How wetland ecosystem services are underpinned by ecological functioning

Jos T.A. Verhoeven

Universiteit Utrecht

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- Why are wetlands champions?
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- Current debates from the ecosystem function side:
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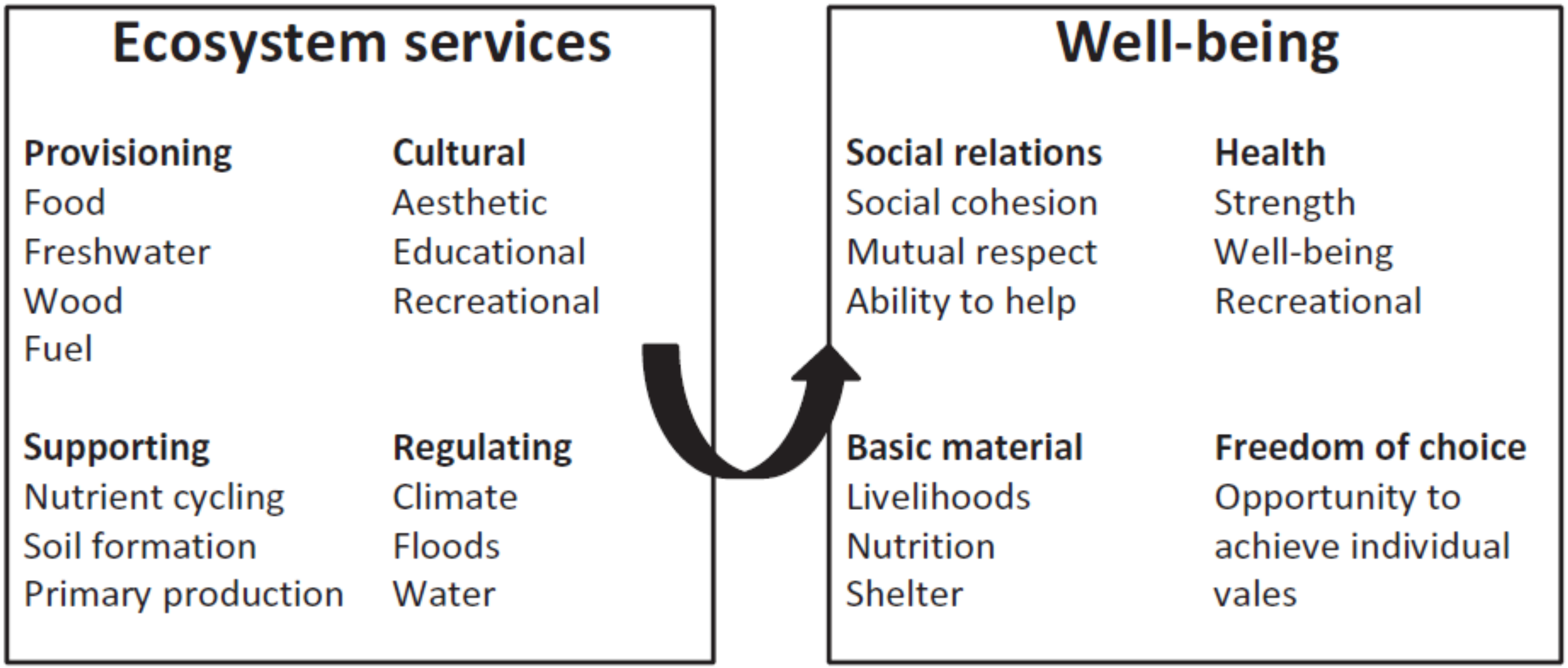
  - Regulating services: (debate: does nutrient retention have side effects?)
  - Climate regulation (debate: C storage vs. methane emissions)
- Combined wetland services and livelihoods: constructed wetlands Florida; Inner Niger delta

Ecosystem Services vs. Ecosystem Functions

- Ecosystem Services: benefits (goods and services) that people obtain from the functioning of ecosystems
- Ecosystem Functions: interactions between ecosystem structure and processes that underpin the capacity to provide goods and services

- Millennium Ecosystem Assessment (2005)

Four groups of ecosystem services



Millennium Ecosystem Assessment, 2005

Maltby & Acreman 2011

Provisioning		
1	*Food*	Presence of edible plants and animals
2	*Water*	Presence of water reservoirs
3	*Fiber, Fuel & other raw materials*	Presence of species or abiotic components with potential use for timber, fuel or raw material
4	*Genetic Materials*	Presence of species with (potentially) useful genetic material
5	*Biochemical and medicinal resources*	Presence of species or abiotic components with potentially useful chemicals and/or medicinal use
6	*Ornamental species and/or resources*	Presence of species or abiotic resources with ornamental use

Regulating

7	*Air quality regulation*:	Extraction of aerosols & chemicals from the atmosphere
8	*Climate Regulation*	Influence on local and global climate: soil carbon and methane
9	*Natural Hazard mitigation*	Role of wetlands in dampening extreme events
10	*Water regulation*	Role of wetlands in water infiltration and gradual release of water
11	*Waste & nutrient treatment*	Role of biota and abiotic processes in removal or breakdown of organic matter, nutrients and compounds
12	*Erosion protection*	Role of vegetation and biota in soil retention
13	*Soil formation & regeneration*	Role of natural processes in soil formation and regeneration
14	*Pollination*	Abundance and effectiveness of pollinators
15	*Biological Regulation*	Control of pest populations through trophic relations

Habitat or supporting

16	*Nursery habitat*	Importance of ecosystems to provide breeding, feeding or resting habitat for transient species
17	*Gene pool protection*	Maintenance of a given ecological balance and evolutionary processes

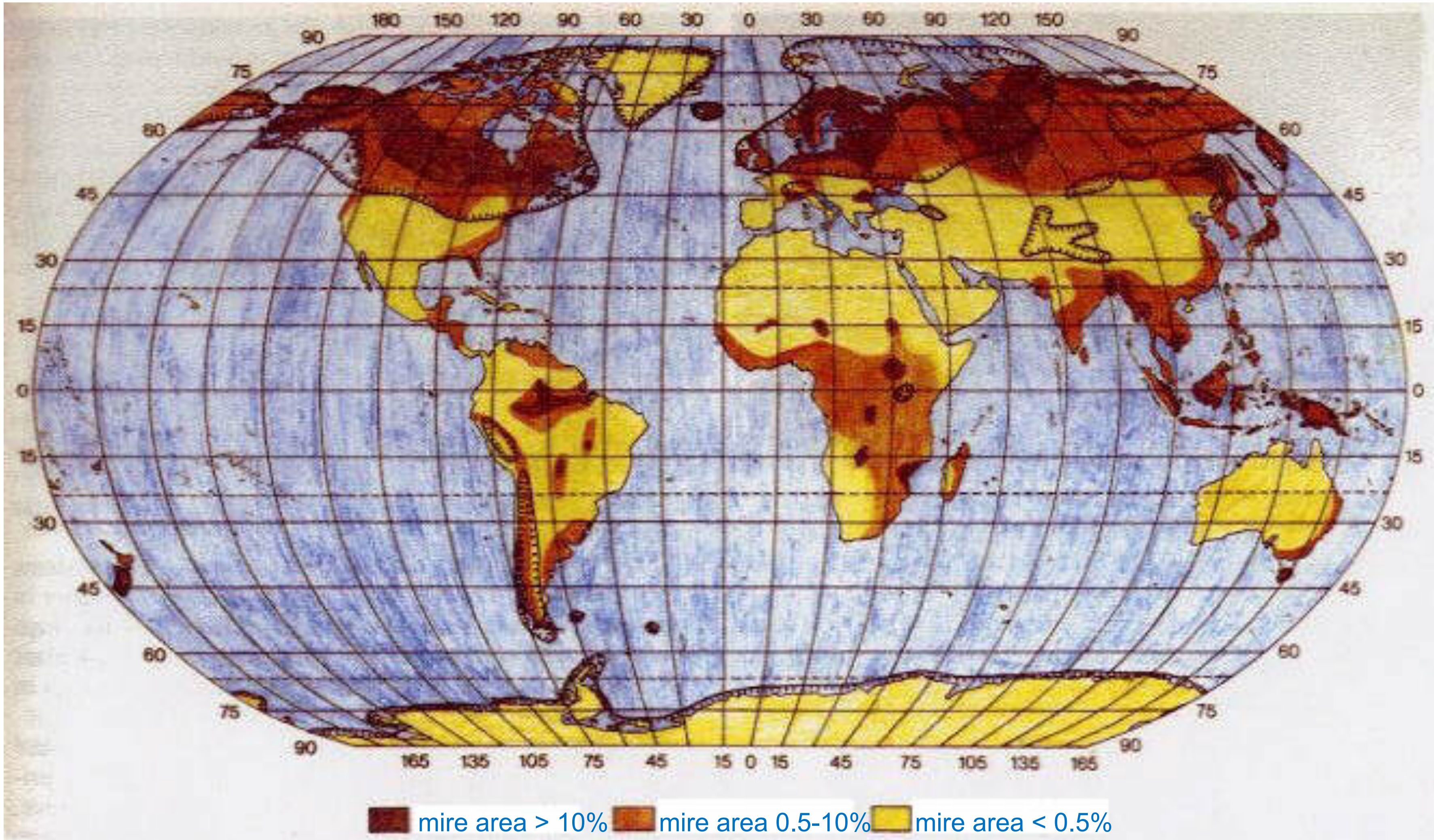
Cultural & amenity

18	*Aesthetics*	Aesthetic quality of the landscape, based on e.g. structural diversity, "greenness", tranquility
19	*Recreation, ecotourism*	Landscape-features Attractive wildlife
20	*Inspiration for culture, art and design*	Landscape features or species with inspirational value to human arts, etc.
21	*Cultural heritage and identity*:	Culturally important landscape features or species
22	*Spiritual & religious inspiration*	Landscape features or species with spiritual & religious value
23	*Education & science*	Features with special educational and scientific value/interest

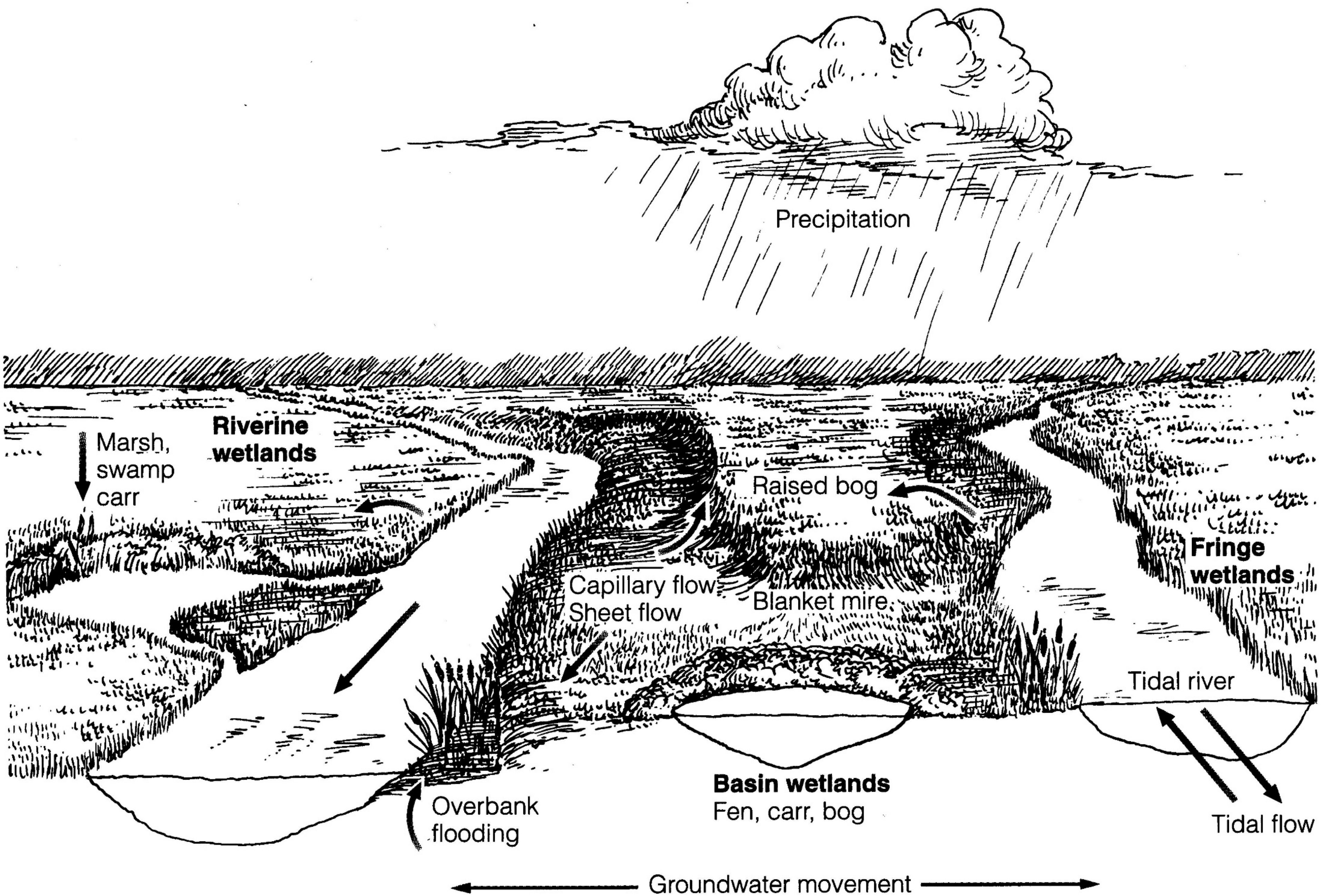
Definition of wetlands

- Areas with water level near soil surface (at least 6 months per year)
- Sediments with indications for anaerobic conditions (rusty brown and en black-grey mottling)
- Vegetation consists of plants with special adaptations: submerged life form or flood tolerance

Wetlands of the world



Wetland types and hydrology



Why are wetlands champions?

