University of Florida Water Institute Distinguished Scholar Seminar
April 1, 2010

Disturbing the Water: The Rise of Ground Water in Wetland Biogeochemistry and Plant Ecology

Barbara L. Bedford
With
Kathy Bailey Boomer, Kathy Crowley, Sam Simkin

Photographs by F. Robert Wesley
unless otherwise noted

Kathy Crowley

Sam Simkin

F. Robert Wesley

Seminar Road Map

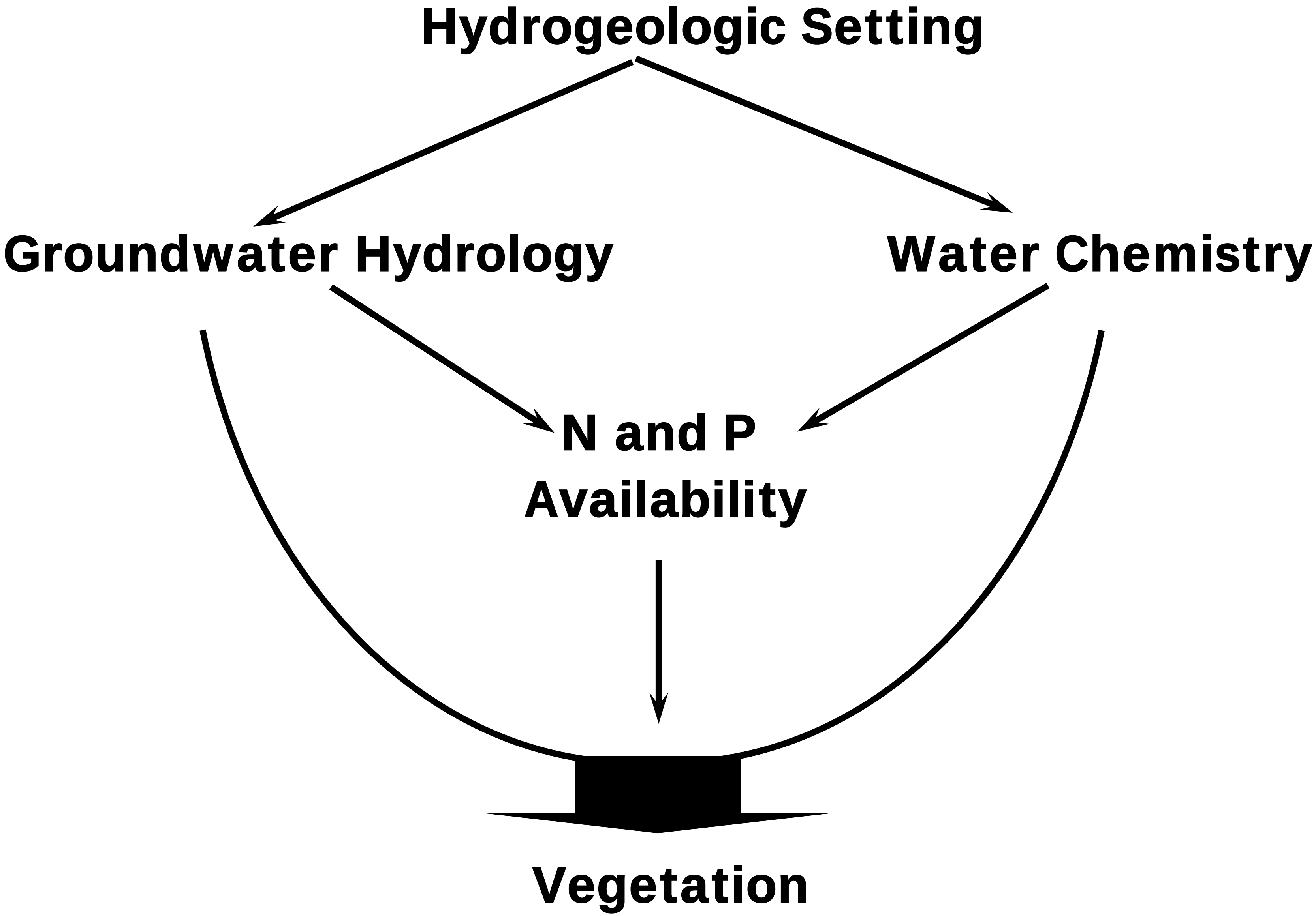
Caveats, biases, and blind spots

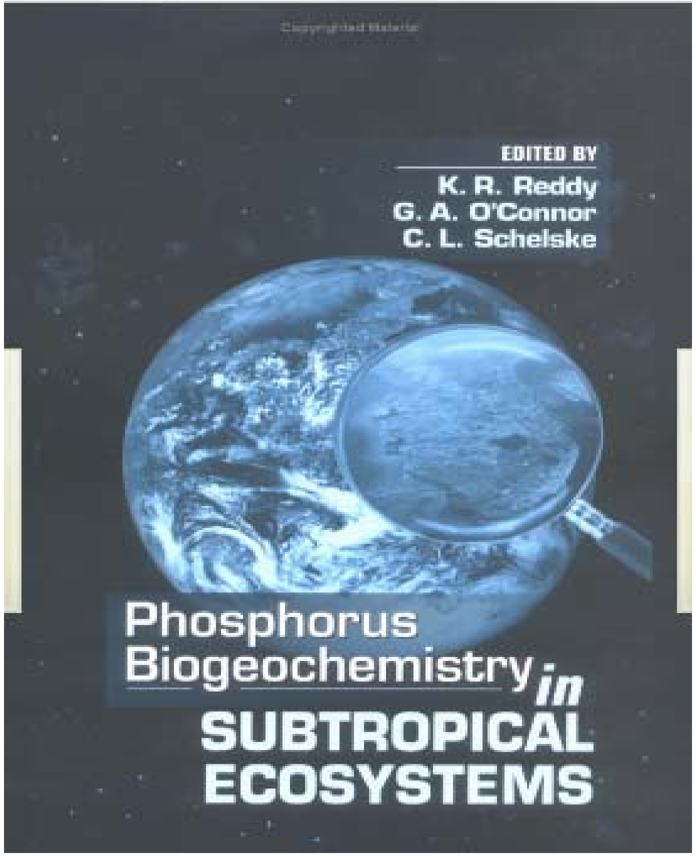
An apocryphal & abbreviated history of the infiltration of groundwater hydrology and biogeochemistry into the mind of a wetland plant ecologist

