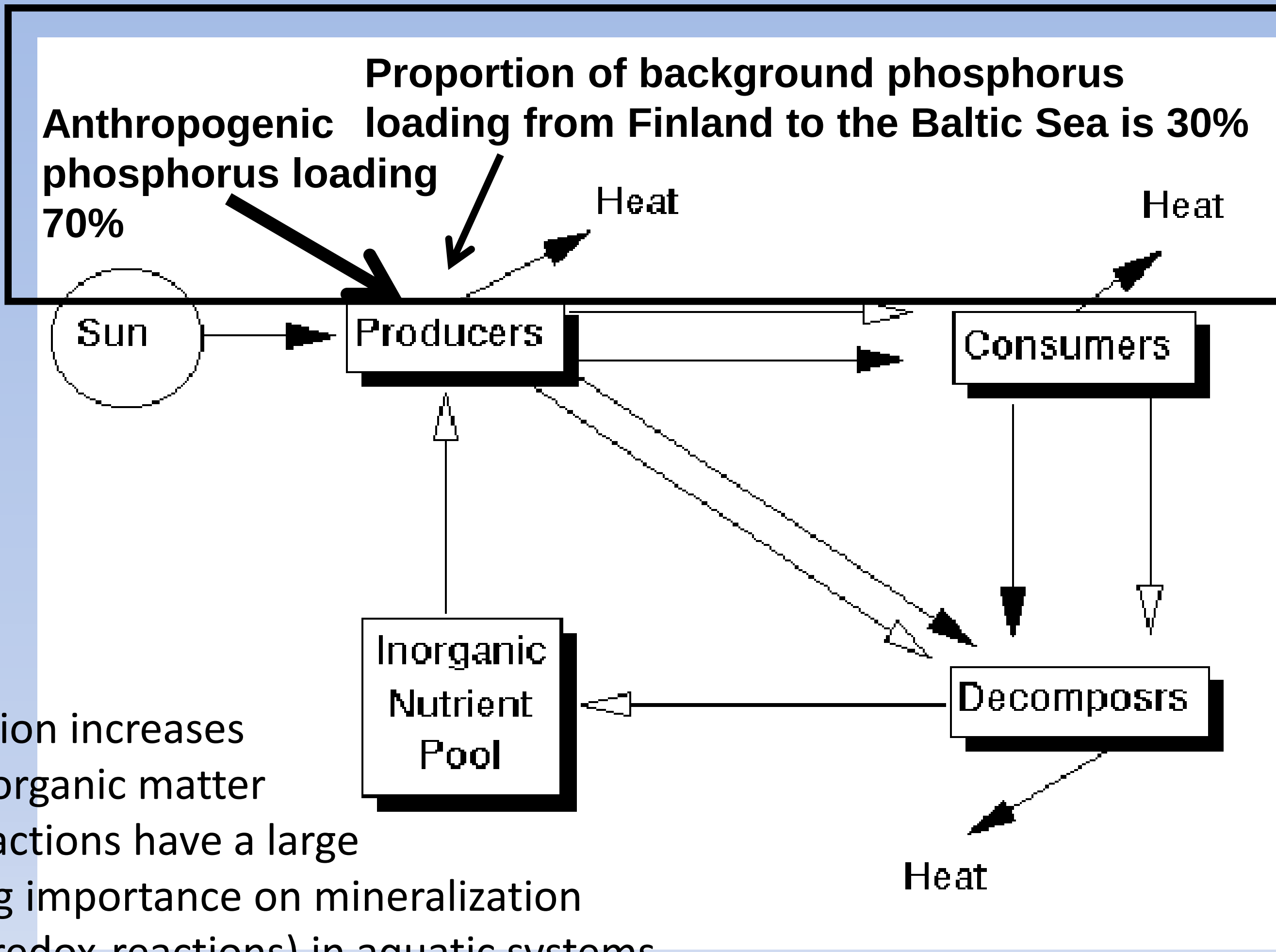


Terminal electron acceptors (TEAs)

Inkoo

Energy flow

goes through the system (open system)

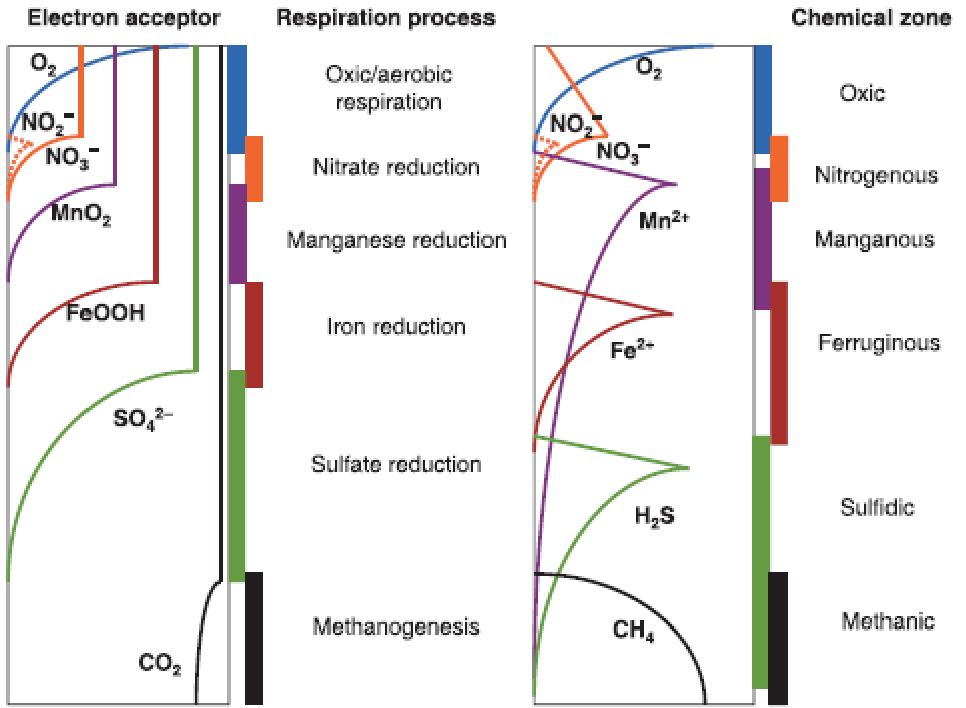


Eutrophication increases amount of organic matter

- Human actions have a large and growing importance on mineralization processes (redox-reactions) in aquatic systems