- Wetlands have water: abundant life!
- Many wetlands have a catchment → rich in nutrients
- Combination of water and nutrients → high productivity
- Fish and crustacean production! Waterfowl!
- Wetlands have water-logged soils → anaerobic conditions
- Slow decomposition and organic matter storage
- Complex biogeochemistry resulting in denitrification and methane emission

Wetland ecosystem services

- Provisioning:
  - Biomass/ food production
  - Enhancement of fisheries (riverine, coastal)
  - Water?
- Regulating:
  - Flood detention and storm protection
  - Nutrient/sediment retention: better water quality
  - Carbon storage vs. GHG emissions (climate)
- Cultural:
  - Heritage and use by livelihoods
  - Biodiversity, esthetics and ecotourism

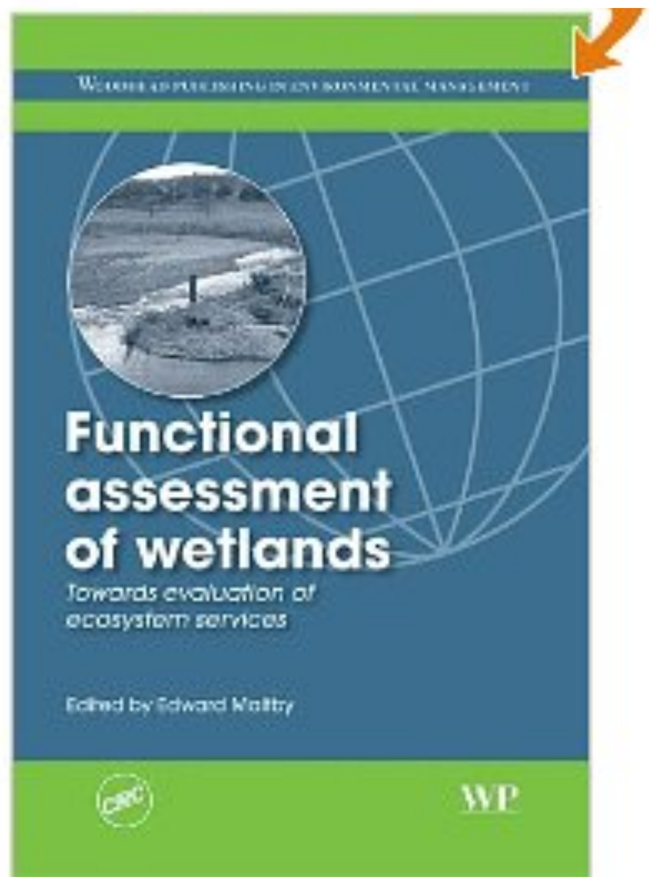
Combinations?

Underpinning wetland services

- Goods and services are produced through ecosystem functioning
- Underpinning requires very good knowledge of wetland ecology
- Complex interactions among plants, animals, microbes and the environment
- Hydrology, hydrogeochemistry, energy flow, food web, carbon and nutrient cycling
- Use of expert knowledge to use assessment systems based on indicators

Methodology to estimate wetland functions/services: FAPs

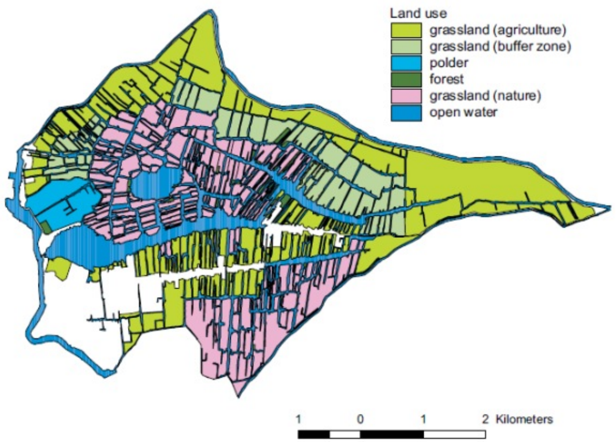
Functional Assessment Procedures



Maltby et al. 2009

- Wetland services brought about by functions
- Functions are based on processes
- Processes: environmental variables and biota

- Assessment of functions with field indicators:
- Desk study
- 1-2 days in the field
- Questionnaires
- Calculations through decision tree