The particular nature of New York's groundwater-dependent rich fens

Vegetation response to N and P enrichment

Explaining responses: gradients of Fe, S, P interactions


Hydrogeologic Setting
Groundwater Hydrology
Water Chemistry
N and P
Availability
Vegetation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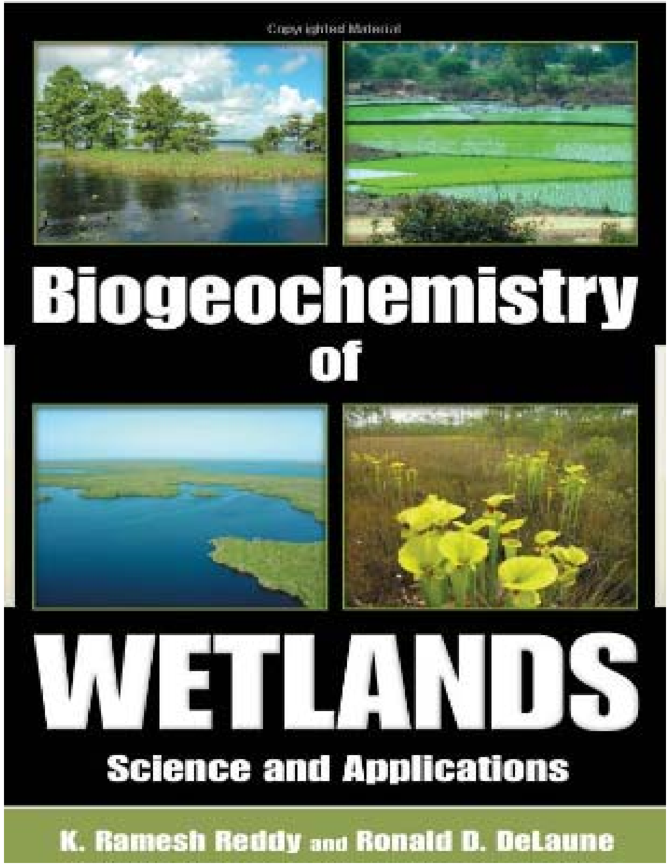
Phosphorus Biogeochemistry in SUBTROPICAL ECOSYSTEMS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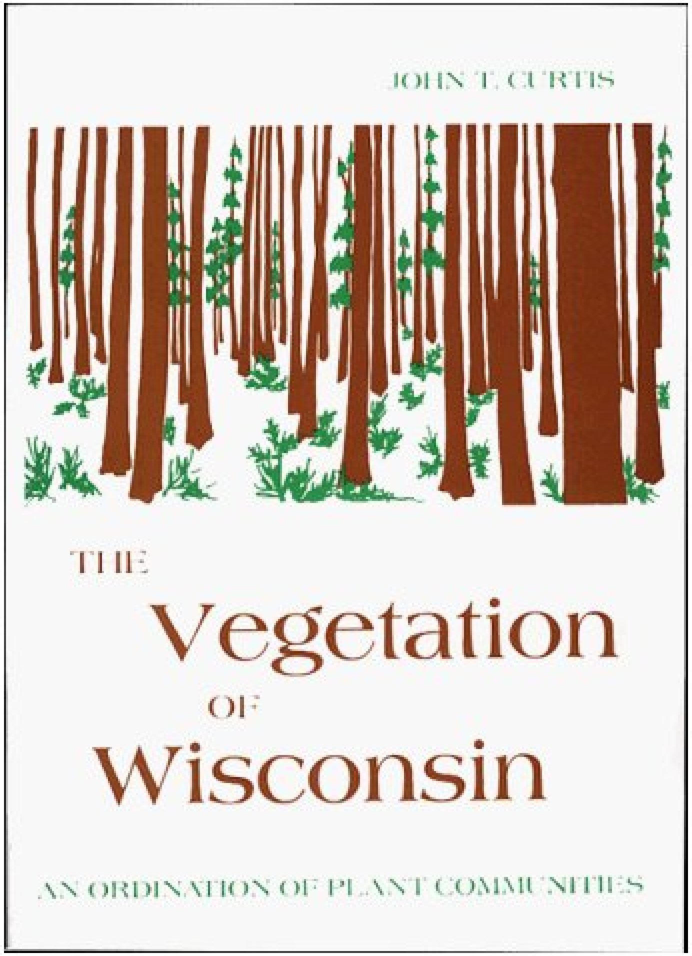
Biogeochemistry of WETLANDS
Science and Applications
K. Ramesh Reddy and Ronald D. DeLaune


