Understanding and Managing the Range of Phosphorus Forms Contributing to Eutrophication

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Session 3: Monitoring and evaluation of the immission situation in surface waters: Chemical water quality

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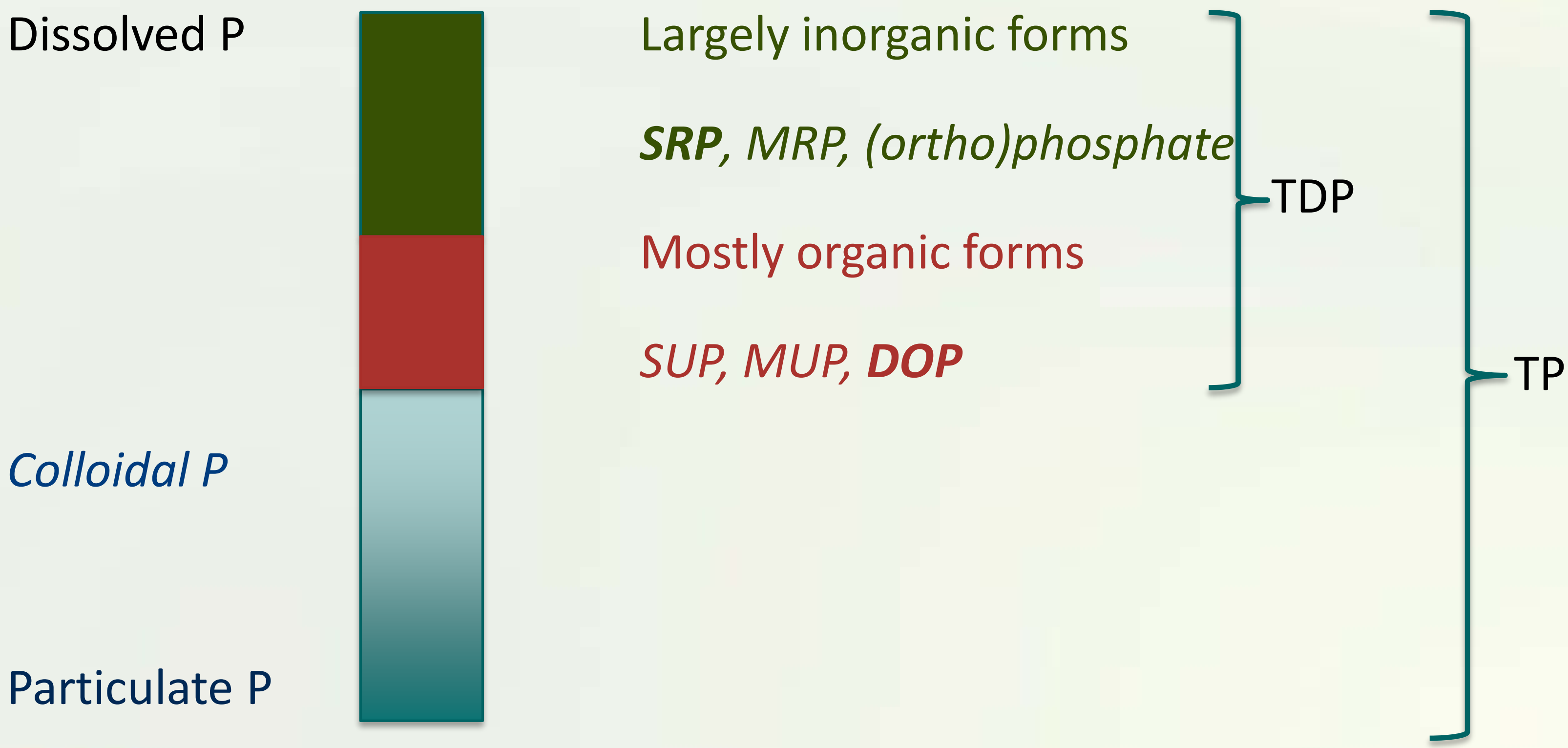
Talk structure

- Forms of P in freshwaters
- Background to chemical water quality standards for P
- Relationships between P concentrations and eutrophication
- Tools and goals for managing P concentrations
- Key messages for P water quality standards

Forms of P in freshwaters

- Different analytical conditions give numerous definitions of P forms (depends on filtering and analysis method)

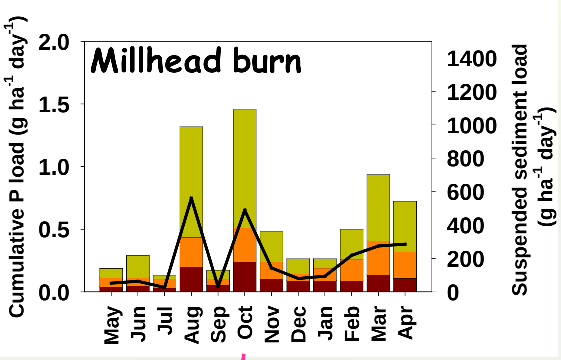


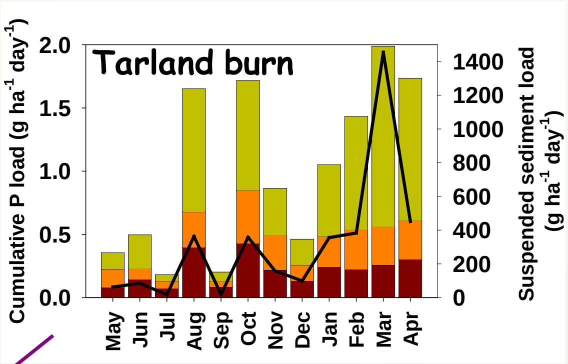
Forms of P in freshwaters

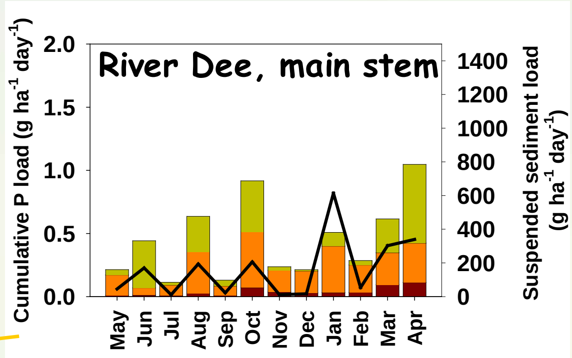
- The different notations and their governing methodologies give confusion across scientific and regulatory communities
- A standardisation of methods is required. Different extractants measure P of varying bioavailability.
- Example: Total P may be determined as TP = TDP+PP determined individually, or as a digest of an unfiltered water sample

P in a mixed land use UK river system – River Dee, NE Scotland

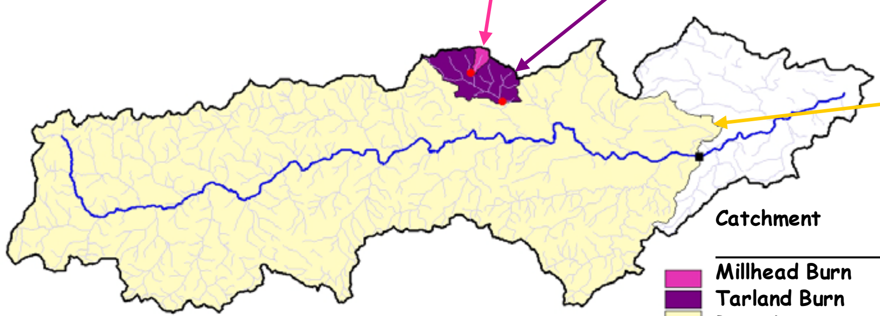
Spatio-temporal variability in P loads







- Suspended sediment (>0.45µm, dry mass)
- Particulate P (>0.45µm)
- Dissolved organic P
- SRP