Pathways of organic matter oxidation

	Reduction reaction	Formula	Depth in sediment
oxic	Aerobic respir		mm
anoxic	Denitrification		mm
anoxic	Manganese re		cm
anoxic	Iron reduction		cm
anoxic	Sulfate reducti		m
anoxic	Methanogenes		m



Canfield and Thamdrup 2009, Geobiology 7: 385-392

One element is missing **Phosphorus**

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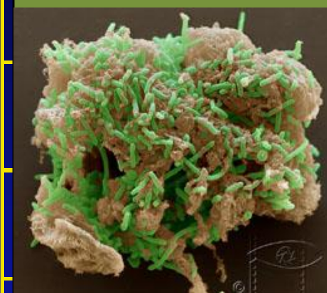
Phosphorus: What kind of sediment we would like to have considering mineralization pathways?

If you have an extra electron (organic matter) where do you put it (which electron acceptor you prefer)

Pathways of organic matter oxidation



Geobacter metallireducens

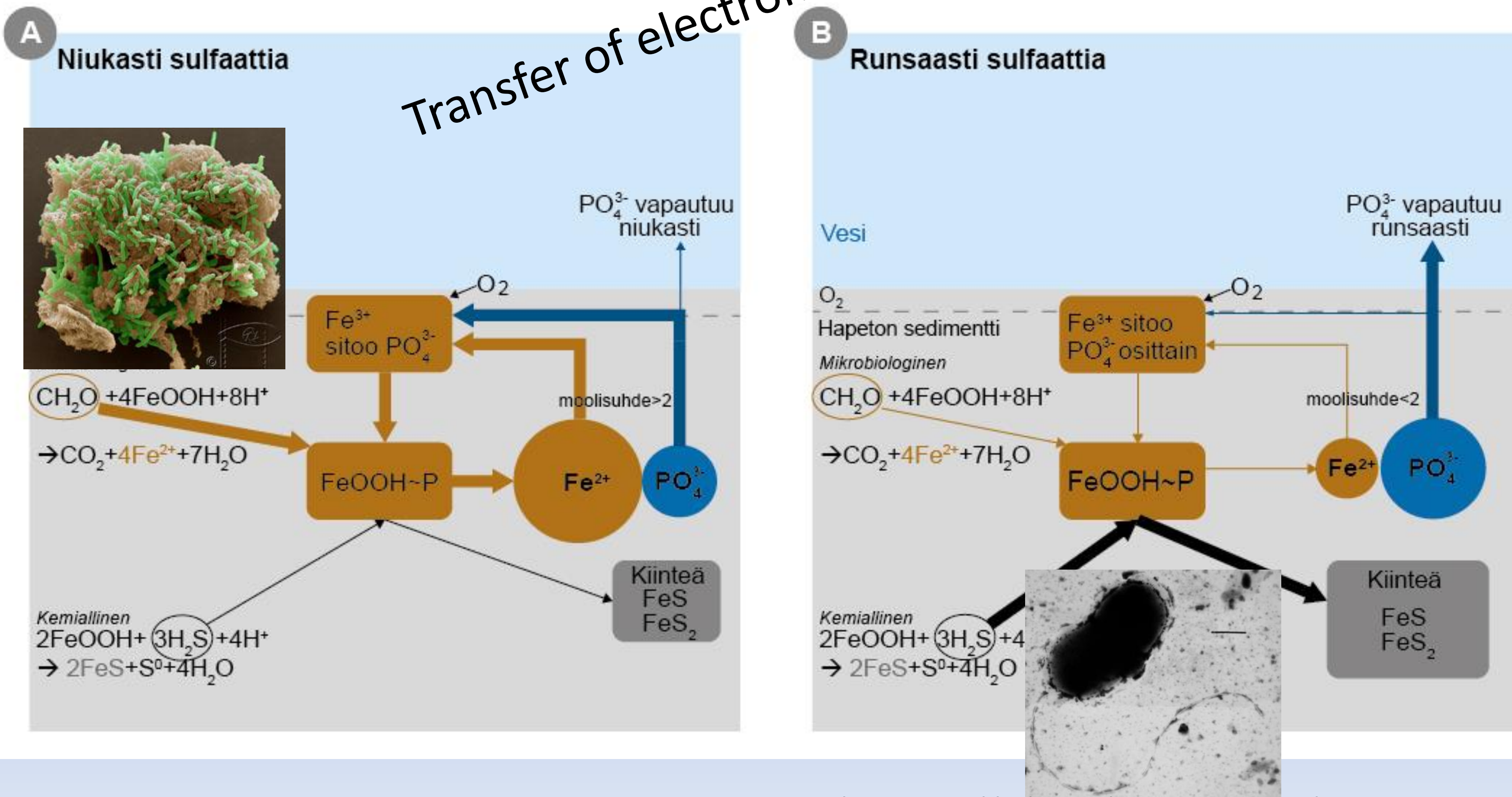
	Reduction reaction	Formula	Depth in sediment
anoxic	Iron reduction	$CH_2O + 4FeOOH + 8H^+ \rightarrow CO_2 + 4Fe^{2+} + 7H_2O$	cm
anoxic	Sulfate reduction	$2CH_2O + SO_4^{2-} + 2H^+ \rightarrow 2CO_2 + H_2S + 2H_2O$	m

