Netherlands Environmental Assessment Agency

Modelling Aquatic Biodiversity

Presentation for the Modelling Planning Workshop

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Presented by Wilbert van Rooij

Presentation made by Jan H. Janse (jan.janse@pbl.nl)

Netherlands Environmental Assessment Agency (PBL)

Outline

1. Introduction and Objective
2. Aquatic ecosystems
3. Pressures on aquatic biodiversity
4. Description of models
5. Results, Global scale
6. Results, Regional scale: Nicaragua
7. Summary and conclusions

1. INTRODUCTION

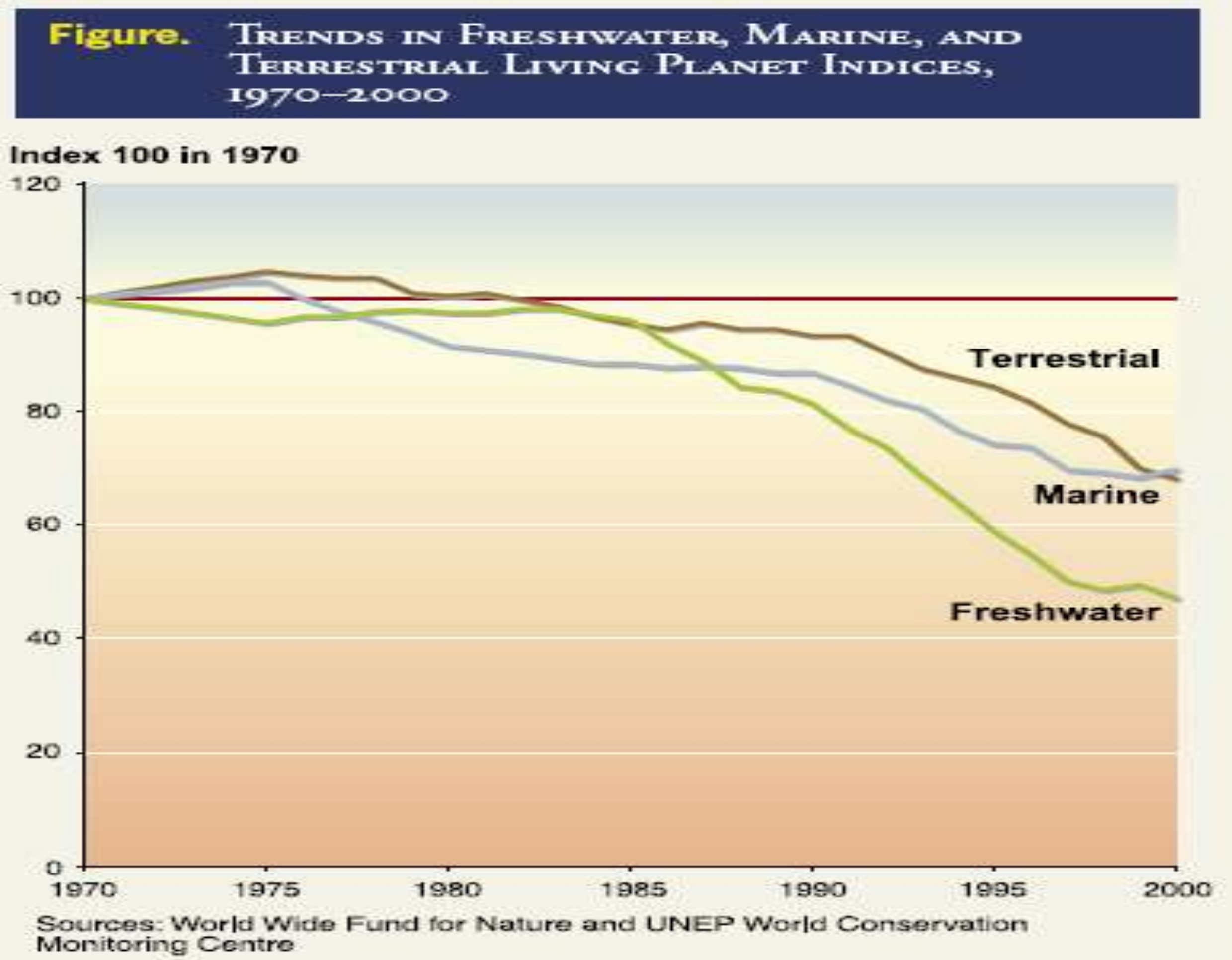
Objective:

- A tool for projections of aquatic biodiversity as a function of anthropogenic pressures
- To be combined with GLOBIO-terrestrial in order to get a global biodiversity coverage
- To be used in policy making

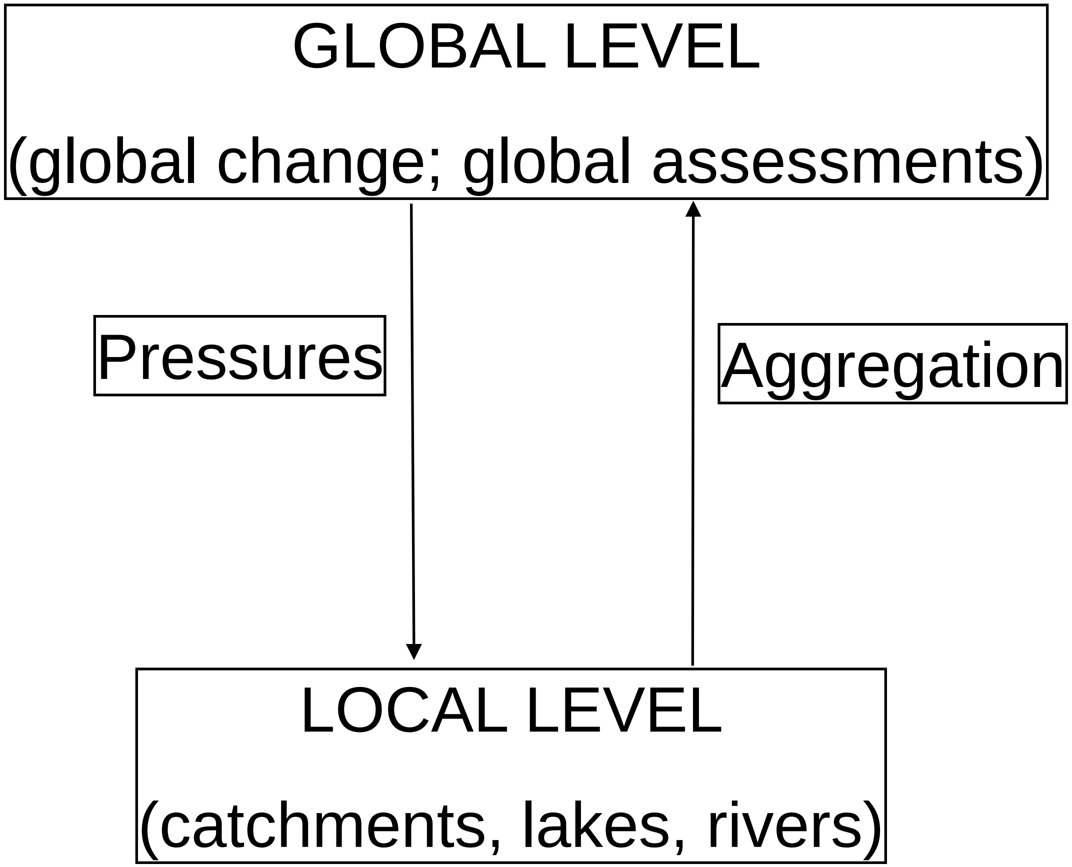
Background

Freshwater biodiversity is declining fast,

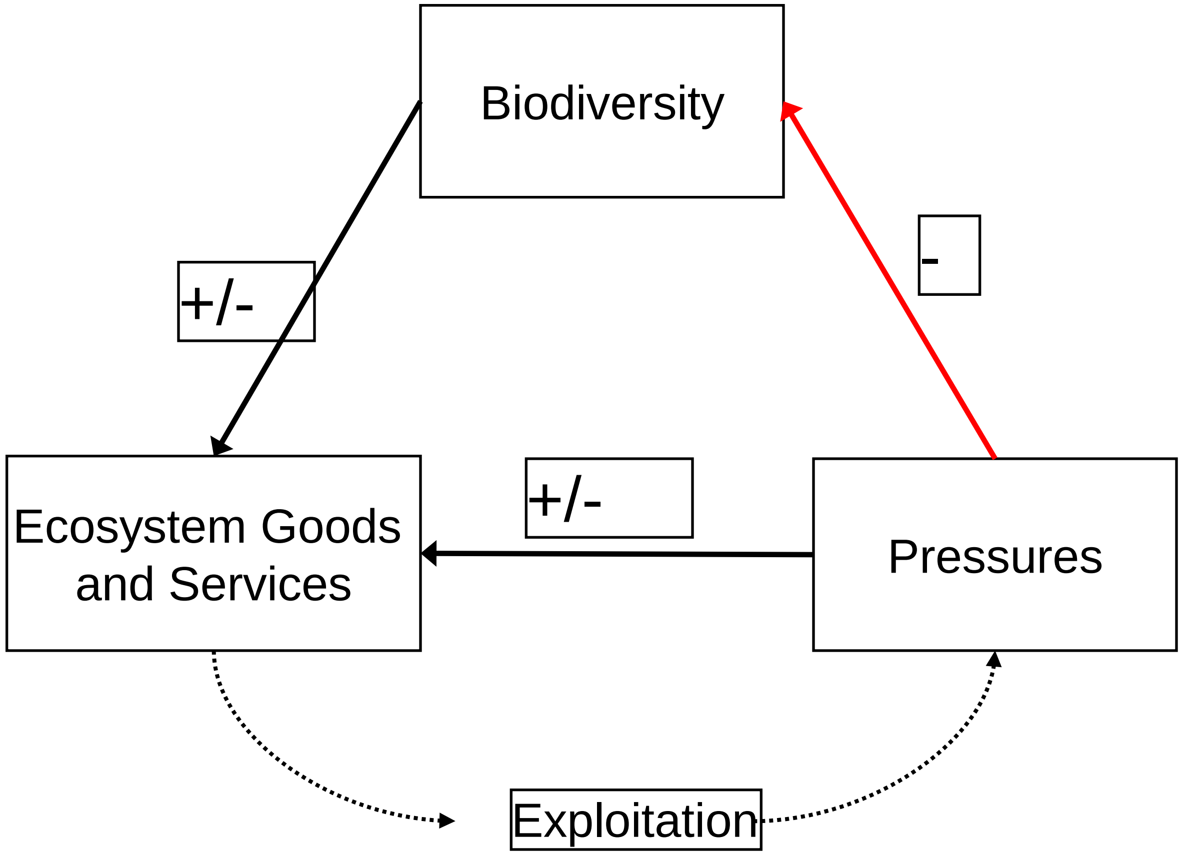
even faster than biodiversity in terrestrial systems.



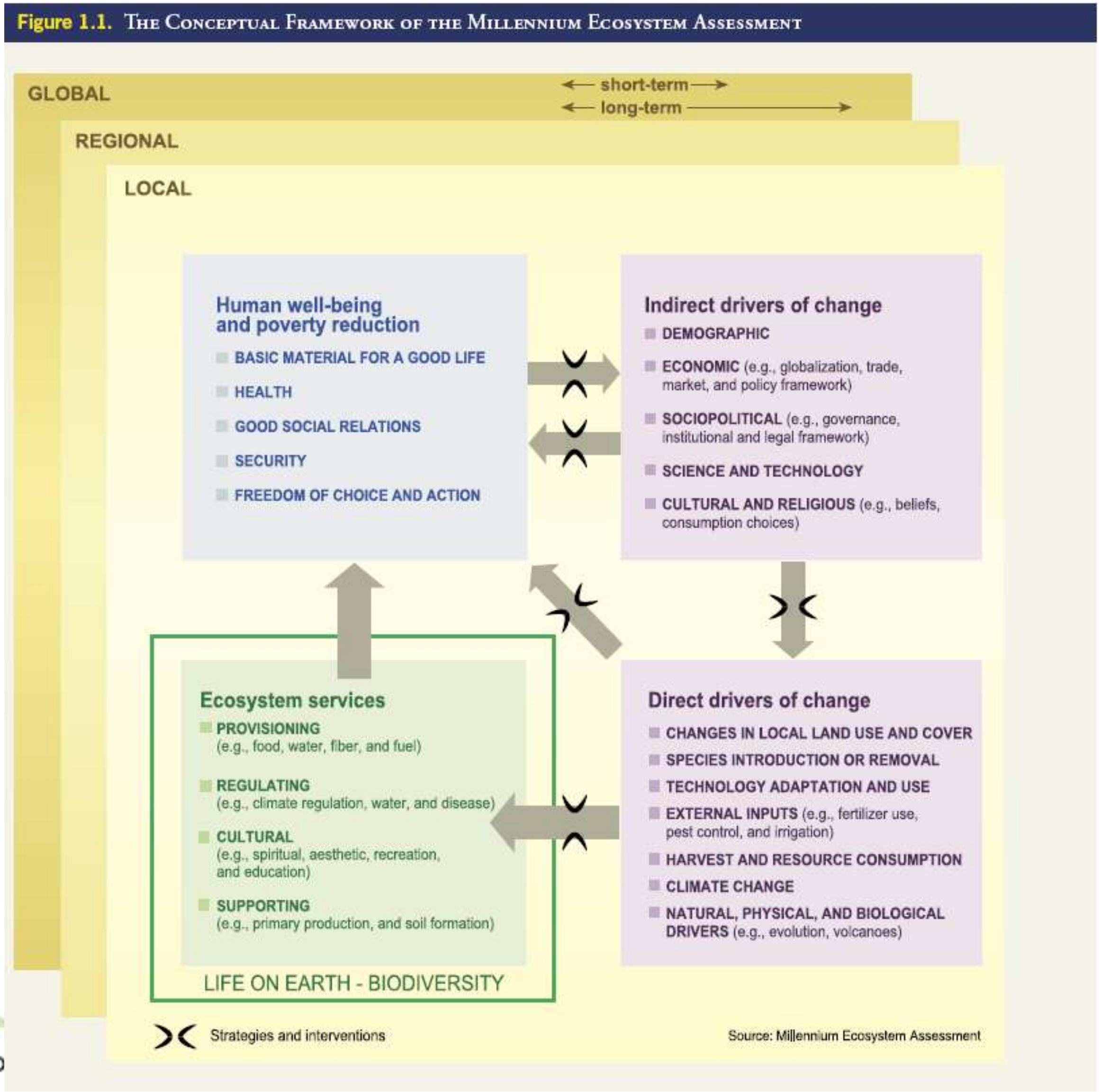
Linkages between scales



Linkage of biodiversity and ecosystem services



Drivers of change and ecosystem services

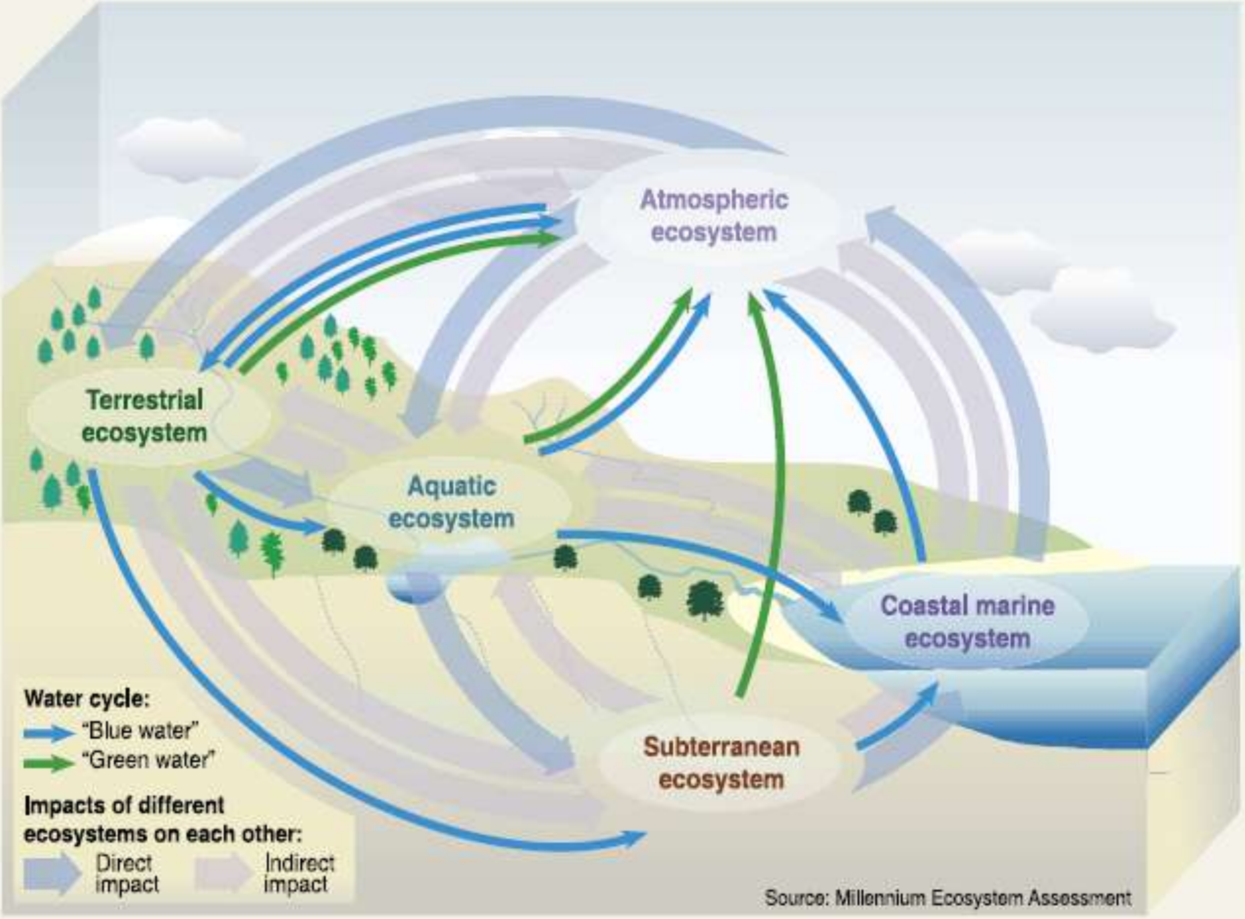


Cultural service: Intrinsic value

Provisioning service: Food

Regulating service: water retention

Figure 3.1. Interrelationships Among Environmental Components of Global Water Cycle, Including Cycling of "Green Water" and "Blue Water" (Derived from C7 Box 7.1)



2. AQUATIC ECOSYSTEMS

Highly different types of systems!

Criteria for typology:

- flow
- dimensions: size, depth
- connectivity
- salinity
- soil type
- climate (latitude, altitude)

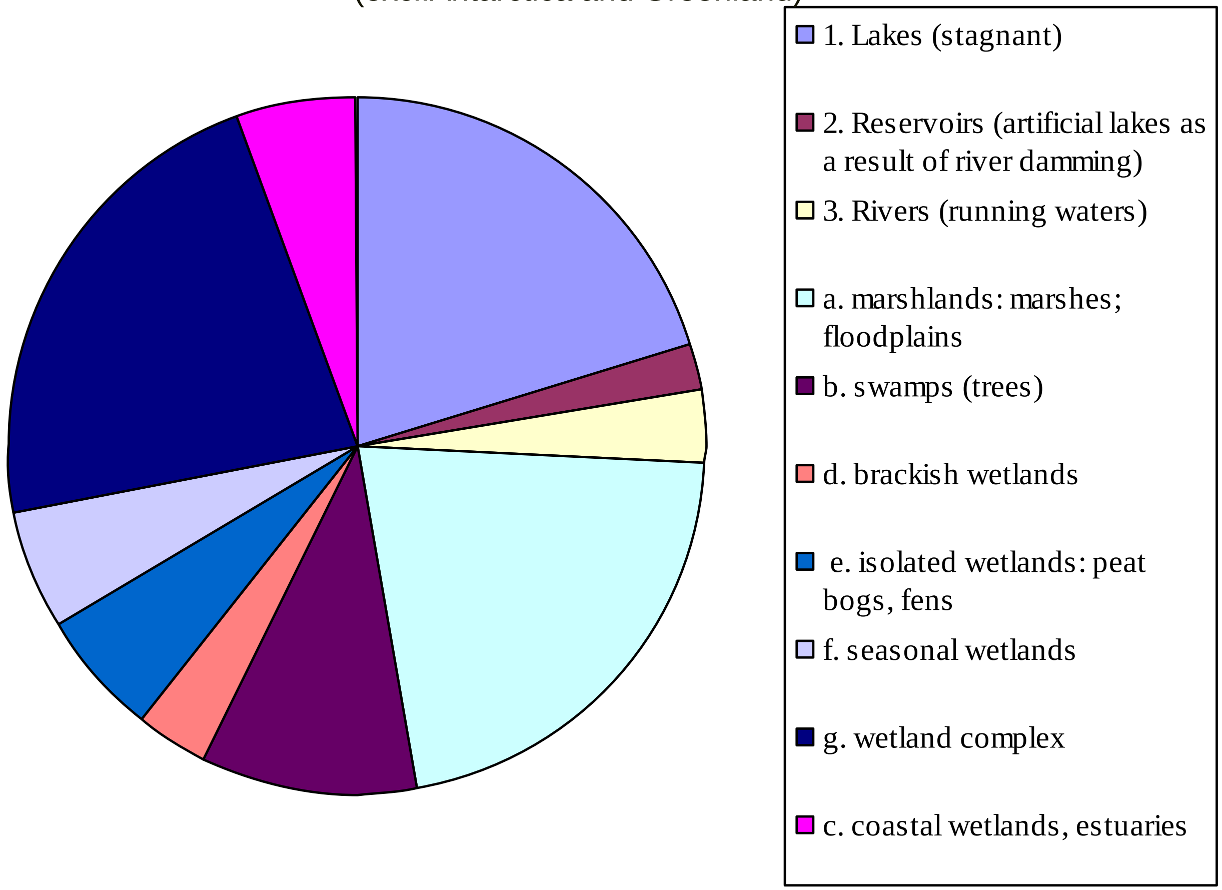
Types of aquatic ecosystems

1. Lakes (stagnant waters)
   a. deep lakes   b. shallow lakes
2. Reservoirs (artificial lakes as a result of river damming)
3. Rivers (running waters)
4. Wetlands (emergent vegetation)
   a. marshlands: marshes, floodplains
   b. swamps (trees)
   d. brackish wetlands
   e. isolated wetlands: peat bogs, fens
   f. seasonal wetlands
5. Coastal wetlands: estuaries, mangroves, etc.
6. Seas and oceans