Catchment	Area (km2)	%Improved grassland	% Arable
Millhead Burn	4.3	21	25
Tarland Burn	51	25	35
River Dee	1844	8	6

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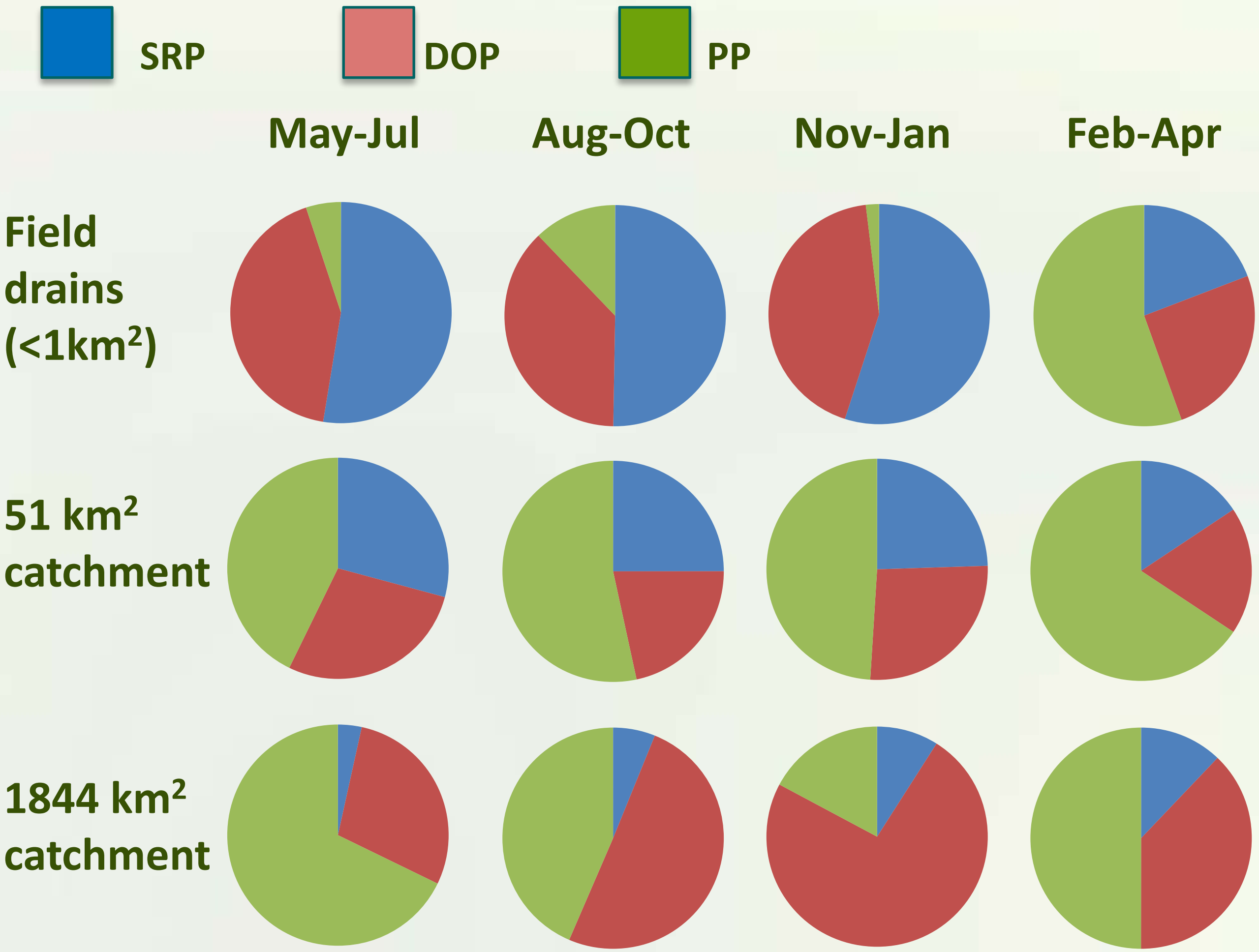
Spatio-temporal variability in P concentrations

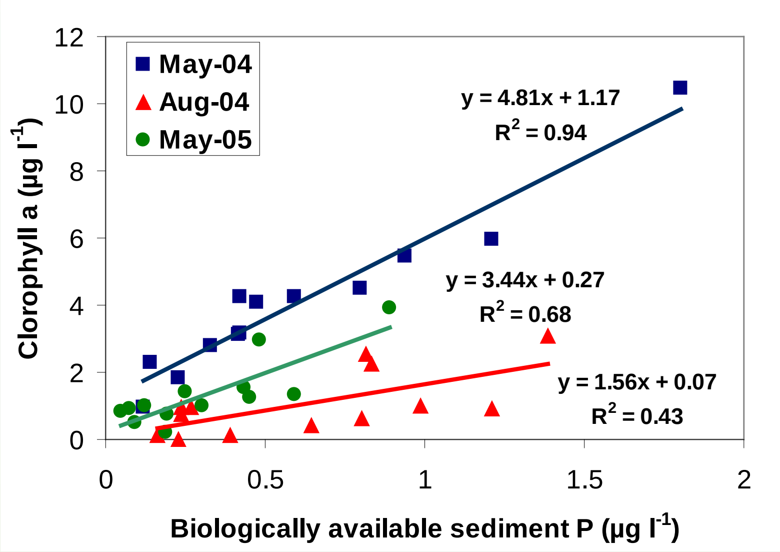


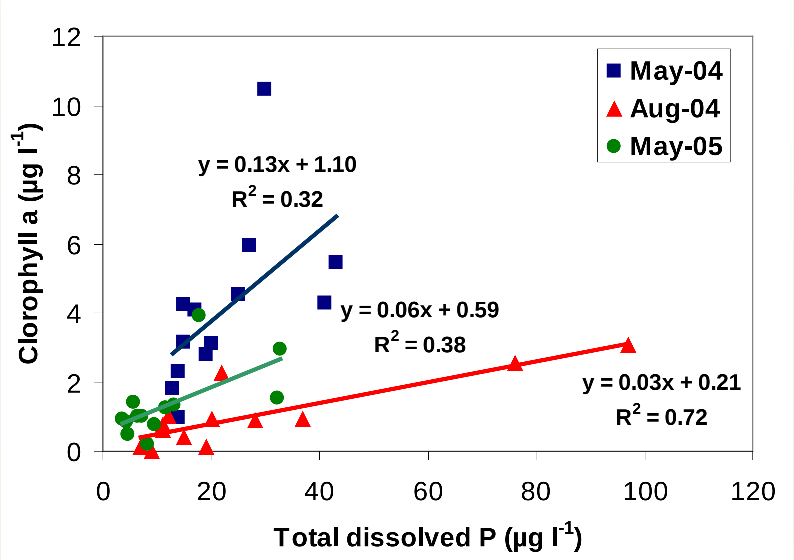
Mostly dissolved P apart from flush of particulate P in spring

Half particulate P, but equal DOP and SRP

Little SRP, but variable dominance of DOP and particulate P

How important are forms of P to biota?