FAEWE
Protowet
Evaluwet

Ecosystem service

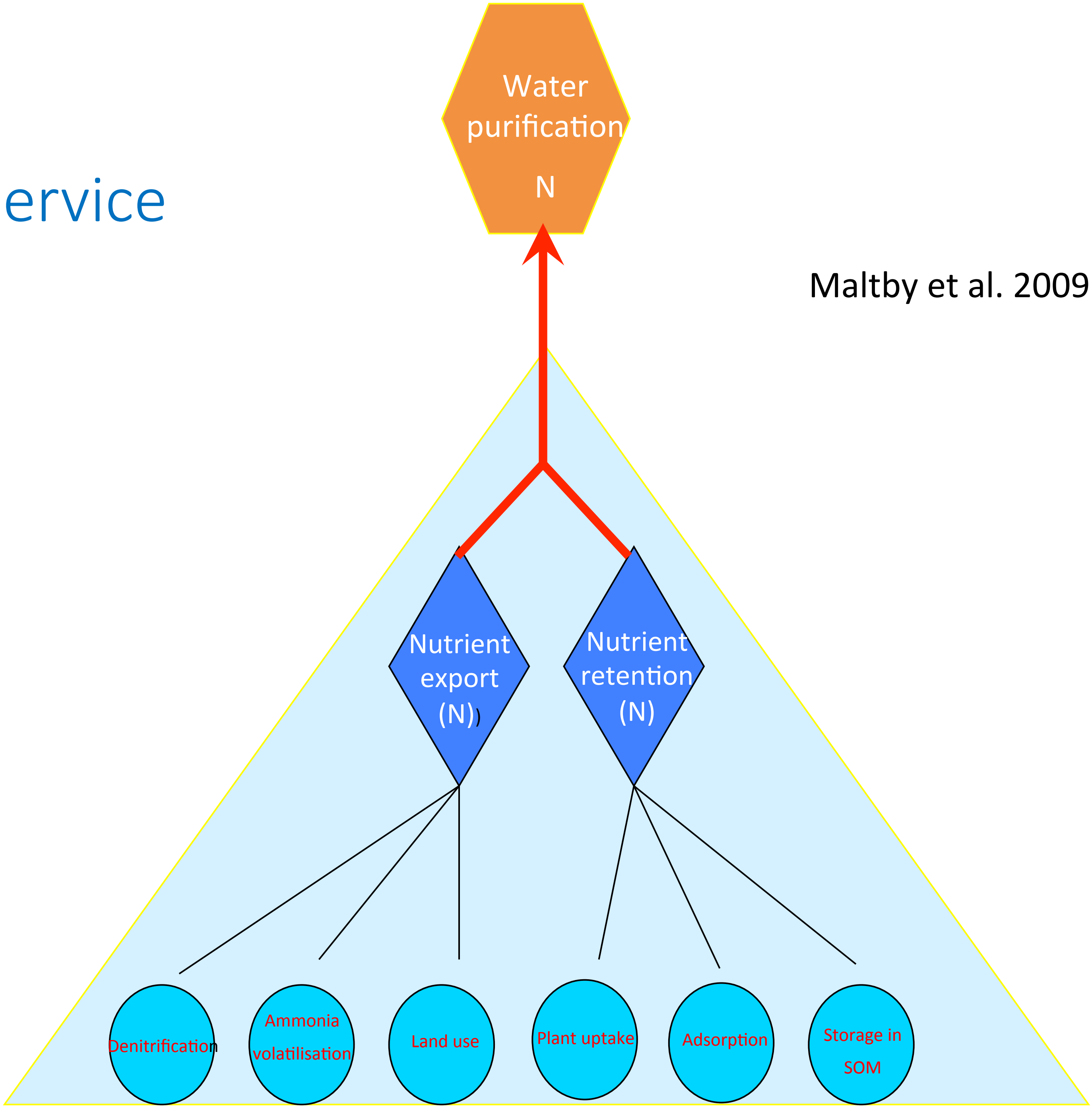
Maltby et al. 2009

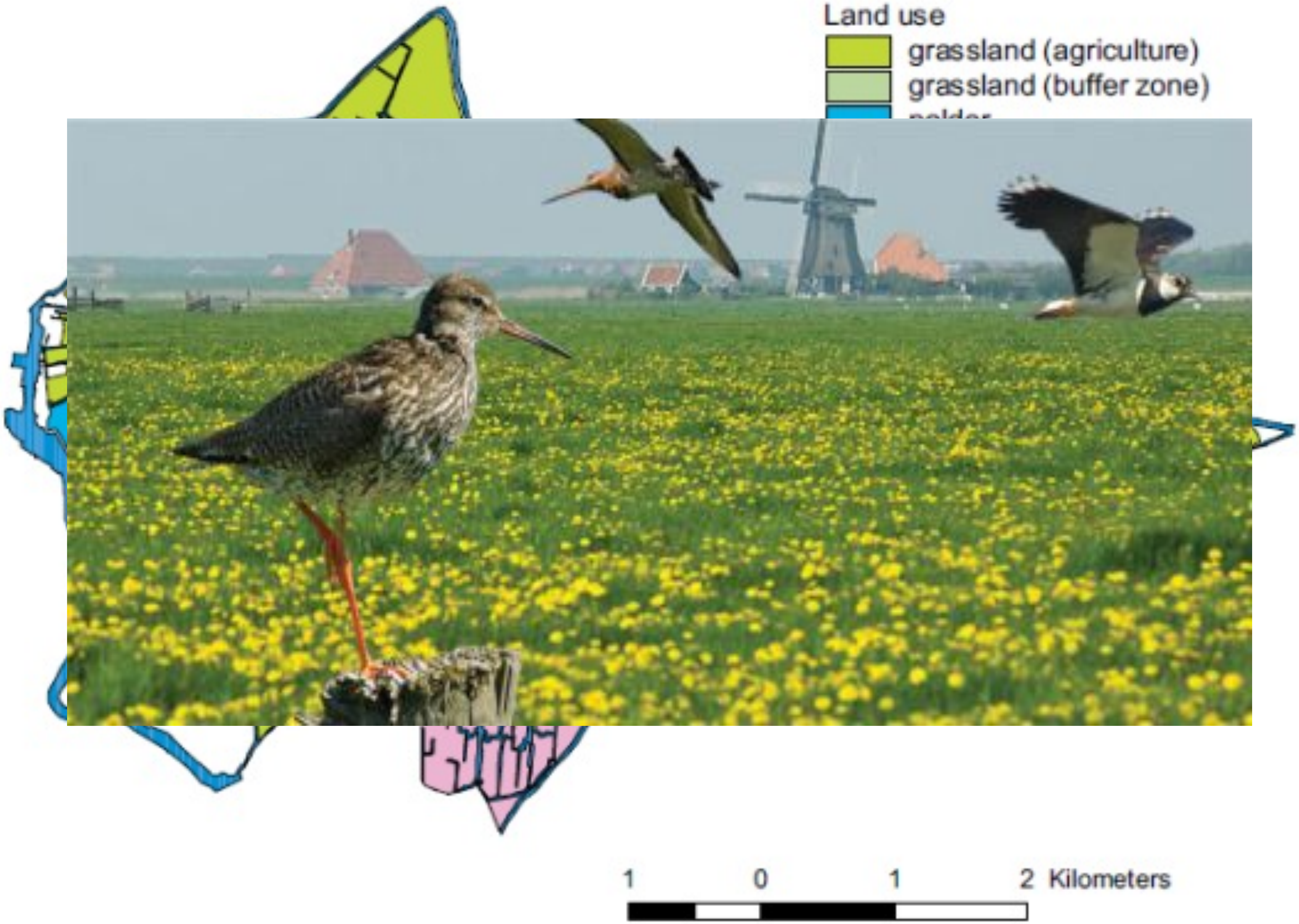
based on

Functions

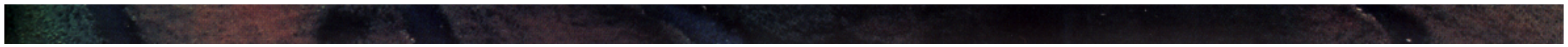
based on

Processes

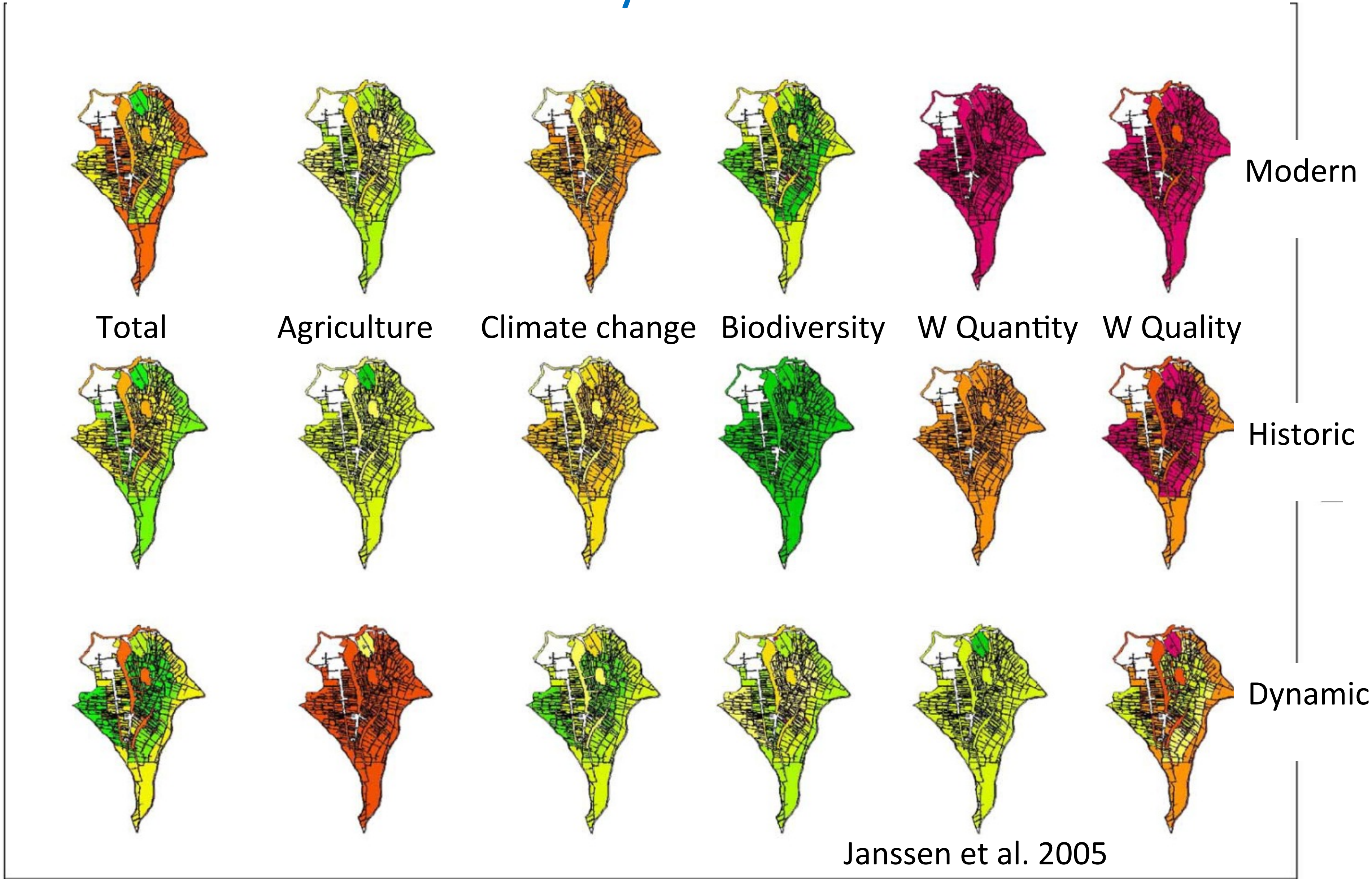




Land use
grassland (agriculture)
grassland (buffer zone)
1
0
1
2 Kilometers



Multicriteria Analysis based on FAPs



Provisioning and food chain support

Provisioning services: examples

- Spawning and nursery habitat for fish: saltmarsh & mangrove

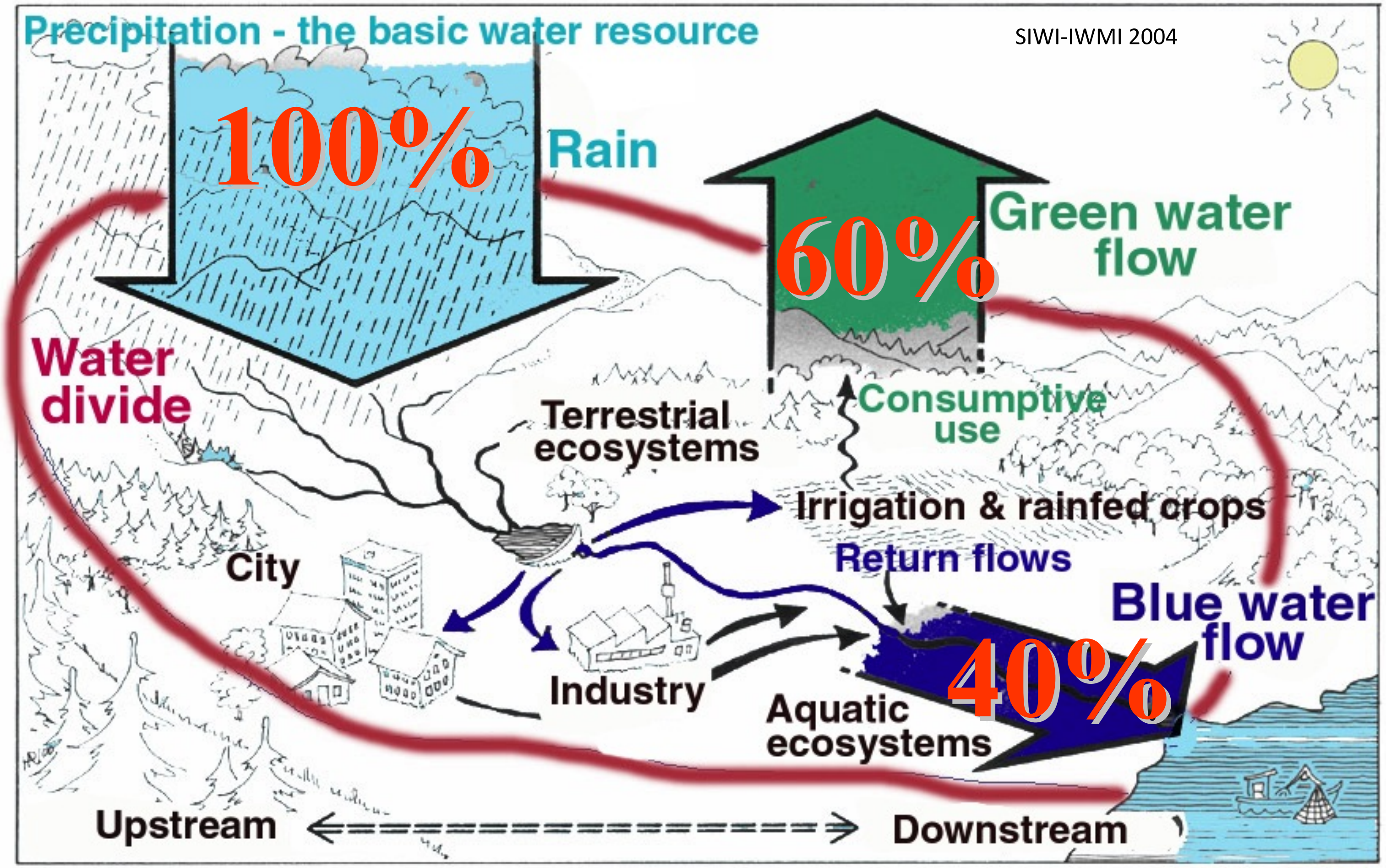
- Reeds for thatching, paper or woodwind instruments

- Waterfowl: ducks, geese

Are wetlands provisioning water?

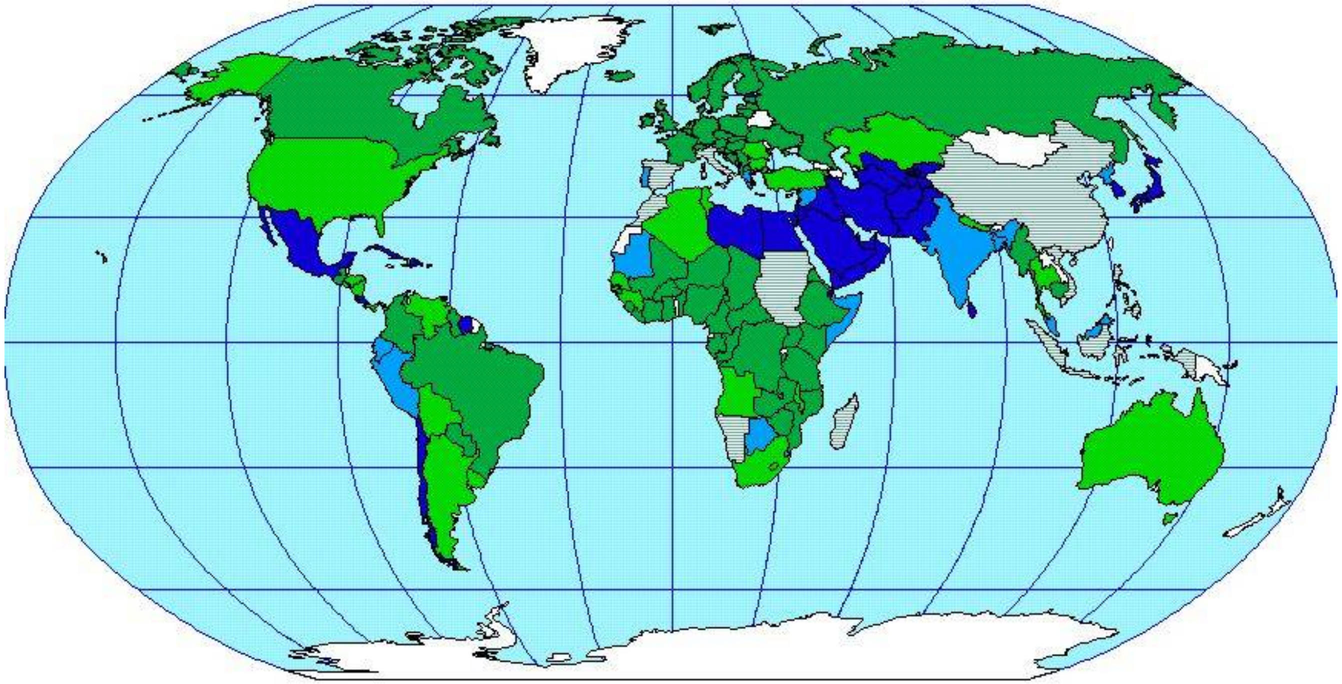
- Confusion over the relation between wetlands and water
- “Wetlands have a water-provisioning function”
- In reality, wetlands lose water through evaporation or groundwater seepage
- Wetlands need much water
- Withdrawal of water from rivers is detrimental for wetlands
- Current paradigm in water resource management: “Blue” and “Green” water

The Blue and Green water catchment perspective



Water and agriculture

Rain-dependent
Irrigation-dependent



Need for 50% increased crop production in 2035 will create a world water crisis

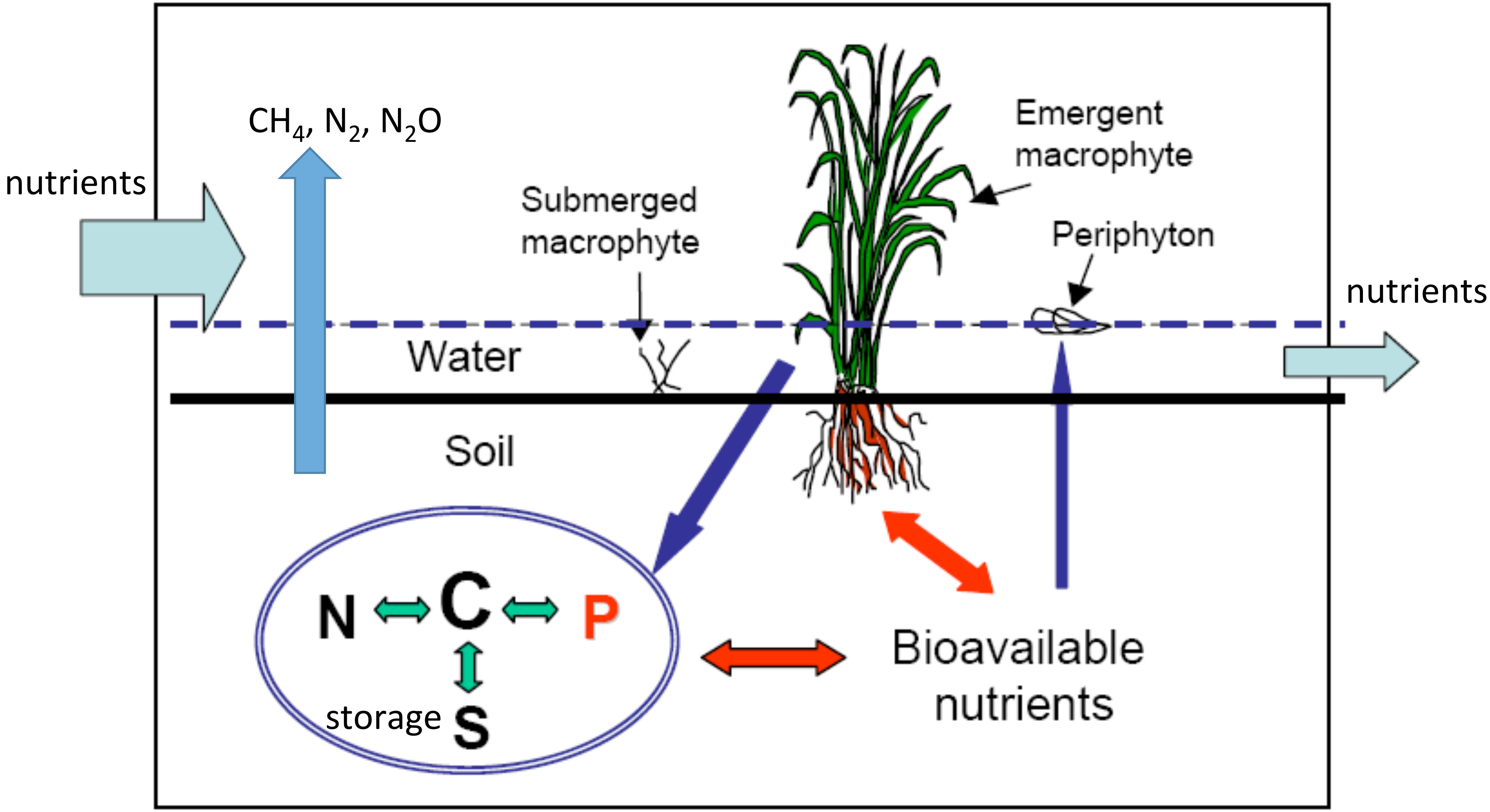
- Agriculture and wetland ecosystems are dependent on water
- Irrigation is using Blue water for agriculture
- This Blue water is extracted from rivers at the expense of natural wetlands