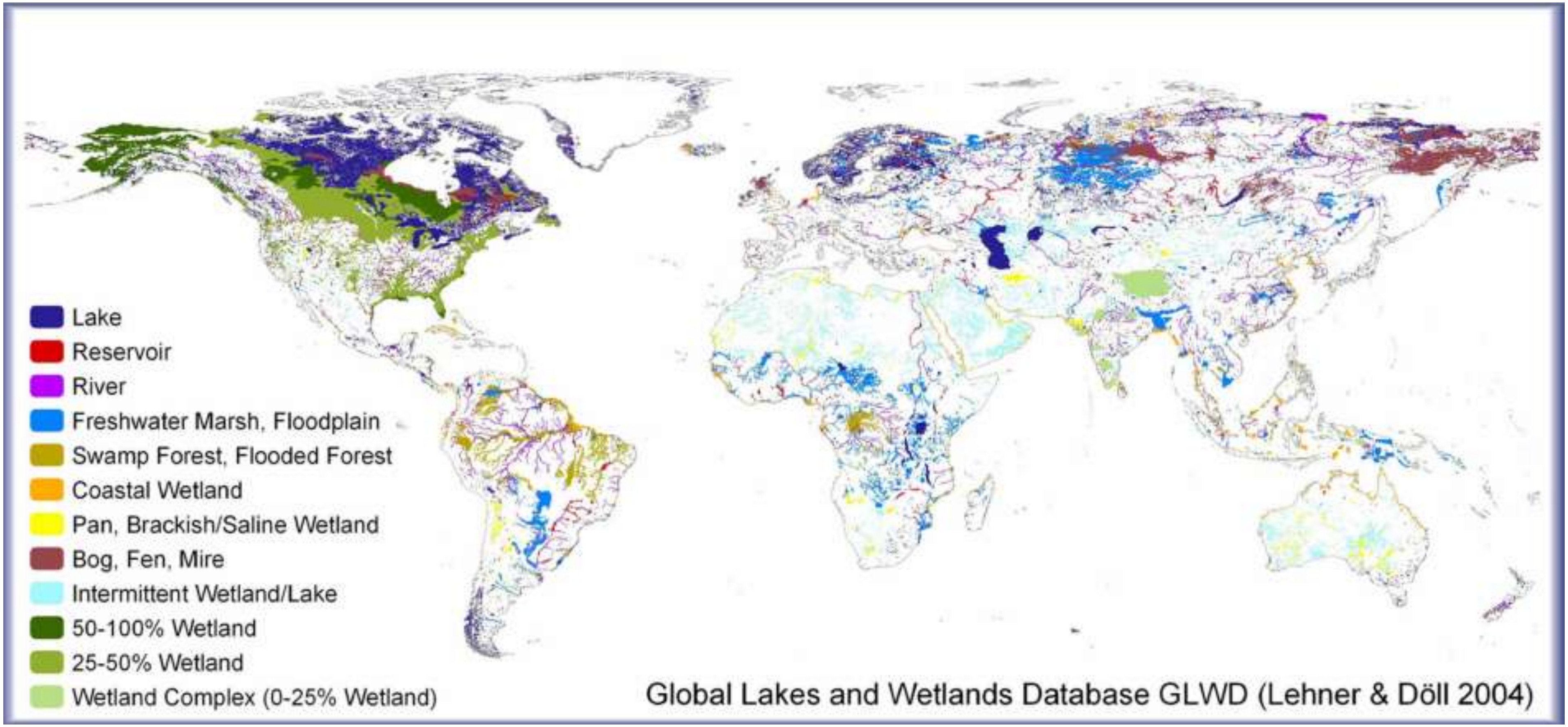
Global area per water type **(GLWD, 2004)**

Total = 8.9% of global land surface area

(excl.Antarctica and Greenland)



Global Lakes and Wetlands Database (GLWD)



Aquatic biodiversity

s Environmental Assessment Agency

Freshwater species richness

Phylum	Described Species
	(number)
Porifera (sponges)	197
Cnidaria (hydra, freshwater jelly fish)	30
Nemertea (ribbon worms)	12
Plathelminthes (flatworms)	c. 500
Gastrotrichia	c. 250
Rotifers	1,817
Nematods (microscopic worms)	3,000
Annelids (segmented worms)	c. 1,000
Bryozoa (moss animals)	70—75
Mollusks (mussels, snails, slugs, etc.)	c. 6,000
Crustaceans (crabs, crayfish, etc.)	c. 12,000
Arachnids (spiders, etc.)	5,000
Insects	> 50,000
Vertebrates	
Fish	13,400
Amphibians	3,533
Reptiles	c. 250
Birds	c. 1,800
Mammals	c. 122

Ecosystems	Habitat Extent	Species Diversity	Relative Species Richness [b]
	(percent of world)	*(percent of known species)[a]*	
Freshwater	0.8	2.4	3.0
Marine	70.8	14.7	0.2
Terrestrial	28.4	77.5	2.7

Natural species richness

Natural species richness dependent on (a.o.):

- latitude
- altitude
- dimensions of lake
- size of catchment
- …….
- connectivity / isolation
  (“lakes are like islands”)

Hotspots of biodiversity: Endemism

Percentage of endemic mollusk species in selected water bodies

Inland Waters	Gastropods	Bivalves	Total
	%	%	%
Ancient lakes			
Baikal	78	52	73
Biwa	50	56	52
Sulawesi	c. 80	25	c. 76
Tanganyika	66	53	64
Malawi	57	11	46
Victoria	46	50	48
Ohrid	76		
Titicaca	63		
Major river basins			
Mobile Bay Basin	93	54	78
Lower Uruguay River and Rio de la Plata	48	21	37
Mekong River (lower 500 km)	92	13	73
Lower Congo basin	25	n/a	
Lower Zaire basin	25	n/a	

INDICATORS of biodiversity

-*CBD (Convention for Biological Diversity):*

Indicator 1: trends in characteristic species and habitats

- Intactness, naturalness: proportion of original species composition (in pristine or reference state) remaining.

- BII = Biodiversity Intactness Index (Scholes & Biggs, 2000)
- MSA of original species
- IBI: Index of Biotic Integrity
- EQR Ecological Quality Ratio

Summarized: relative taxon richness or relative biodiversity value ~ MSA

Calculation of 'naturalness' of biota ('Relative Biodiversity', 'MSA')

[Abundance = # of sites where species occurs, or # of specimens found]

Species no.	Abundance in Pristine state	Abundance in Disturbed state
Spec. 1	100	80
Spec. 2	60	12
Spec. 3	27	0
Spec. 4	6	60
Spec. 5	0	20

Species 1: 80/100 = 0.8

Species 2: 12/60 = 0.2

Species 3: 0/27 = 0.0

Species 4: 1.0 (maximum)

Species 5: -- (not original)

Σ (ratio)/ # of native species

= Relative Biodiversity = 0.5

cf IBI or O/E indices

Example: quality of small streams in the Netherlands

0.8

0.6

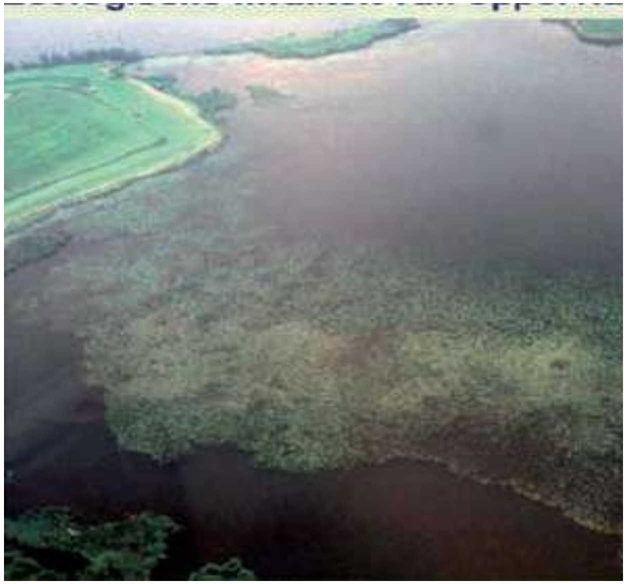
0.4

<0.2

Example: quality of shallow lakes

0.8

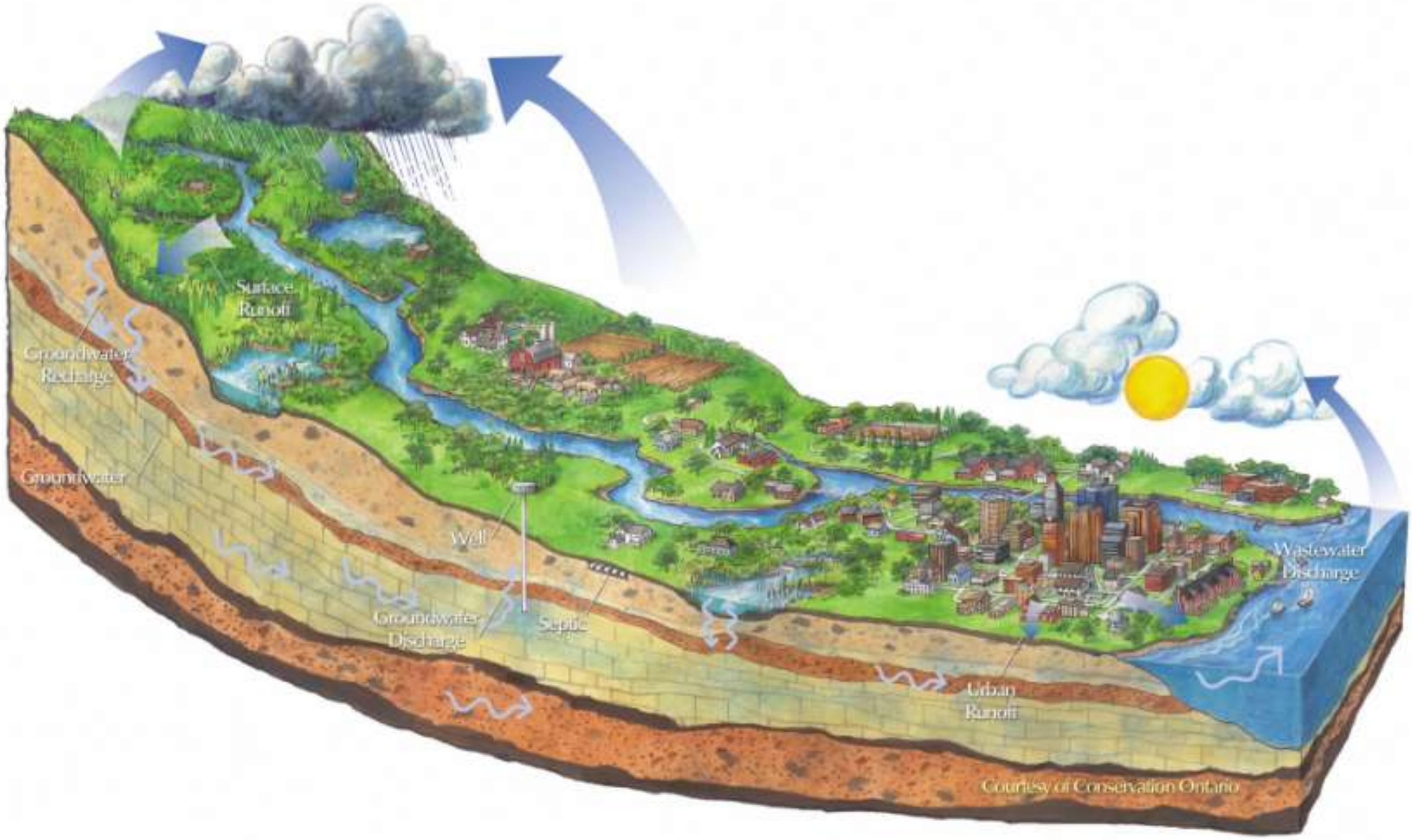
0.6



0.4

<0.2

Spatial relations: CATCHMENT APPROACH!



3. PRESSURES
Drivers of biodiversity change in aquatic systems

(from: MEA, 2005)

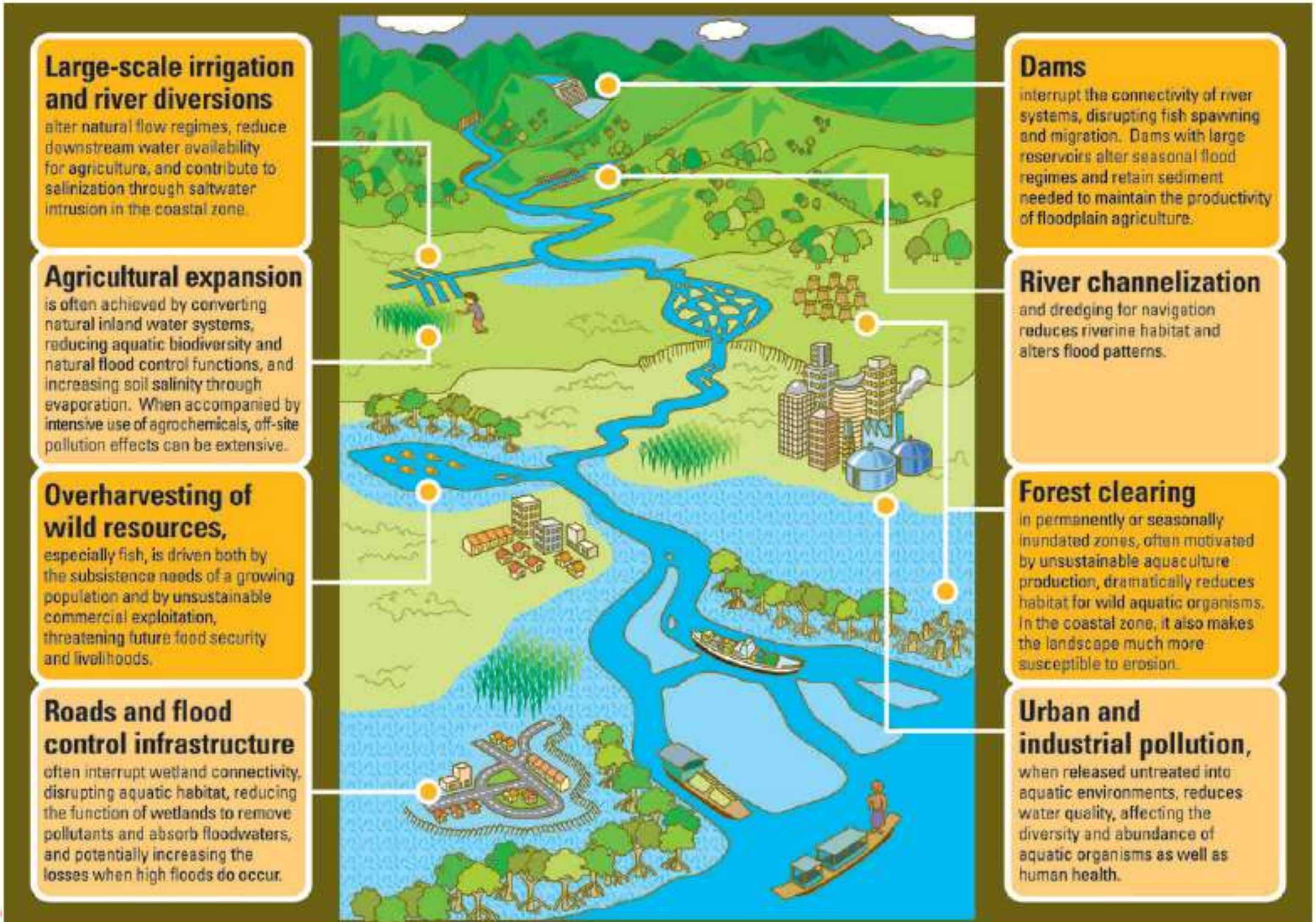
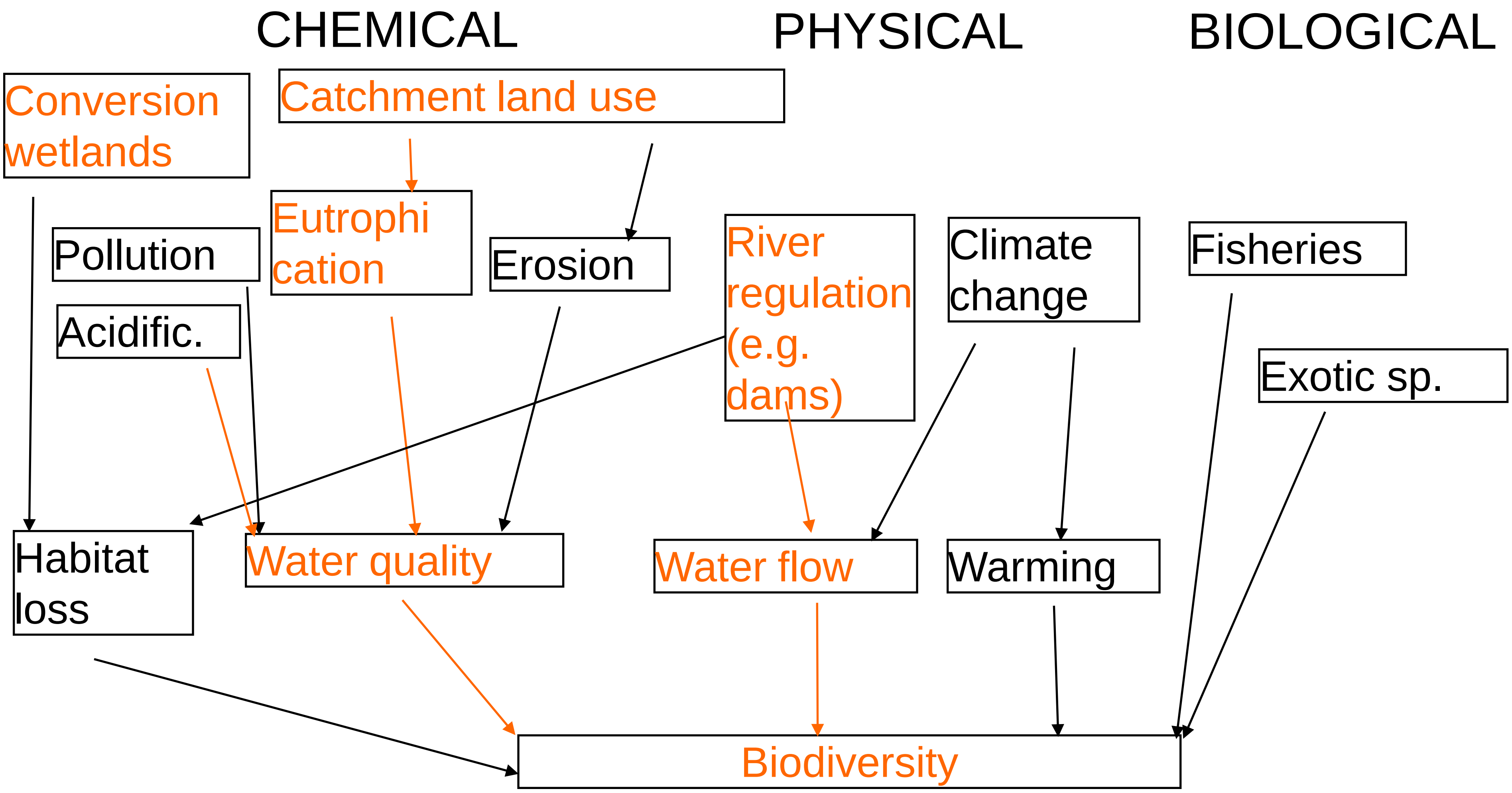


Figure 20.7 Pictorial Presentation of the Direct Drivers of Change in Inland Waters (Ratner et al. 2004)

Source:

MEA, 20050

Pressures



red = now implemented

Global river regulation

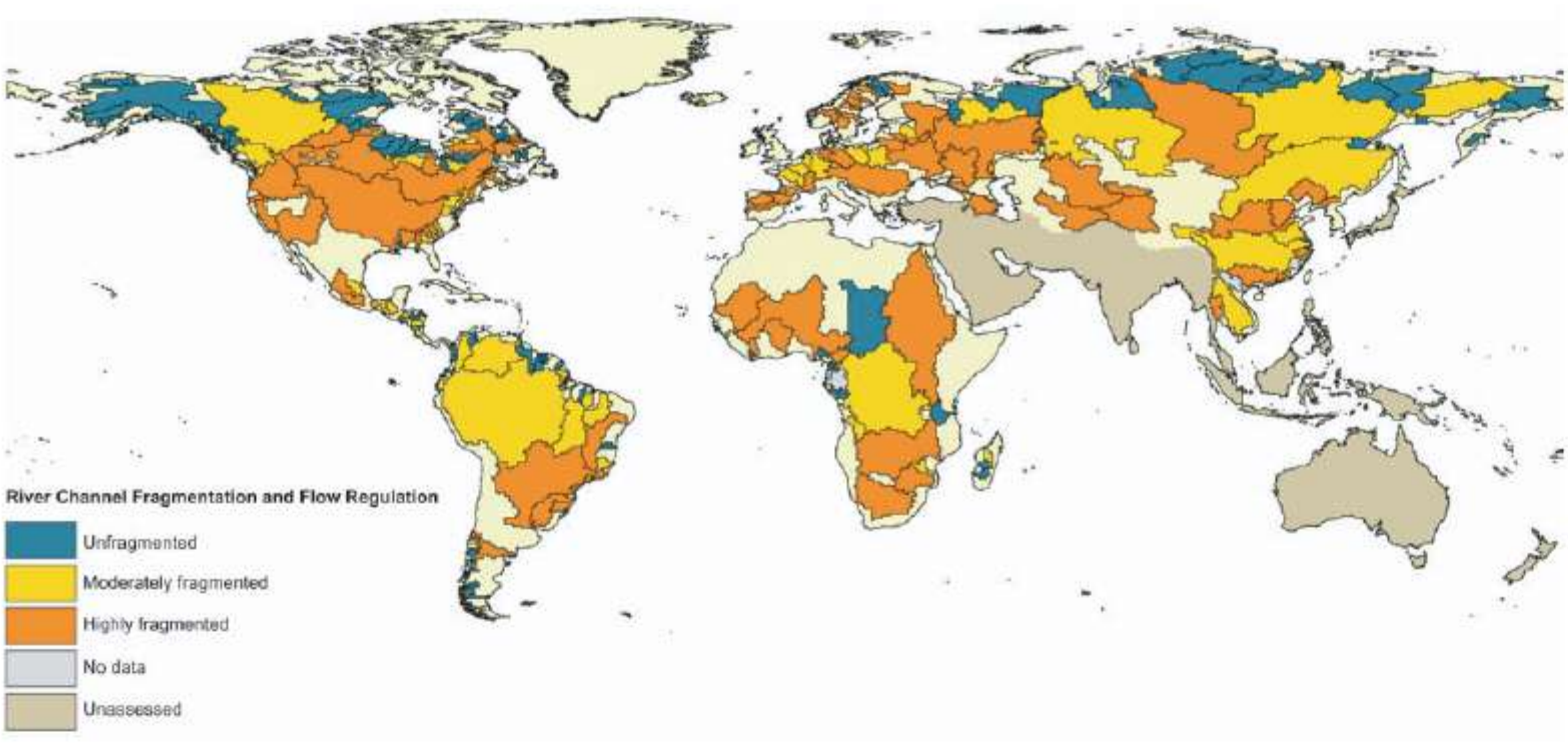


Figure 20.11 Fragmentation and Flow Regulation of Global Rivers (Revenga et al. 2000)