In spring chlorophyll *a* concentrations are related to suspended sediment bioavailable P concentrations

In late summer the relationship is better with dissolved P

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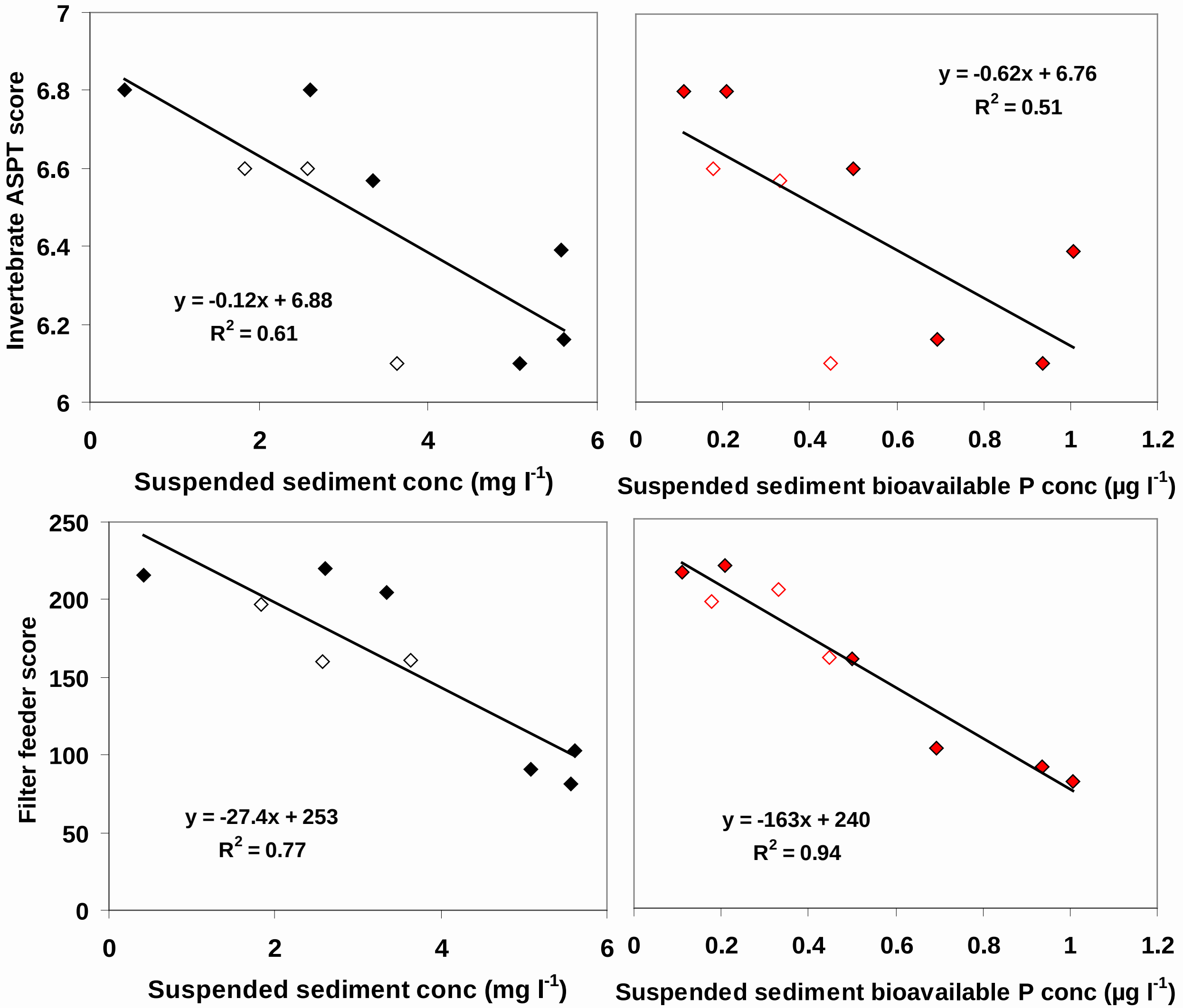
How important are forms of P to biota?



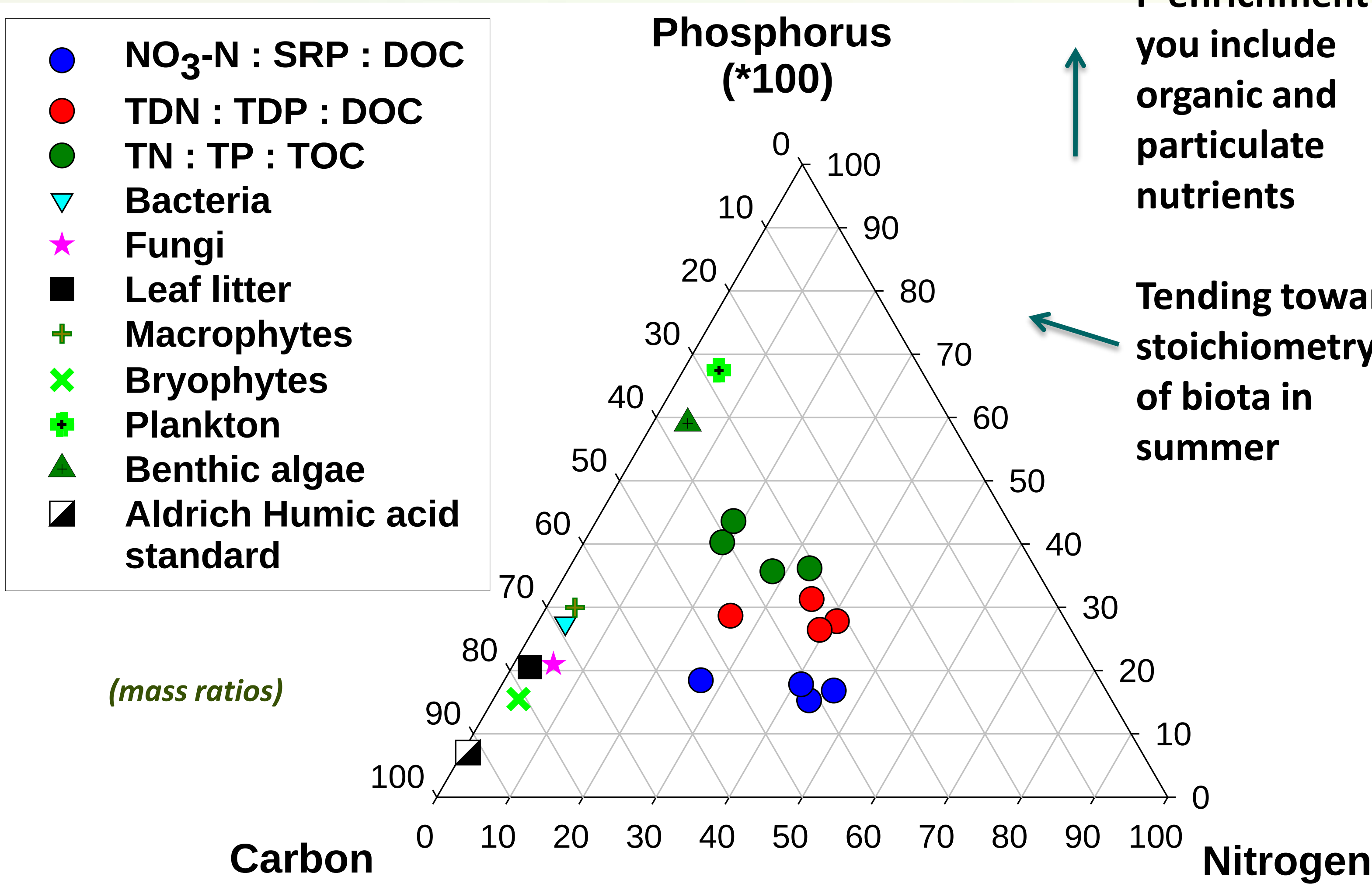
General metric:

Average Score Per Taxa

Targeted metric:

Site abundance of filter feeding invertebrates

Forms of P in freshwaters

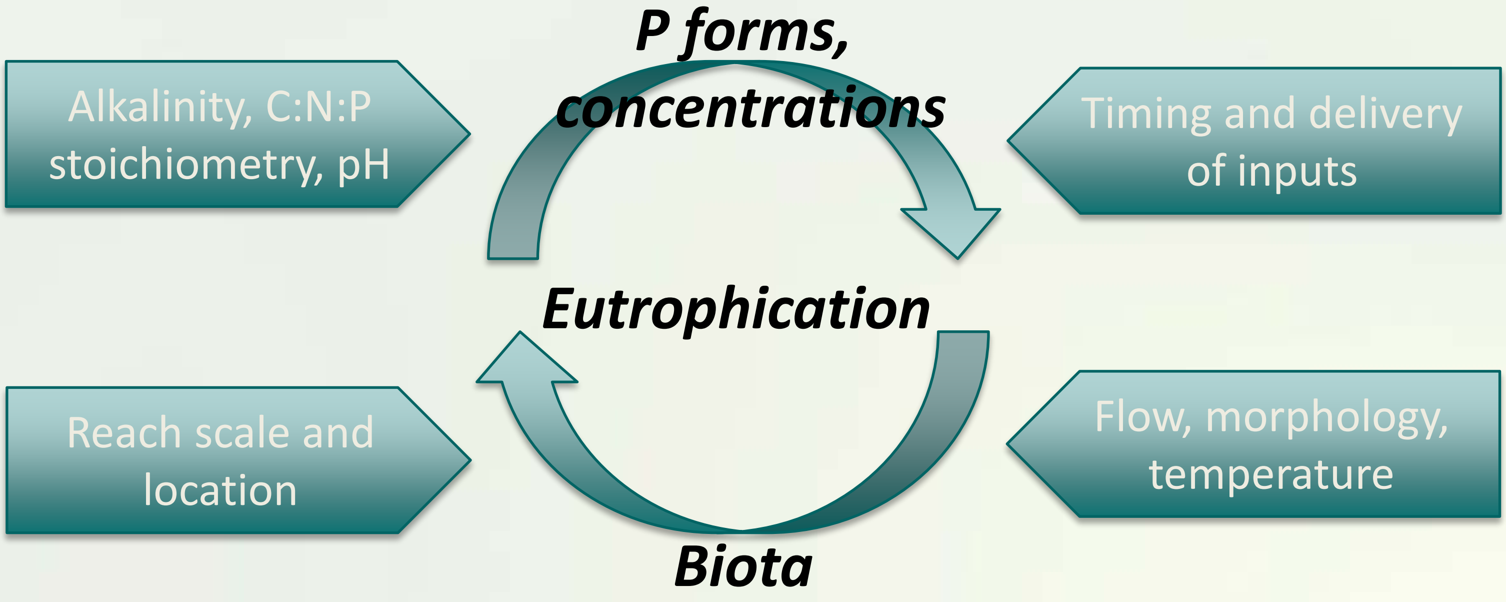


P enrichment as you include organic and particulate nutrients

Tending toward stoichiometry of biota in summer

Forms of P in freshwaters

- Question: To what extent do these forms of P *contribute* to eutrophication and how much do they *result* from eutrophication, for various components of the stream biota?



Water quality standards for P

- WFD uses *chemical classification* alongside *ecological classification* – waterbodies must achieve both to attain good status.
- WFD has a *risk based* approach – to identify waterbodies at risk of failing GES and derive priorities for the RBMP process
- WFD has inherent simplifications. Only a simple range of parameters having ‘established’ relationships with eutrophication are used (SRP for rivers, TP for lakes).
- Guards against:
  - Wrongly classifying sites that are ecologically poor
  - Using standards that are not driving the biological deterioration

Water quality standards for P
UK rivers

- Standards for SRP, based on relationships with diatoms as the most sensitive ecological component. DARES project (Diatoms for assessing river ecological status, using 608 samples)

Table 2: Standards for river water quality covered in this report

Conditions	Parameter	Biological Element
Oxygen	BOD, Dissolved Oxygen	Macro-invertebrates
Ammonia	Ammonia	Macro-invertebrates
Acid	pH	Fish
Nutrient	Phosphorus	Diatoms

Standards from: UK TAG Environmental standards and conditions. Final Report, 2008.

Water quality standards for P
UK lakes

- Standards for total P

Table 13: Summary of standards for lakes		
Conditions	Parameter	Biological Element
Oxygenation	Dissolved Oxygen	Fish
Salinity	Conductivity	All
Acidification status	Acid Neutralising Capacity	Diatoms
Nutrient conditions	Total Phosphorus	Phytoplankton biomass (Macrophytes and phytobenthos)

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Water quality standards for P
UK transitional waters

- No P standards for transitional waters – although it is now suggested that N is not always more limiting!

Table 20: Summary of the standards for transitional and coastal waters		
	Parameter	Biological Element
Oxygenation conditions	Dissolved oxygen	Fish
Nutrient Conditions	Dissolved Inorganic Nitrogen	Plants

- Inconsistencies between the range and forms of P considered does not allow protection of connected aquatic ecosystems

Water quality standards for P
UK *rivers*

- UK P standards separate rivers into typologies:

Table 9: Typology for nutrient conditions for rivers

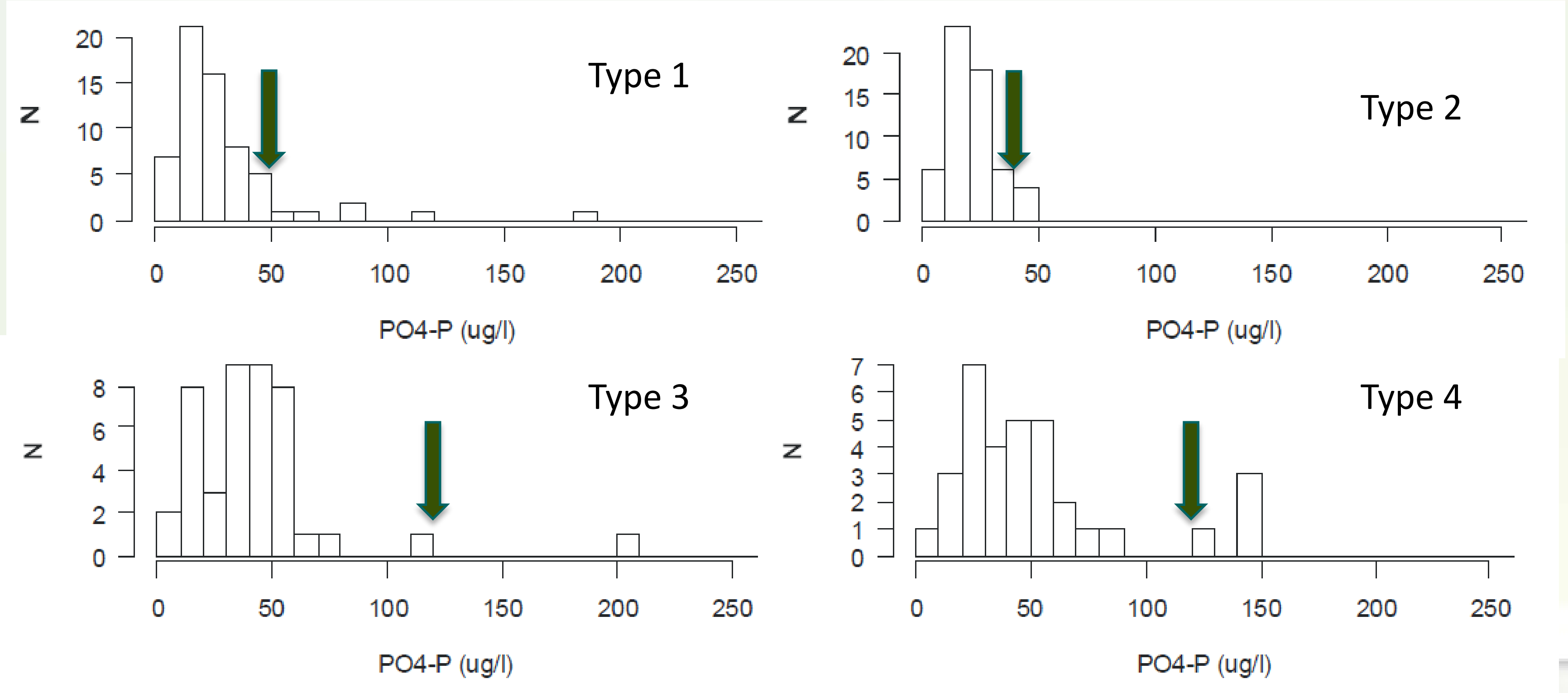
Altitude	Annual mean alkalinity (as mg/l calcium carbonate)	
	< 50	> 50
Under 80 metres	Type 1n	Type 3n
Over 80 metres	Type 2n	Type 4n