Fe(III) is sensitive towards mineralization processes

→ Phosphorus starts react on redox-reactions

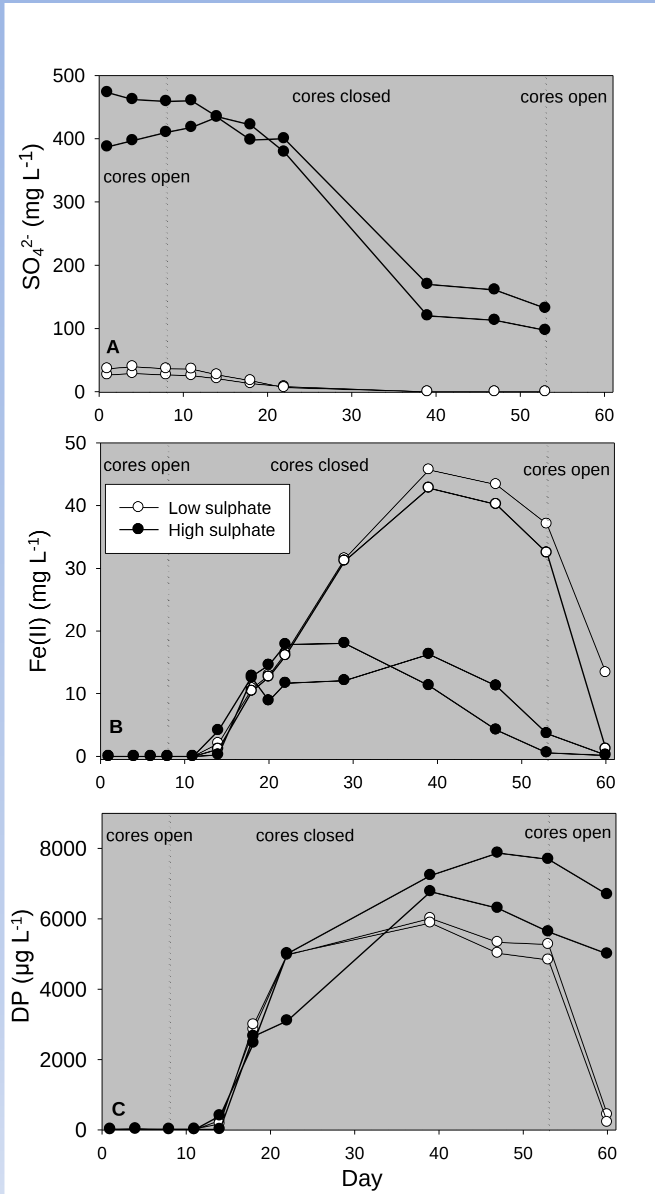
Significance of sulphate

Transfer of electrons from org.C to Fe or SO4



Lehtoranta, Ekholm, Pitkänen 2009. Ambio 38:303-308
Lehtoranta & Ekholm 2013 Vesitalous 2: 40-42

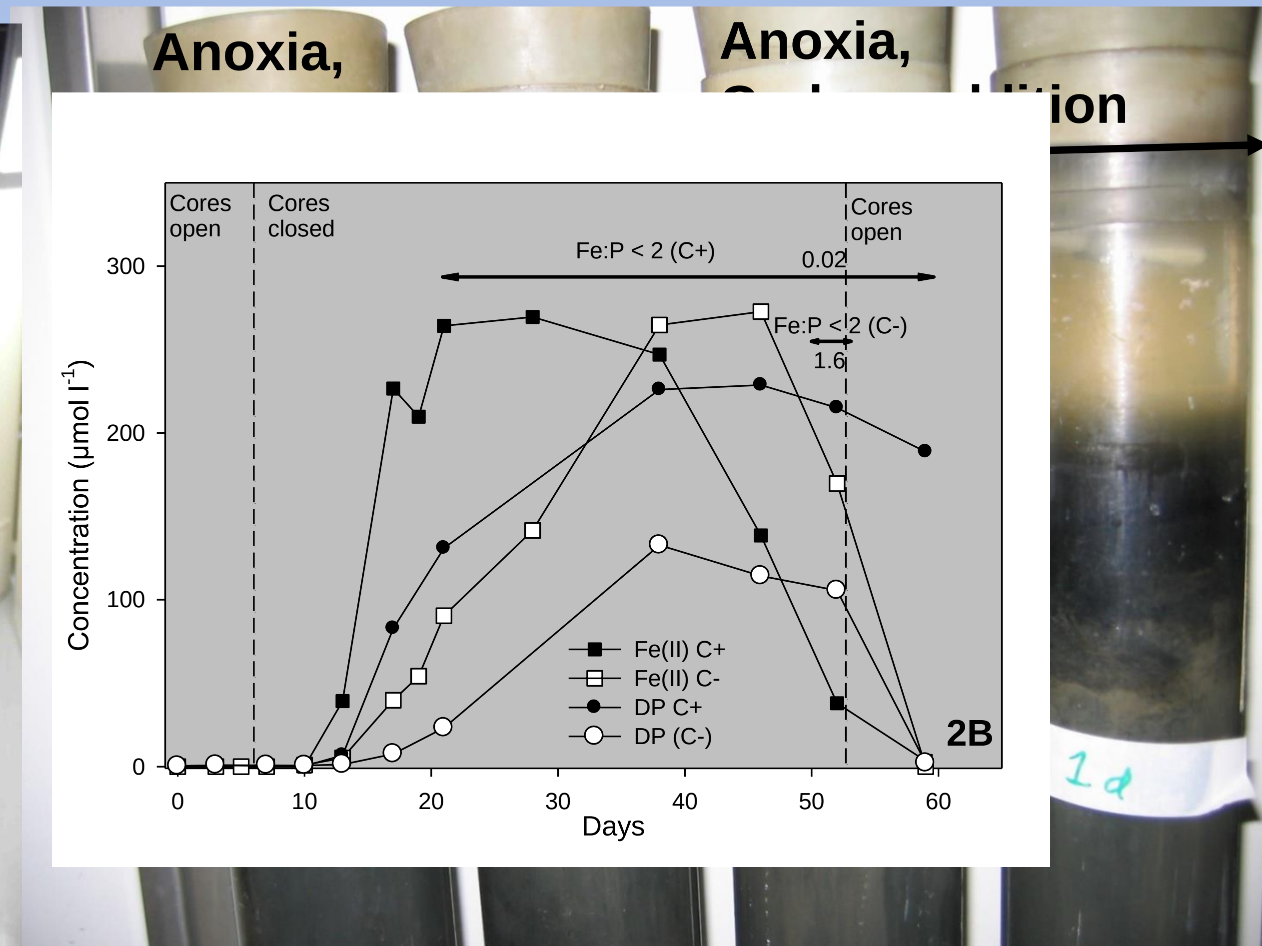
Sulphate removed i.e. change in electron acceptor