'Environmental flow' = (minimum) flow needed for ecosystem

Water abstraction: Lake Aral 1970-2002

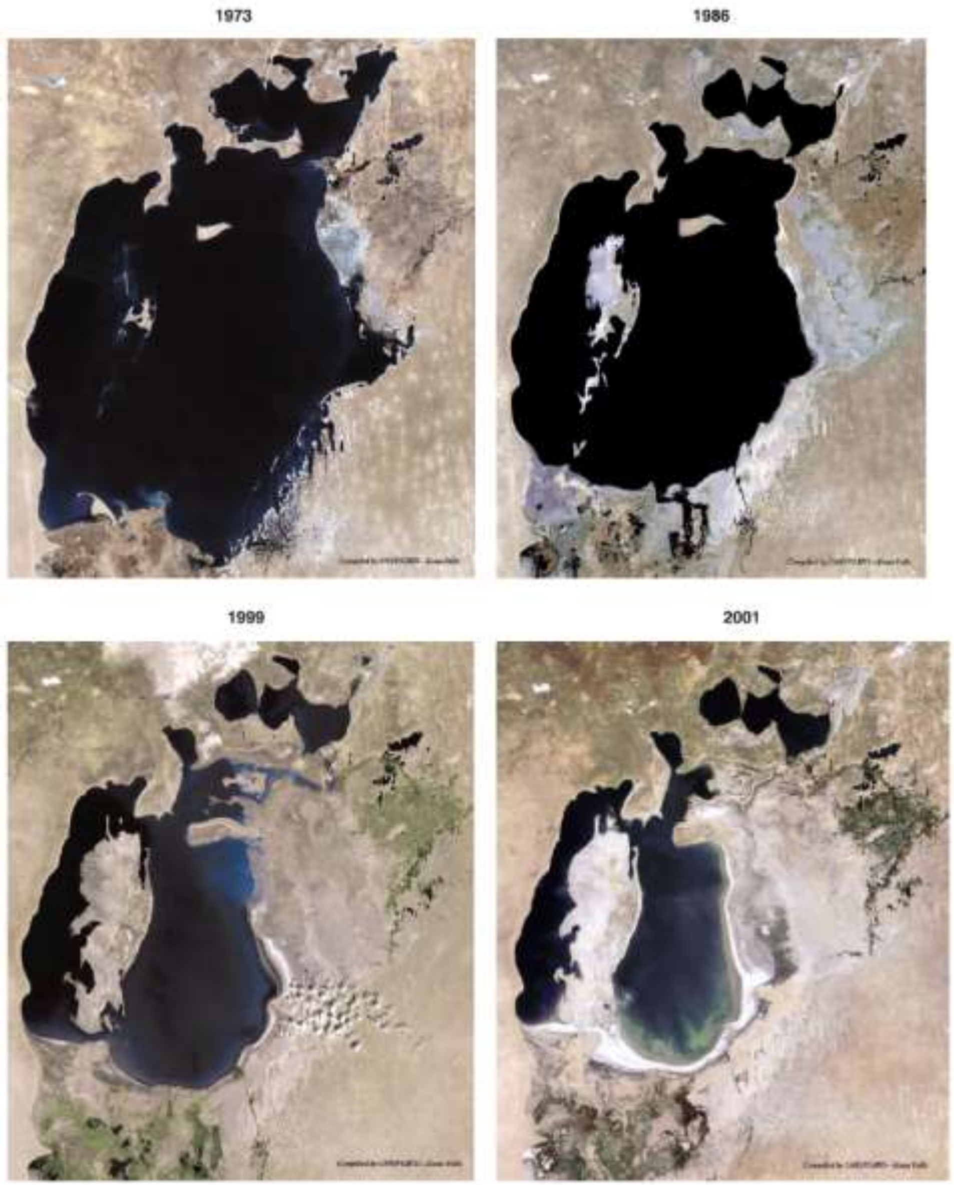


Figure 20.8 Changes in the Aral Sea, 1960–2001 (UNEP 2002)

Comparison with GLOBIO-terrestrial:

- **TERRESTRIAL <-> AQUATIC**
- Land use of cell <-> Wetland conversion of cell
- Land use of cell <-> Land use in upstream catchment (<u>all upstream cells</u>)
- N only from air <-> air + P and N from leaching
- Infrastructure <-> Dams, river regulation
- - <-> Water abstraction, flow change
- Climate change: T <-> Climate change: T, flow
- *Hunting* = *Fisheries*
- *Exotic species* = *Exotic species*

4. MODELS used for assessment of aquatic biodiversity

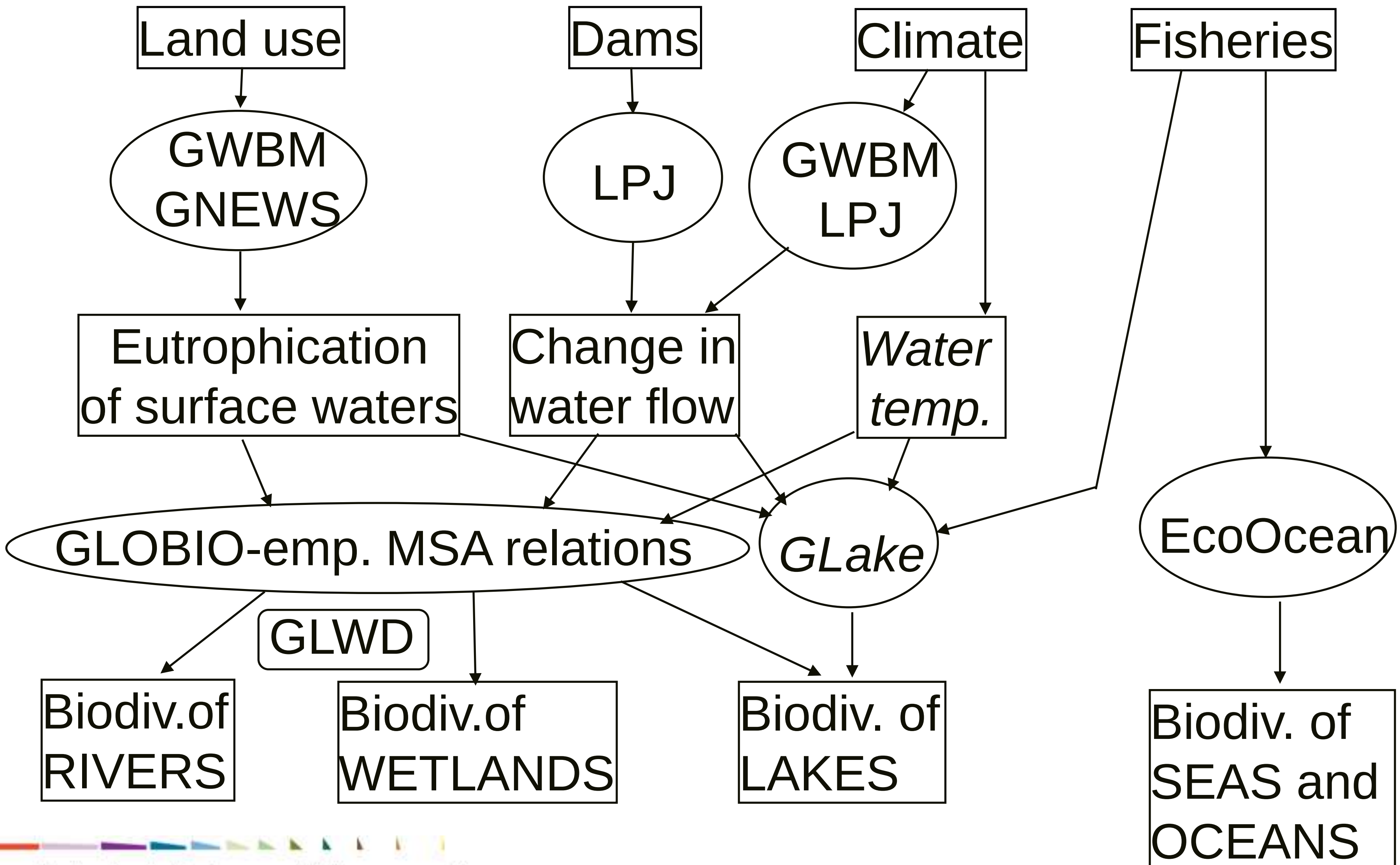
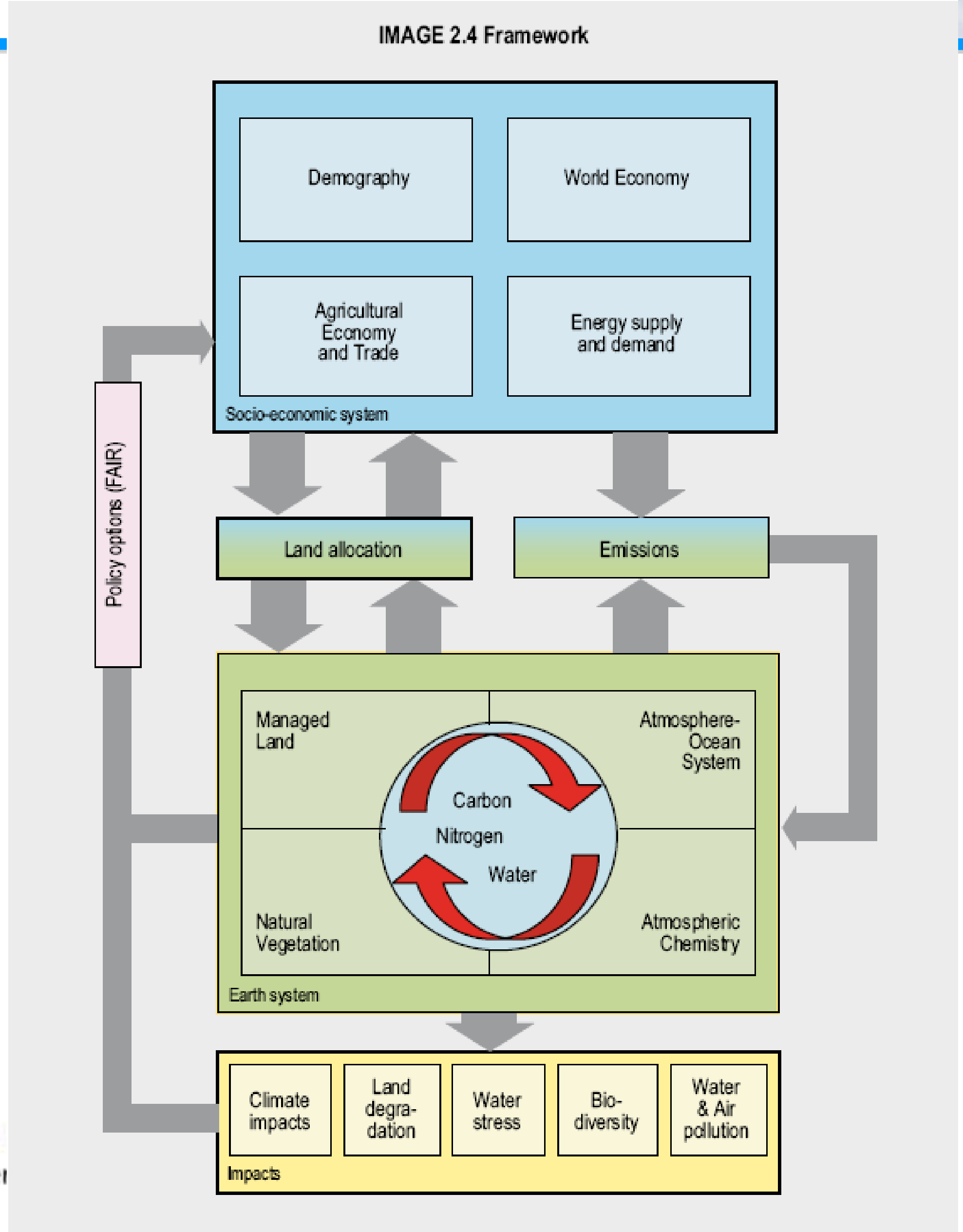
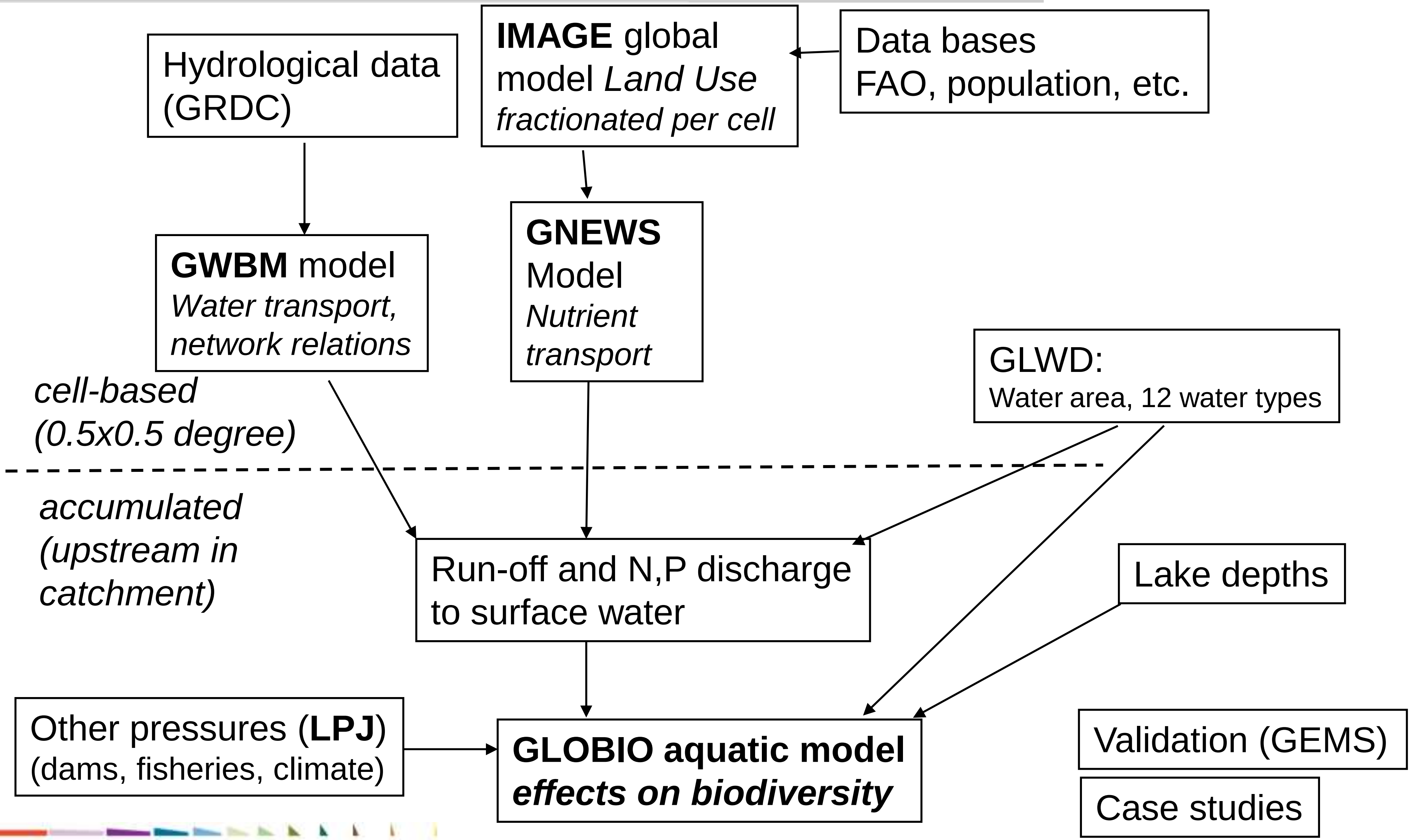


IMAGE: economy, land-use and climate

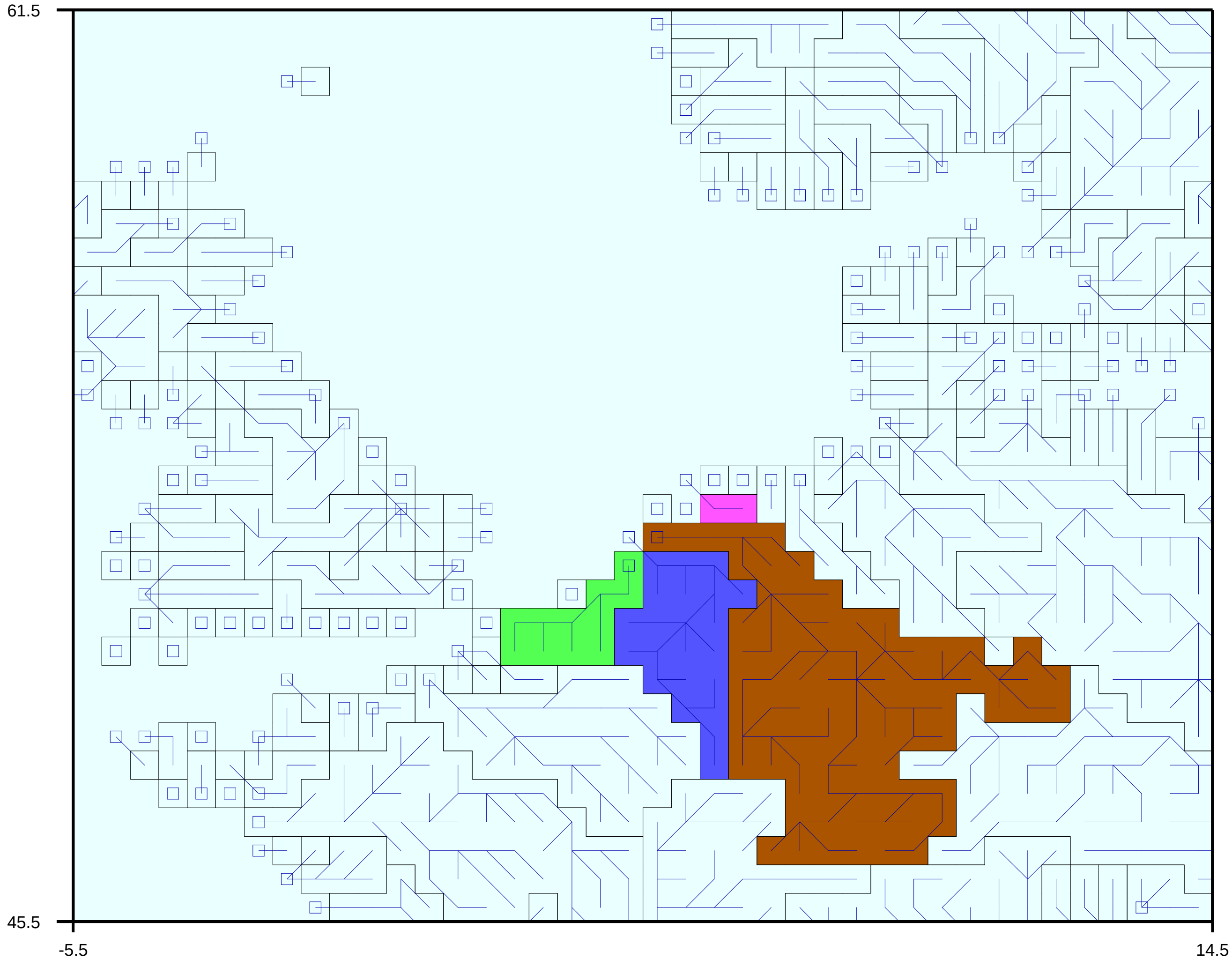


Modelling pressures: land use and eutrophication



Global Water Balance Model (GWBM): Flow direction (DEM) and catchments map (0.5x0.5 deg.).

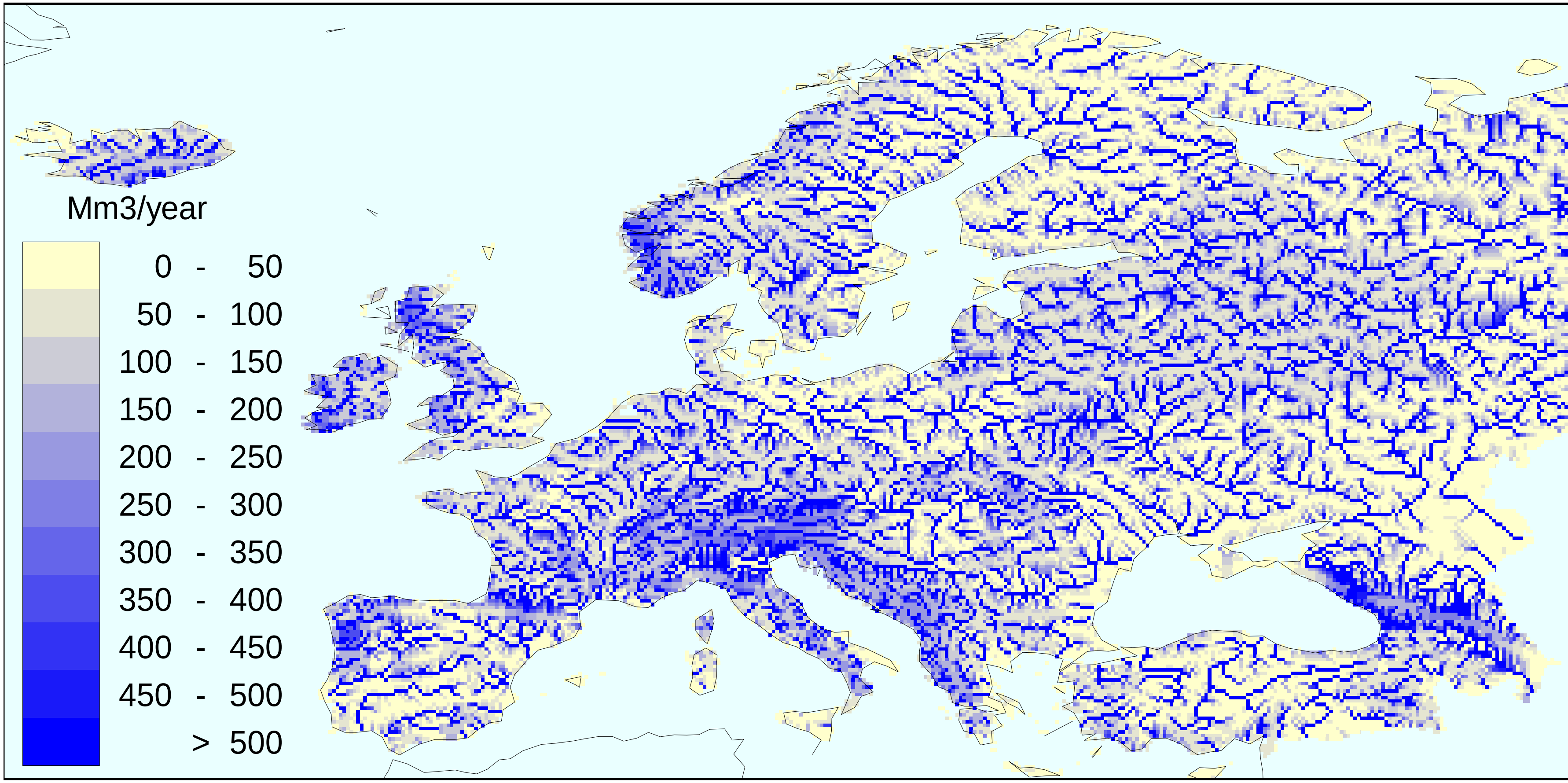
Adjusted River basins, based on UNHGRDC



Vorosmarty et al (2000)