Table 10a: Standards for phosphorus in rivers

Soluble Reactive Phosphorus (µg/l) (annual mean)				
Type (Table 9)	High	Good	Moderate	Poor
1n	30	50	150	500
2n	20	40	150	500
3n + 4n	50	120	250	1000

Water quality standards for P
UK rivers *(Kelly et al.)*

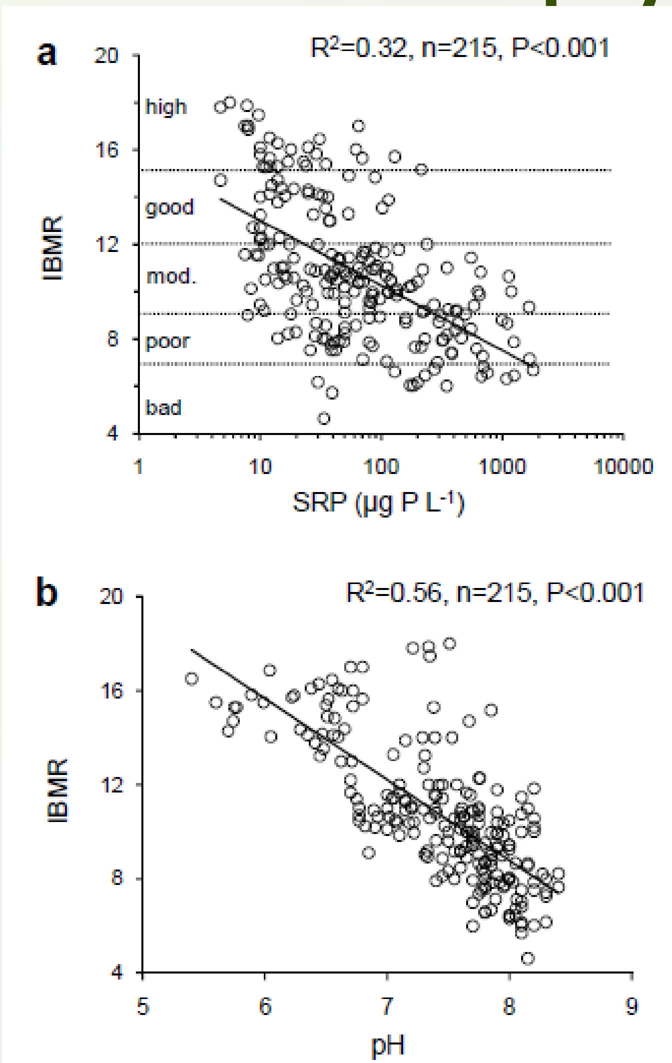
- The DTI gave considerable variability in the range of SRP concentrations for systems judged as ‘good’ ecologically, ie. ‘acceptable’ and that would require no remedial action



Water quality standards for P

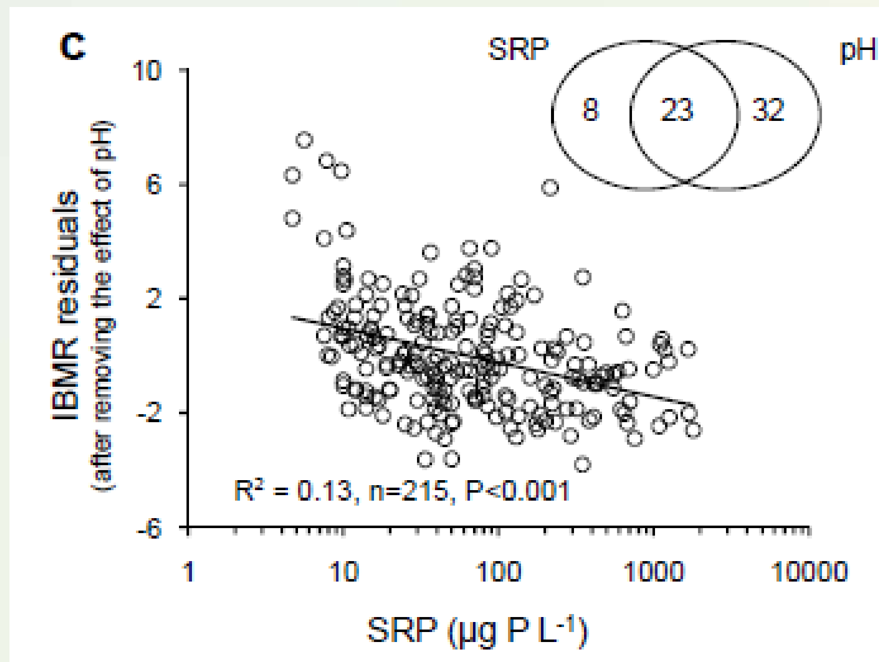
- Standards based on bioassay results would have dangerous scaling factors applied to transfer concentrations to real systems
- The scatter in chemical *vs* ecological response relationships is due to confounding factors – temperature, flow velocity, reach scale, nutrient stoichiometry (including C availability)
- Many of these factors make the relationship between concentrations of P forms and eutrophication difficult to predict and susceptible to environmental change (climate, land use, water abstraction)
- This is a problem given the goal of WFD to integrate chemical, biological and physical factors in guarding against impaired ecological function

French macrophyte index (IBMR)



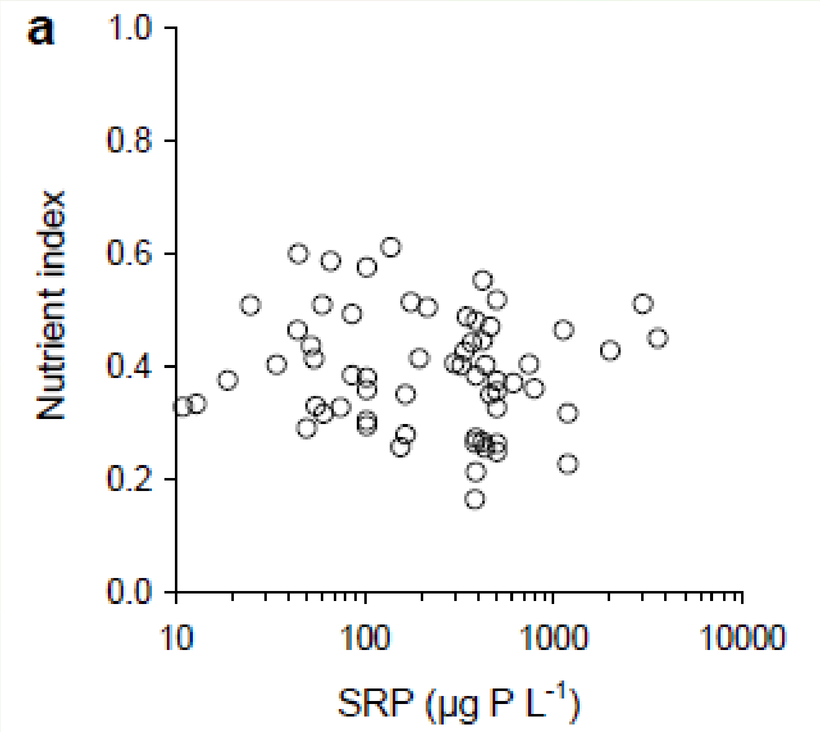
Scatter represents error in correct diagnosis of waterbody status