JOHN T. CURTIS
THE
Vegetation
OF
Wisconsin
AN ORDINATION OF PLANT COMMUNITIES



Contribution of Rich Fens to Floristic Diversity of the United States

State	# vascular species	# non-vascular species	# of uncommon and rare species	% state uncommon and rare species	% state area
CO	~500		20	3.3	0.08-0.15
ID	327	20	35	12	
IA	320		135	12	0.01
MT	174	60	40		0.0015
NH	340	91	52	13.7	0.078
NJ			96	13.5	0.0073
NY	440	77	55	7	0.07

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The particular nature of New York's rich fens

Vegetation response to N and P enrichment

Explaining responses: gradients of Fe, S, P interactions

First figure in the chapter on hydrology, 4th edition (2007) of *Wetlands* by Mitsch and Gosselink.

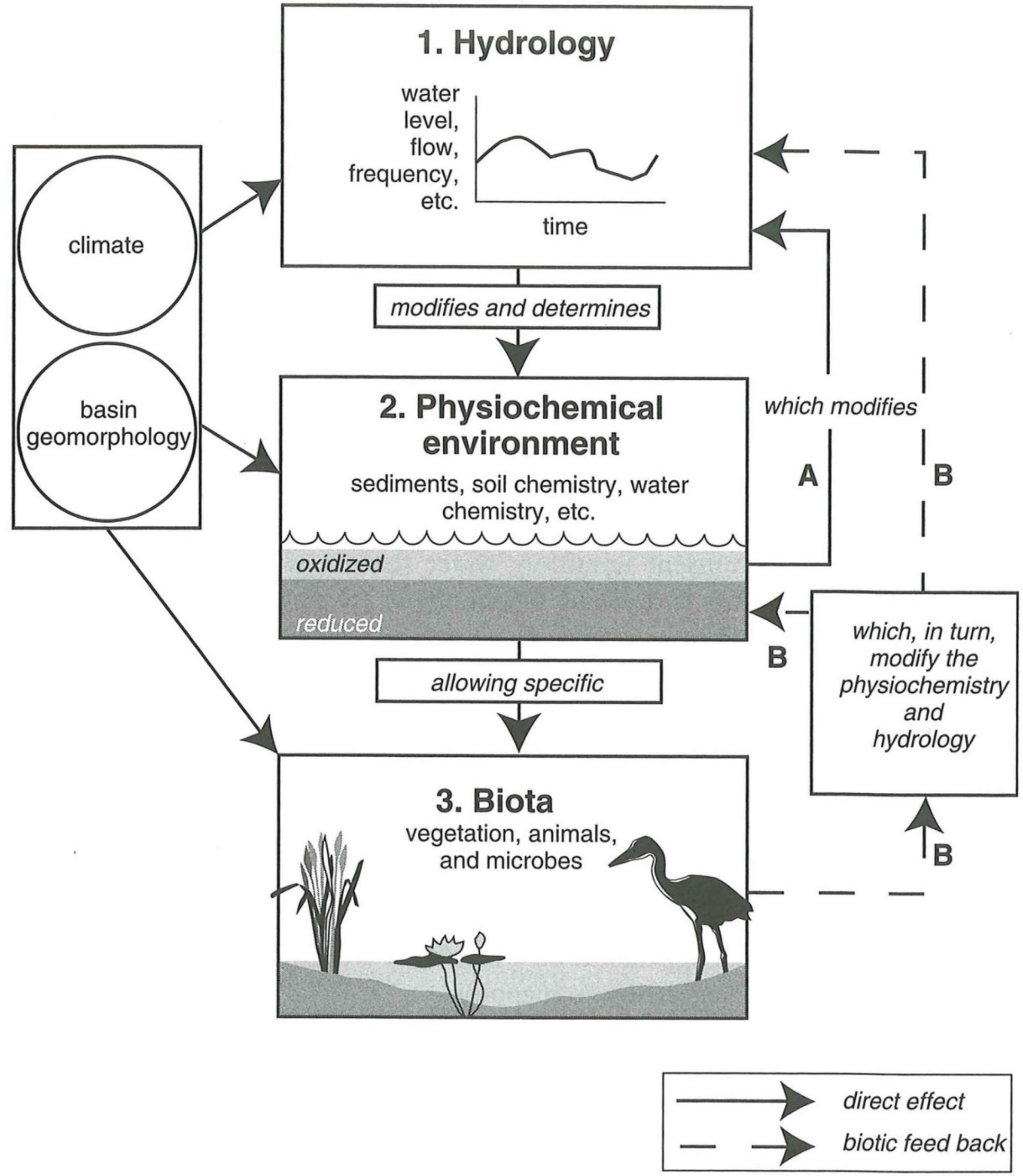


Figure 4.1 Conceptual diagram illustrating the effects of hydrology on wetland function and the biotic feedbacks that affect wetland hydrology. Pathways A and B are feedbacks to the hydrology and physiochemistry of the wetland.

First figure in the chapter on hydrology, 4th edition (2007) of *Wetlands* by Mitsch and Gosselink.

Note how hydrology is pictured and described.