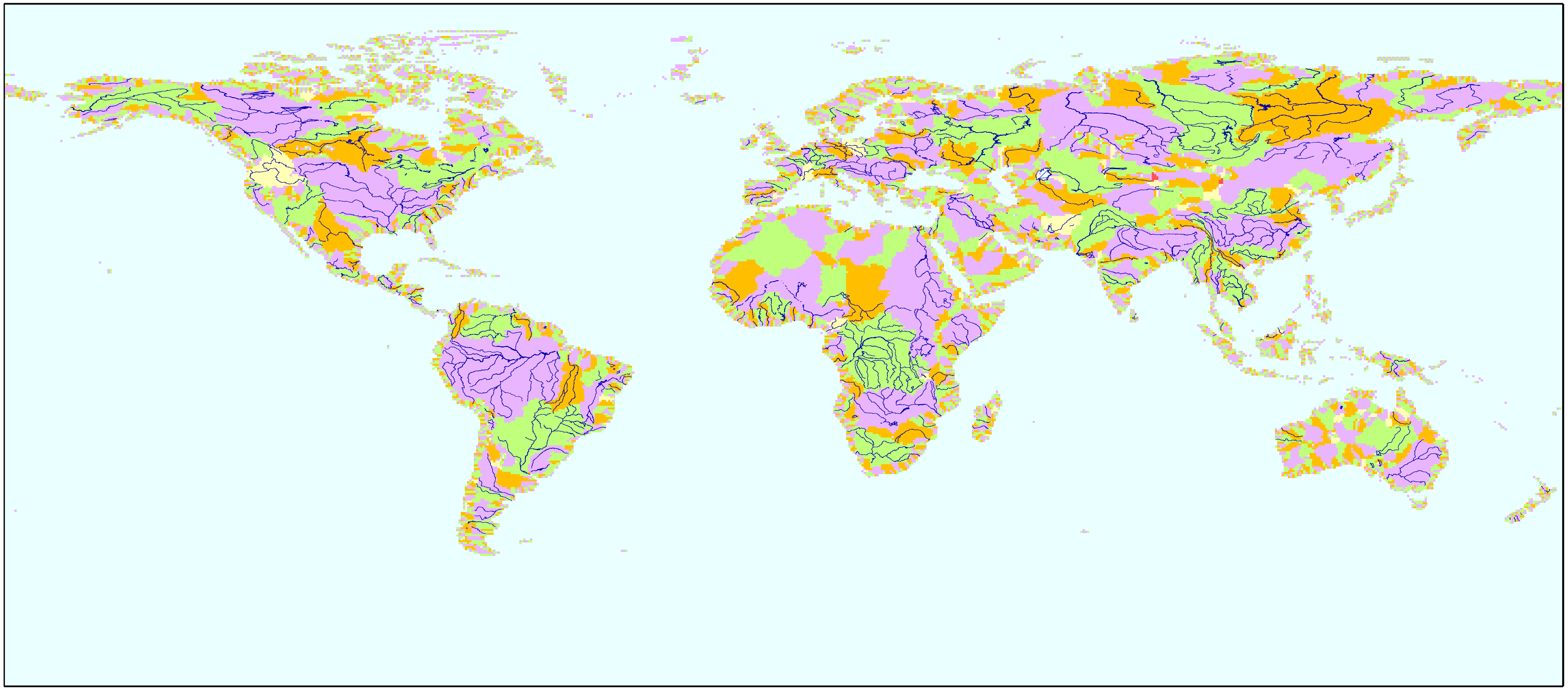
Global Water Balance Model (GWBM):

Annual accumulated total run-off for Europe



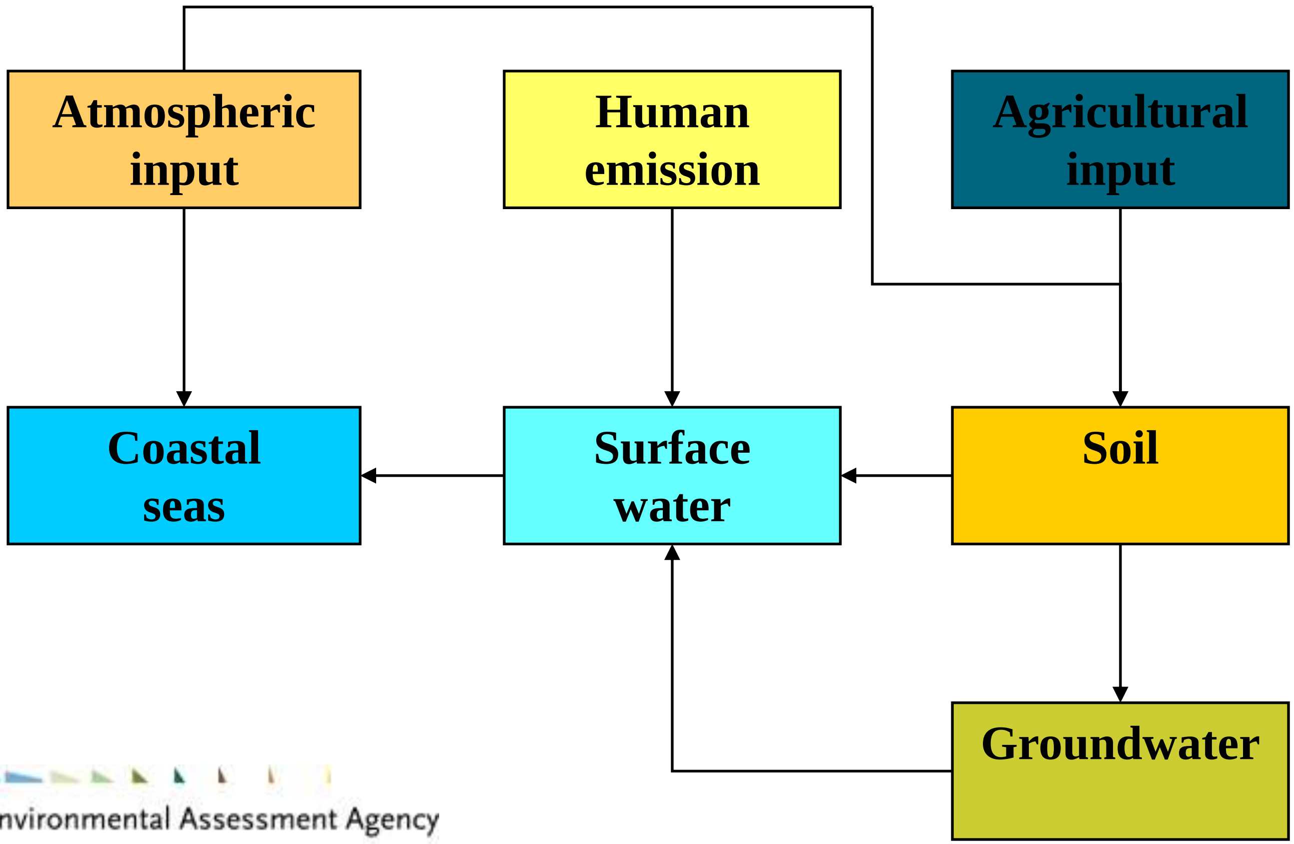
GWBM: Modelled global river basins

River basins UNHGRDC, Feteke et al.



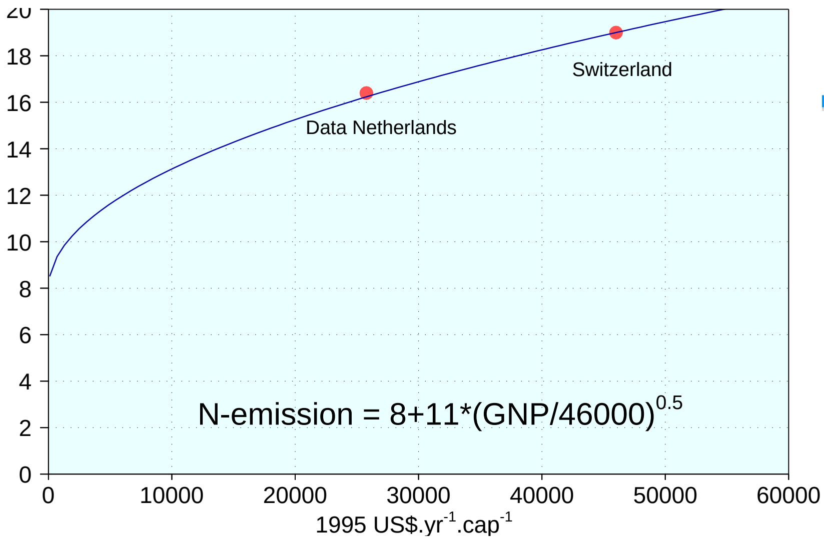
Nutrient model (GNEWS)

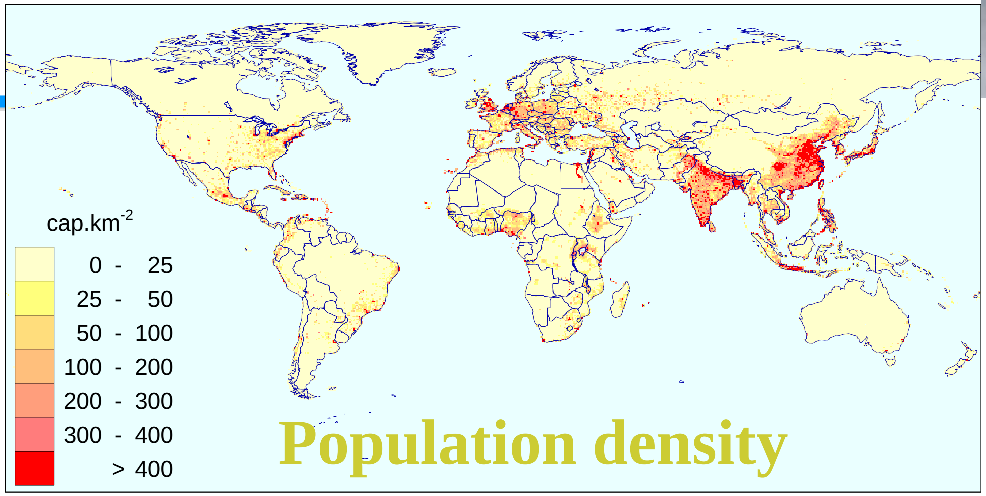
- **GIS-based distributed modelling of surface balance and processes in soil and groundwater**
- **River basins**
- **0.5 degree resolution up till surface waters**

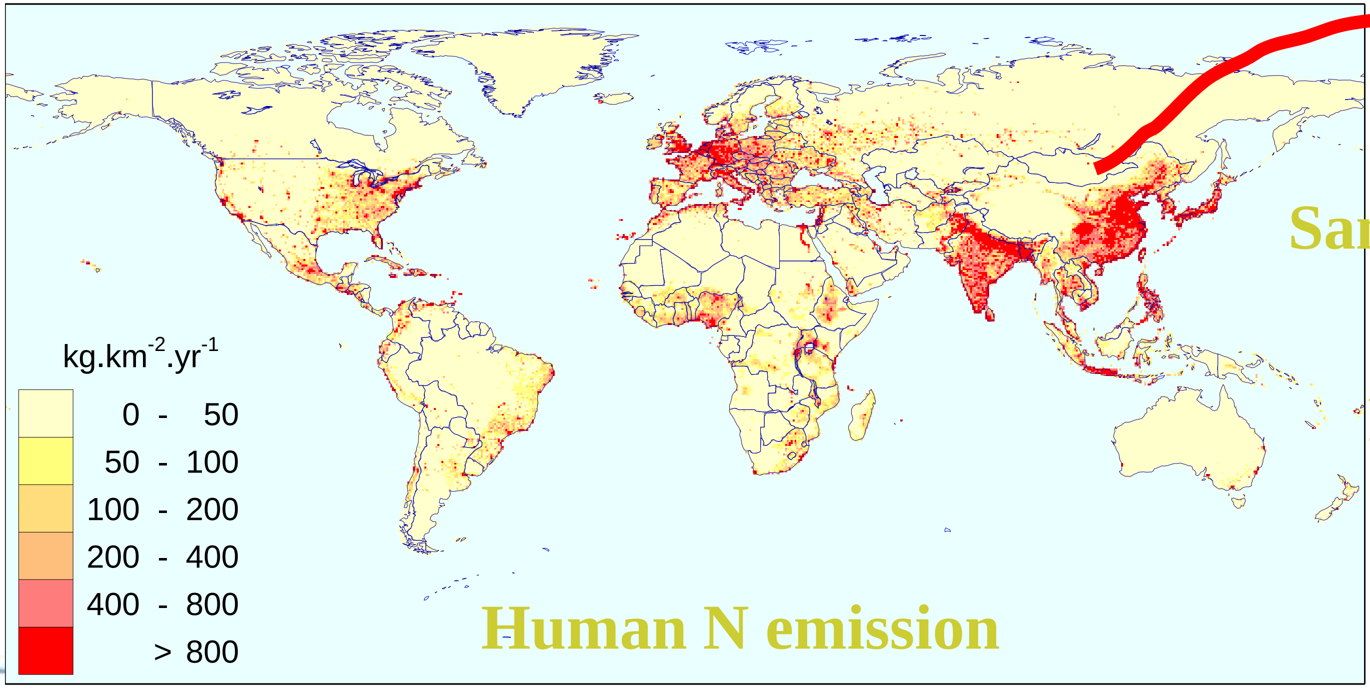


Point sources

N in g cap^{-1} day^{-1}



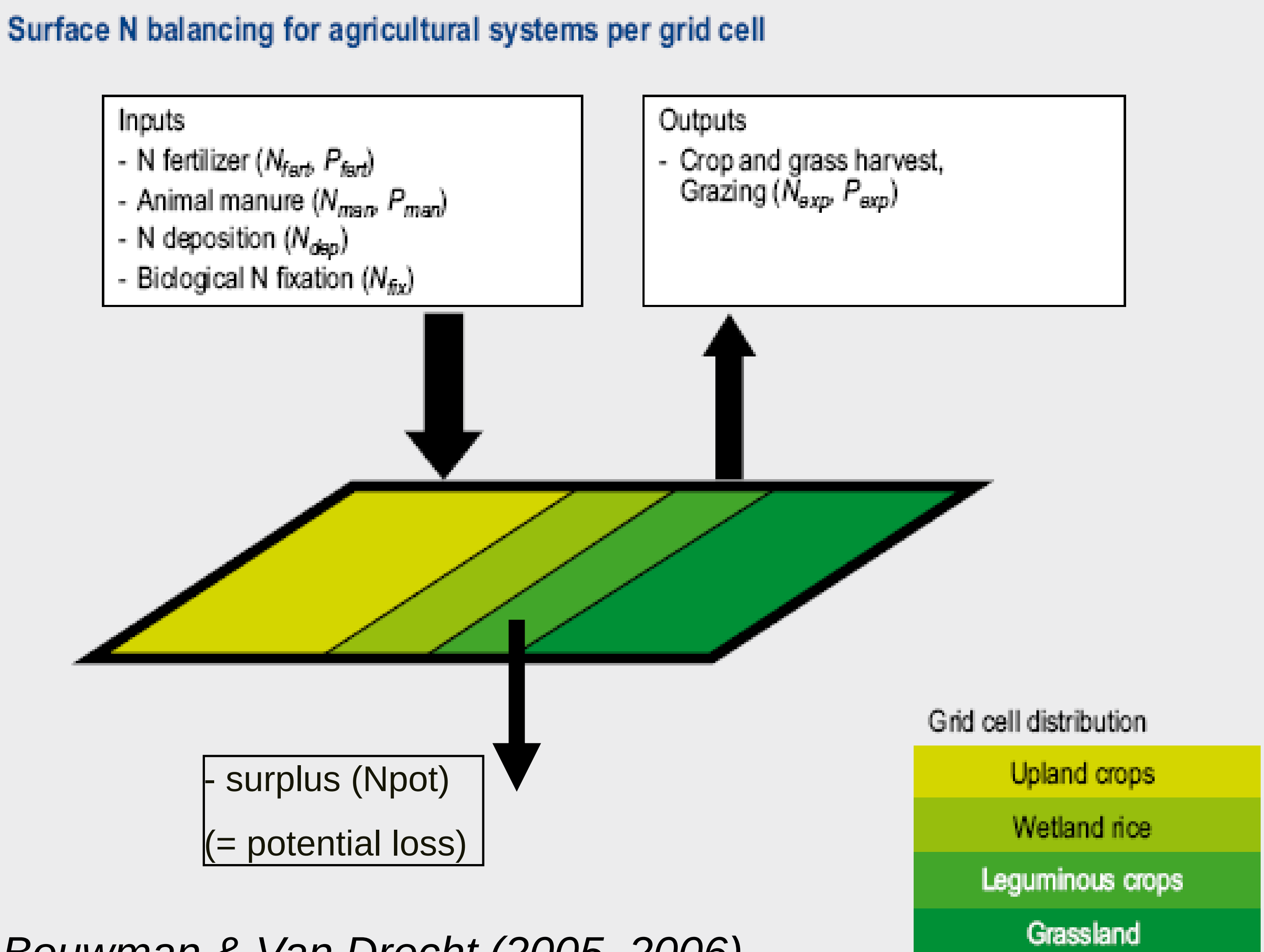




Sanitation

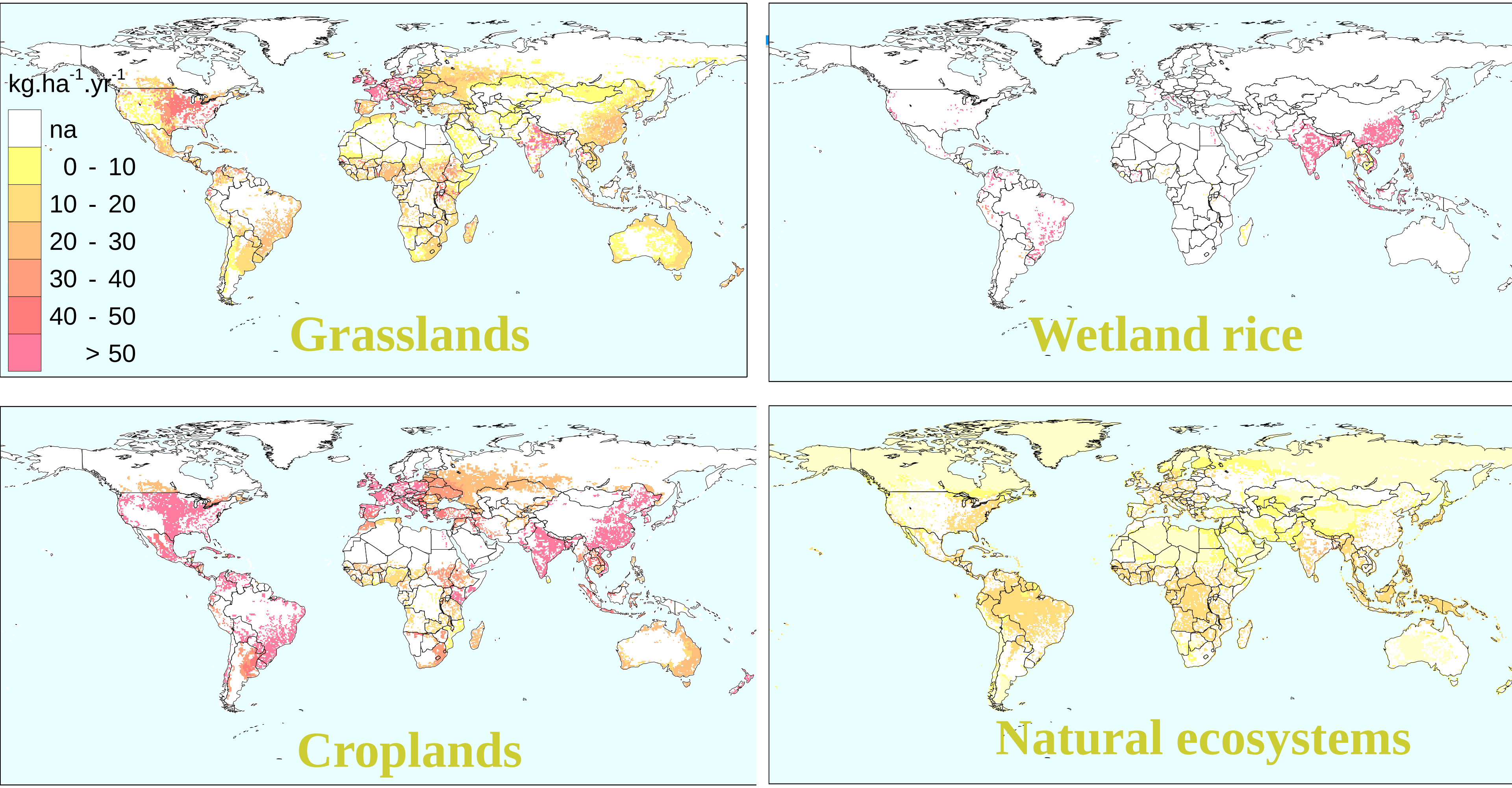
Rivers

GNEWS: Non-point sources from Agriculture: Nutrient balance per cell

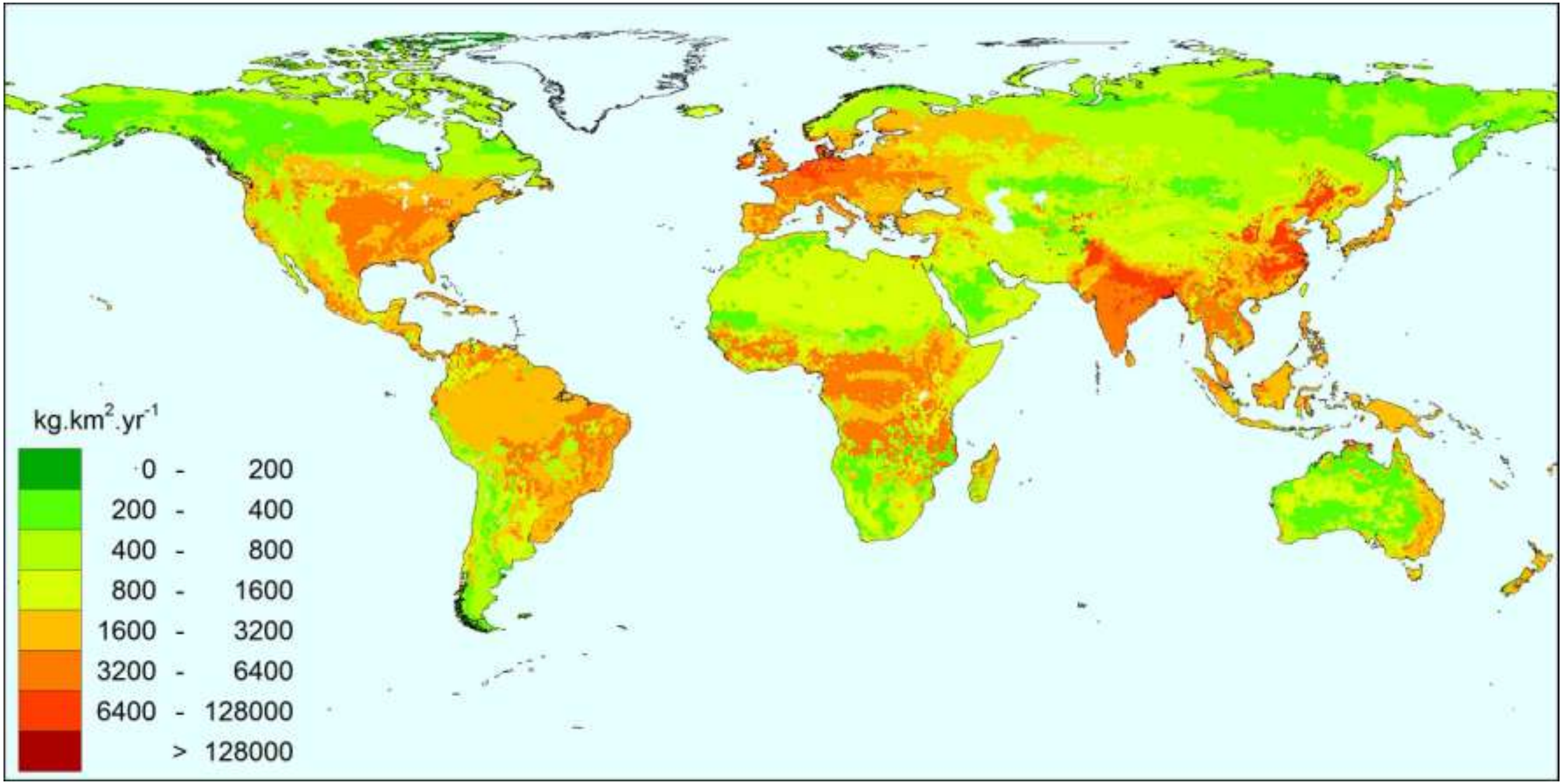


Bouwman & Van Drecht (2005, 2006)