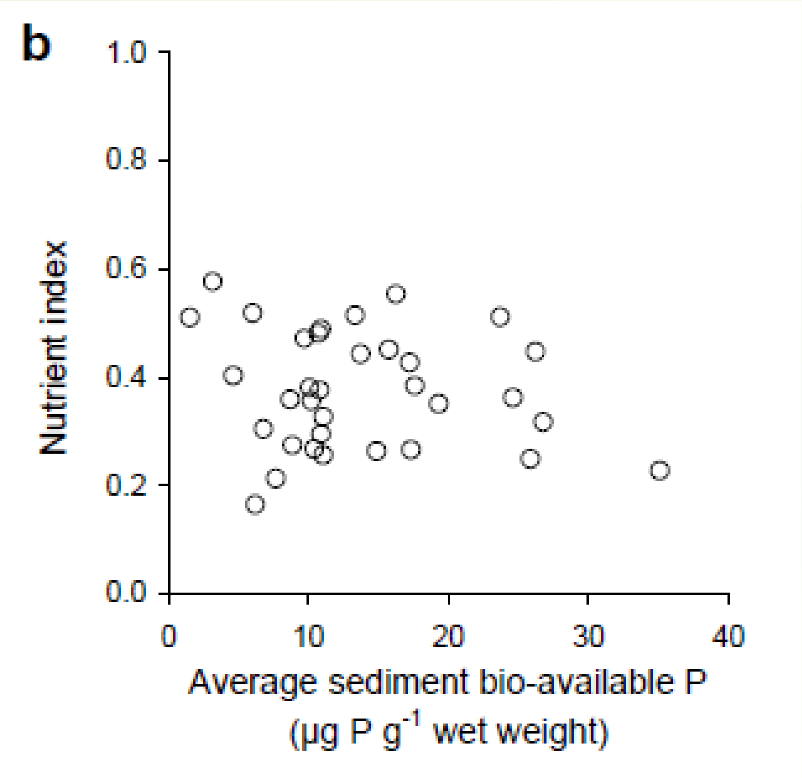
P concentration ranges are large but for individual systems of interest may be narrow



Demars et al (in preparation)

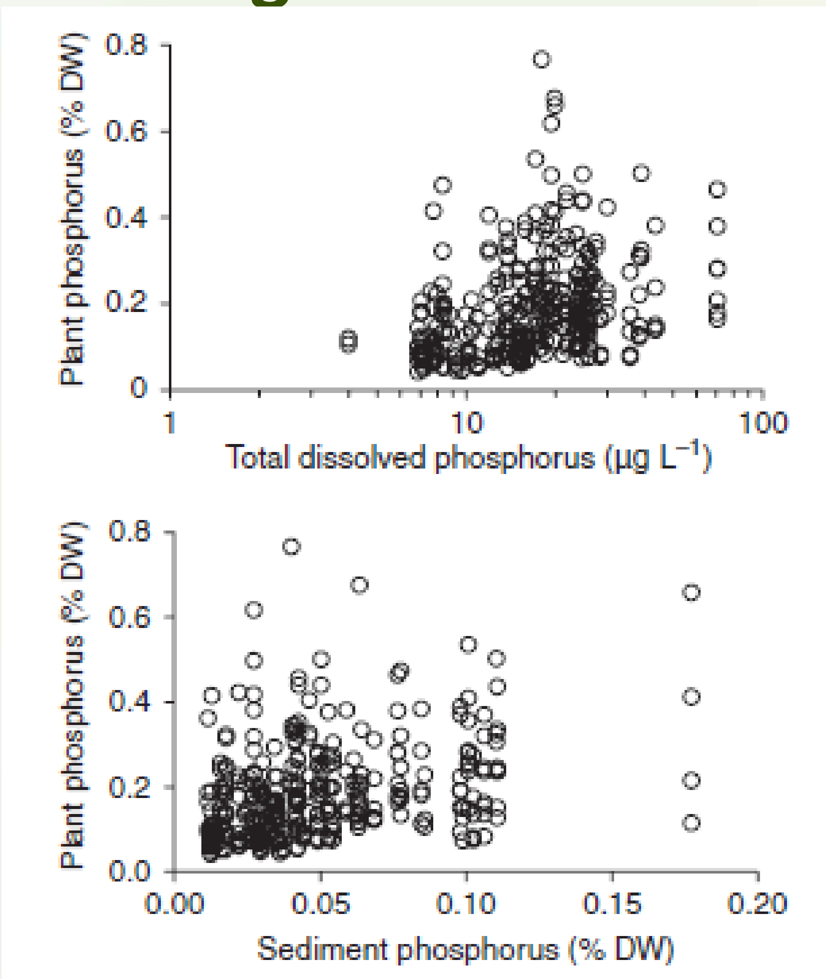
UK macrophyte index (LEAFPACS)

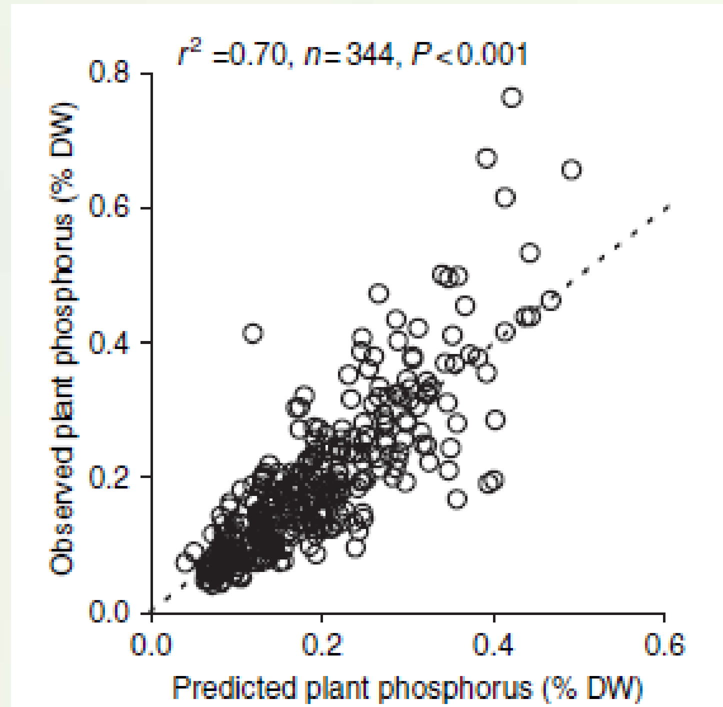




Demars et al (in preparation)