Protecting wetlands’ water needs

- ‘Environmental flow’ approach in river basins helps protecting the mere existence of wetlands
- Loss of wetland ecosystem services may outnumber short-term economic benefits
- Integrated water resources management needed

Irrigation or flooding? rice fields versus floodplains

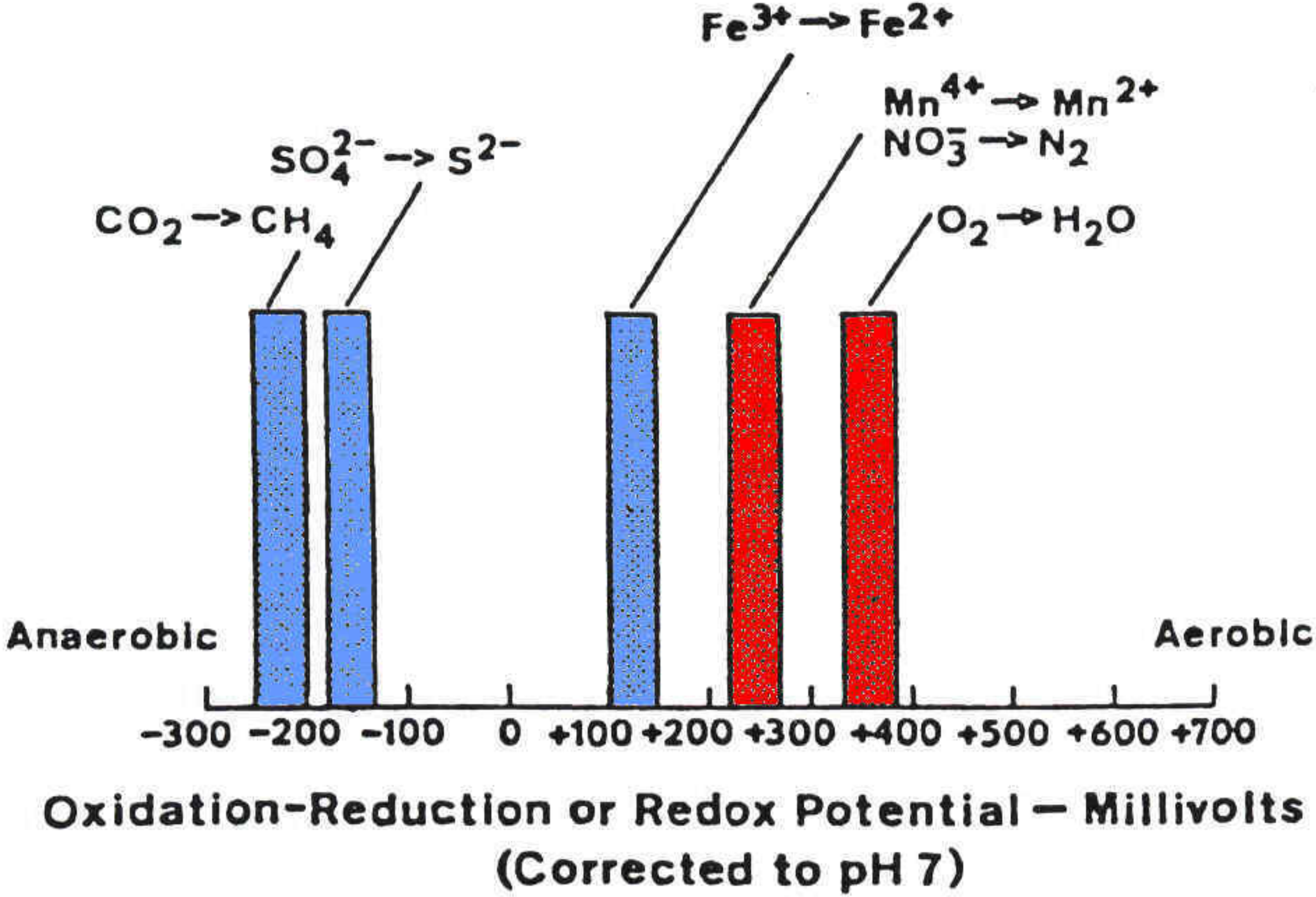
Regulating services: biogeochemistry



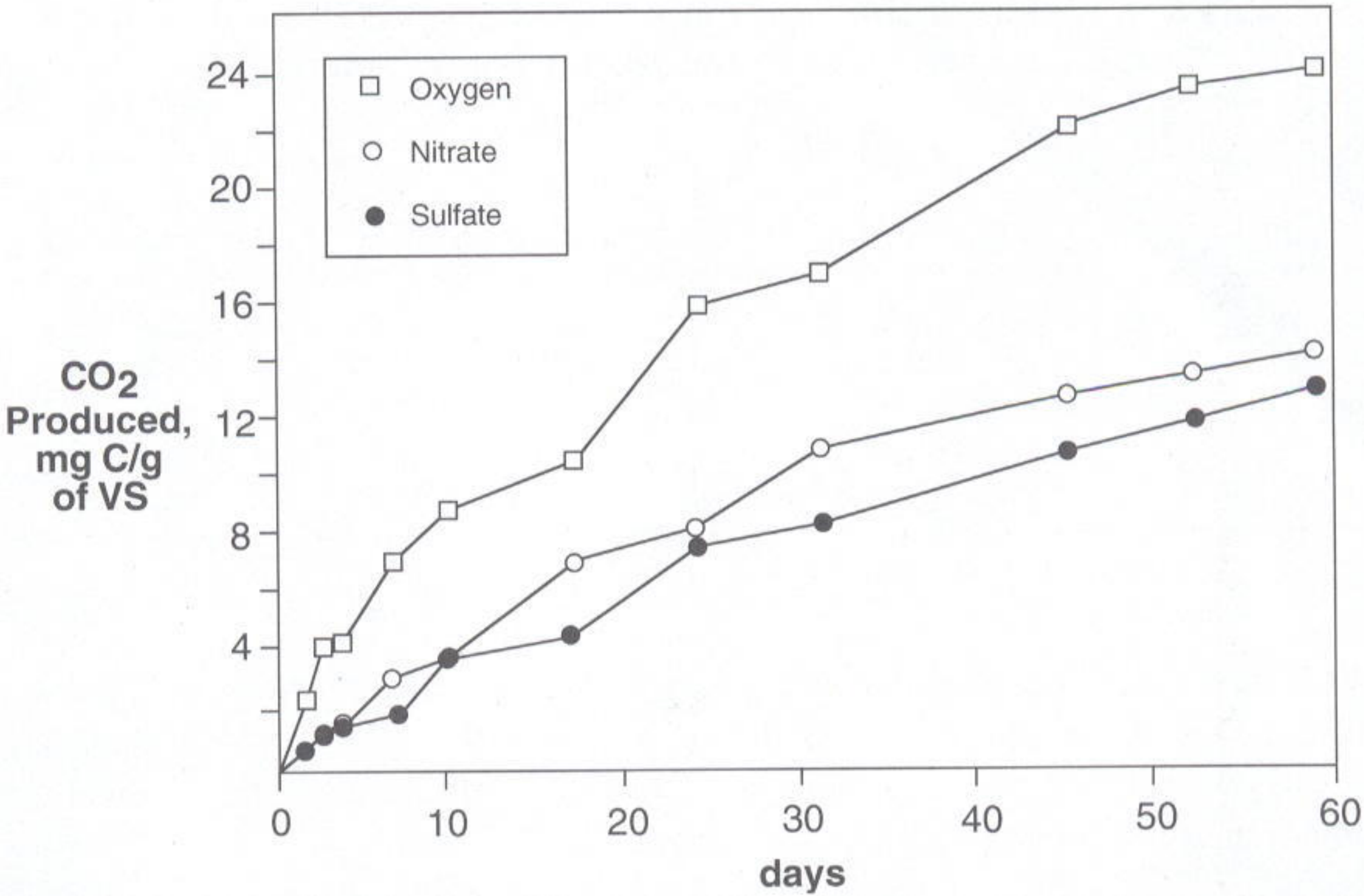
Element cycles in wetlands

- Wetlands: surplus of water, shortage of oxygen in the soil
- Plants and animals need special adaptations
- Drastic consequences for biogeochemistry: anaerobic decay processes
- Electron acceptors other than oxygen: nitrate, iron, manganese, sulphate, carbon dioxide

Redox-couples show a sequence:



Decomposition rate declines in anoxic conditions



Key wetland biogeochemical processes

- In anaerobic wetland soils:
  - Nitrate is denitrified towards N_2O and $N_2\uparrow$
  - Sulphate is reduced to sulfide
  - Methane is produced
  - Carbon is sequestered because of incomplete decomposition

→ Water quality enhancement (N_2O?)

→ Climate regulation (carbon? methane?; N_2O?)

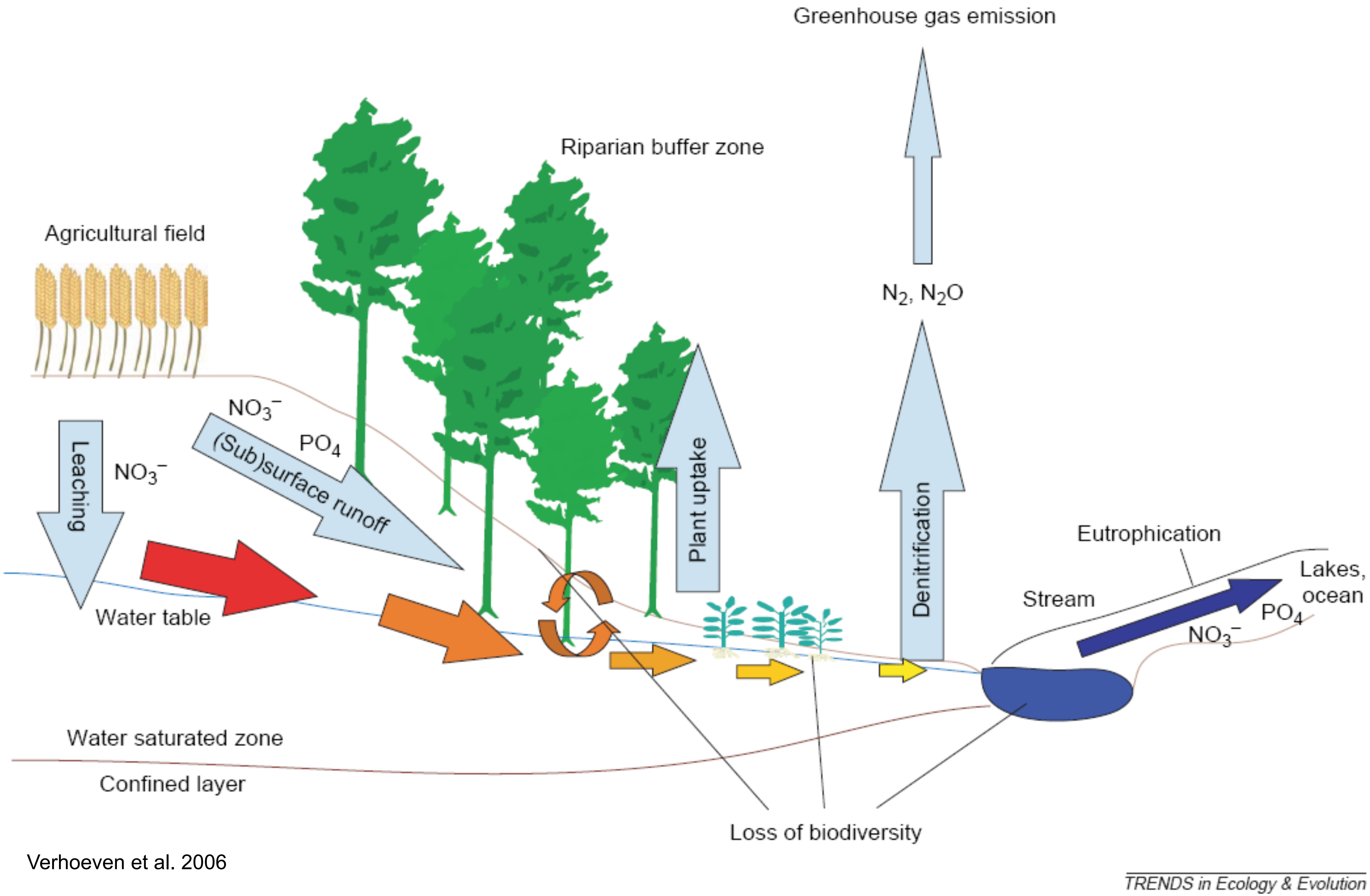
Nutrient loading of wetlands

- Increase of primary productivity
- Shifts in species composition of algae, aquatic plants and fauna

- Shifts from one stable state to another (e.g. shallow lakes)
- Loss of functional integrity, dramatic fish kills and nutrient flush