Non-point sources: surface N balance surplus



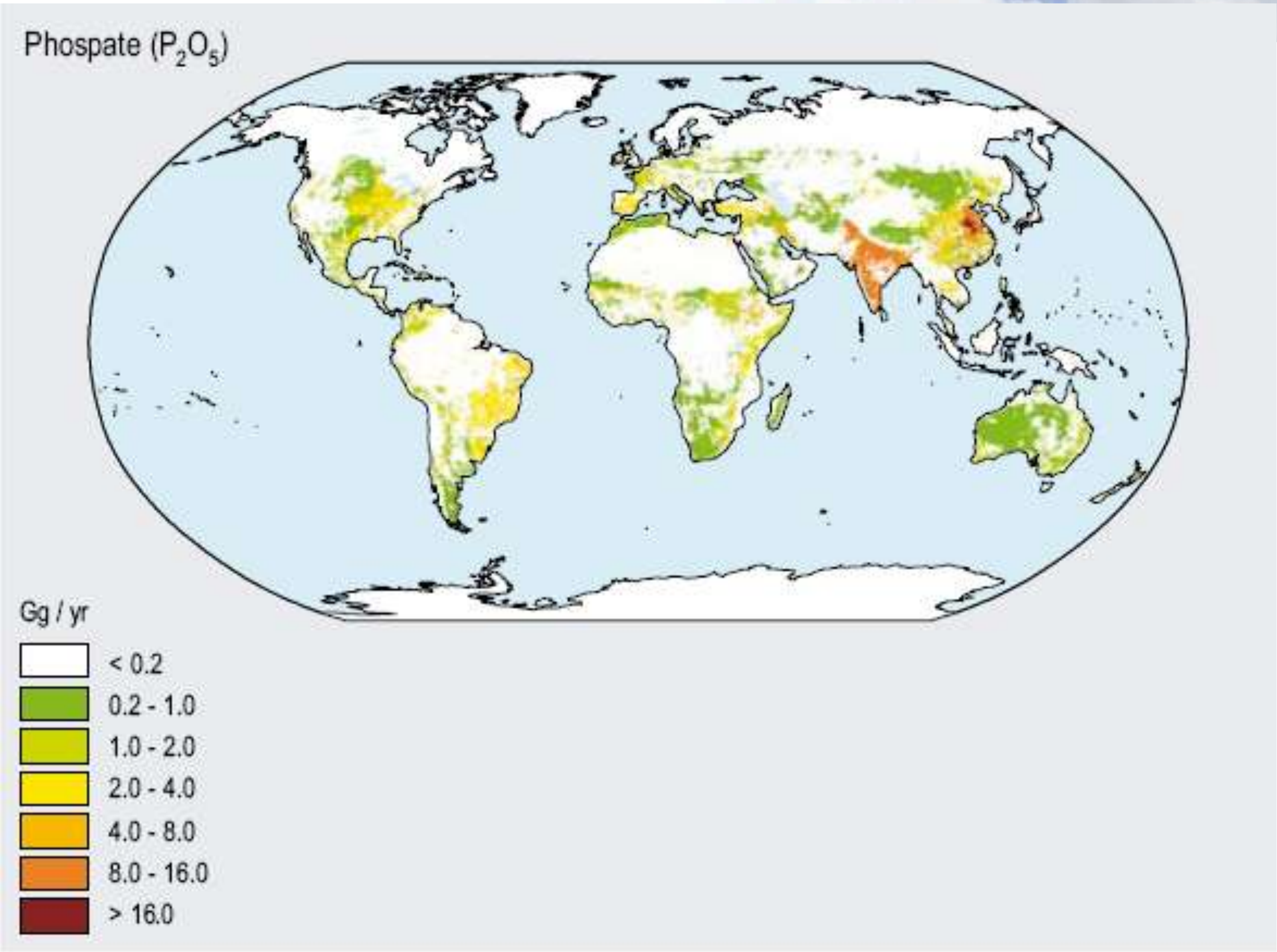
GNEWS: N loss from soil to water



World agricultural areas, as well as regions with high N-fixation, appear to have the highest N loss

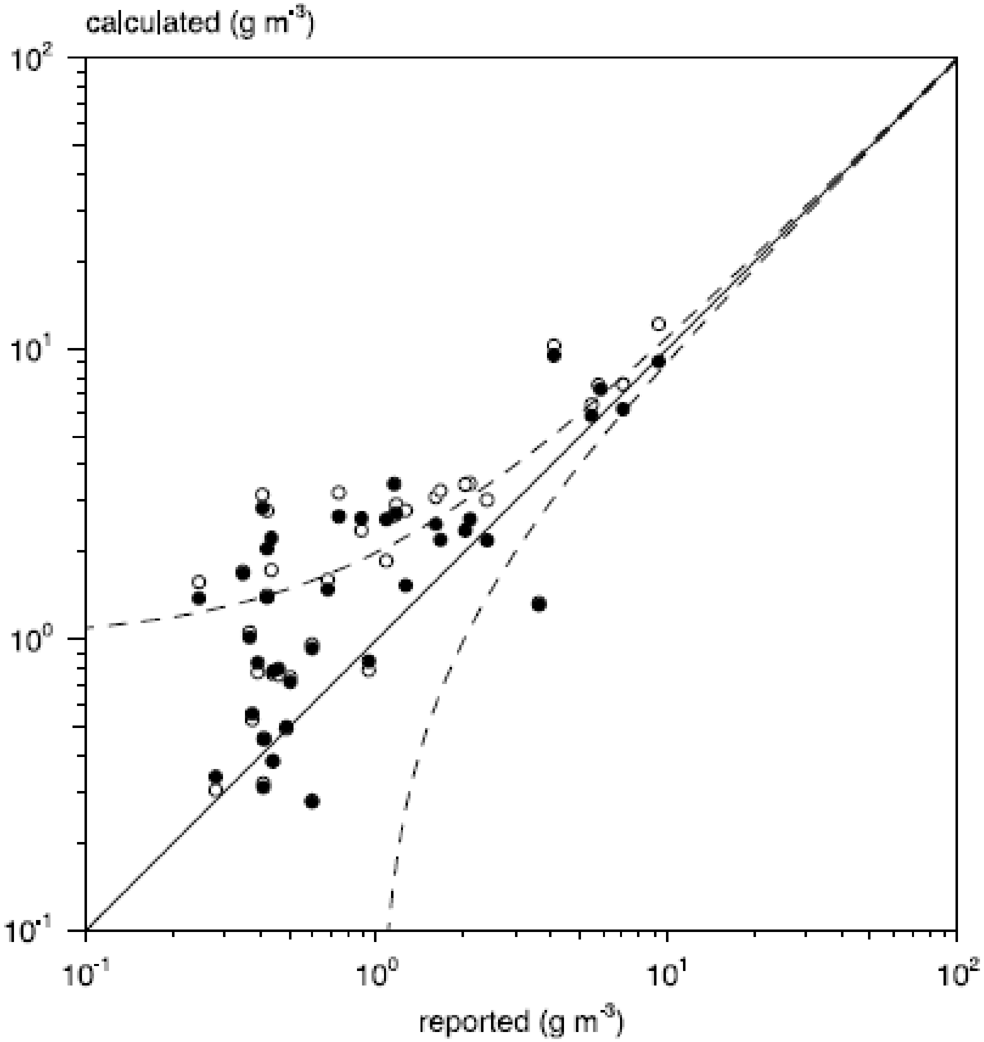
From: Bouwman et al., 2006

GNEWS: P loss from soil to water



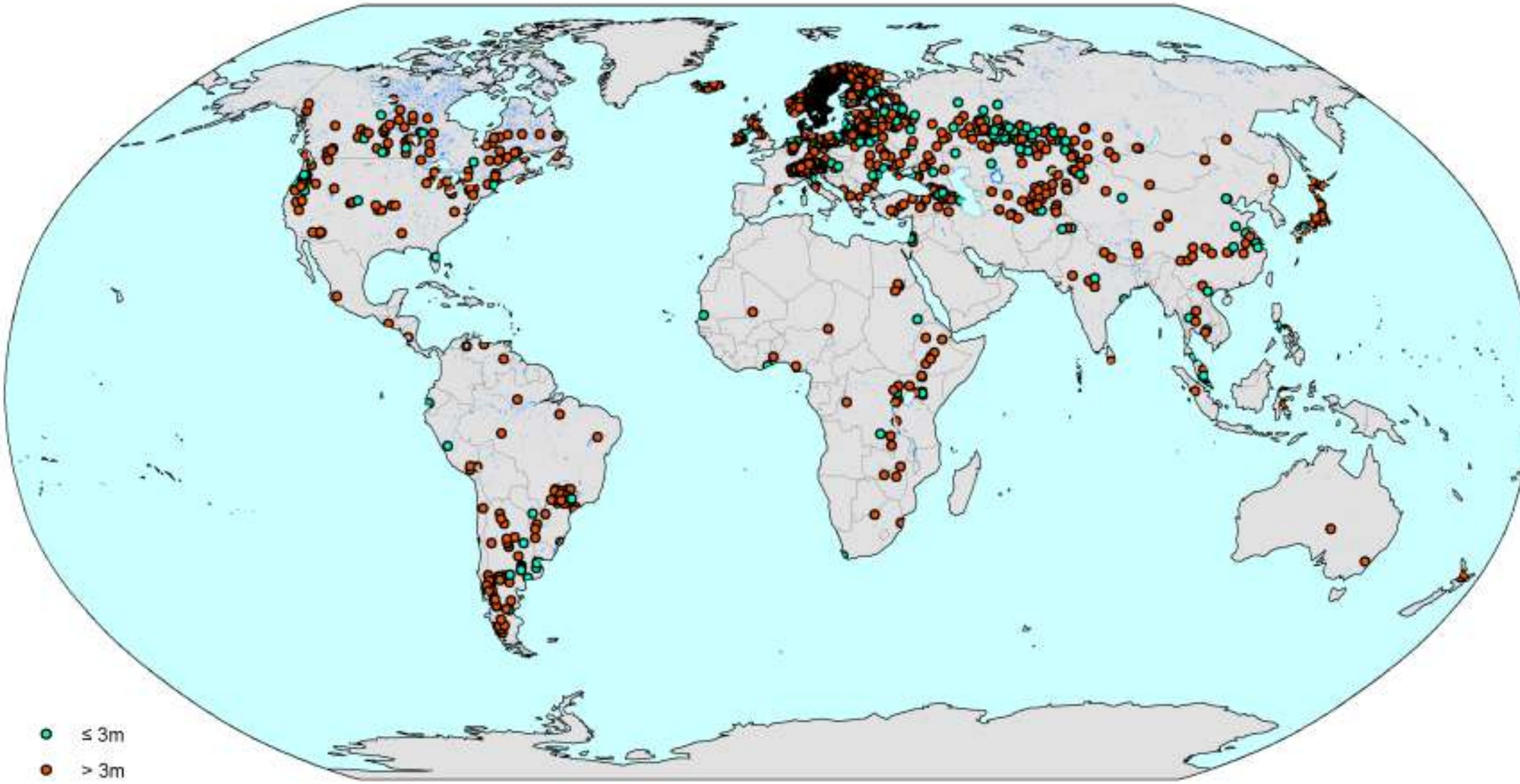
Validation of GNEWS for N

Based on TN concentrations at river mouths.
Not yet validated within catchment (GEMS data).



Lake depths

Lake depth (Kourzeneva, 2008) & GLWD (Lehner & Doll, 2004)



Steps calculation impact N & P on MSA

1. Calculate loading (N & P)
2. Classify water types
3. Determine dose – response
4. Calculate $MSA_{\_N,P}$

GLOBIO: empirical biodiversity relations

Based on literature data, per ecosystem type:

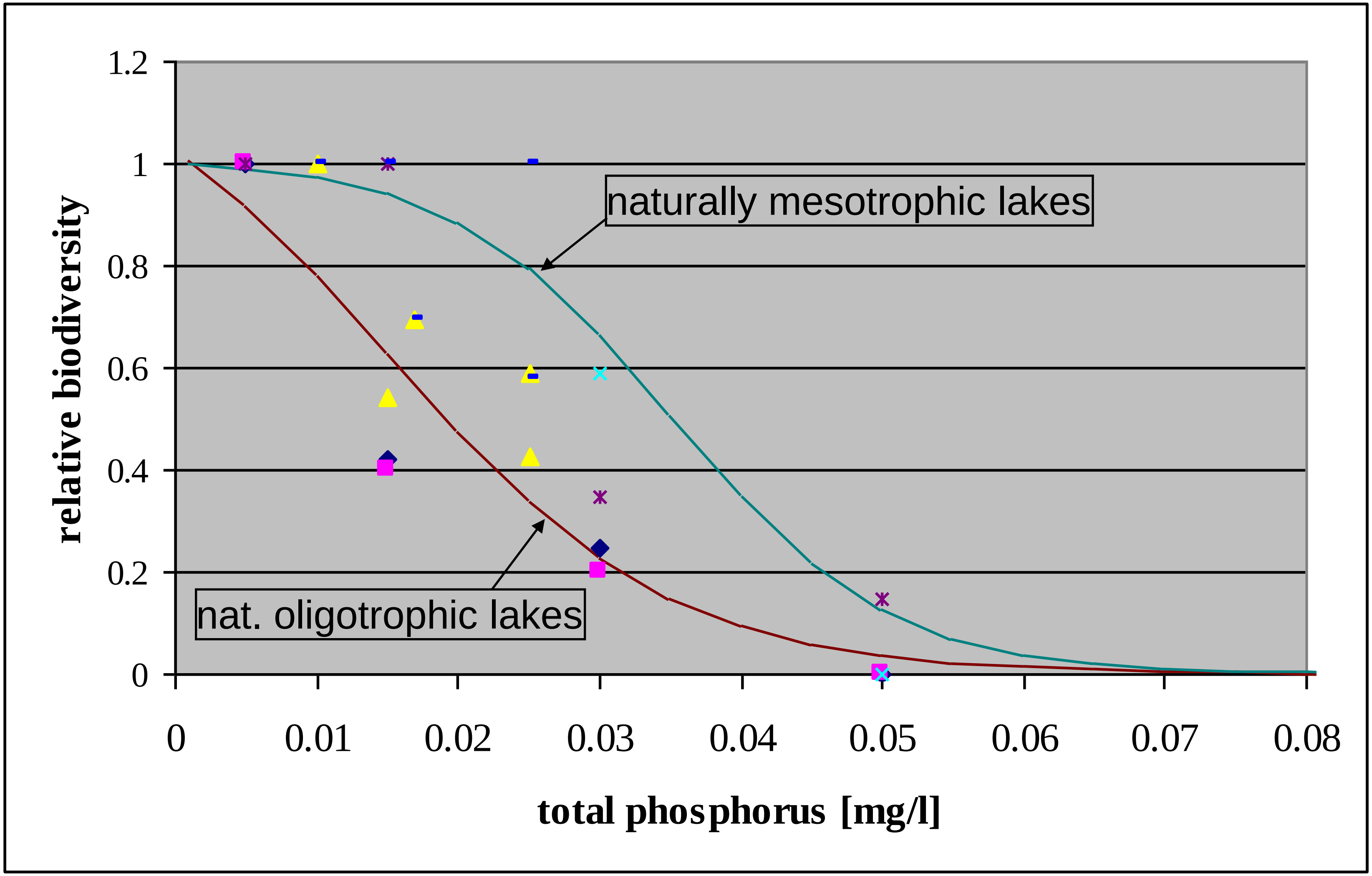
- Comparing pristine and impacted locations
- Gradient studies
- Trend studies: time series following impact
- Restoration studies: time series following restoration

Additional info:

- General ecological knowledge and models

Example dose – response relation

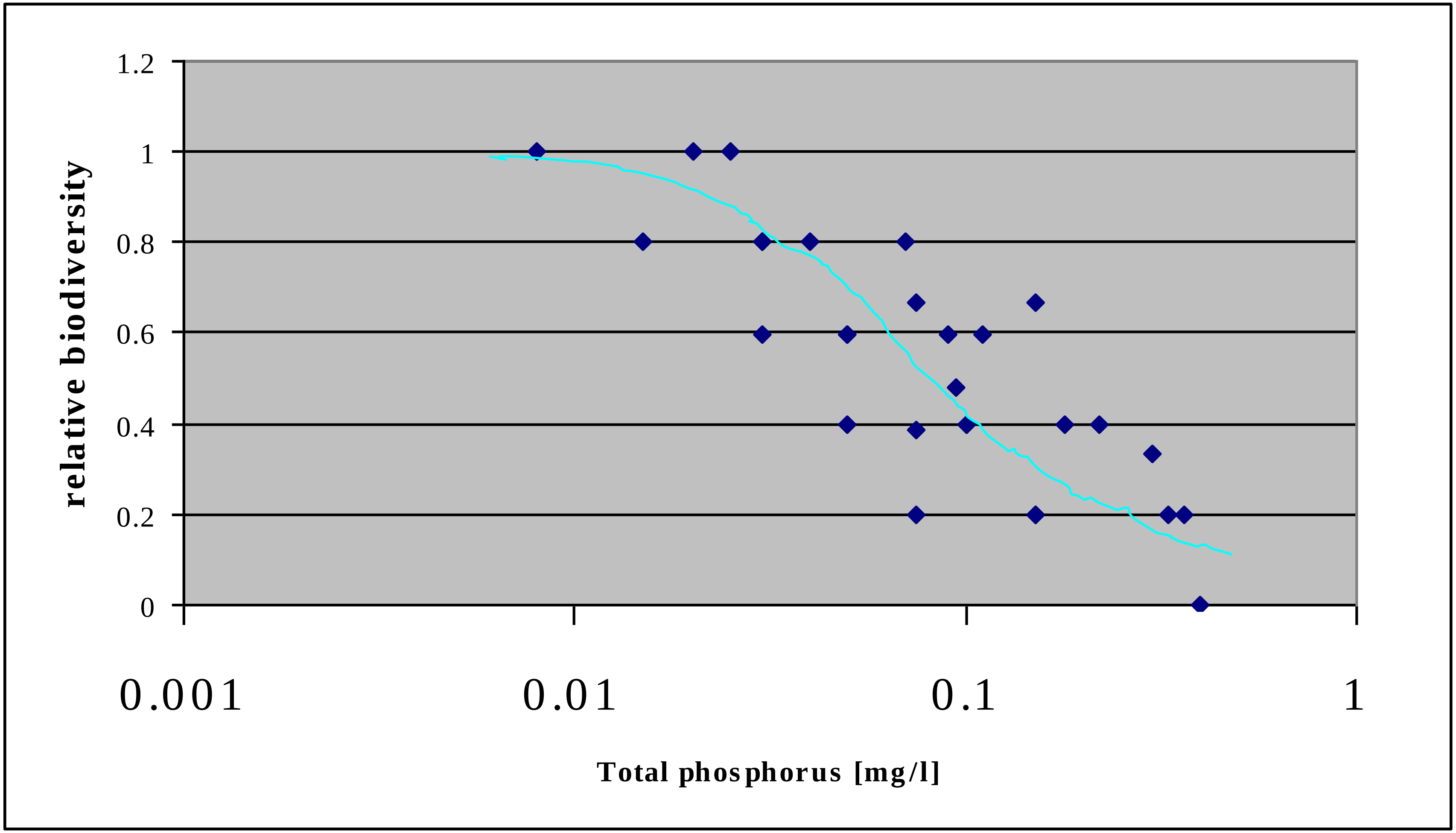
Eutrophication and biodiversity in deep lakes



Oligotrophic lakes of forested catchments

Example dose – response relation

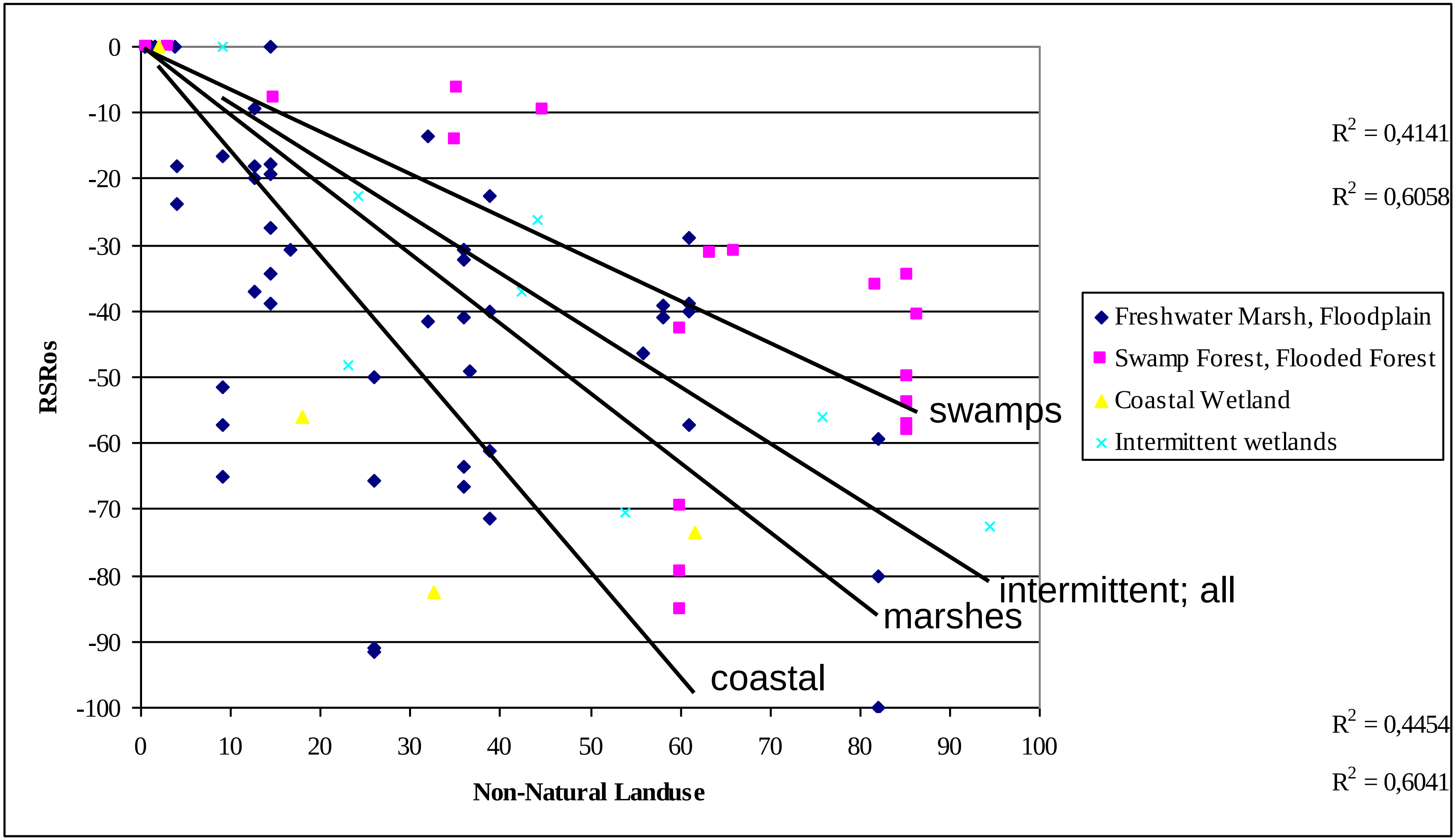
Eutrophication and biodiversity in shallow lakes