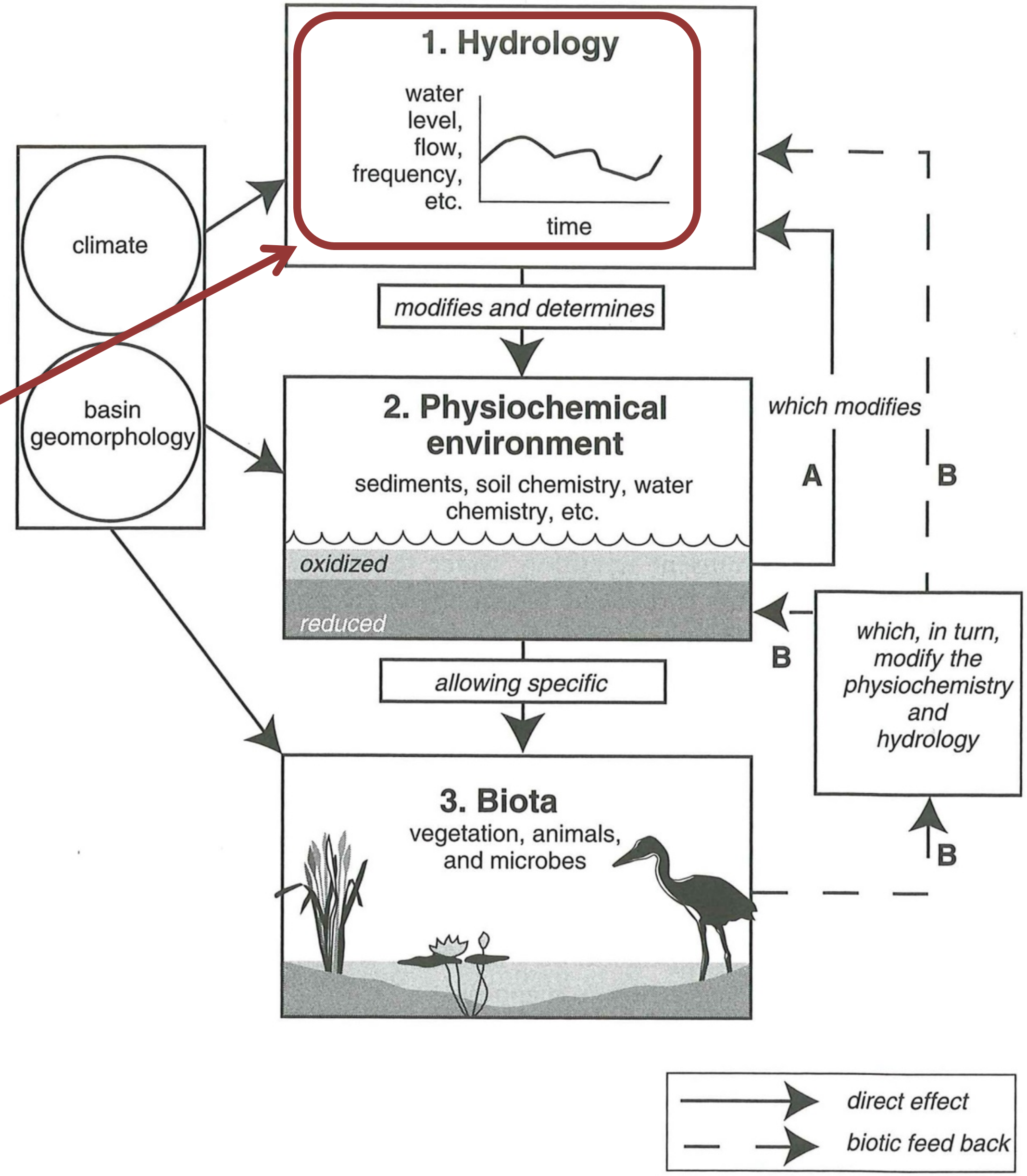


Figure 4.1 Conceptual diagram illustrating the effects of hydrology on wetland function and the biotic feedbacks that affect wetland hydrology. Pathways A and B are feedbacks to the hydrology and physiochemistry of the wetland.

Second figure in Mitsch and Gosselink's (2007) hydrology chapter, where