Ekholm et al. 2011. The effect of gypsum on phosphorus losses at the catchment scale. **THE FINNISH ENVIRONMENT 33 | 2011**

Addition of organic carbon
(i.e. change in electron donor)

How microbial iron and sulphate reduction can be noticed after organic matter addition?



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Lehtoranta, Ekholm and Pitkänen 2009 Ambio 38: 303-308

Up-stream thinking: Soil erosion and anerobic microbial processes in brackish sediment

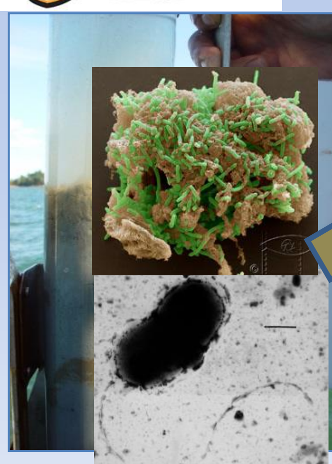
Incubation:

- At dark
- (a) +10 °C, (b) +8 °C
- (a) 308 d, (b) 745 d

Standard field soil
Sandy clay
(60–1000 mg)

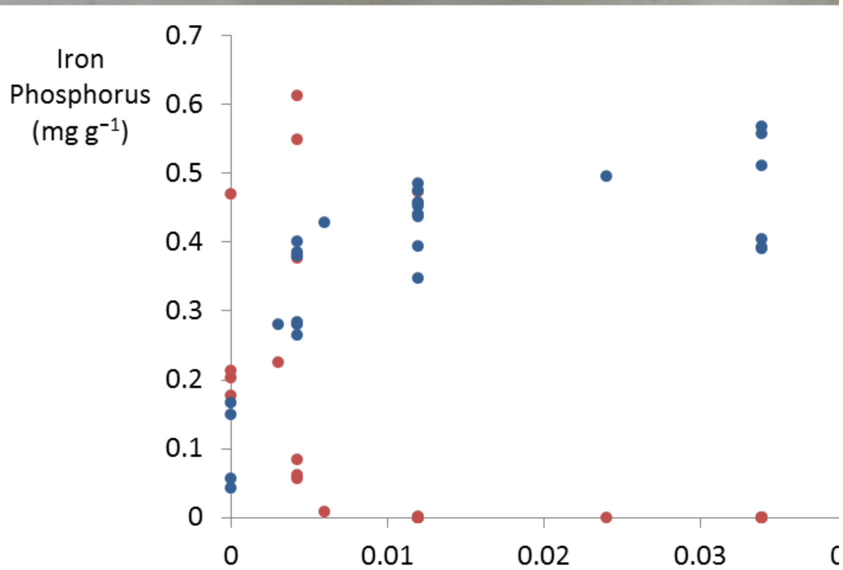
80 ml filtered
Gulf of Finland water

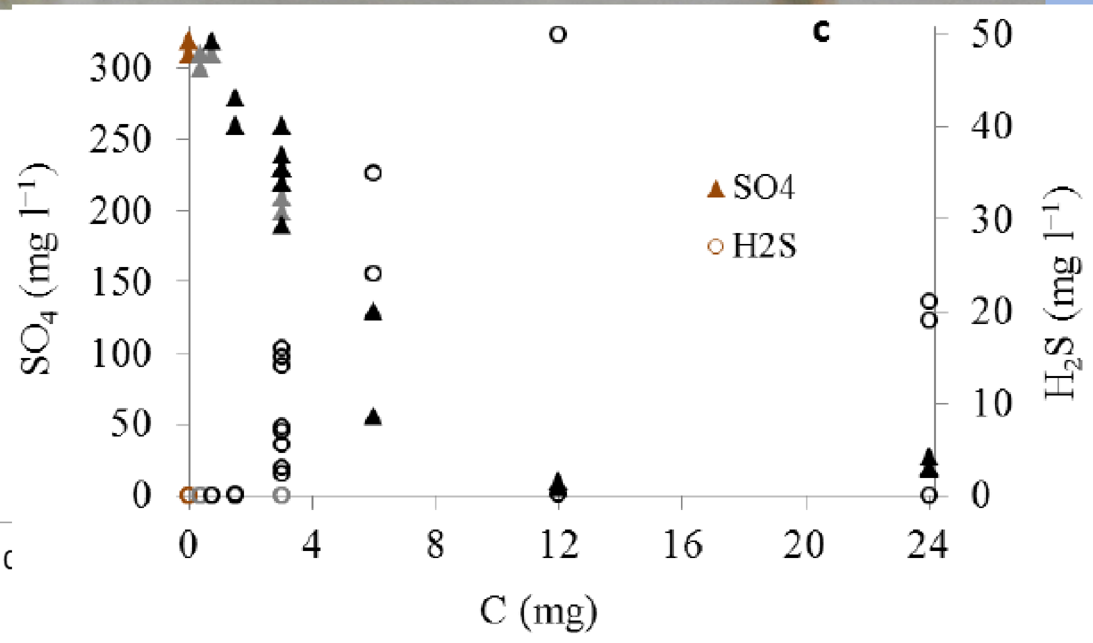
Natrium acetate
(0.375–24 mg C)