Biodiversity of shallow peat lakes

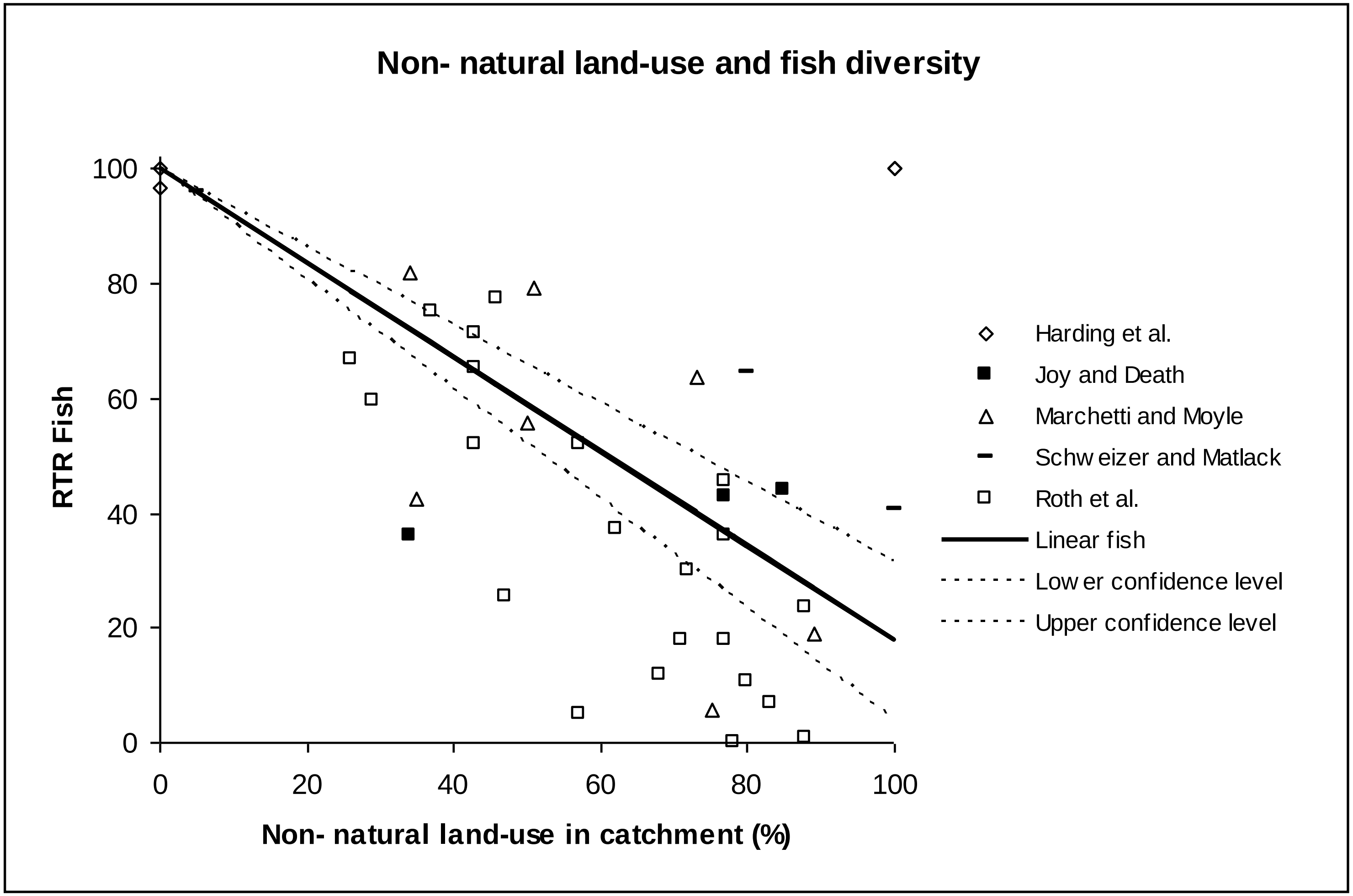
Example dose – response relation

Land-use and biodiversity in wetlands



Example dose – response relation
Land-use and relative fish diversity in rivers

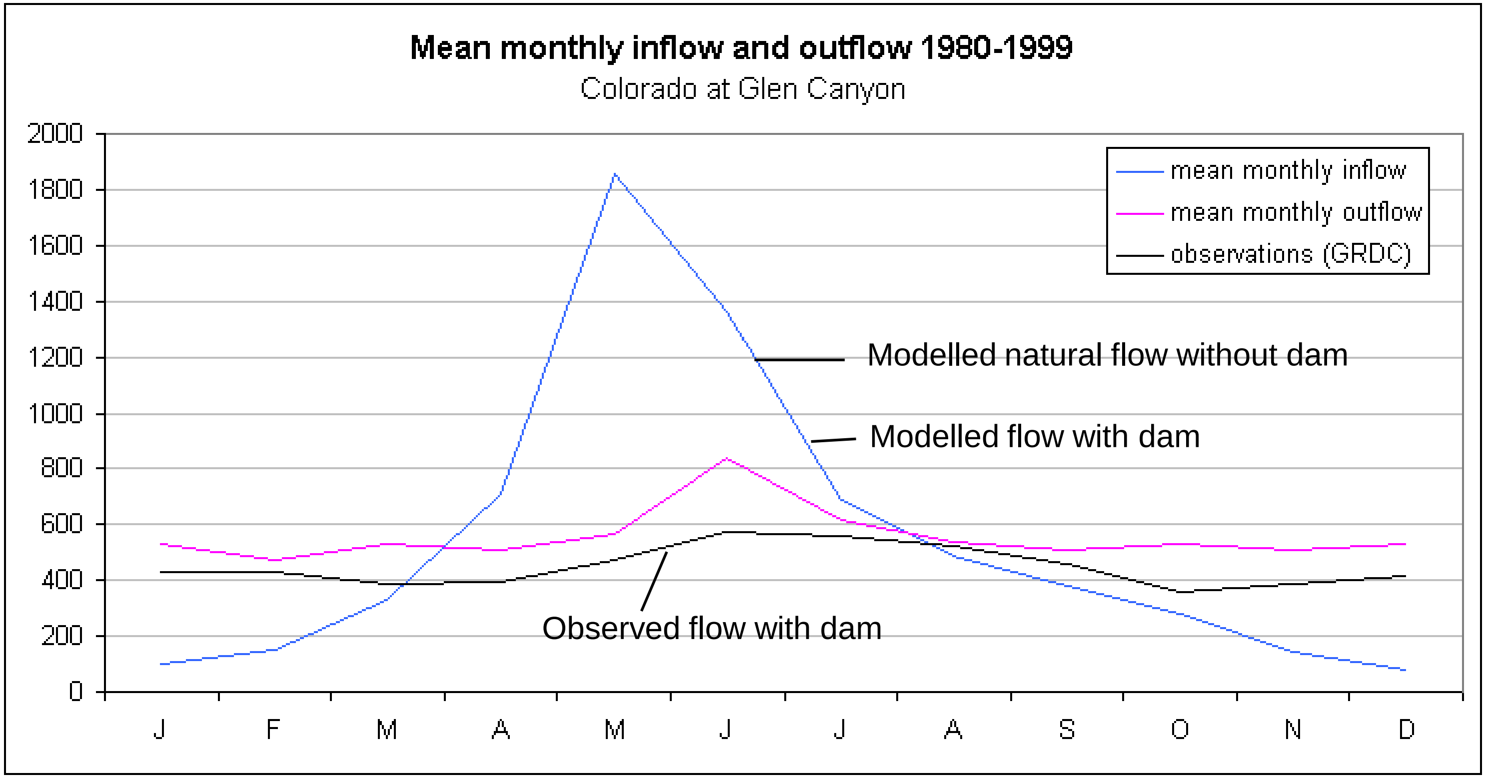
RTR = relative biodiversity of original species



From: Weijters et al., Aquat. Cons. (2009)

Flow regulation

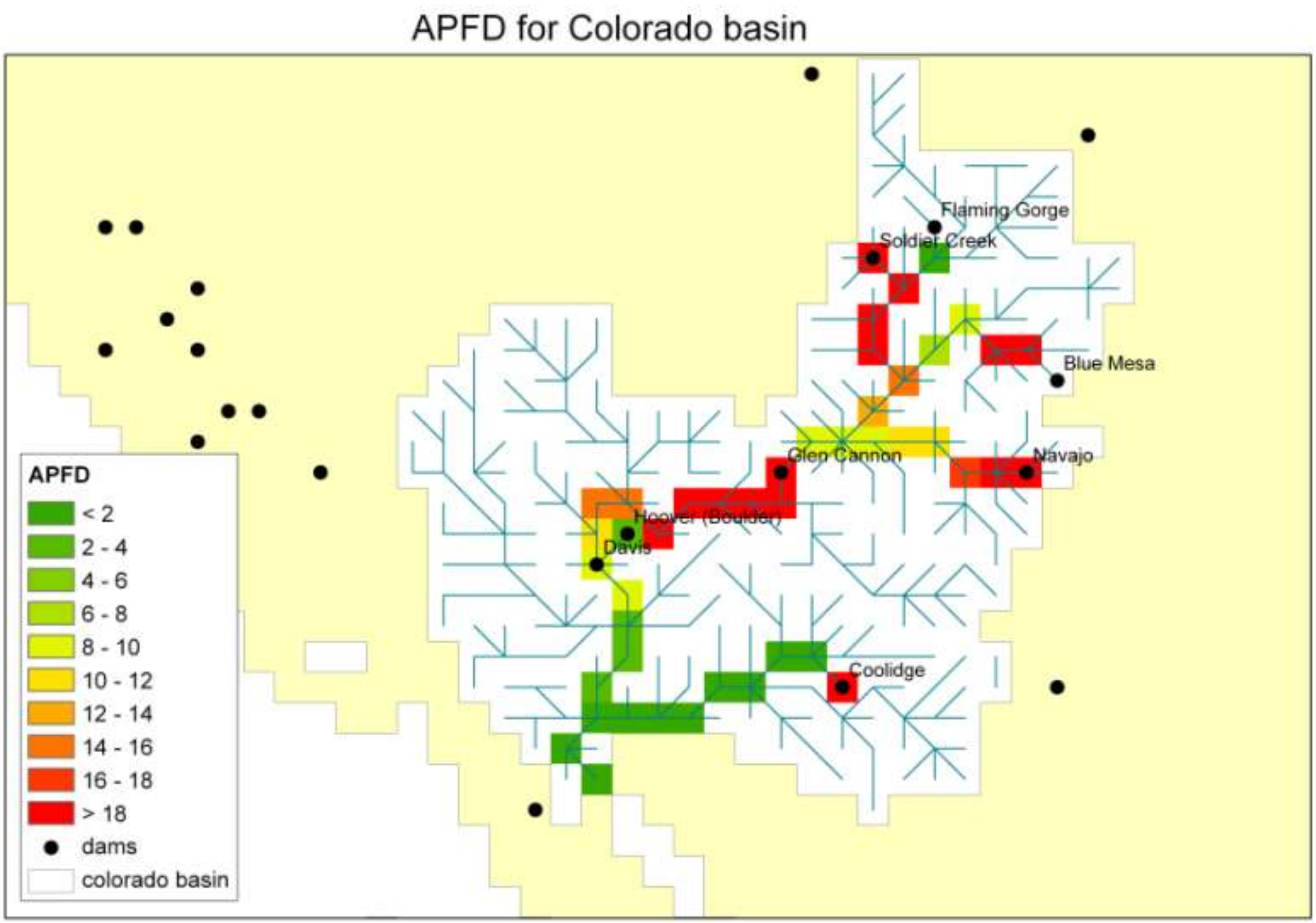
River regulation: impact of a dam on the water flow



⇒ APFD: annual proportional flow deviation

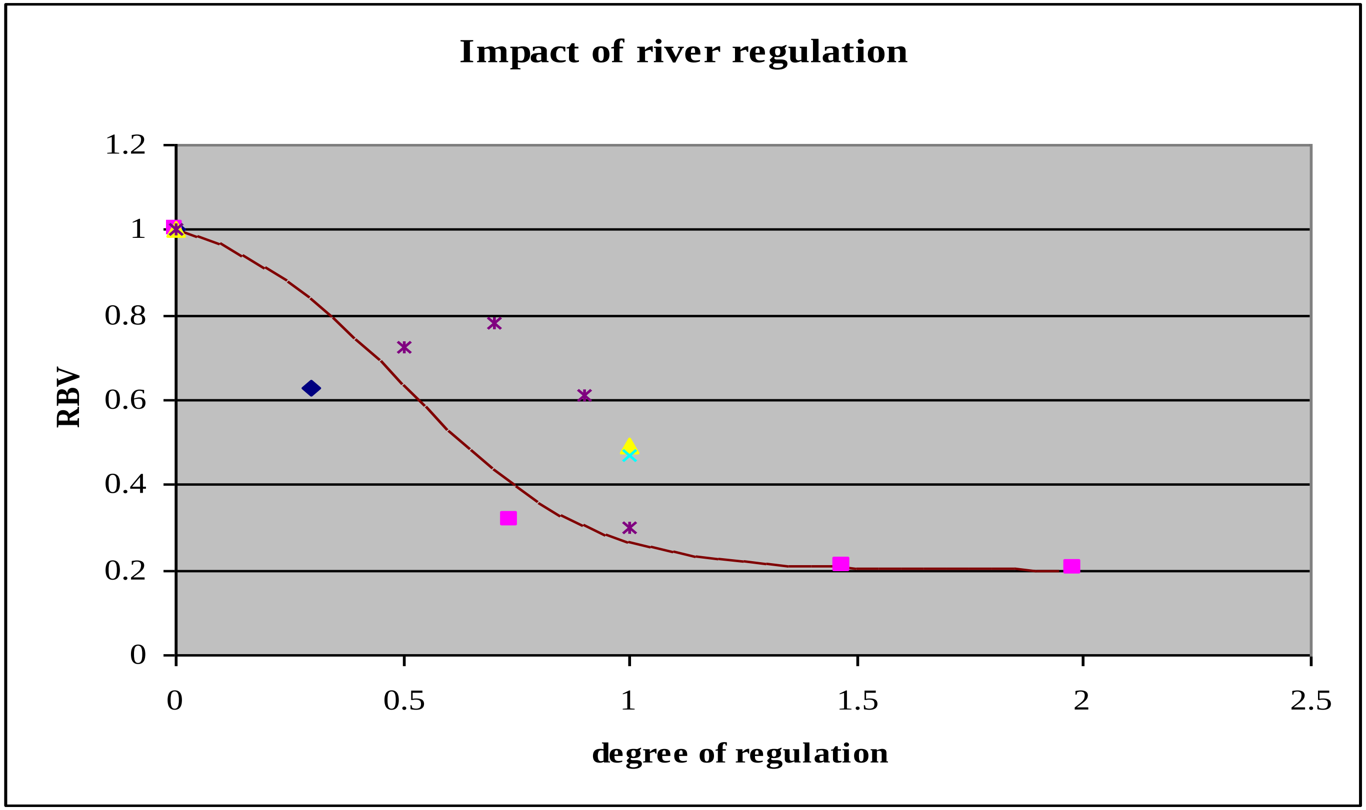
(based on monthly data)

River regulation: example: Colorado river (USA)



Example dose – response relation

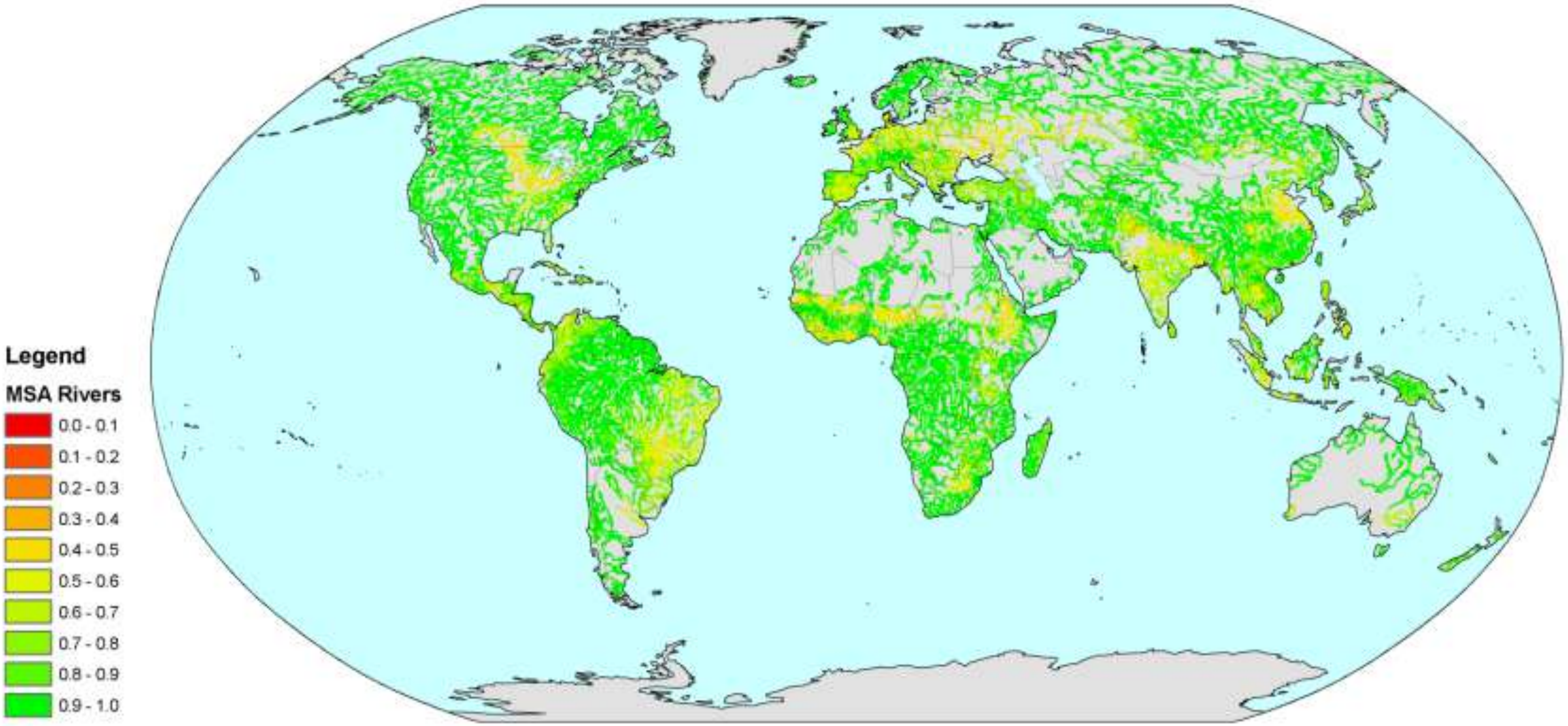
River regulation: effect on relative biodiversity



5. GLOBAL APPLICATION

Preliminary results: Relative biodiversity in rivers

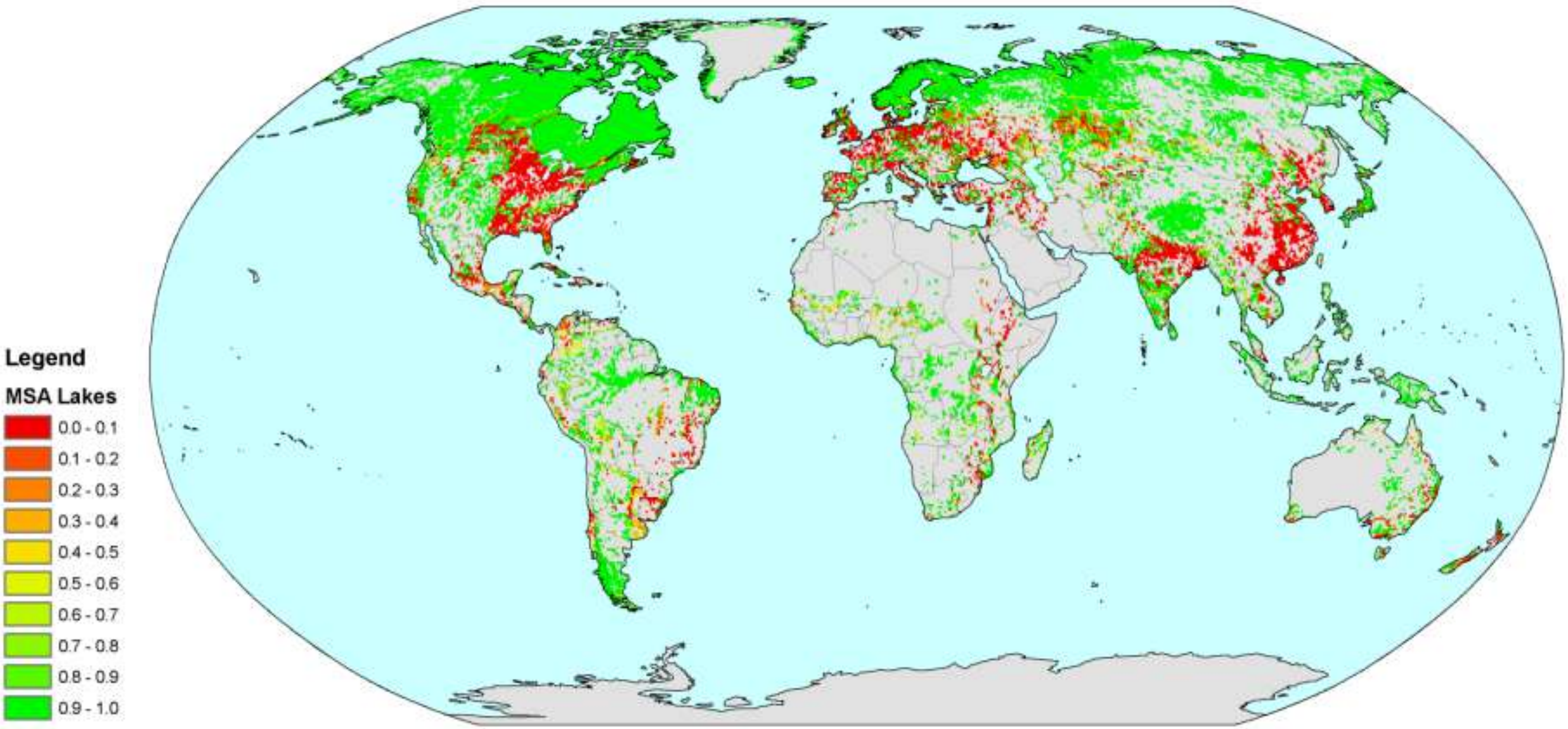
Based on non-natural land use upstream in catchments



Remaining biodiversity in river grid cells due to land use impact (Brazil)

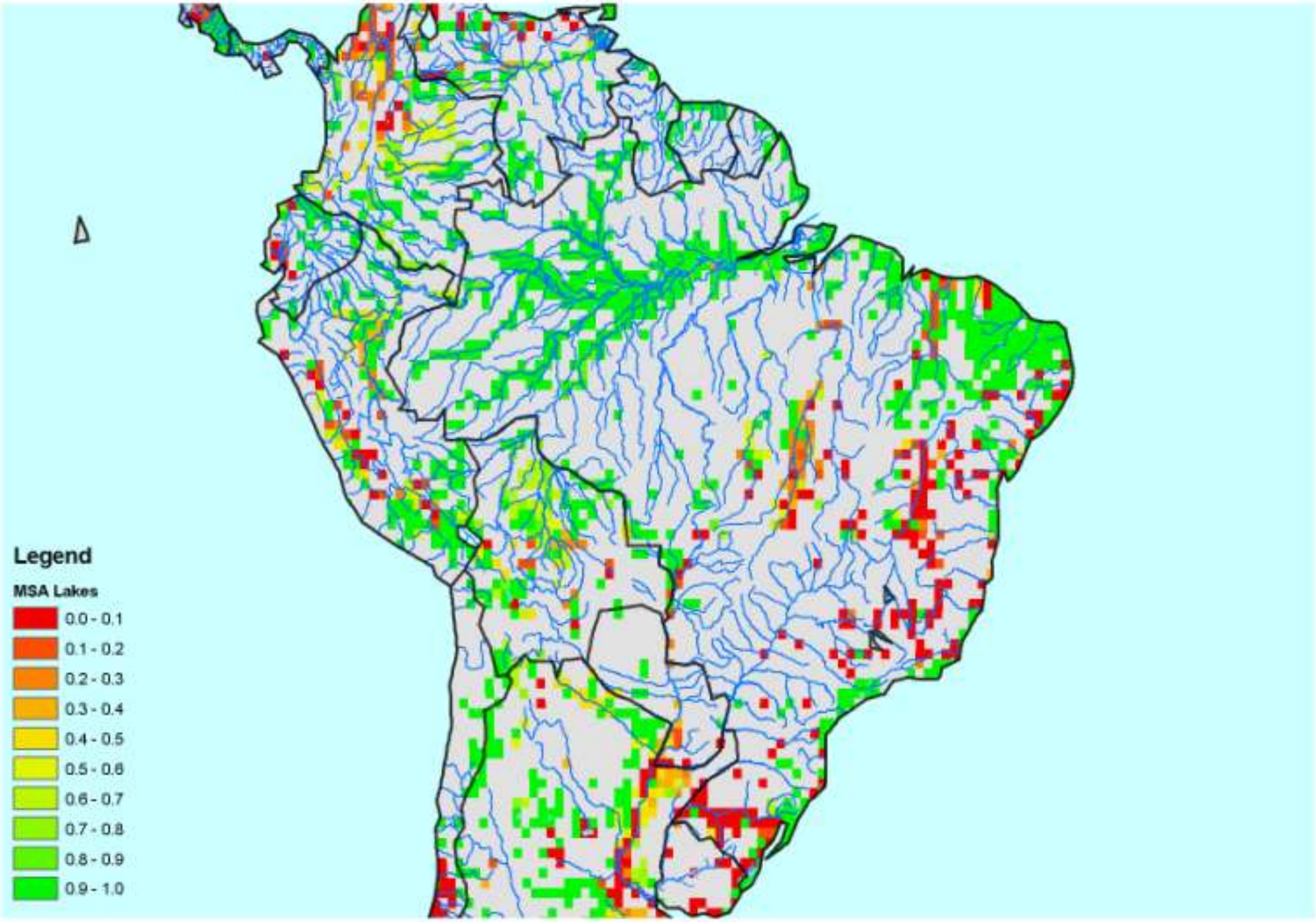
Preliminary results: Relative biodiversity in lakes