(1) Riparian zones; (2) Constructed wetlands

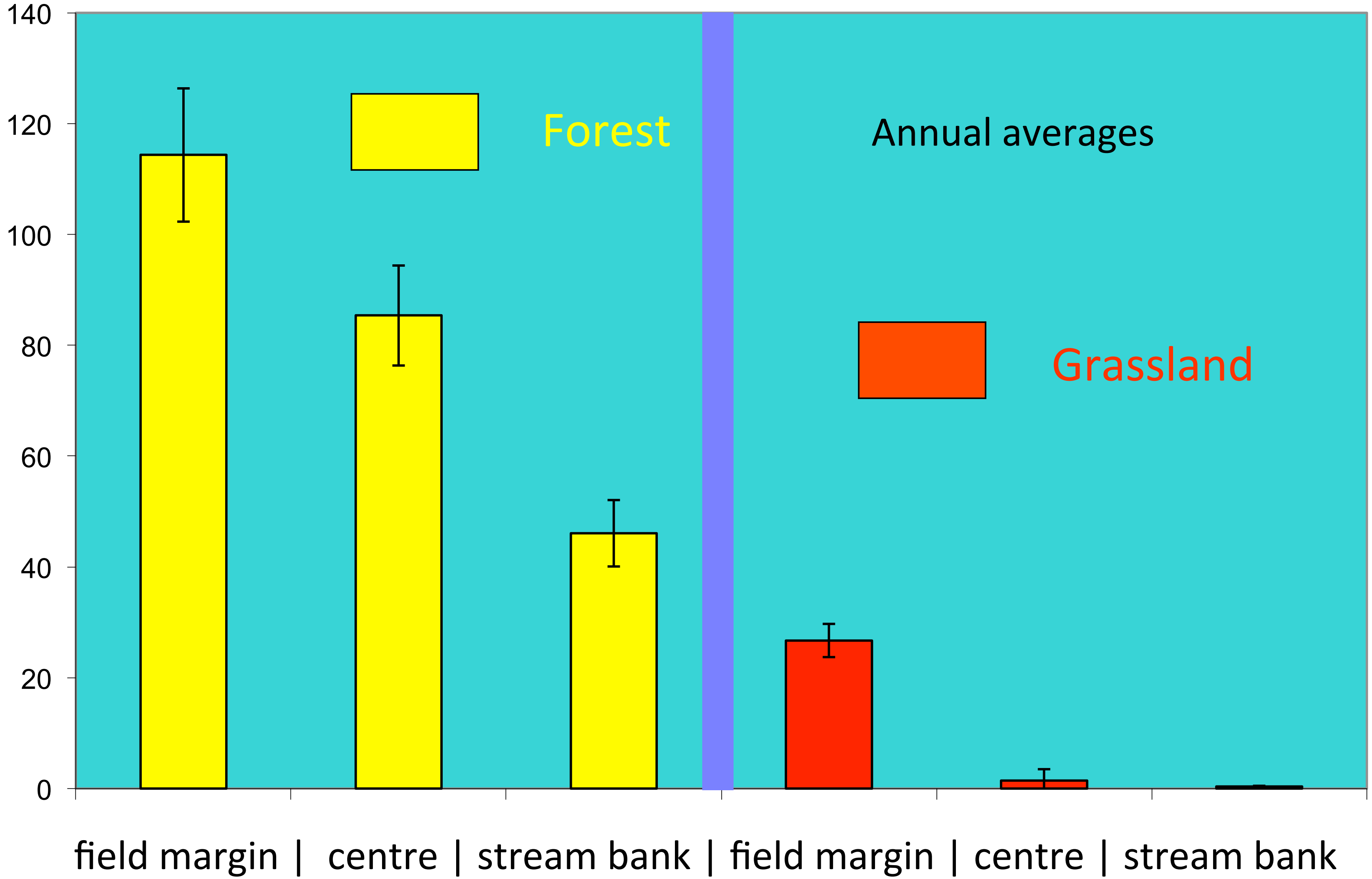
Nutrient flows in agricultural landscapes



Verhoeven et al. 2006

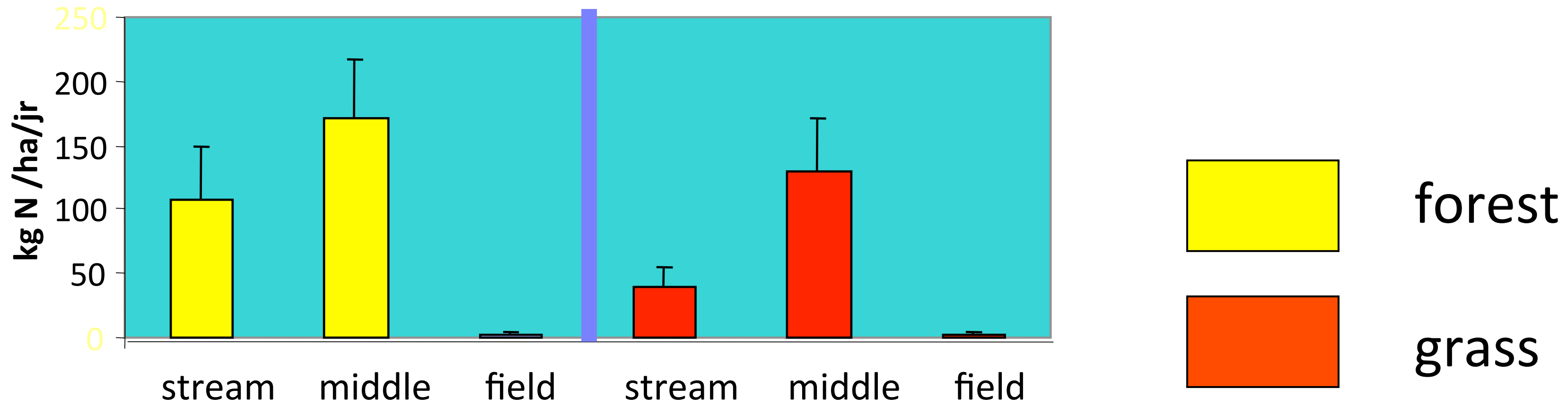
Riparian carr forest

Nitrate concentrations in riparian zones

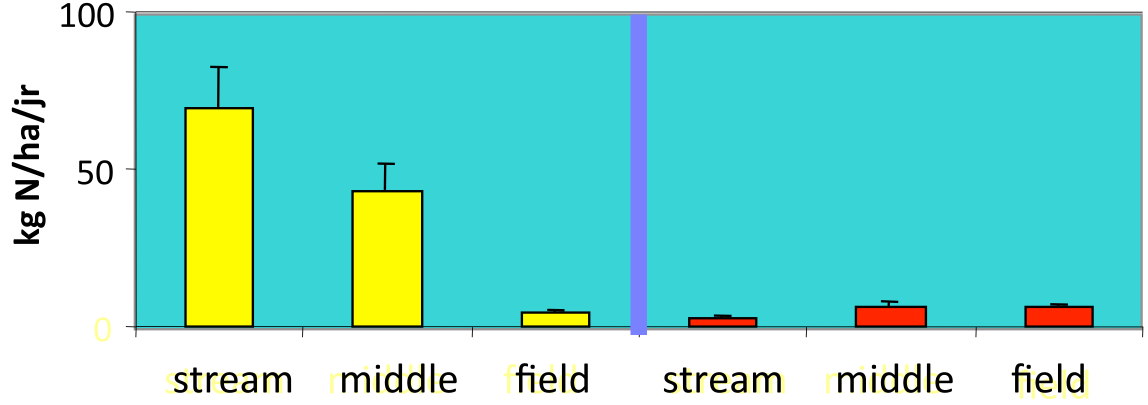



55


Denitrification in upper 10 cm

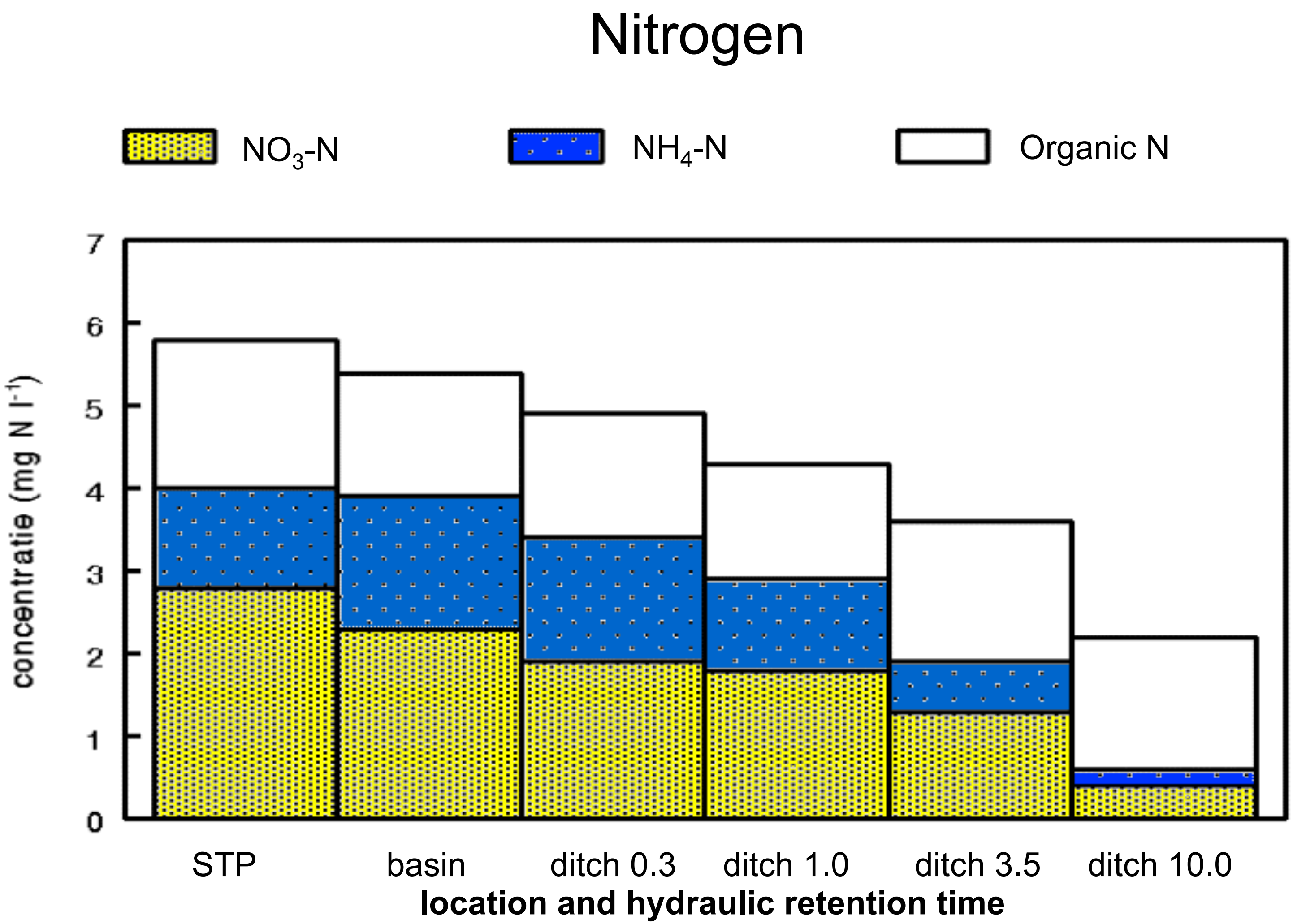


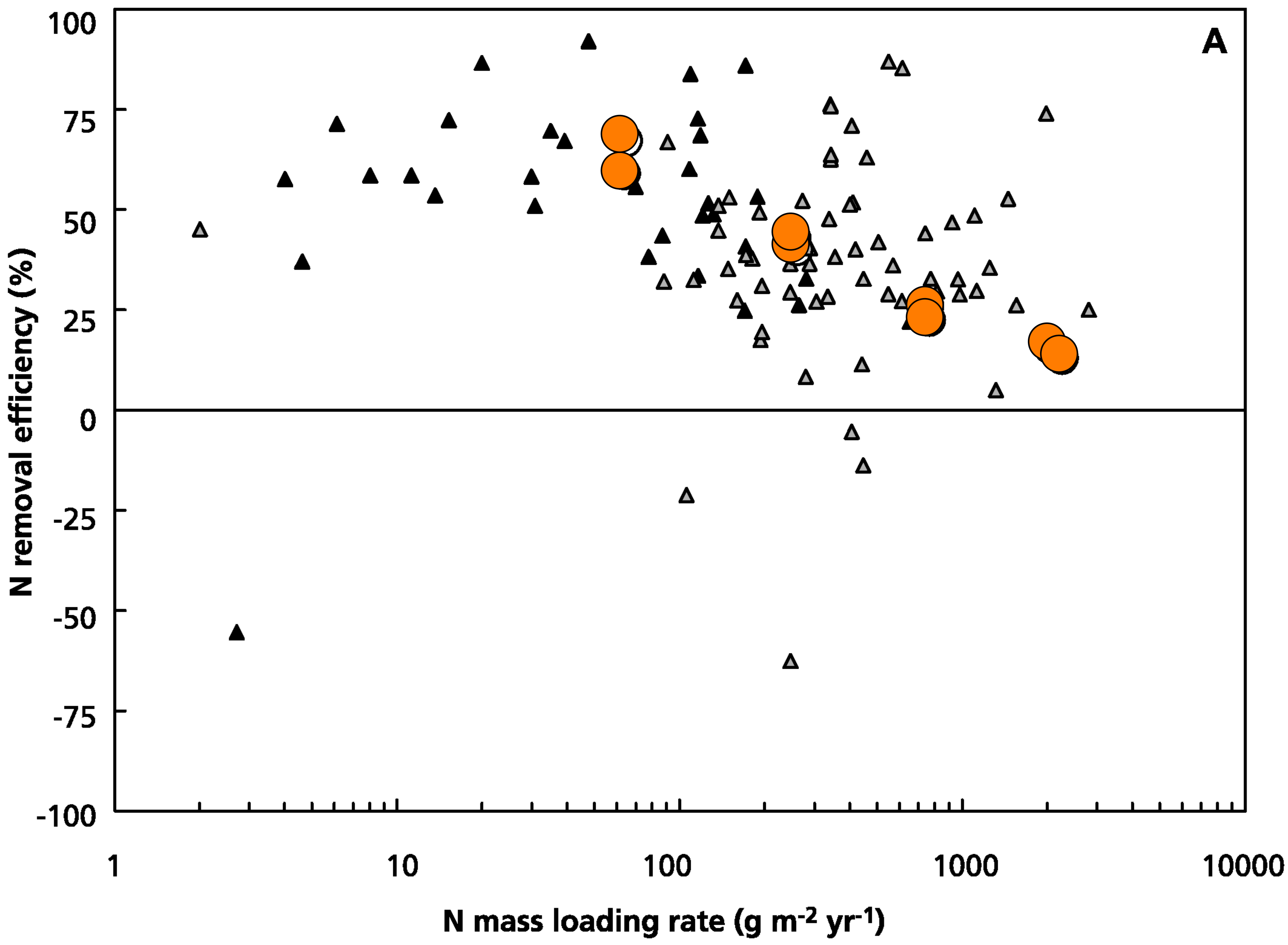
Nitrous oxide emission



STP Everstekoog and wetland

Water quality and hydraulic retention time





A
100
75
50
25
0
-25
-50
-75
-100
N removal efficiency (%)
1
10
100
1000
10000
N mass loading rate (g m-2 yr-1)