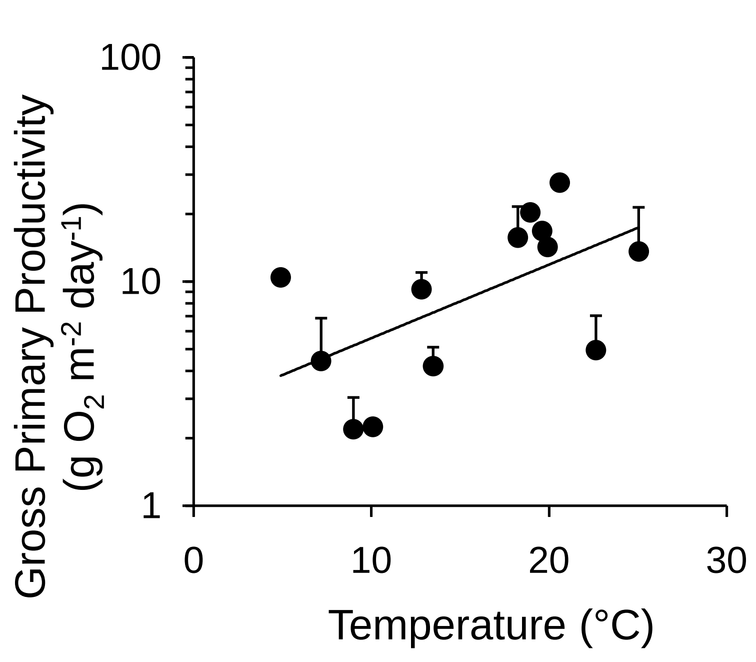
Plant stoichiometry: taxonomic effect is far stronger than water and sediment supply

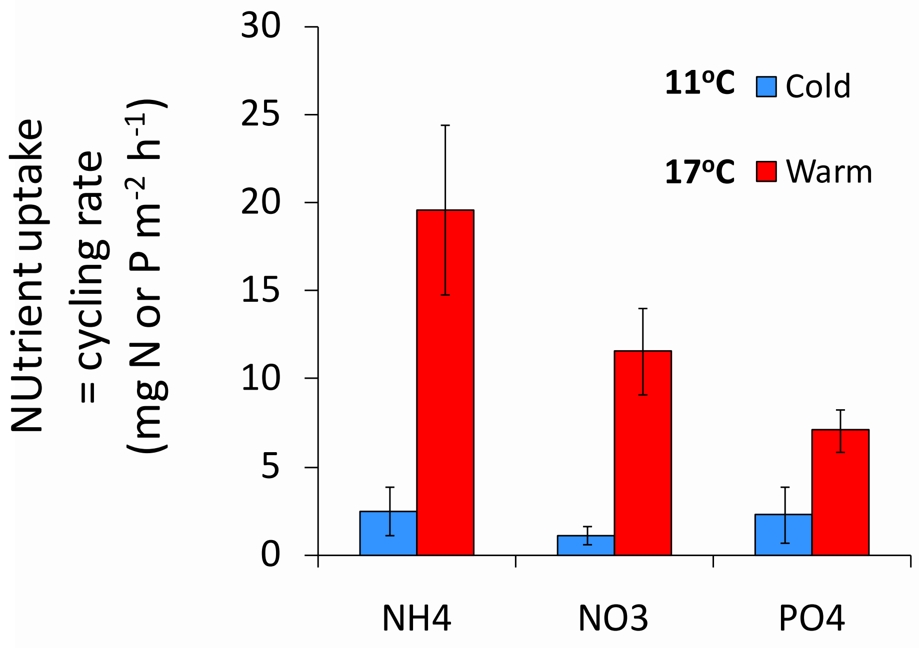




Demars & Edwards (2007) Freshwater Biology

The importance of stream *nutrient cycling rates:* nutrient limited Icelandic geothermal streams

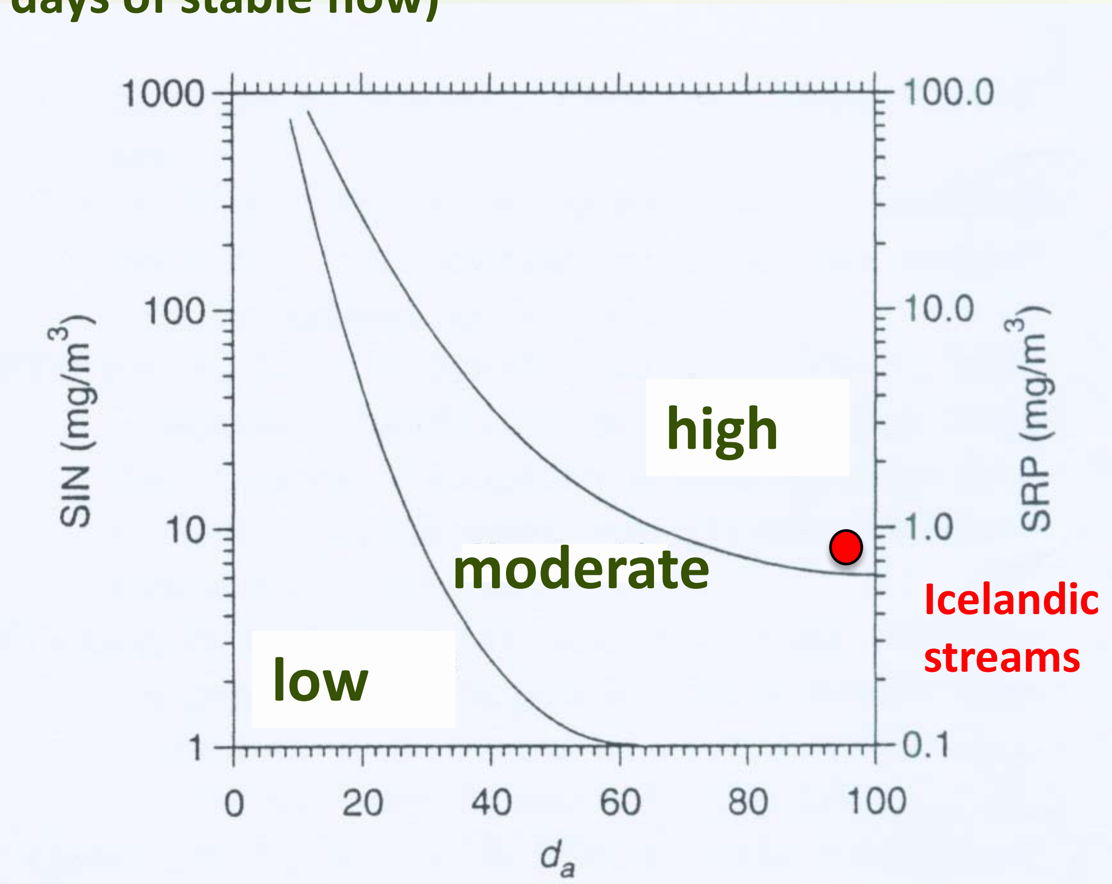




Demars et al (submitted)

Cycling rate may not just be confounded by temperature, but also flow

(da = number of days of stable flow)



modified from Biggs (2000) J.N.Am.Benthol.Soc.

Alternative approaches

- An alternative approach to setting goals for managing P inputs might be based on provision of watercourse ecosystem goods and services:
  - An acceptable ecosystem balance for all trophic levels (microbes, invertebrates, fish, humans?)
  - Ecosystem resilience and protection of downstream communities
  - Whole stream metabolism approaches (nutrient spiralling)
- How could these be implemented as practical metrics, not just as research tools?