MSA remaining in lake cells based on phosphorus loading upstream

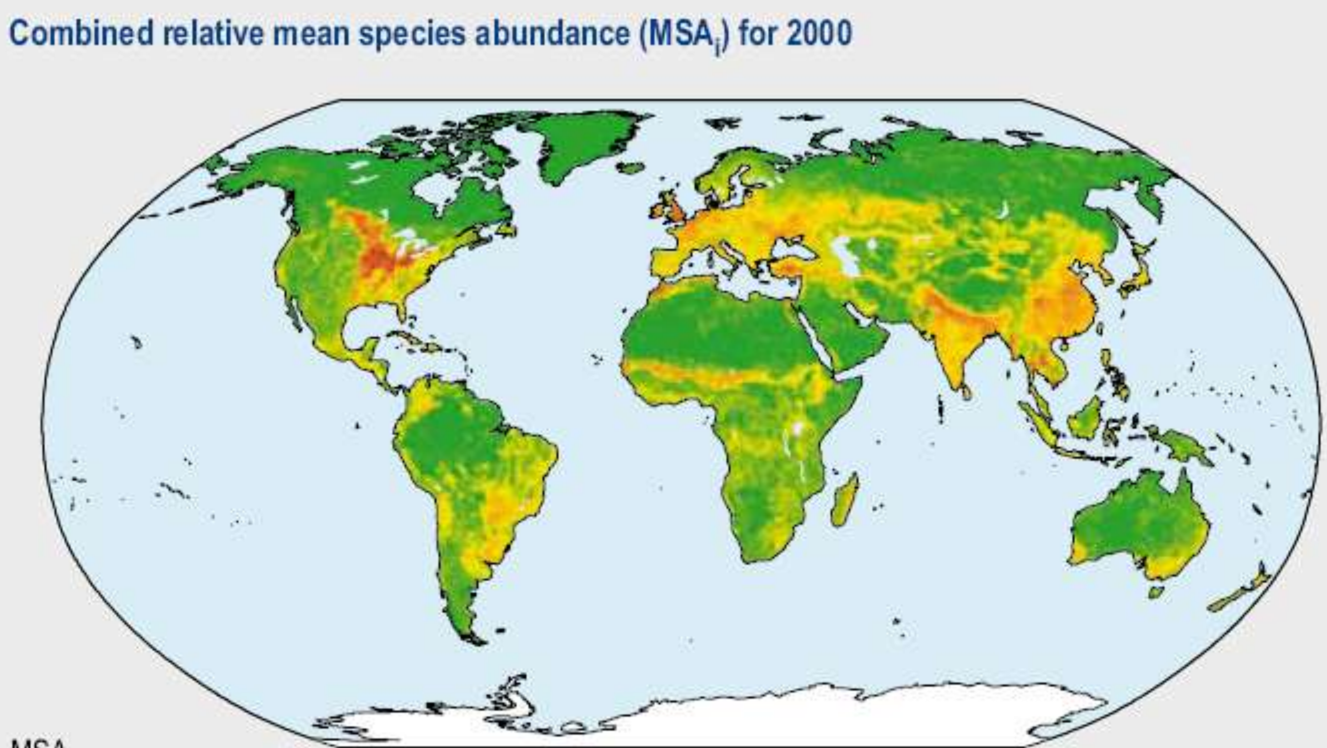


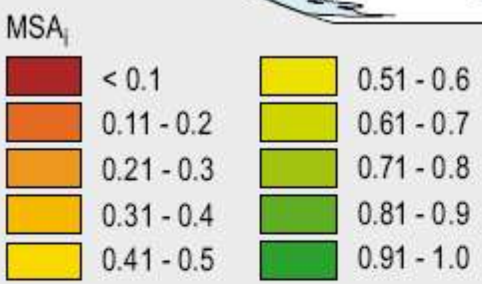
Relative biodiversity in lakes (Brazil)

MSA remaining in lake cells based on phosphorus loading upstream



For comparison: GLOBIO terrestrial model





MSA_terrestrial =
MSA_Lu * MSA_Infra * MSAFrag * MSA_N * MSA_Climate

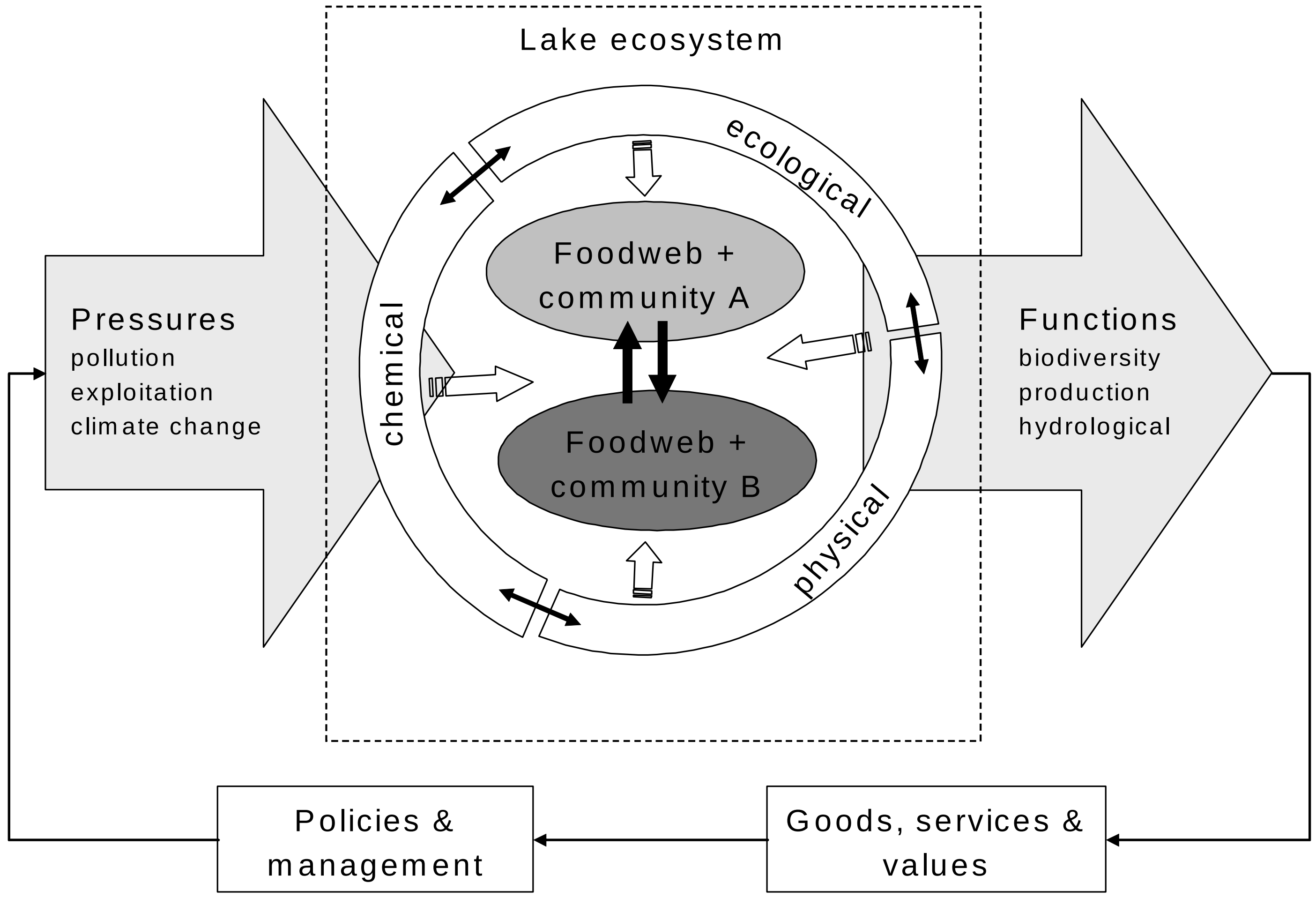
MSA_aquatic (lakes, rivers & wetlands) =
MSA_Lu/Nutrients * MSA_flow * MSA_Climate * MSA_fishery

6. INTEGRATED APPROACH: Functional lake module

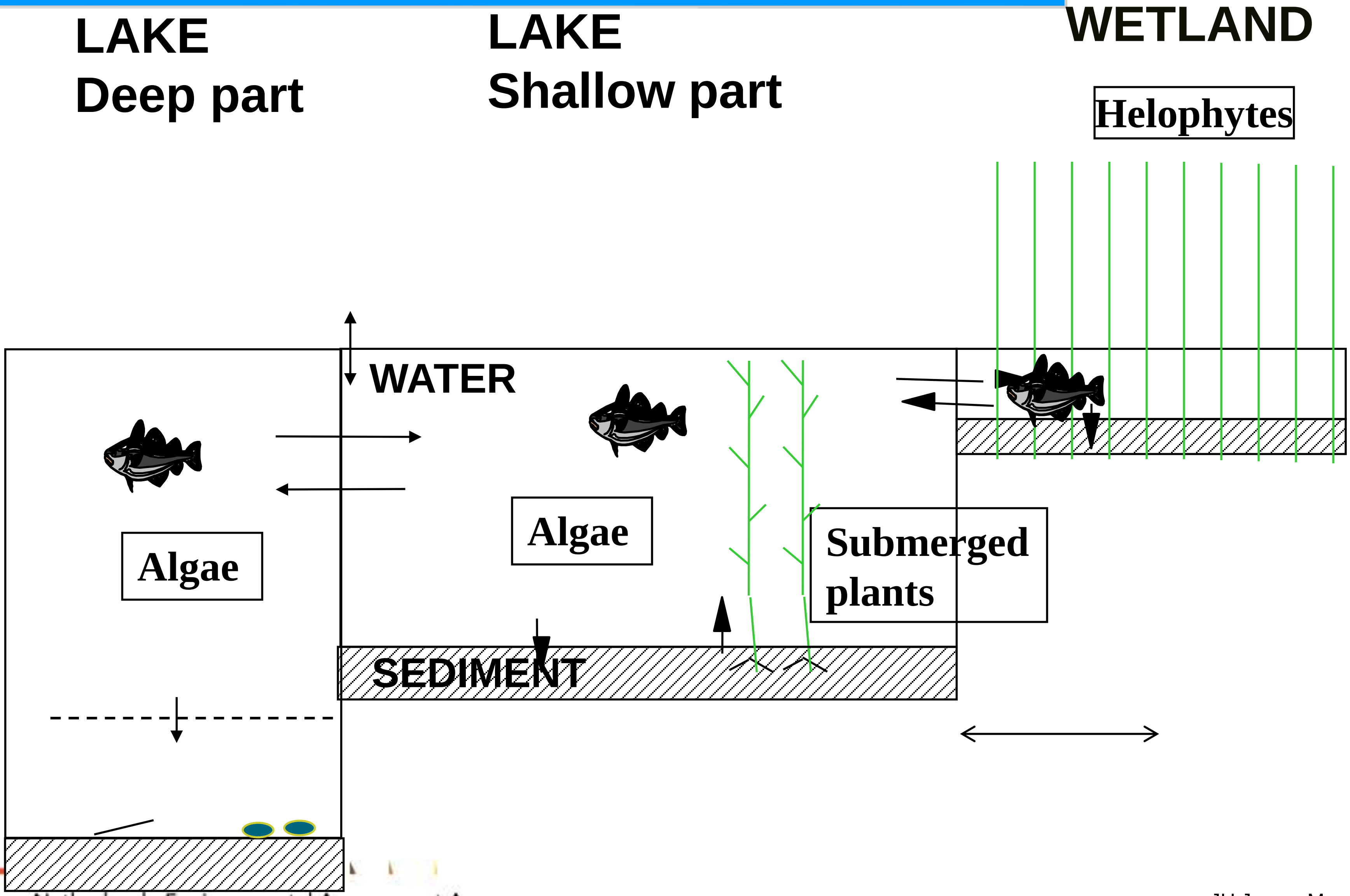
Aim: integrative tool for environmental quality and exploitation of lakes.

- Combination of mass fluxes, ecological processes + food web (functional groups)
- To be parameterized based on (regional) lake features
- To be coupled with global aquatic MSA model

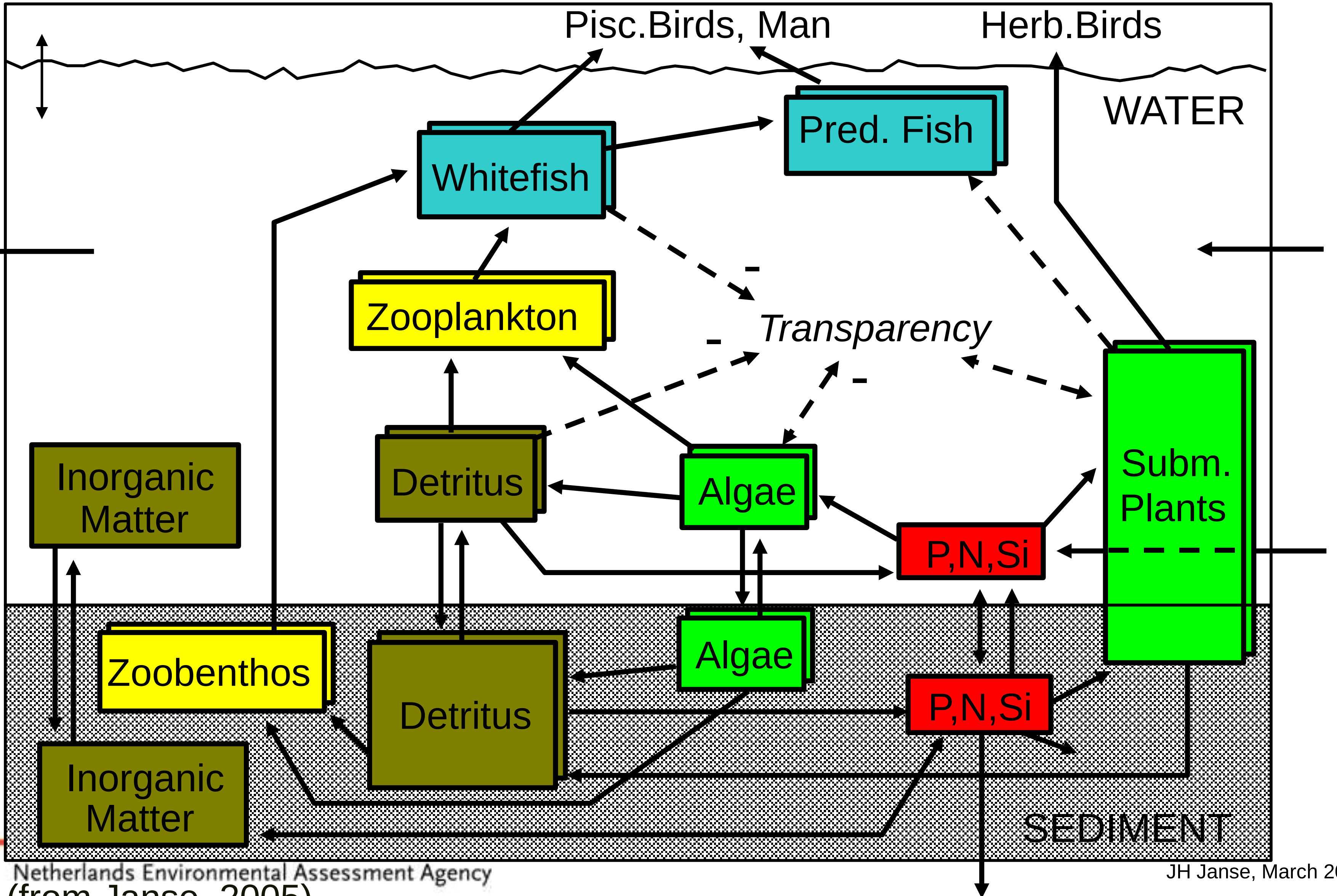
Pressures, processes and states in lakes



Functional lake model: *GLake (in dev.)*

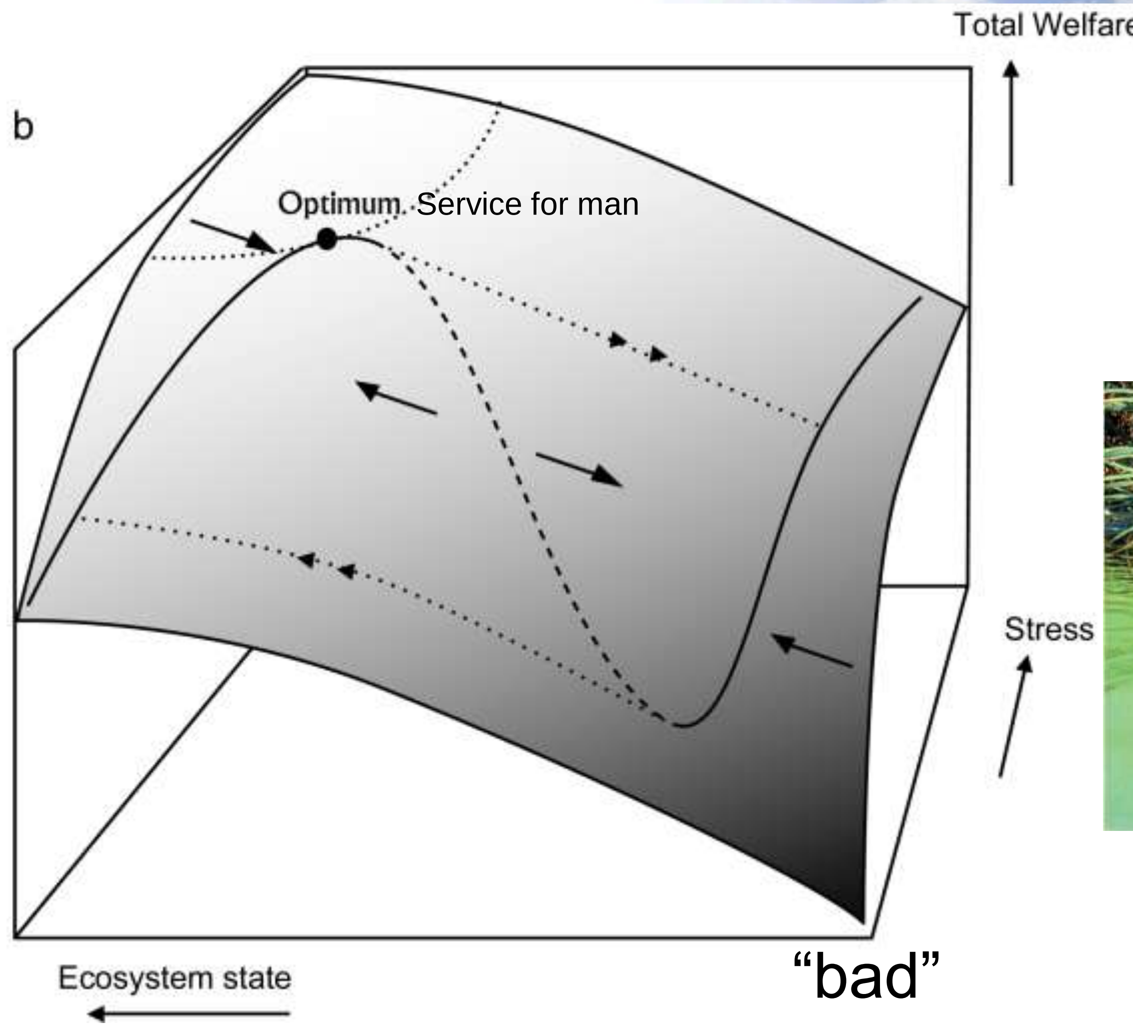


Functional lake model: *GLake*, shallow lake part



(from Janse, 2005)

Pressure, ecosystem quality and ecosystem services



“good”

“bad”

The optimum for multi-stable systems is typically at the edge of collapse

Scheffer, Brock and Westley, *Ecosystems, 2001*

7. REGIONAL APPLICATION: Lake Cocibolca and its catchment, Nicaragua

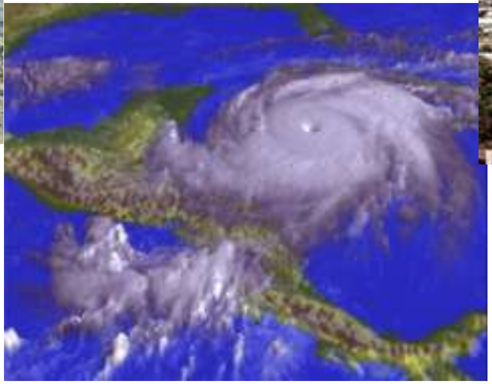
C.Poveda, Y.Flores, CIRA-UNAN, Managua

Some factors that affect water quality in Central America

Extensive Agriculture

Domestic Use

Climate Change



Erosion

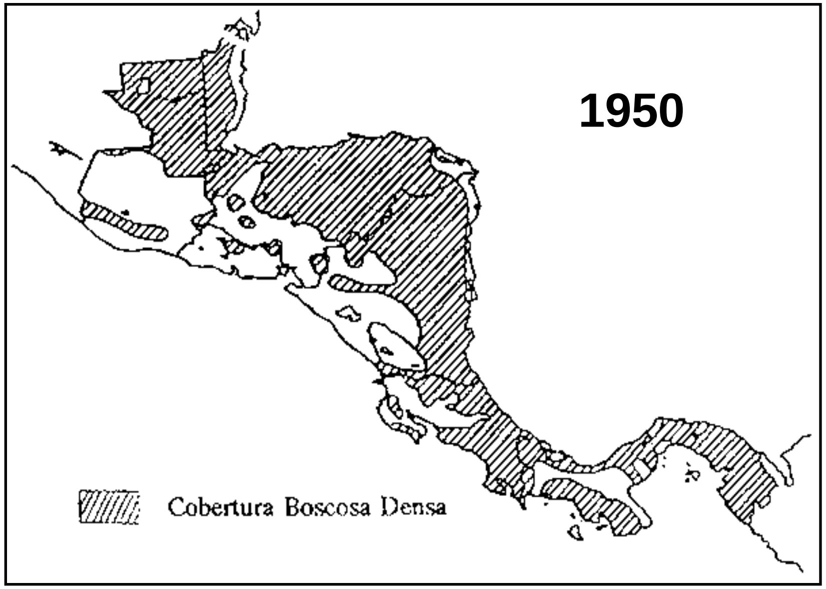
Solid and waste water

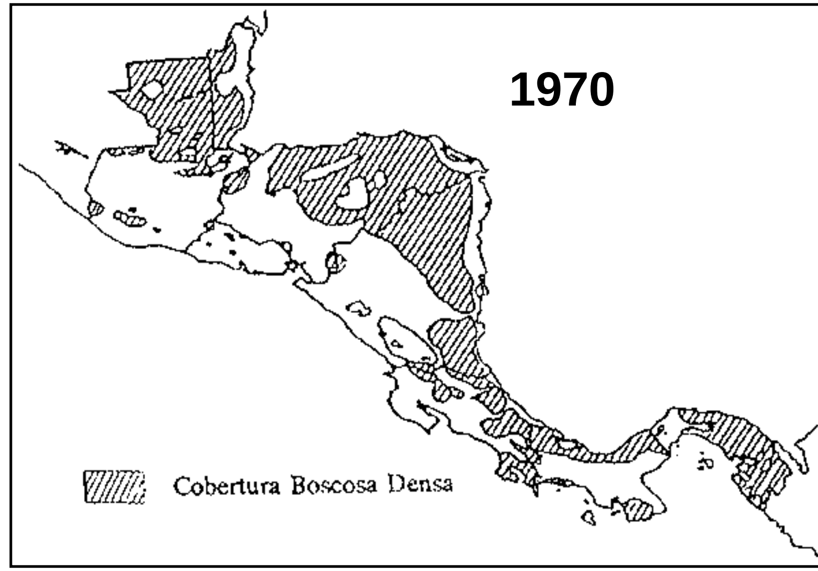
Signs of Progressing Eutrofication of Lago Cocibolca