The Water Harmonica

- Water from sewage treatment plant was polished effectively:

- 99.9% removal of E. coli
- 25% additional N removal
- No additional P removal

- Particles in water changed from sewage sludge to freshwater biota (phytoplankton and zooplankton)

Loading rates in wetlands: literature data

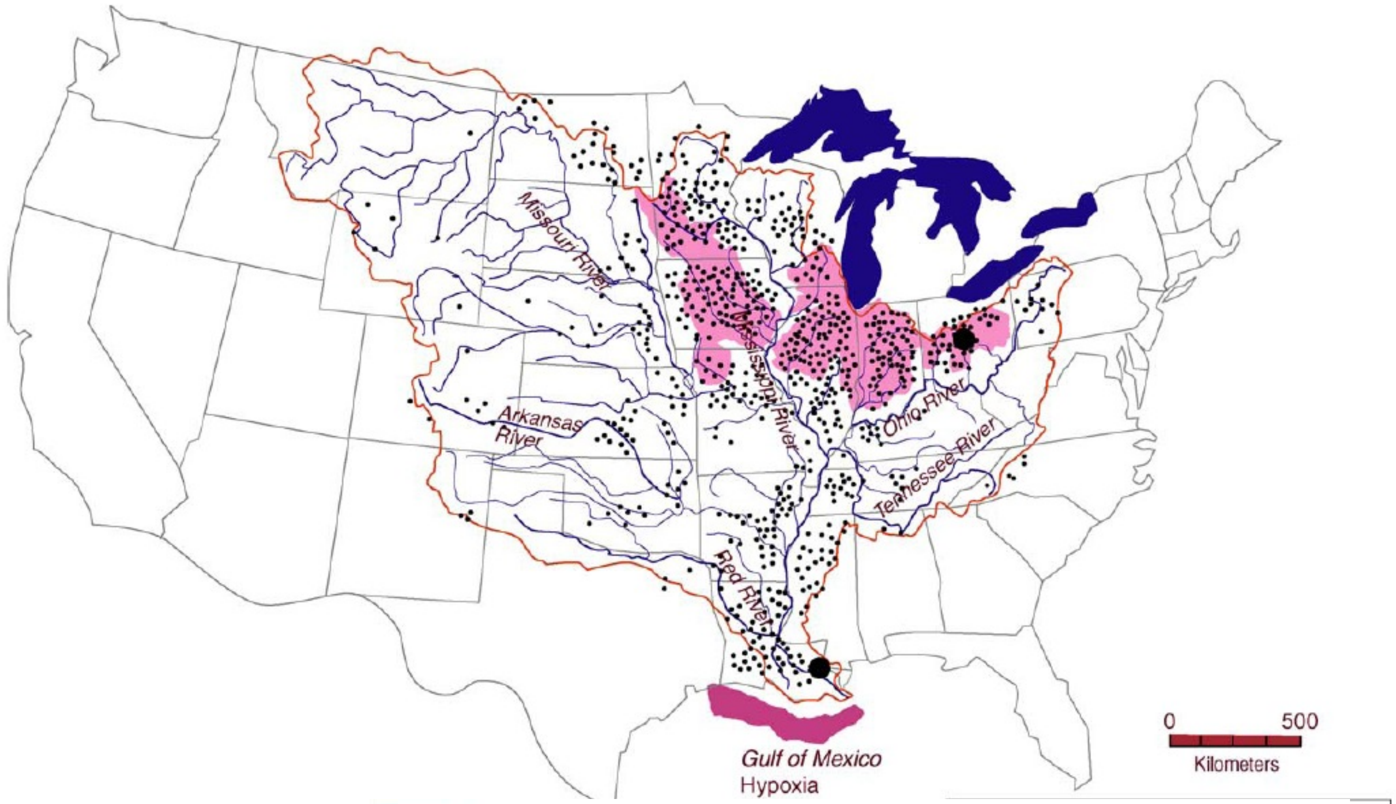
Catchment	Location	Wetland type	Origin	N load g $m^{-2}y^{-1}$	P load g $m^{-2}y^{-1}$
Liuchahe	PR China	Multipond	Constructed	>50	>5
Regge, Twente	Netherlands	Riparian	Natural	20 – 114	
Everglades	USA	Marsh	Natural		0.2 – 4
Mississippi	USA	Forested	Natural	1.9 – 3.9	0.02 – 0.09
Various	USA	Riparian	Natural	2 – 15.5	
Treatment wetlands in USA and Europe			Constructed	50 – 900	10 – 200
Critical load		Biodiversity		*4.0*	*1.0*
Maximum load		Integrity		*100*	*6*

Verhoeven et al. 2006 TREE

N and P loading thresholds

- There are two types of ‘threshold relationships’ for N and P loading
- For natural, sensitive wetlands (loss of biodiversity):
  - critical N load of 4 g N m^{-2} y^{-1} (Bobbink et al. 2003)
  - critical P load of 1 g P m^{-2} y^{-1}
- For all (including constructed) wetlands (loss of integrity):
  - maximum N load 100 g N m^{-2} y^{-1}
  - Maximum P load 6 g P m^{-2} y^{-1}

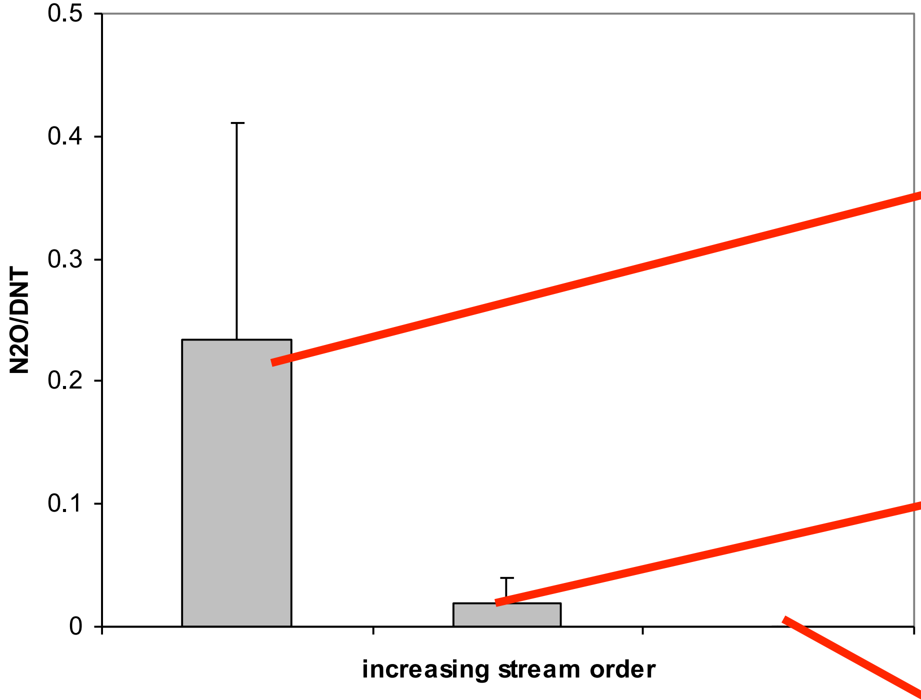
The Mississippi River Basin (MRB)

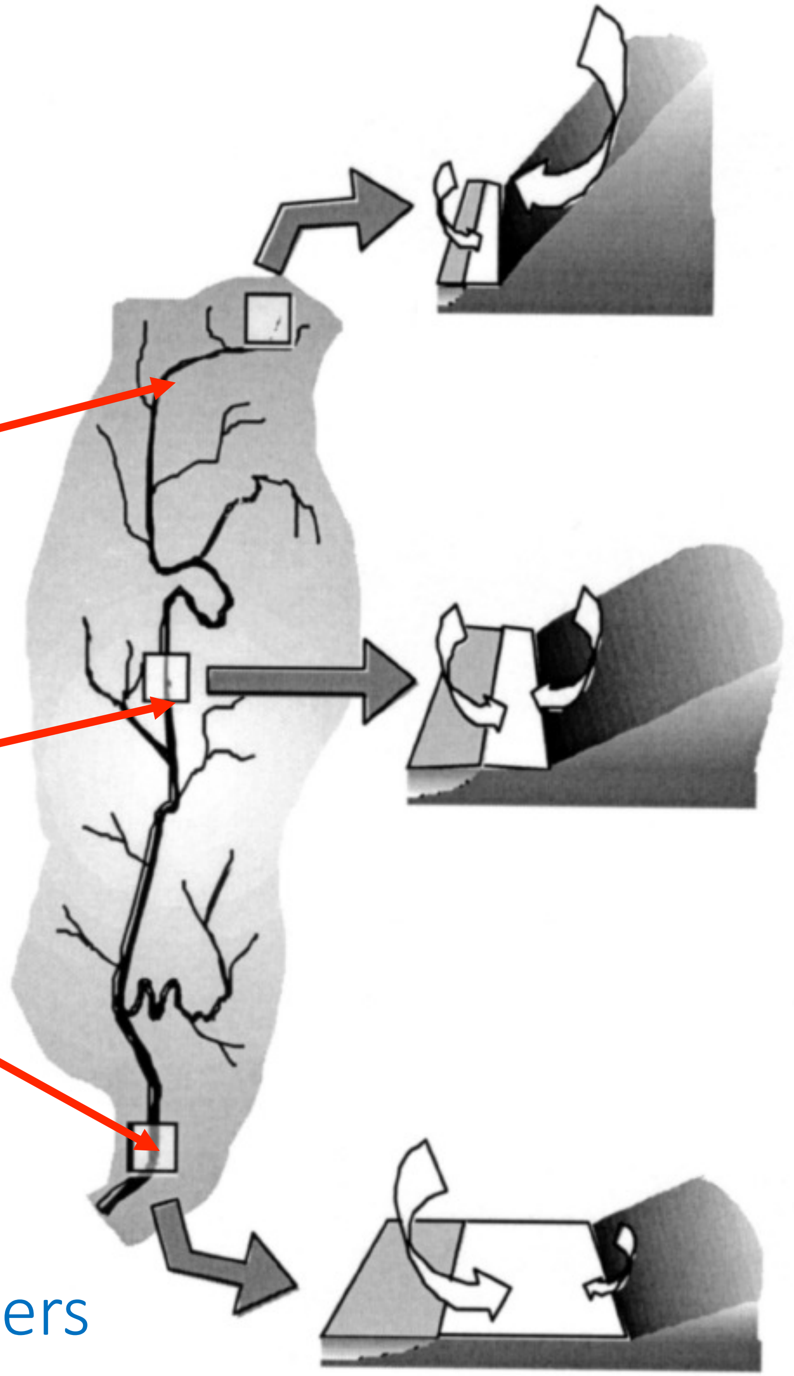


Mitsch et al. 2005
Day et al. 2009

Major nitrate sources in MRB
General extent of hypoxia in Gulf of Mexico
Mississippi River Basin boundary
8,000 ha of drained land in MRB