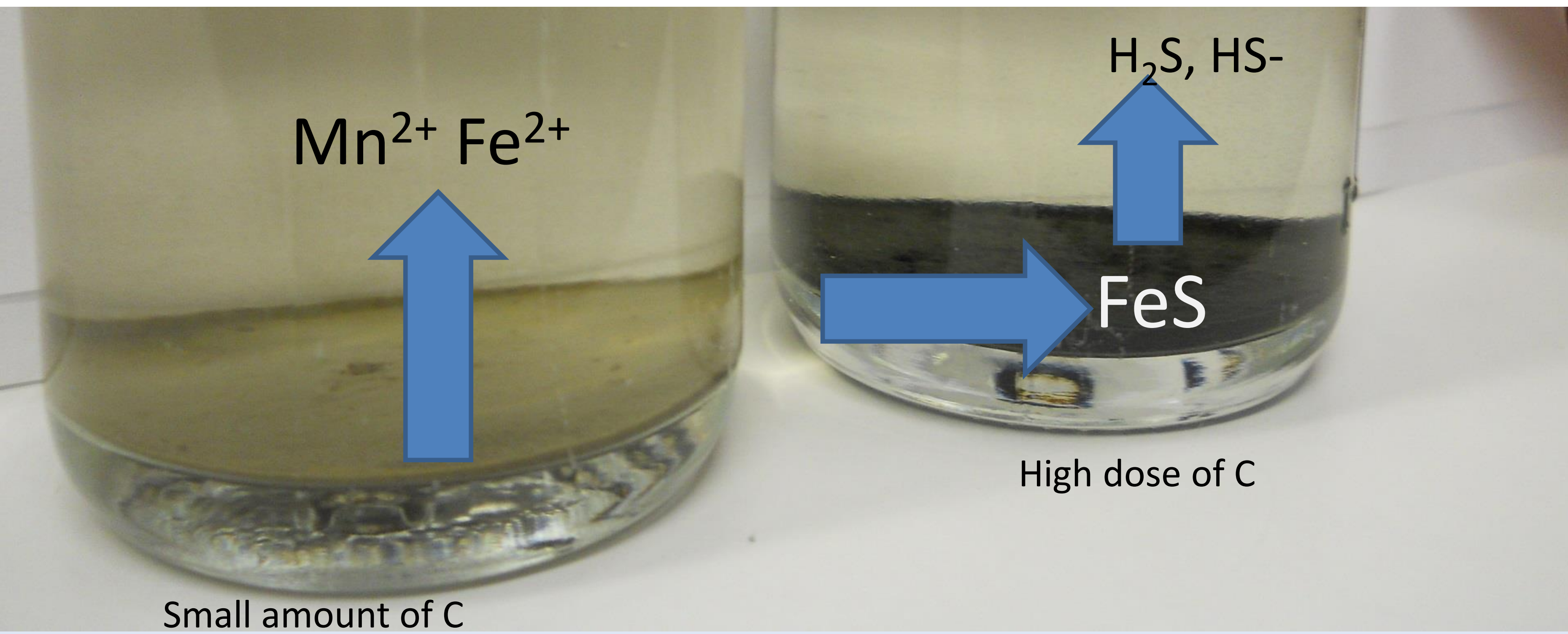


10 µl sediment

Lehtoranta, J., Ekholm, P., Wahlström, S. Tallberg, P. and Uusitalo, R. Under revision


Iron
Phosphorus
(mg g-1)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.01
0.02
0.03


c
SO4 (mg l-1)
H2S (mg l-1)
300
250
200
150
100
50
0
50
40
30
20
10
0
SO4
H2S
0
4
8
12
16
20
24
C (mg)


Mn2+ Fe2+
H2S, HS-
FeS
High dose of C
Small amount of C

Constructed wetland of Ojainen in Jokioinen

Black sediment indicating presence of Fe sulphides

Laakso Johanna, Kahma Tuomas, Ekholm Petri, Lehtoranta Jouni, Uusitalo Risto, Yli-Halla Markku