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Reach-scale SRP addition experiment

- We tried to separate abiotic (ie sediment) and biotic (autotrophs and heterotrophs) P cycling
- We used a range of complimentary, independent assessments
- Test of hypotheses:
  - That a river system switches from a P sink to source when point source P inputs are removed
  - That SRP uptake is dominated by biology, hence leading to eutrophication
  - That SRP uptake provides only temporary protection of downstream reaches

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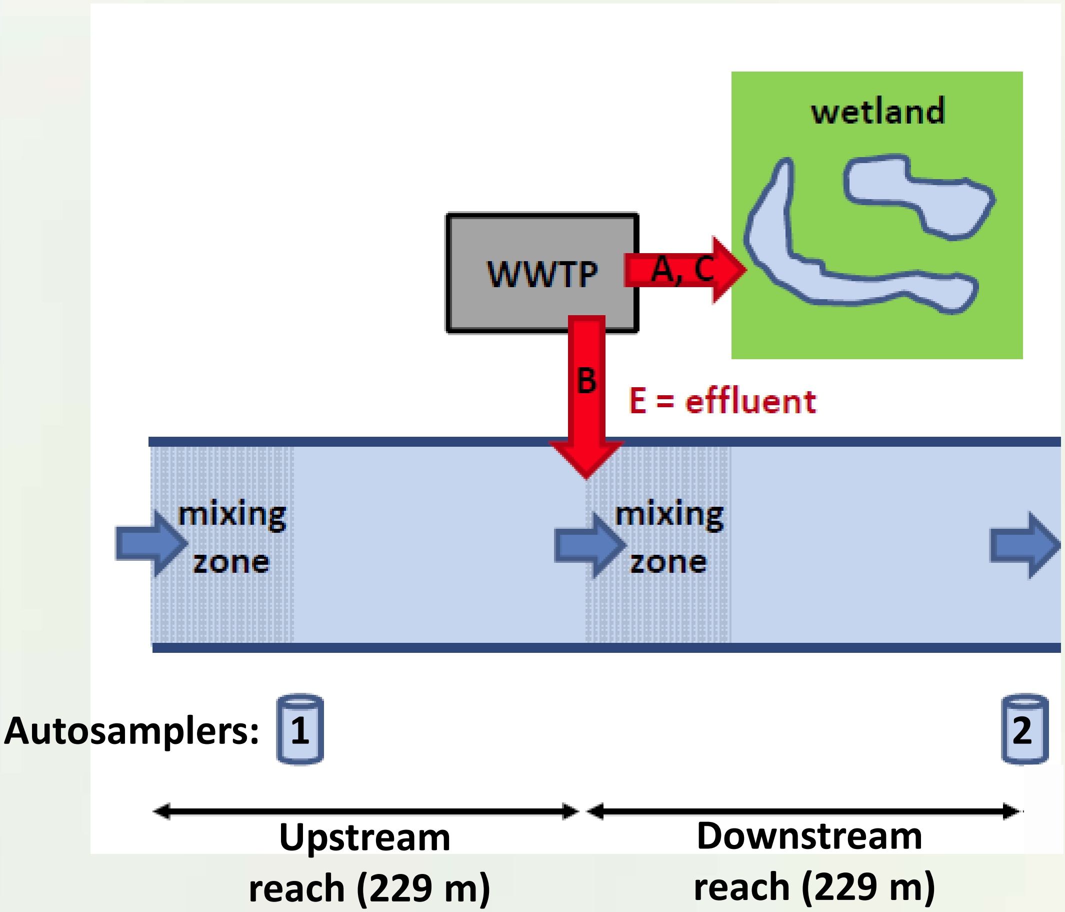
Reach-scale SRP addition experiment



	Before	During	After
NO_3-N (mg L^{-1})	3.3	3.8	3.5
DOC (mg L^{-1})	2.5	2.6	2.5
SS (mg L^{-1})	1.9	1.7	2.6
SRP (µg L^{-1})	19	118	17
DOP (µg L^{-1})	14	29	10
PP (µg L^{-1})	8	10	6

Reach-scale SRP addition experiment

Uptake rates (positive values) as mmol P m^{-2} day^{-1}

Methods	Whole river	Sediment	Algae	Heterotrophs
SRP mass balance	Equilibrium Mean 4.4, max 25 Max -9 (release)			
Laboratory sediment columns				- 0.9 -
Introduced substrate algal growth rates			0.05 0.23 0.12	
Whole stream metabolism		1.00	0.17 0.27 -	0.61 0.78 -
% contributions	-	*49%*	*13%*	*38%*

Before
During
After
(In relation to effluent exposure)

Stutter, Demars & Langan. River phosphorus cycling: separating biotic and abiotic uptake during short-term changes in sewage effluent loading. Water Research. In Press.

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Specific issues in managing P forms

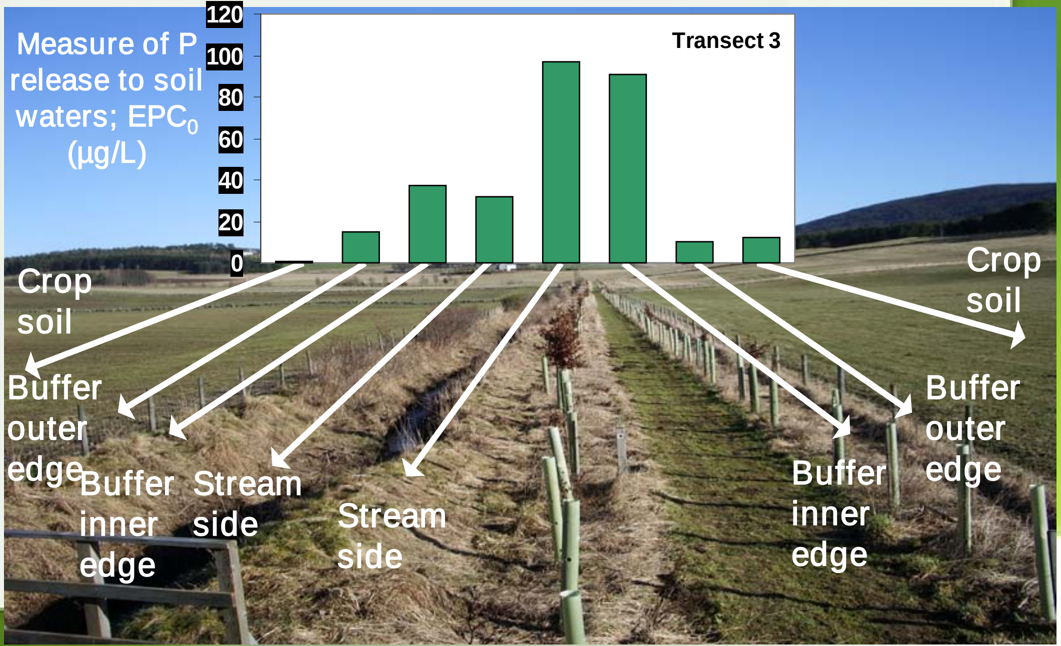
- Sediment management – sediment can be a major transport mode for P, but in the channel can be a P sink by sorption – what happens if we severely limit sediment inputs?
- Small point sources e.g. septic tanks
- The effects of mitigation activities such as buffers
- Spatial connectivity of systems
  - Consider a lake water body that fails to achieve GES through an elevated total P concentration
    - The extent of P mitigation actions in the headwaters is judged on the SRP concentrations in those systems, not total P

Riparian management to alleviate P stress?

- Buffer strips are an increasingly common riparian management measure thought effective for P retention,
  - … on the one hand soil P cycling may ‘swap’ particulate for dissolved P
  - … however, microbial, leaf litter inputs and enhanced nutrient residence times that result from a properly managed riparian system increase reach P processing

Soil properties	Established buffer soil (n=3)	Adjacent cropland soil (n=3)
Organic matter (g kg^{-1})	164	89
Leachate SRP (µg L^{-1})	202	82
Leachate DOP (µg L^{-1})	1810	215
Leachate DOC (mg L^{-1})	86	15
Microbial biomass P (µg g^{-1})	108	33
Phosphatase activity µg NP g^{-1} dm $hour^{-1}$	1095	673

Stutter et al. *Environ. Sci. Technol.* 2009.



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Key messages

- Phosphorus forms are highly dynamic in aquatic ecosystems and many forms may be bioavailable
- Single species indices show poor relationships with nutrient concentrations that may be non-causal
- Concentration measurements for P may give less protection than a system based on whole ecosystem indicators e.g. cycling rates
- The current system of regulation makes protecting joined up ecosystems difficult. *What are the downstream consequences of P?*
- Evaluation of future threats (management, climate change) should consider a range of physical and chemical factors together