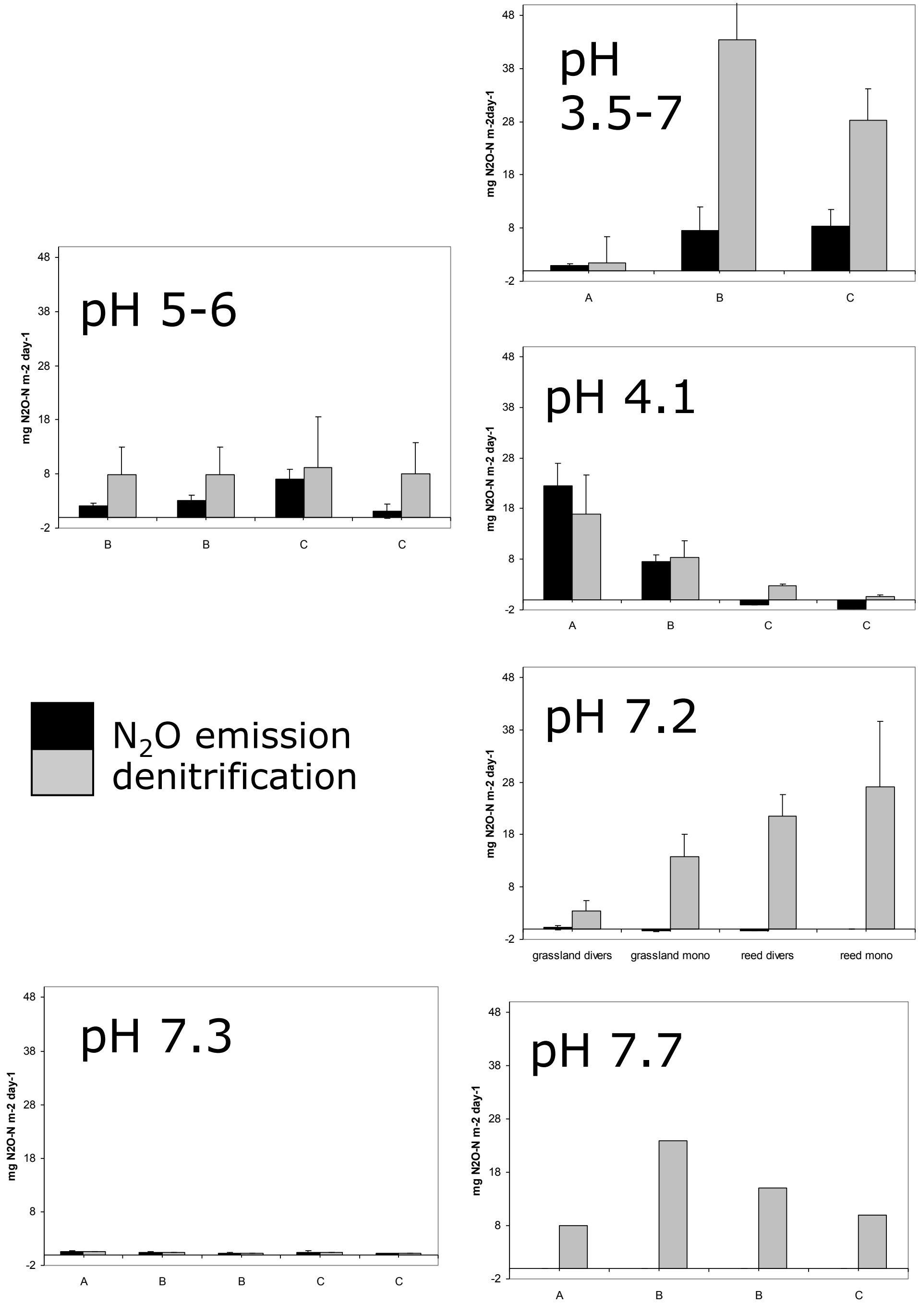
Scaling up: catchments

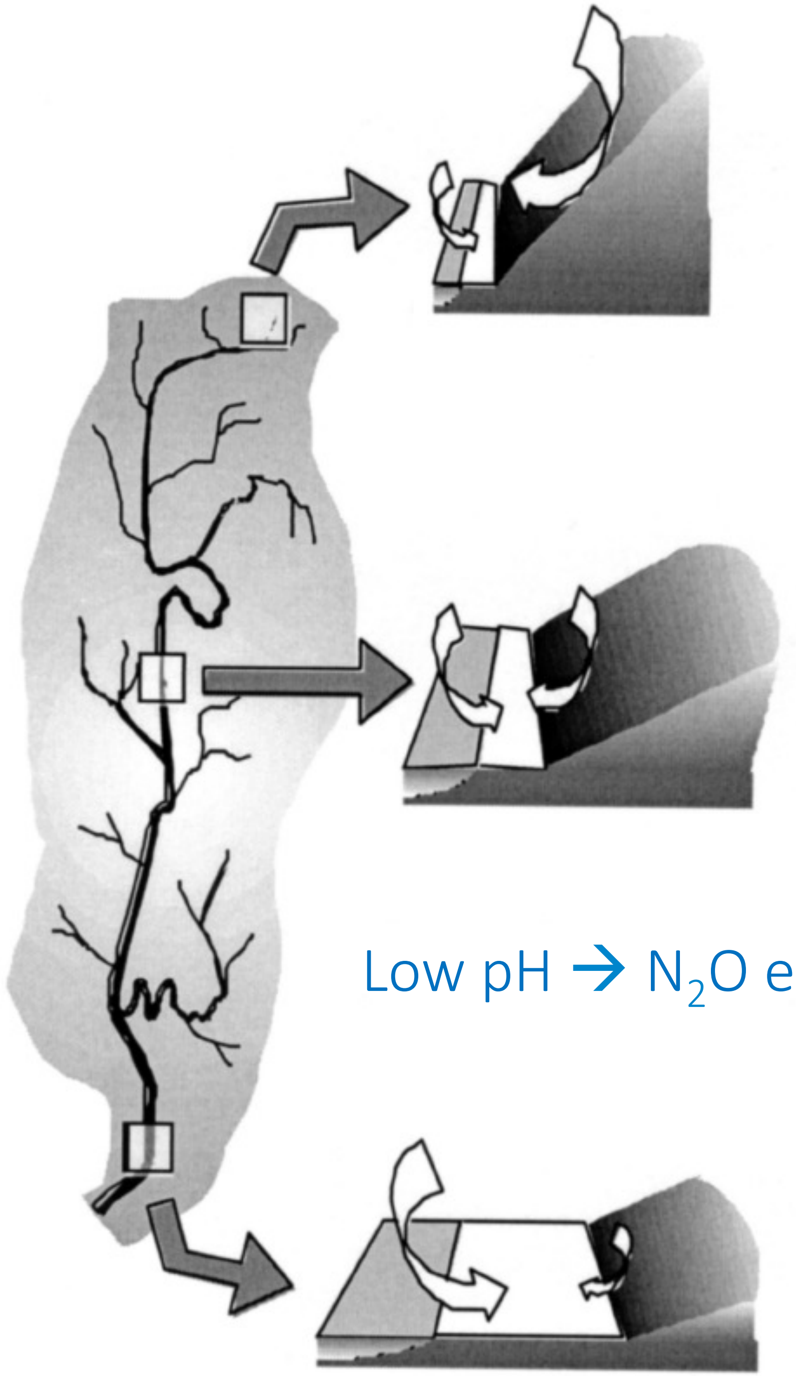




Hefting et al. 2013

Ratio N_2O : N_2 quite high in headwaters


pH 3.5-7
pH 5-6
pH 4.1
pH 7.2
pH 7.3
pH 7.7
mg N2O-N m-2 day-1
grassland divers
grassland mono
reed divers
reed mono
N_2O emission
denitrification

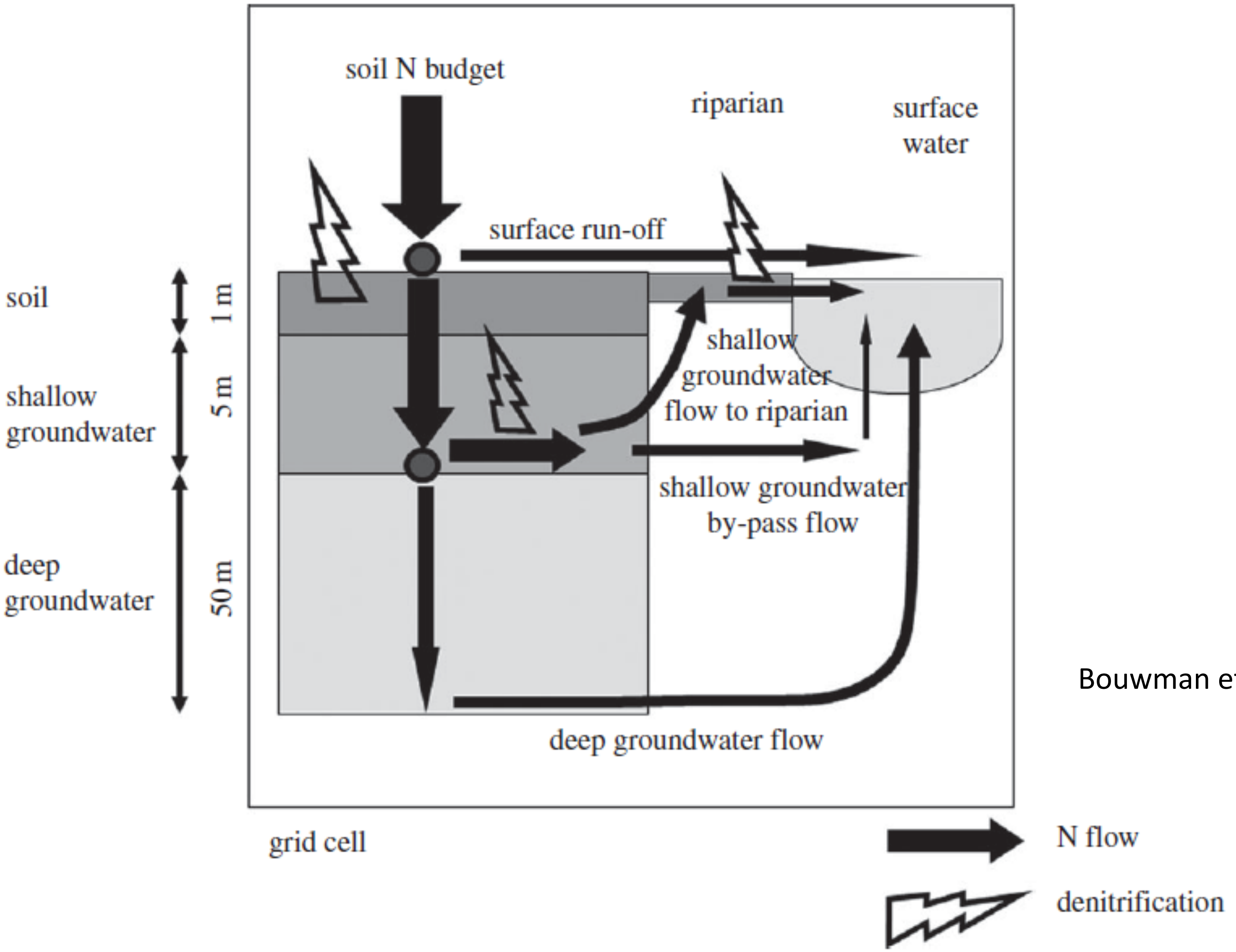


Low pH → N_2O e

N_2O emissions in a catchment context

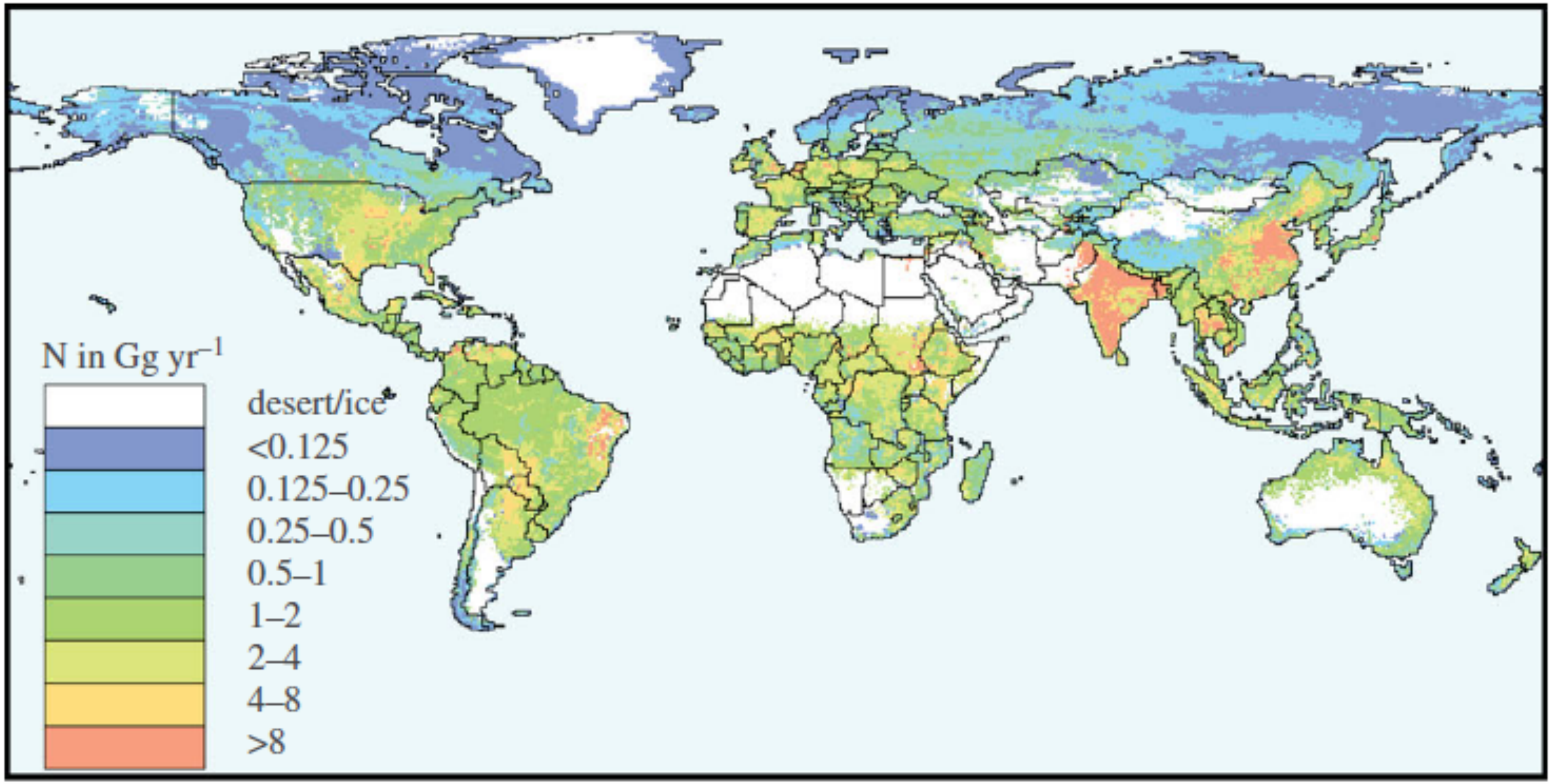
- N_2O emissions are most prominent in the upper parts of the catchment
- Riparian wetlands along lower order streams have high emissions
- Wetlands along higher order streams have low or zero emissions
- pH is the most important regulating factor