Consequences of eutrophication linked to electron transfer in sediments

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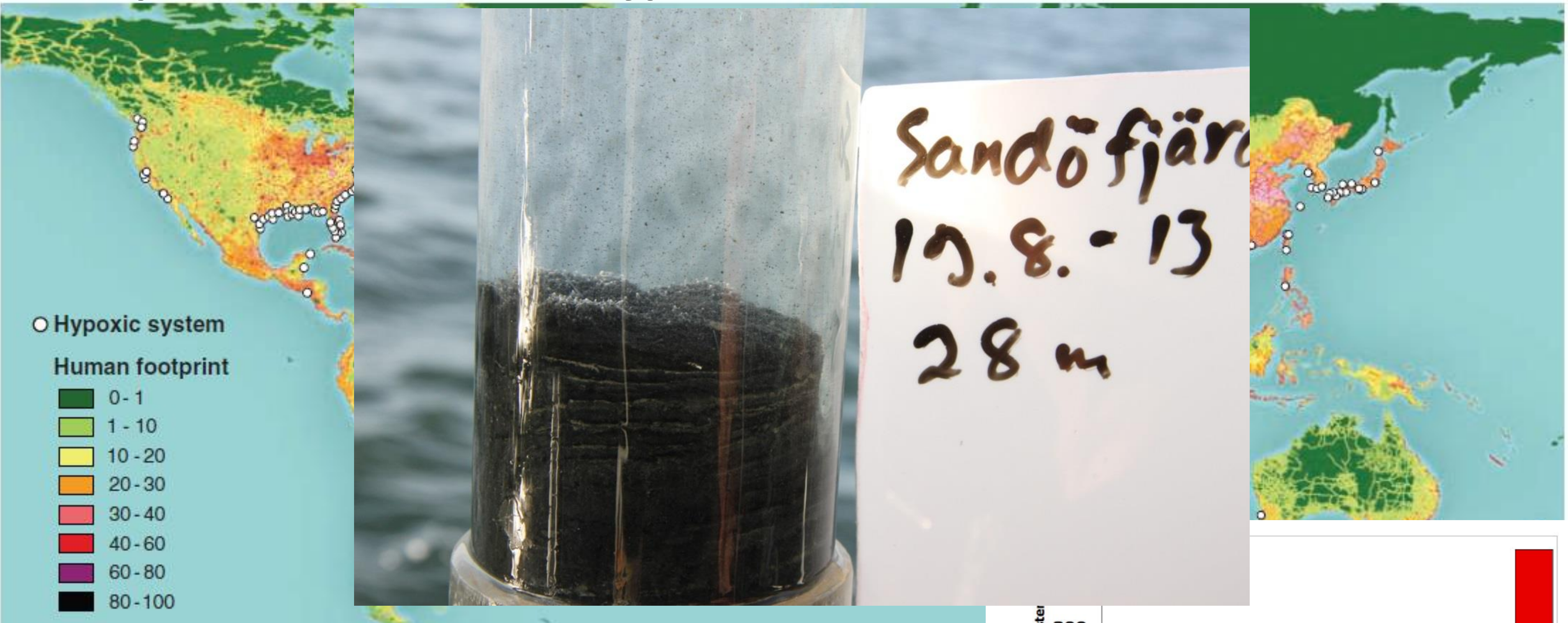
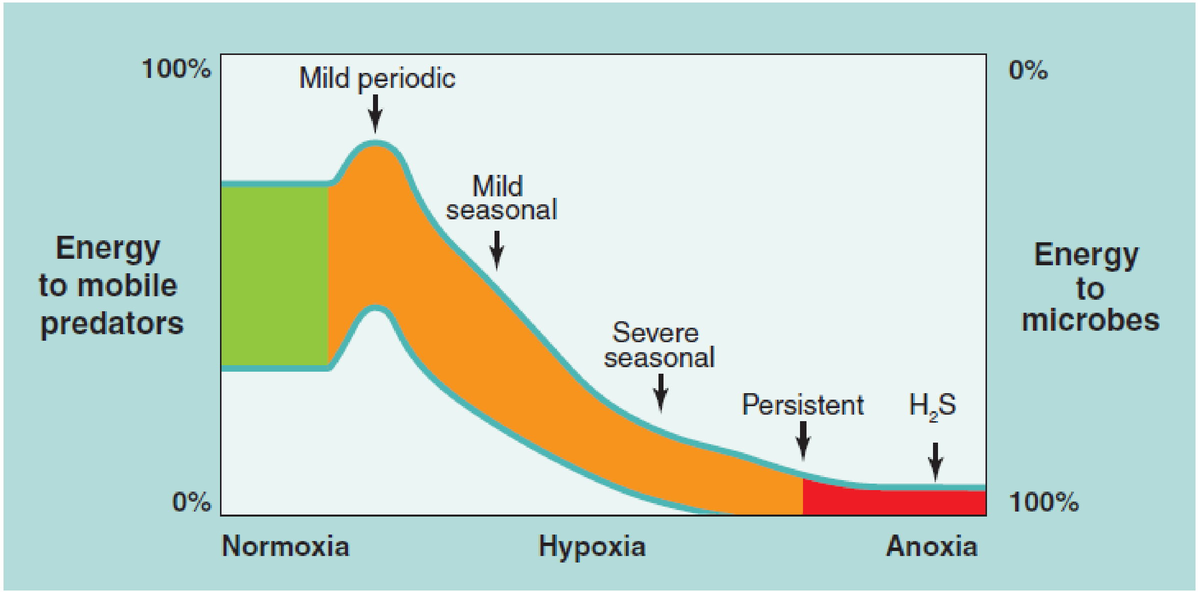
Eutrophication associated hypoxic areas