each wetland type has a distinctive "hydroperiod."

Surface water emphasis dominant among plant ecologists for decades, up to Keddy's 2000 textbook.

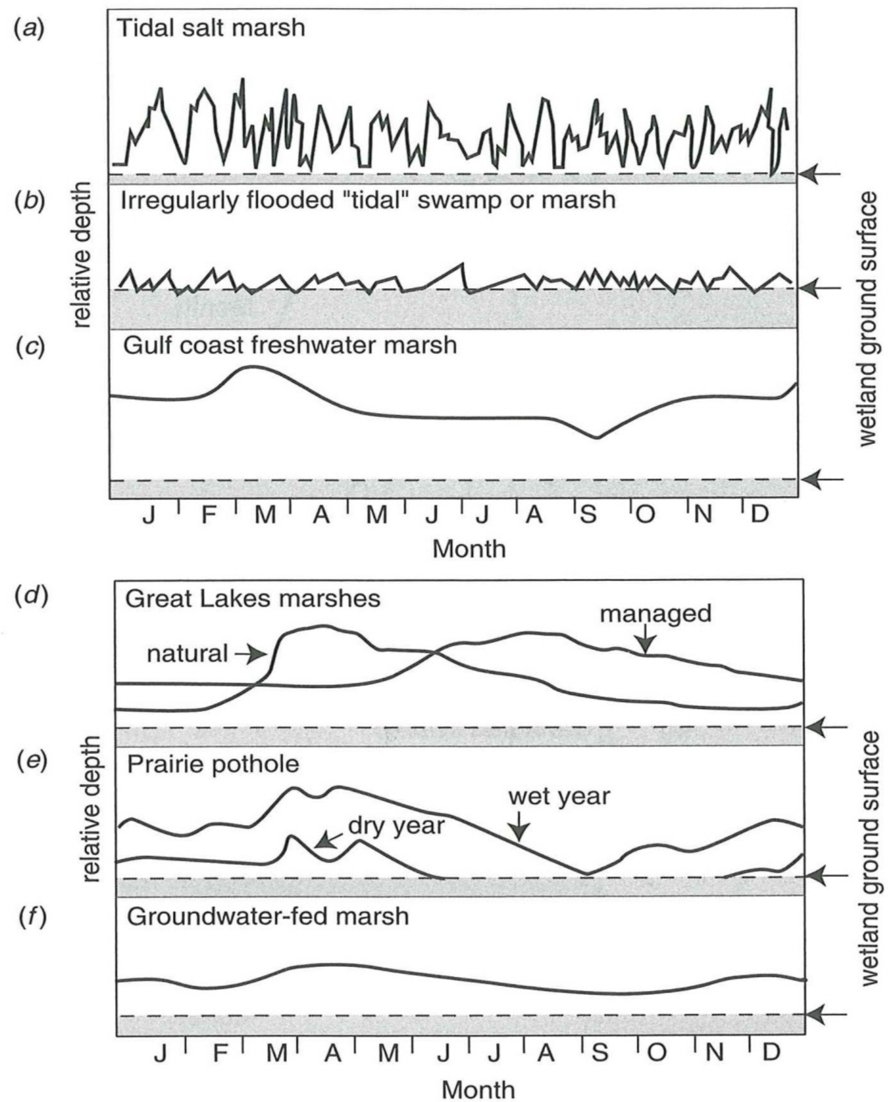


Figure 4.2, from M&G4

First paper in the ecological literature to integrate groundwater hydrology, water chemistry, and plant species composition.