Global Denitrification

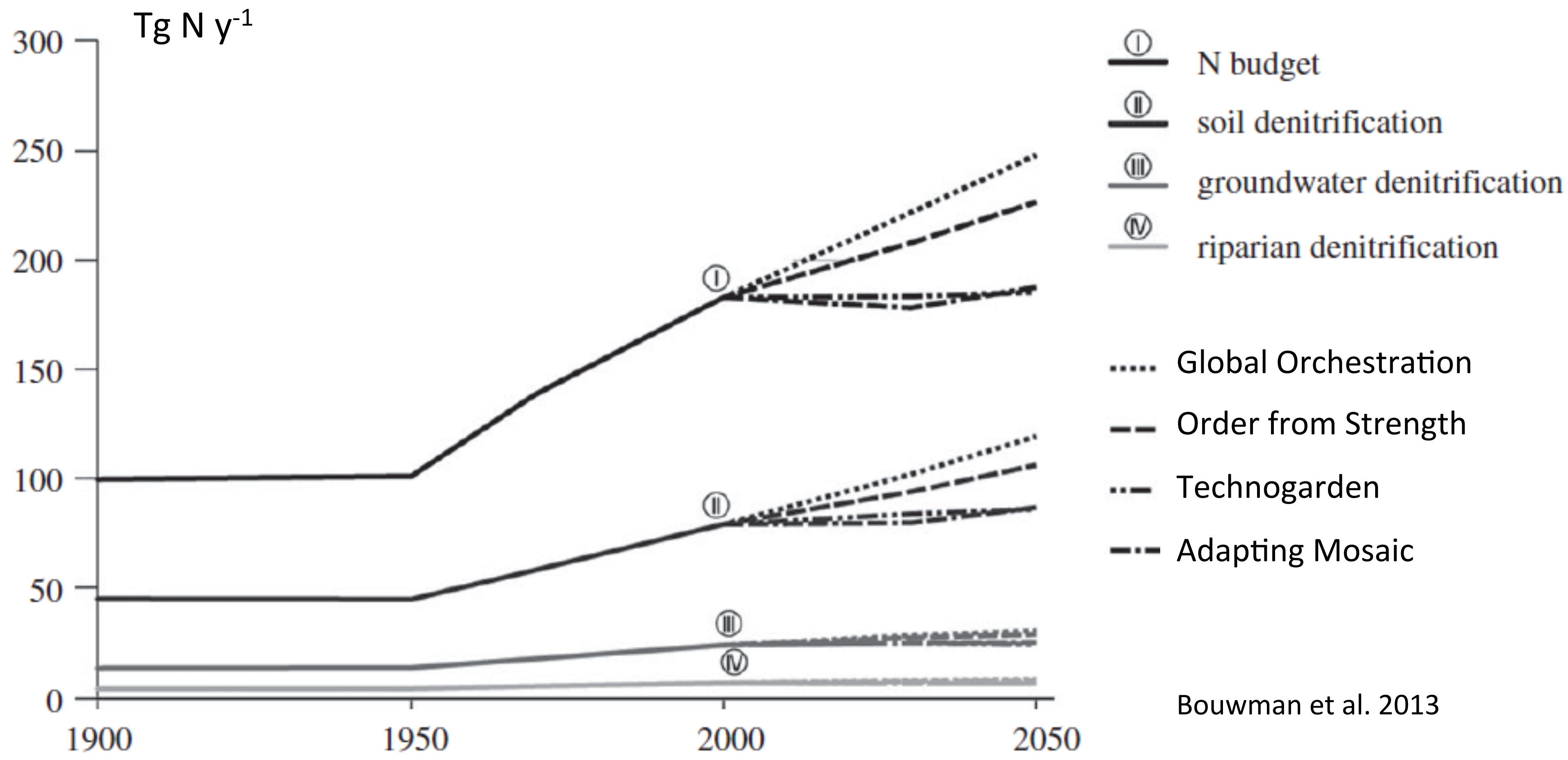


Bouwman et al. 2013

Global Denitrification



Global N budget



Bouwman et al. 2013

Global denitrification

- Denitrification is a world-wide ecosystem service preventing major europhication problems
- Particularly important in areas with intensive agriculture
- Wetlands as well as agricultural soils play a major role
- Riparian wetlands as well as pond depressions are very active
- Advantages outweigh side-effects (N_2O)

Nature

Old effluent plots Godalming Wetland Nature Reserve
#6040067

Are wetlands cooling or warming the climate?

- Wetlands sequester carbon dioxide: cooling
- Wetlands emit methane: warming
- Wetlands emit nitrous oxide: warming

- Balance:
  - How much CO_2 sequestered per CH_4 emitted?
  - Radiative forcing per molecule
  - Life time of molecule in the atmosphere
  - Scientific debate, including IPCC

Global Warming Potential GWP

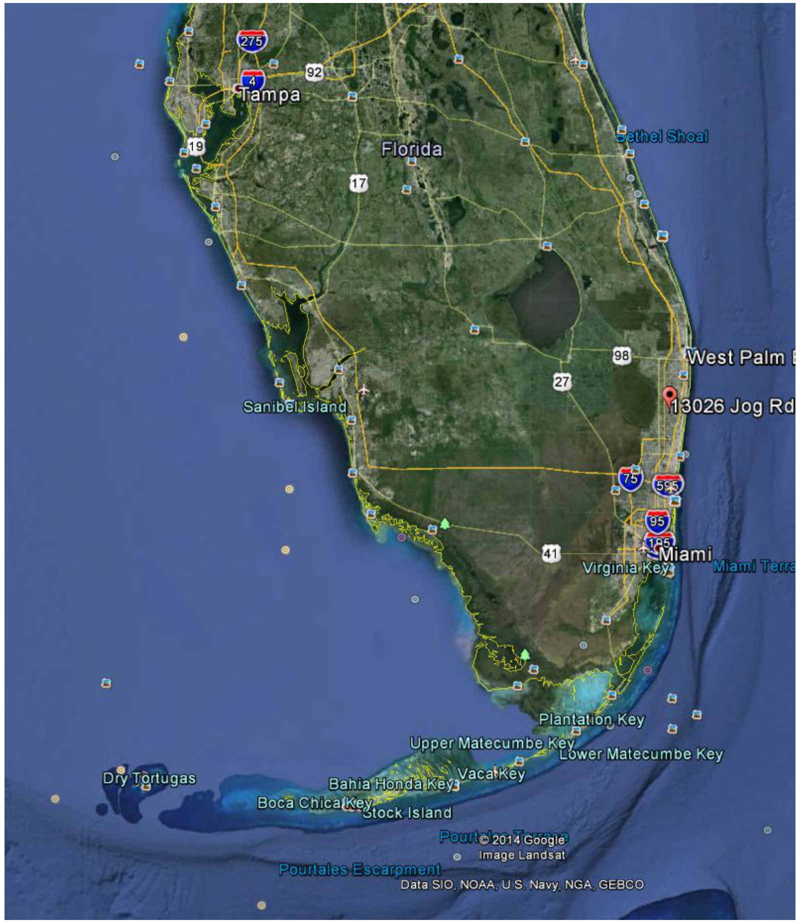
GWP (2013 IPCC AR5)	Lifetime (years)	GWP per time horizon	
		20 years	100 years
Carbon dioxide	∞	1	1
Methane	12.4	86	34
Nitrous oxide	121.0	268	298

Wetlands are eventually cooling

- Instantaneous carbon sequestration is lower than methane emission: warming
- Carbon dioxide remains out of the cycle for a very long time, methane breaks down in the atmosphere → switching point
- Eventually, wetlands have a cooling effect

Champions: peatlands! Leave them intact!

Multiple wetland services: 2 examples



Constructed wetland for wastewater polishing

Inner delta of the Niger, Mali: Floating rice, grazing, fishing


240 bird species spotted!
floridaphotographyguide.com
1995
Imagery Date: 1/19/2014 26°28'44.29" N 80°08'38.43" W elev 19 ft eye alt 4202 ft

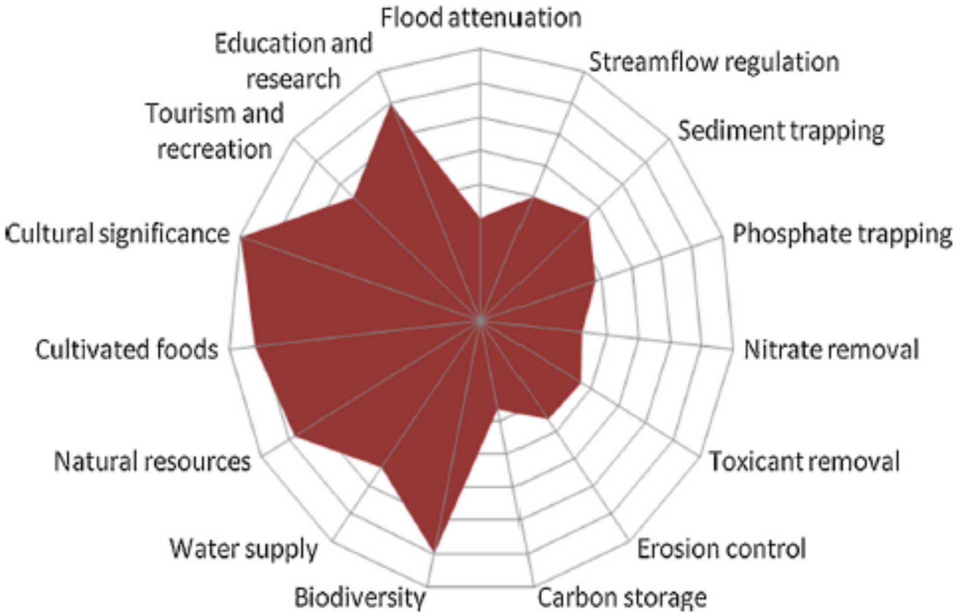


Fig. 2 – Ecosystem services in the Inner Niger Delta.

← Niger Delta, Mali

Lobau floodplain, Danube →

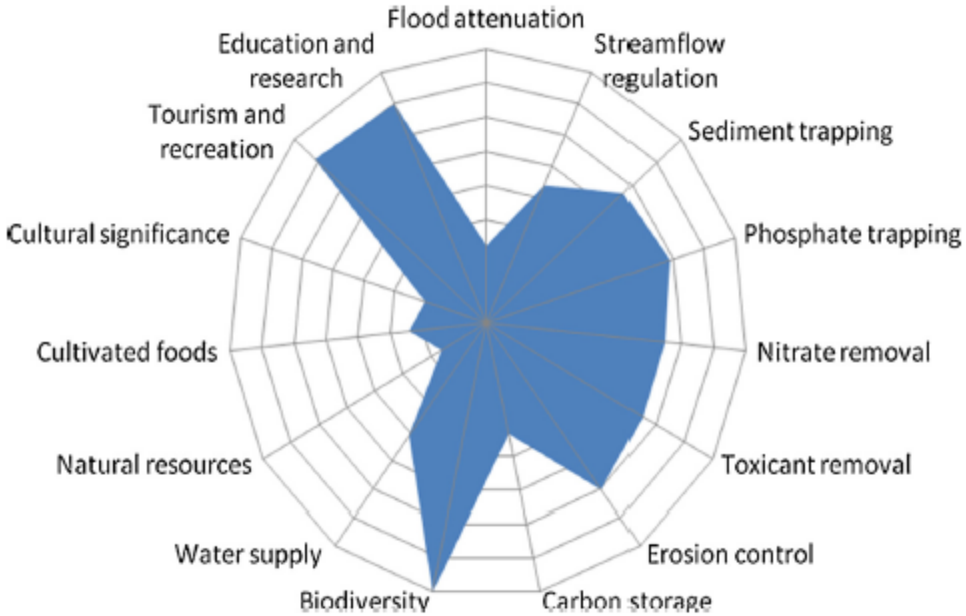


Fig. 4 – Ecosystem services in the Lobau.

WETwin project (2013)

Wetland ecosystem services: some take-home messages

- Wetlands do provide many services because they have (1) water (2) nutrients (3) anoxic soils
- Wetlands do NOT have a water-provisioning function; they compete for water with agriculture
- Wetlands (riparian, constructed) have a robust nitrogen retention function with little side effects
- As long as they are not loaded beyond critical limits
- Wetlands have a cooling effect on climate, if they are long-term carbon accumulators
- If not, they have a warming effect

Wetland ecosystem services: some take-home messages

- Wetlands are often particularly valuable because of multiple ecosystem services
- This is true for developed areas (retention + biodiversity + ecotourism)
- Even more so in developing areas (fisheries + wet agriculture + retention + biodiversity + ecotourism)

- Economic valuation will help recognizing services and protecting wetlands


Questions?
Priya