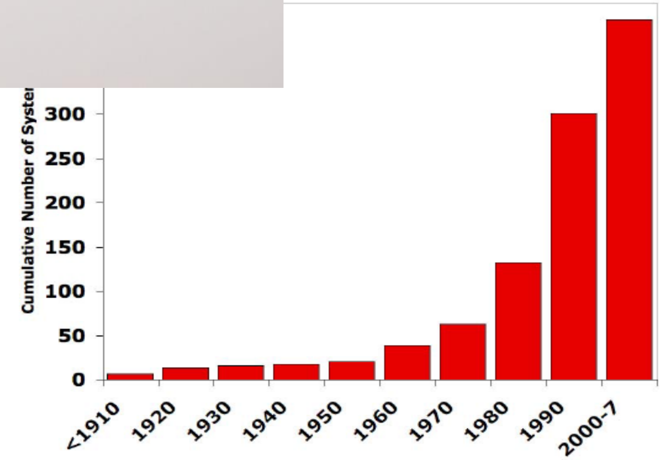
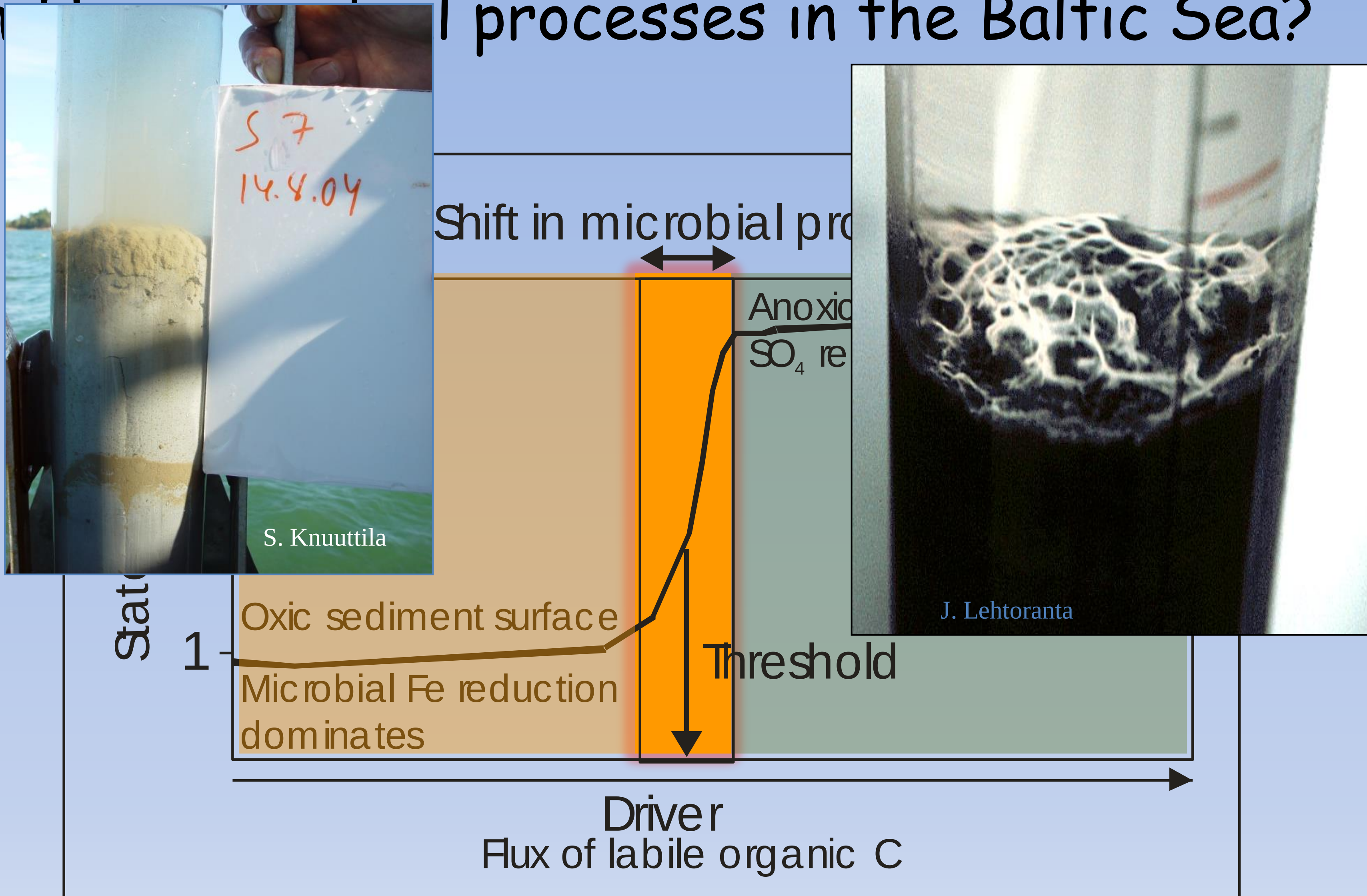


Figure S1. Cumulative increase in dead zones through time reported in the scientific literature. Systems are grouped by decade of first documented account (Table S1). The number of dead zones started to approximately double every ten years starting in the 1960s.

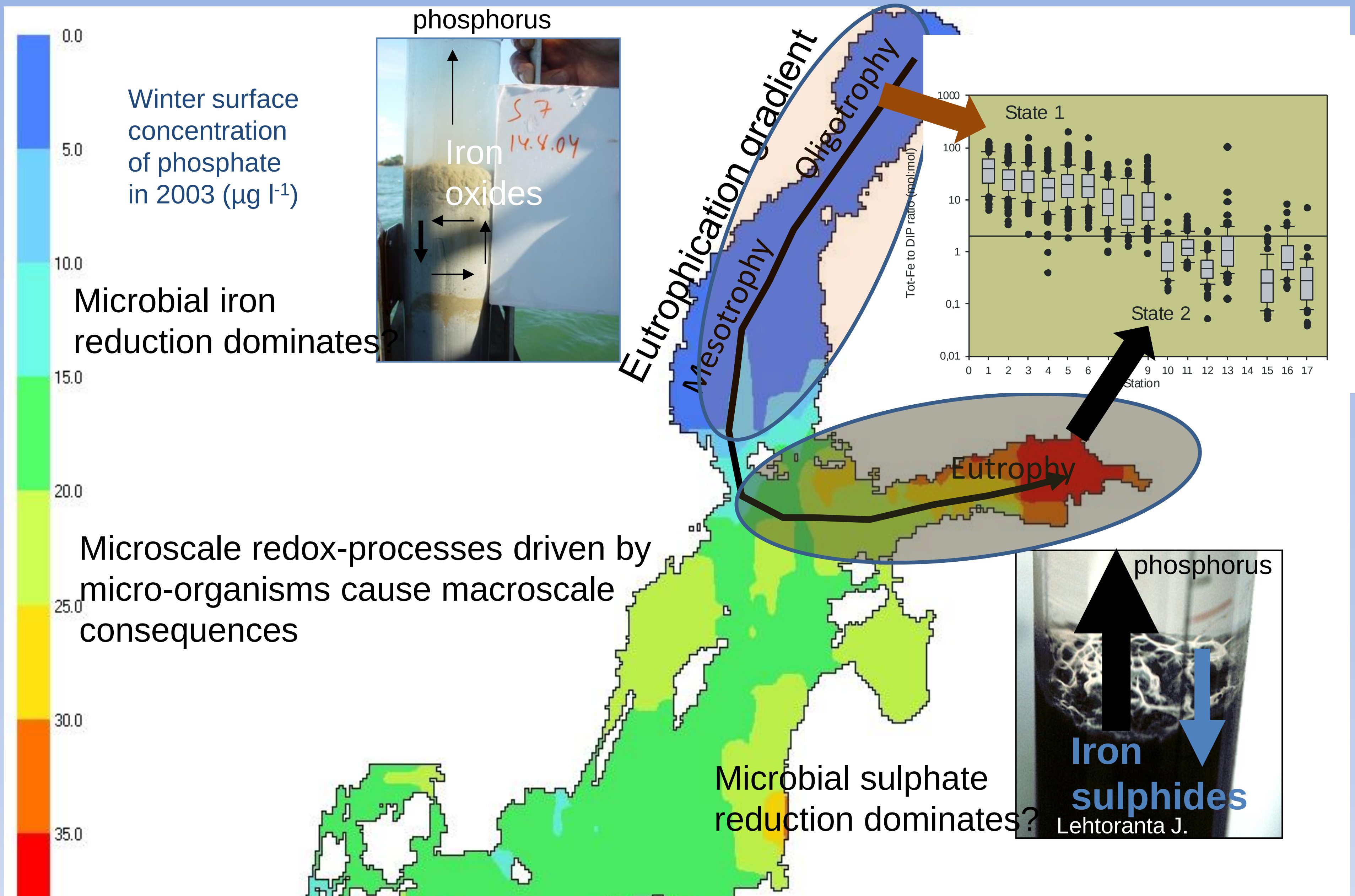
Spreading Dead Zones and Consequences for Marine Ecosystems
Robert J. Diaz, *et al.*
Science **321**, 926 (2008);