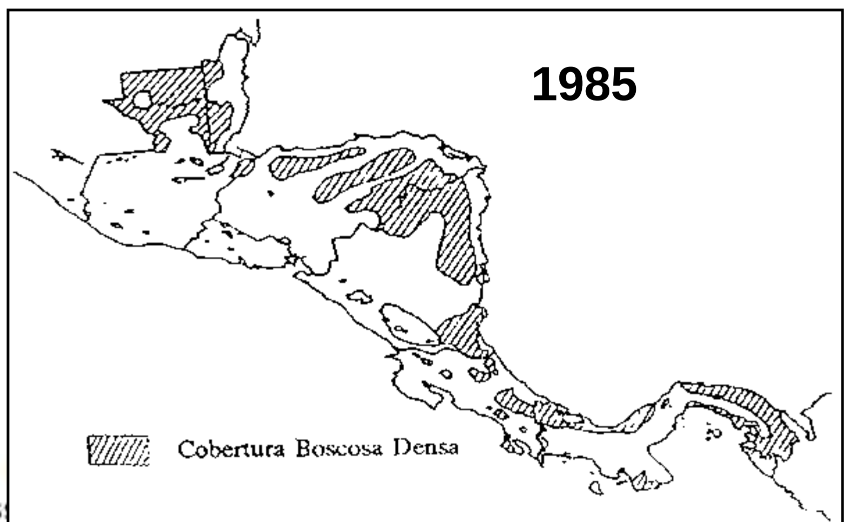
Massive Fish Kills

September, 2004 Isla de Ometepe

Deforestation in Central America
Forest Coverage 1950, 1970 and 1985

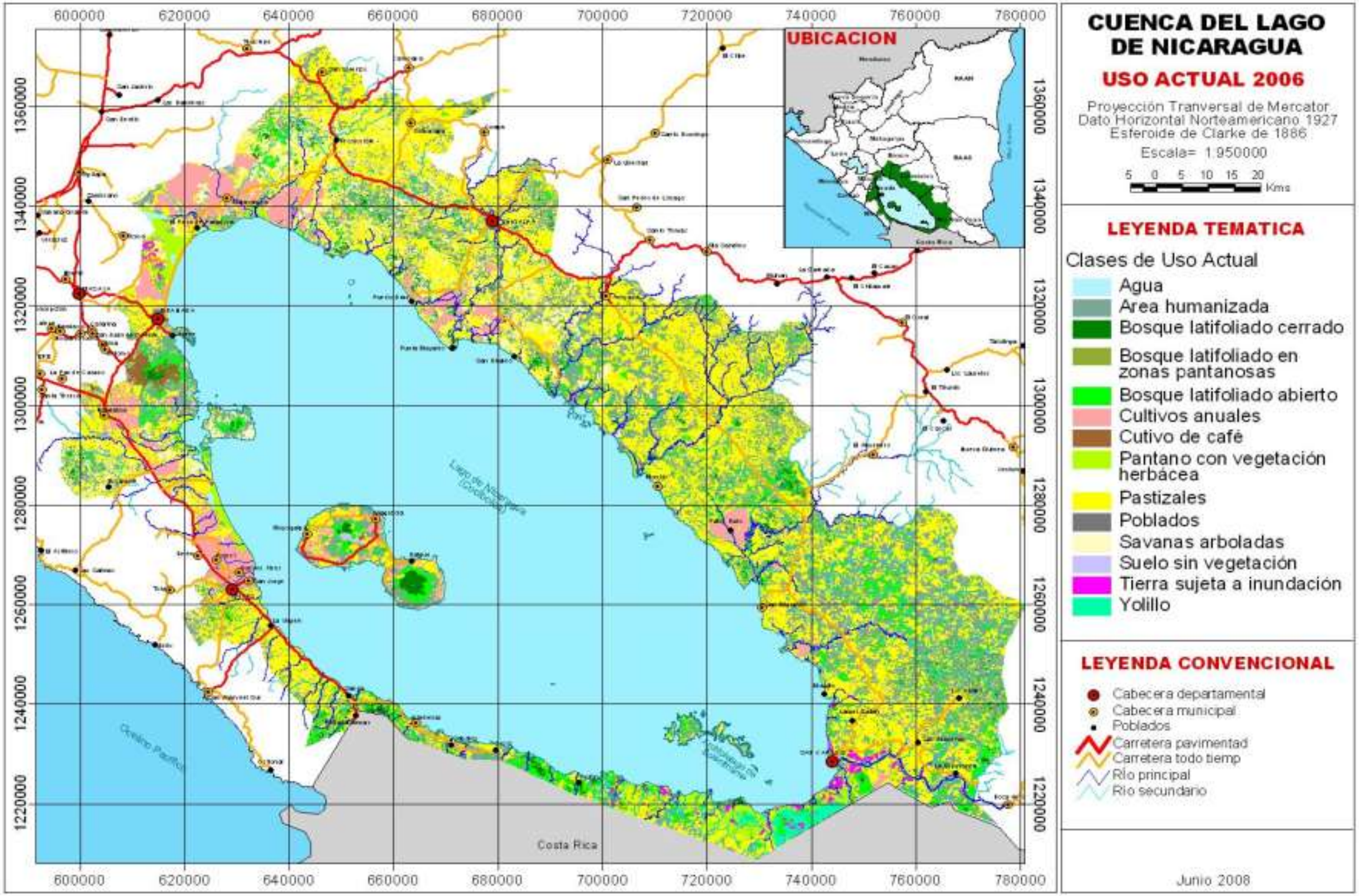




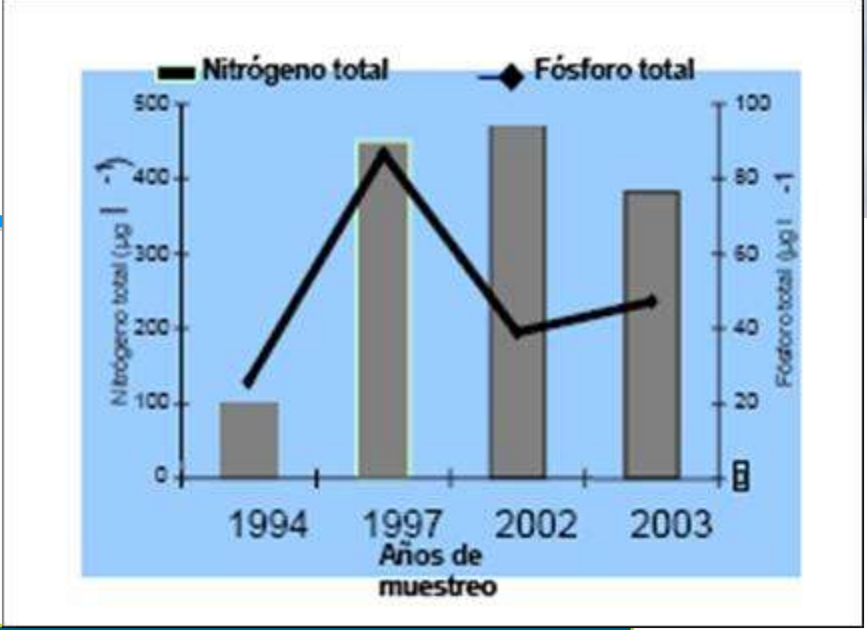


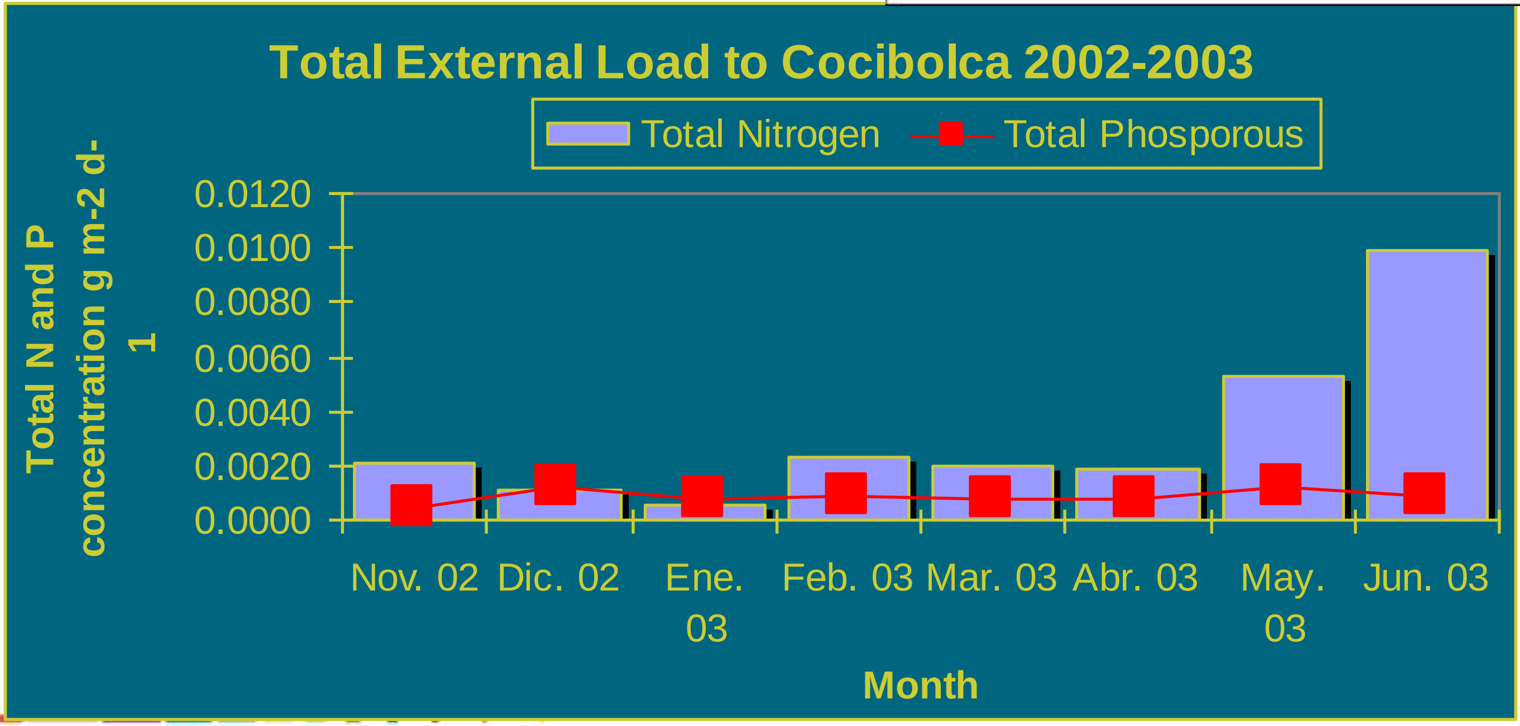
Land Use

Eutrophication of Surface Waters Lake Cocibolca



Nutrient increase

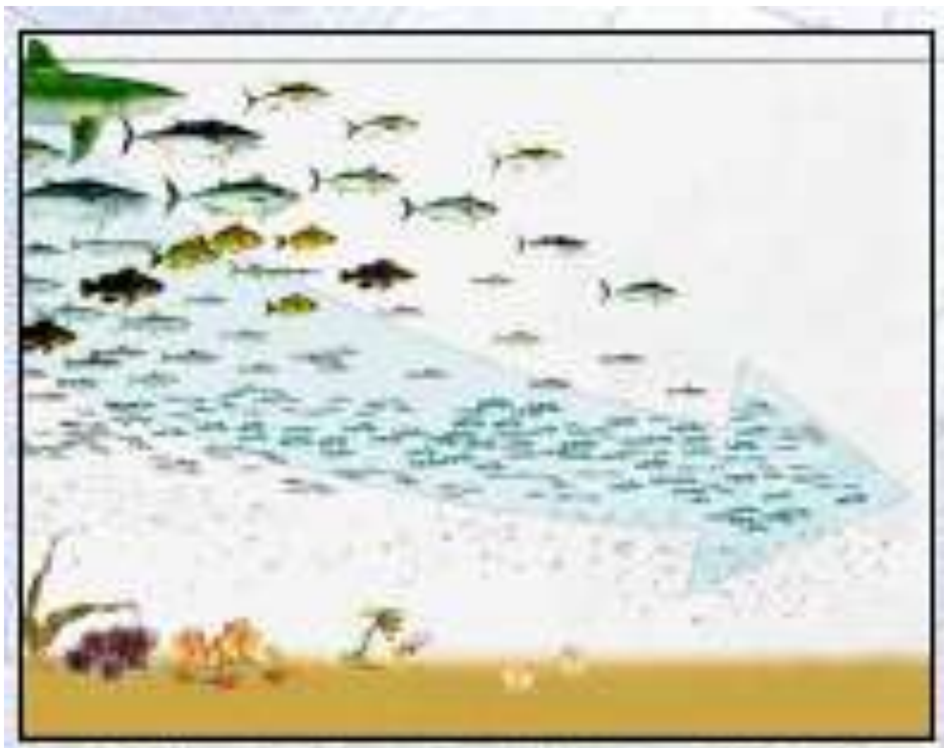




7. MARINE SYSTEMS

EcoOcean model (Christensen & Pauly, UBC)

- Food-web model, built in Ecopath-with-Ecosim
- Indicators: Marine Trophic Index (MTI), Depletion Index



The homogenisation process in the sea, caused by 'Fishing down the food chain'. Source: Pauly et al. 1998

Change in marine biomass N. Atlantic, 1900-2000

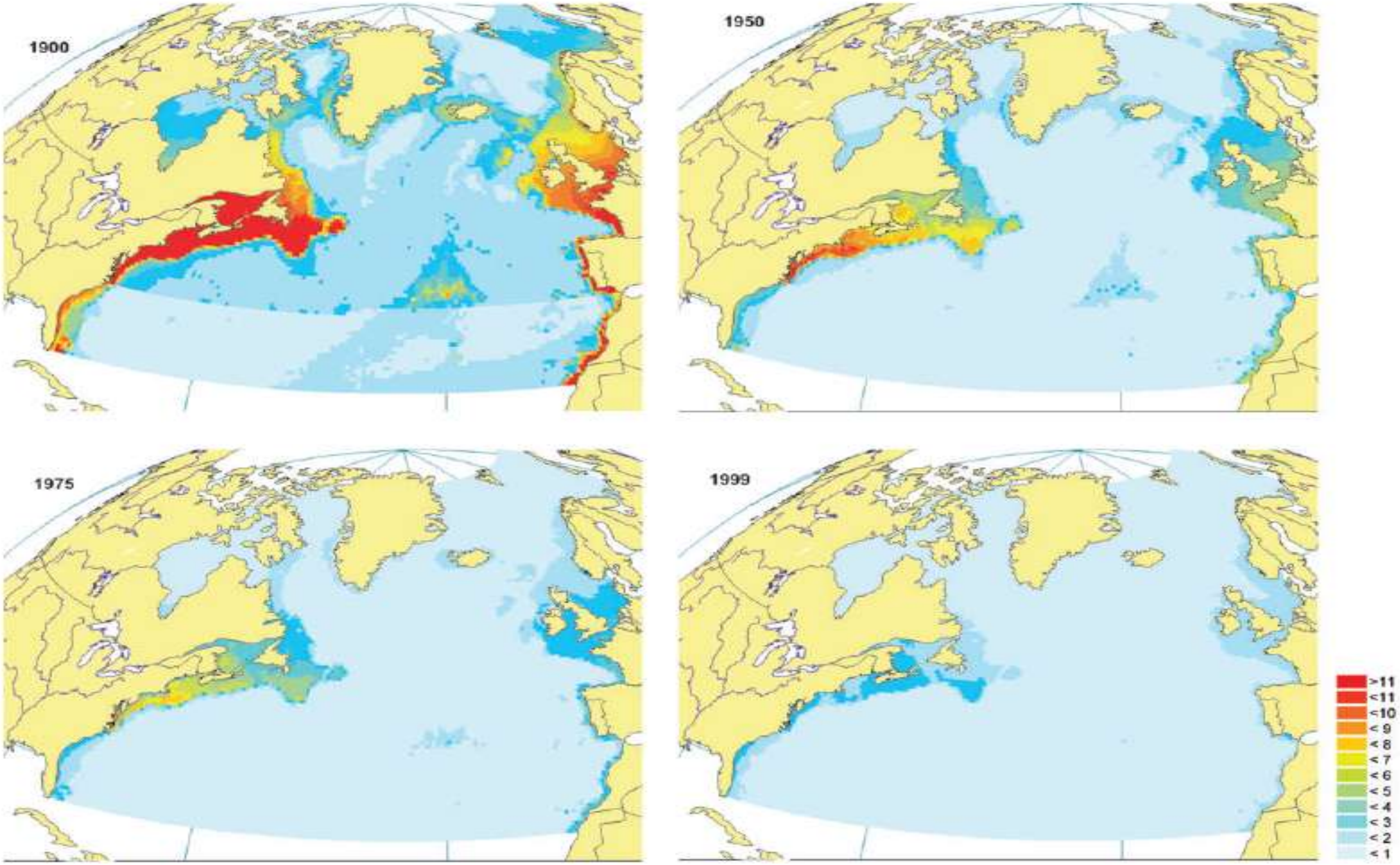
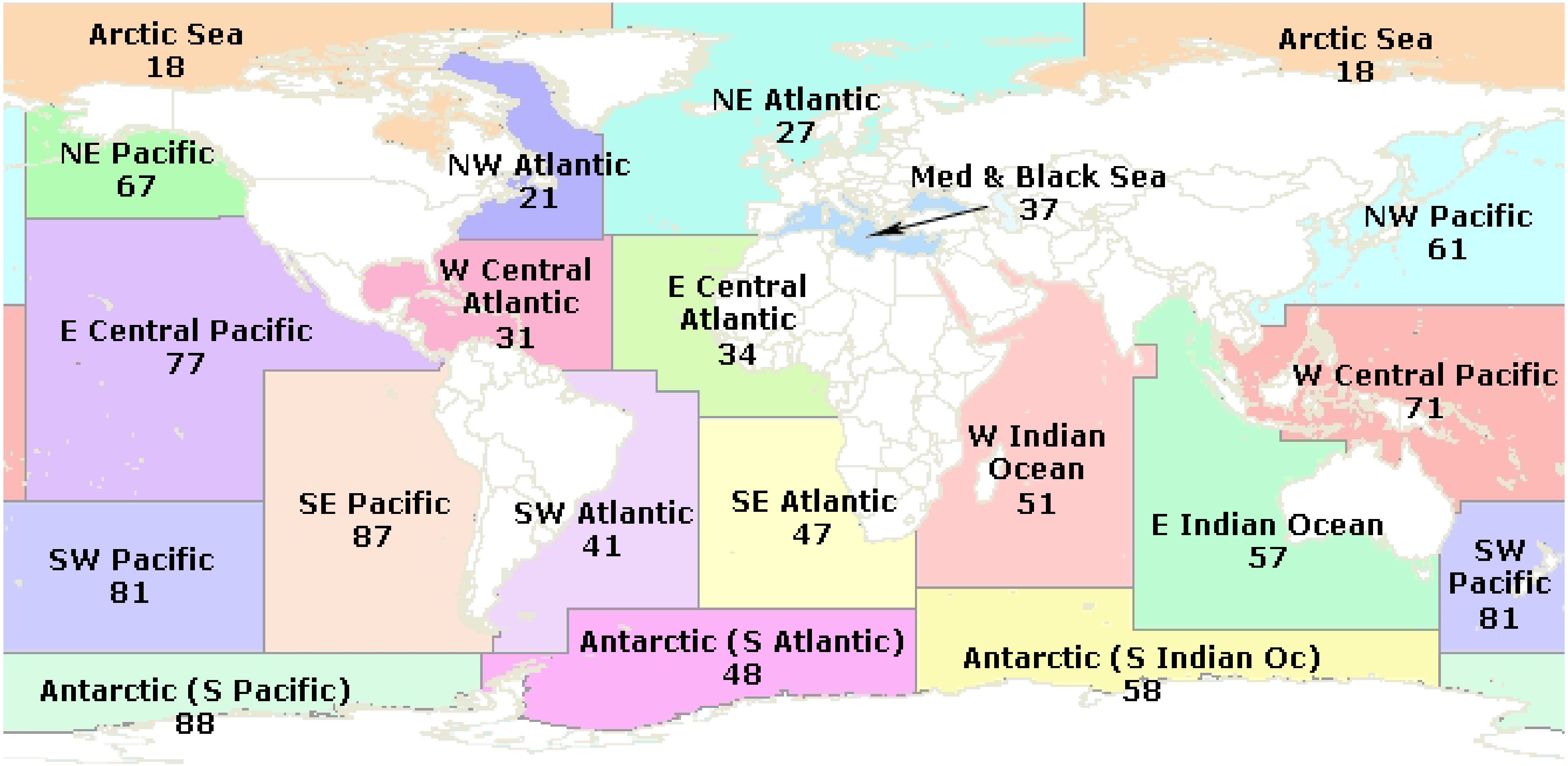


Figure 18.8 Changes in Marine Biomass in North Atlantic in 1900, 1950, 1975, and 1999 (in tons per square kilometer) (Christensen et al. 2003)

FAO marine areas



8. SUMMARY AND CONCLUSIONS

- Different types of aquatic ecosystems, with high biodiversity; arranged in catchments
- Main impacts: land use changes, flow deviations and overexploitation
- Combined model approach: scenarios for catchment land use, eutrophication and river regulation can be applied
- Lack of data, or data in different units
- Often high variability
- Different pressures often occur together

Further developments

- Spatial scale: 0.1 degree grid, and/or improvement of spatial relations
- Improvement of P leaching module
- Extend biodiversity relations, esp. for wetlands
- Integration of different pressures (also climate change, exploitation; invasions?)
- Refinement for subtypes and regions
- Validation: GEMS/ Water database, regional data
- Integrated approach based on functional groups (guilds)
- Link with human functions (G&S)

THANK YOU