Journal of Ecology (1986), **74,** 1103–1117

HYDROLOGY, WATER CHEMISTRY AND ECOLOGICAL RELATIONS IN THE RAISED MOUND OF COWLES BOG

DOUGLAS A. WILCOX*, ROBERT J. SHEDLOCK†
AND WILLIAM H. HENDRICKSON*‡

**National Park Service, Indiana Dunes National Lakeshore, Porter, Indiana 46304, U.S.A. and †U.S. Geological Survey, 6023 N. Guion Road, Indianapolis, Indiana 46254, U.S.A.*

SUMMARY

(1) The Cowles Bog National Natural Landmark and the wetlands between the dunes near the south shore of Lake Michigan, in Indiana, contain plant species that are typical of circum-neutral fens.

Wilcox & others (1986) recognized the influence of subsurface stratigraphy and composition in determining the chemistry of water as it entered the plant rooting zone.

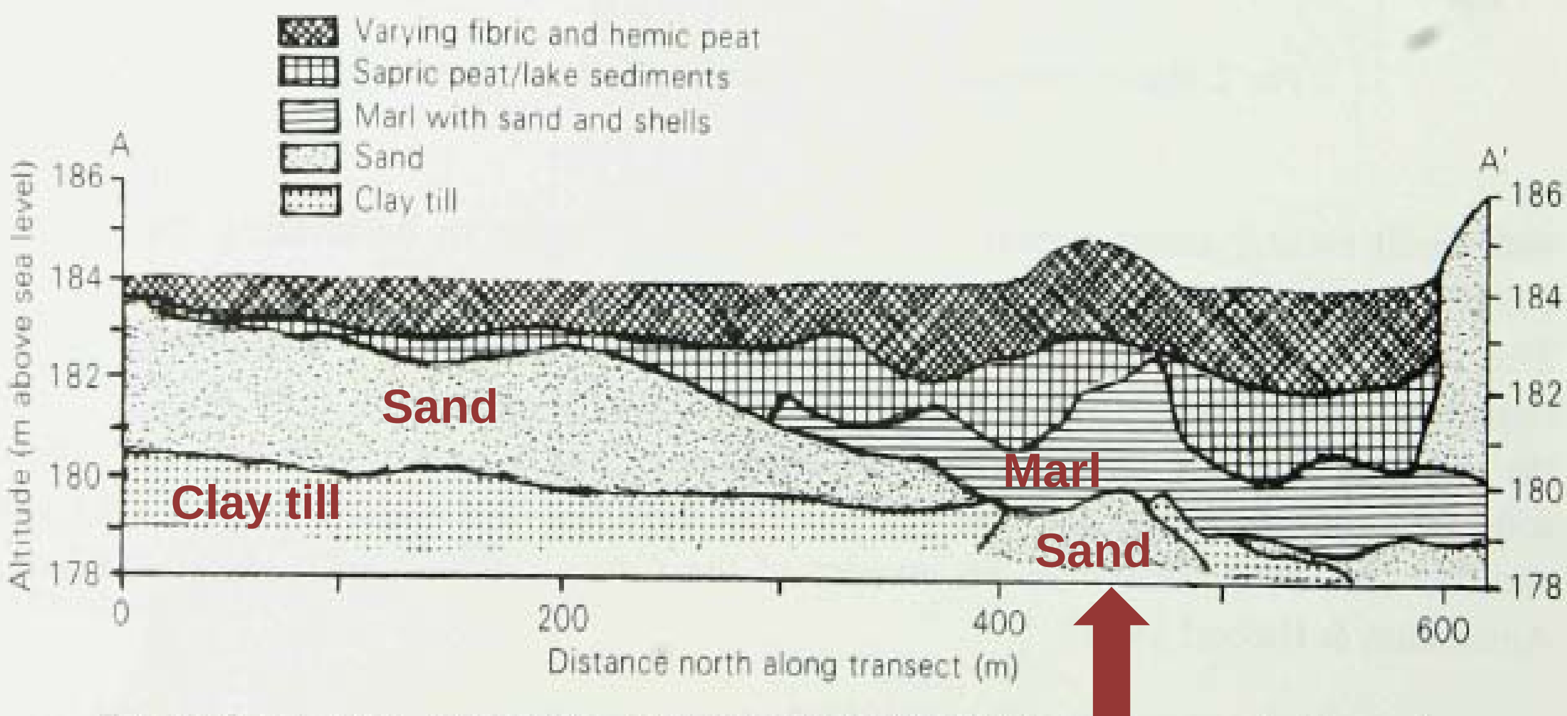
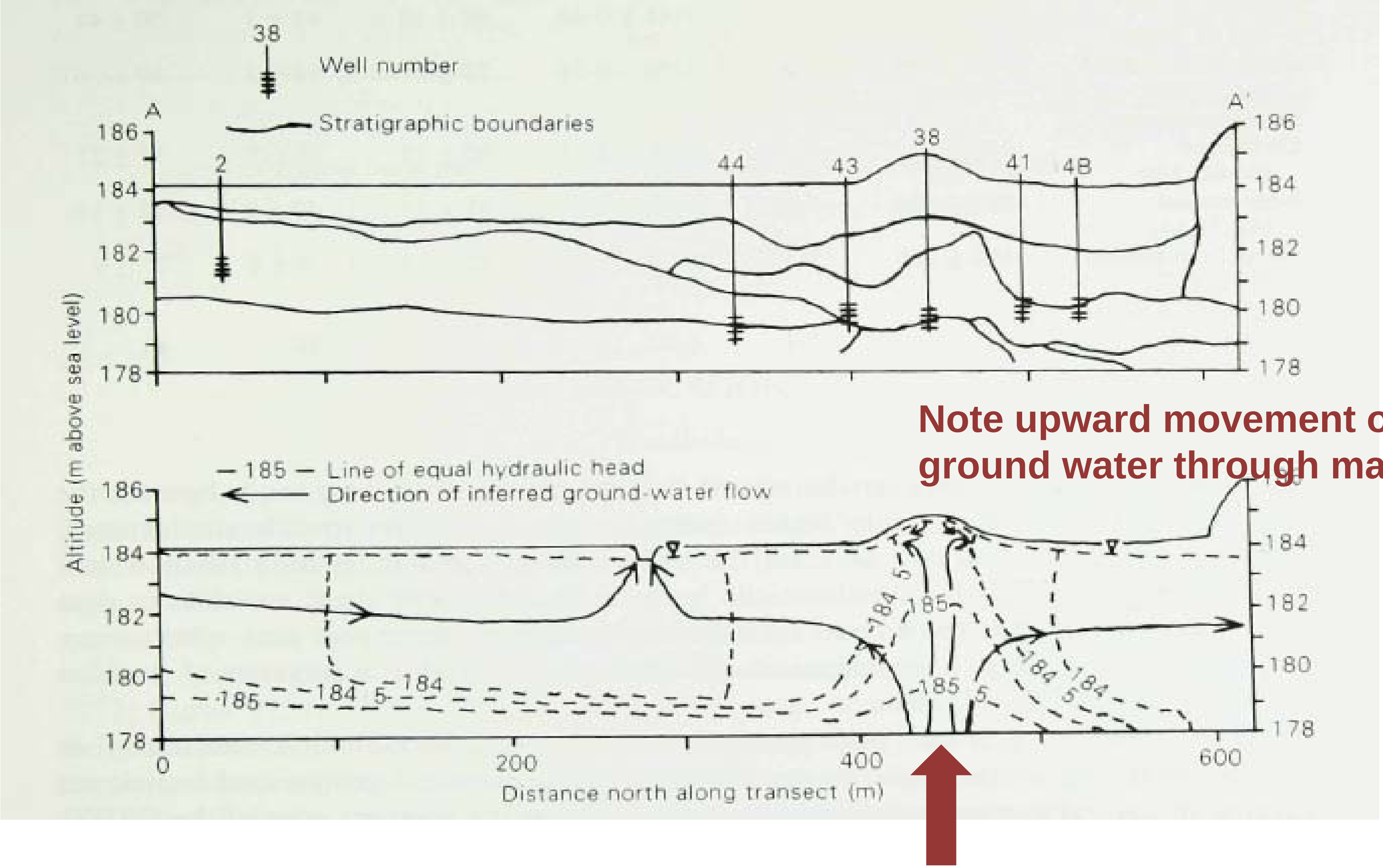


FIG. 4. Stratigraphic cross-section of Cowles Bog Wetland Complex perpendicular to the long dimension of the basin. (From various coring and gamma-ray logs.) Line of transect (A–A′) is shown in Fig. 1. The vertical exaggeration is ×20.

Wilcox & others (1986) used groundwater wells to determine hydraulic head and groundwater flow directions in Cowles Bog.



Note upward movement of ground water through marl.

Wilcox & others (1986) also used wells to sample water chemistry.