Sh l processes in the Baltic Sea?



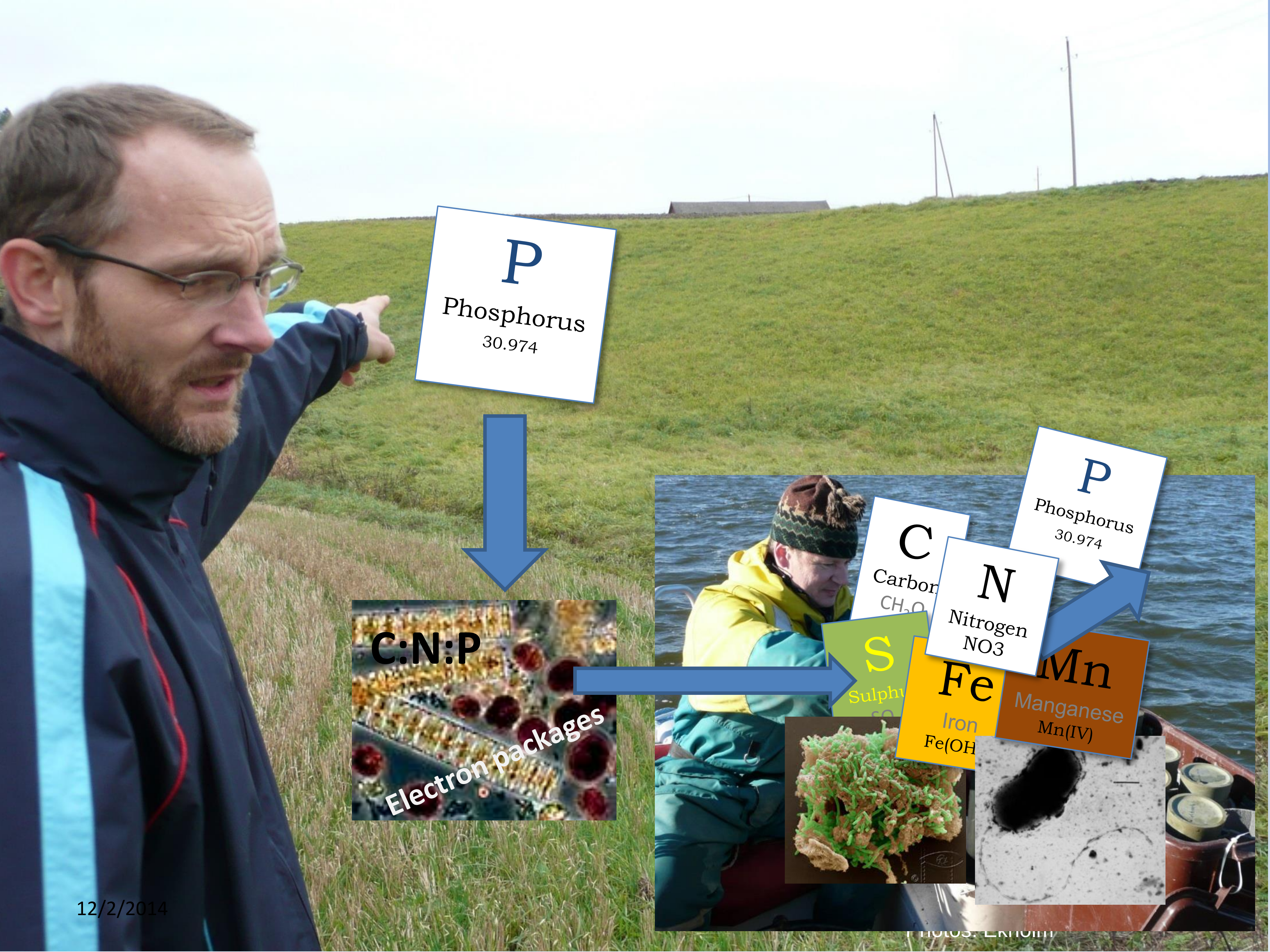
Could change in microscale processes driven by micro-organisms cause macroscale consequences?

Lehtoranta, Ekholm and Pitkänen 2009 Ambio 38: 303-308



Lehtoranta, Ekholm & Pitkänen 2008. (J. Mar. Syst. 74:495-504)

Data: PAPA Partners
Figure: Mikko Kiirikki/SYKE


P
Phosphorus
30.974
C:N:P
Electron packages
C
Carbon
N
Nitrogen
NO3
P
Phosphorus
30.974
S
Fe
Iron
Mn
Manganese
Mn(IV)
12/2/2014

Summary

- Eutrophication increases mineralization
- All terminal electron acceptors used produce CO_2
- Reduced substances formed in the mineralization participate to further redox-reactions (Mn(II), Fe(II), H_2S, CH_4)
- They have different consequences on the element cycles in the system
- So ”if you have an extra electron where do you put it”, depends what you are trying to get

Thank you