TABLE 2. Selected mean water chemistry values (and standard deviations) for well and peat pore-waters collected at sites on the mound, near the mound and away from the mound in the Cowles Bog Wetland Complex. See Figs 1 and 3 for well locations.

Site	Specific conductance ($\mu S\ cm^{-1}$)	pH	Alkalinity (m-equiv. l^{-1})	Ca ($mg\ l^{-1}$)	Mg ($mg\ l^{-1}$)	SO_4 ($mg\ l^{-1}$)
Well waters						
On mound (46,4C,38,43)	832 ± 42	7·44	7·56 ± 0·56	82 ± 8	46 ± 3	93 ± 4
Near mound (4B,41,39,44)	768 ± 50	7·37	7·48 ± 0·40	68 ± 10	45 ± 7	50 ± 44
Away from mound (4A,5,6,7)	363 ± 177	5·89	1·70 ± 0·58	35 ± 3	12 ± 5	50 ± 36
Peat pore-waters						
On mound (46,4C,38)	862 ± 89	7·16	9·58 ± 1·64	90 ± 12	50 ± 5	37 ± 23
Near mound (4B,39,44)	827 ± 106	7·03	9·22 ± 0·94	85 ± 11	45 ± 2	15 ± 14
Away from mound (4A,5,6,7)	190 ± 136	5·51	1·20 ± 1·48	22 ± 13	8 ± 6	27 ± 9
Confined aquifer site						
Ground-water (2)	671	7·1	6·62	87	36	62

A Conceptual Framework For Assessing Cumulative Impacts on the Hydrology of Nontidal Wetlands

THOMAS C. WINTER
U.S. Geological Survey
Denver Federal Center
Mail Stop 413
Lakewood, Colorado 80225, USA

ABSTRACT / Wetlands occur in geologic and hydrologic settings that enhance the accumulation or retention of water. Regional slope, local relief, and permeability of the land surface are major controls on the formation of wetlands by surface-water sources. However, these landscape features also have significant control over groundwater flow systems, which commonly play a role in the formation of wetlar cause the hydrologic system is a continuum, any moc of one component will have an effect on contiguous c nents. Disturbances commonly affecting the hydrologi system as it relates to wetlands include weather modification, alteration of plant communities, storage of surface water, road construction, drainage of surface water and soil water, alteration of groundwater recharge and discharge areas, and pumping of groundwater. Assessments of the cumulative effects of one or more of these disturbances on the hydrologic system as related to wetlands must take into account uncertainty in the measurements and in the assumptions that are made in hydrologic studies. For example, it may be appropriate to assume that regional groundwater flow systems are recharged in uplands and discharged in lowlands. However, a similar assumption commonly does not apply on a local scale, because of the spatial and temporal dynamics of

ENVIRONMENTAL MANAGEMENT
Vol. 12 (5)
September 1988

Strategies for Assessing the Cumulative Effects of Wetland Alteration on Water Quality

MARK M. BRINSON
Department of Biology
East Carolina University
Greenville, North Carolina 27858, USA

ABSTRACT / Assessment of cumulative impacts on wetlands can benefit by recognizing three fundamental wetland categories: basin, riverine, and fringe. The geomorphological settings of these categories have relevance for water quality.

Basin, or depressional, wetlands are located in headwater areas, and capture runoff from small areas. Thus, they are normally sources of water with low elemental concentration. Although basin wetlands normally possess a high capacity for assimilating nutrients, there may be little opportunity for this to happen if the catchment area is small and little water flows through them.

Riverine wetlands, in contrast, interface extensively with uplands. It has been demonstrated that both the capacity and the opportunity for altering water quality are high in riverine wetlands.

Fringe wetlands are very small in comparison with the large bodies of water that flush them. Biogeochemical influ-

The relative proportion of these wetland types within a watershed, and their status relative to past impacts can be used to develop strategies for wetland protection. Past impacts on wetlands, however, are not likely to be clearly revealed in water quality records from monitoring studies, either because records are too short or because too many variables other than wetland impacts affect water quality. It is suggested that hydrologic records be used to reconstruct historical hydroperiods in wetlands for comparison with current, altered conditions. Changes in hydroperiod imply changes in wetland function, especially for biogeochemical processes in sediments. Hydroperiod is potentially a more sensitive index of wetland function than surface areas obtained from aerial photographs. Identification of forested wetlands through photointerpretation relies on vegetation that may remain intact for decades after drainage. Finally, the depositional environment of wetlands is a landscape characteristic that has not been carefully evaluated nor fully appreciated. Impacts that reverse depositional tendencies also may accelerate rates of change, causing wetlands to be large net exporters rather than modest net importers. Increases in rates as well as direction can cause stocks of

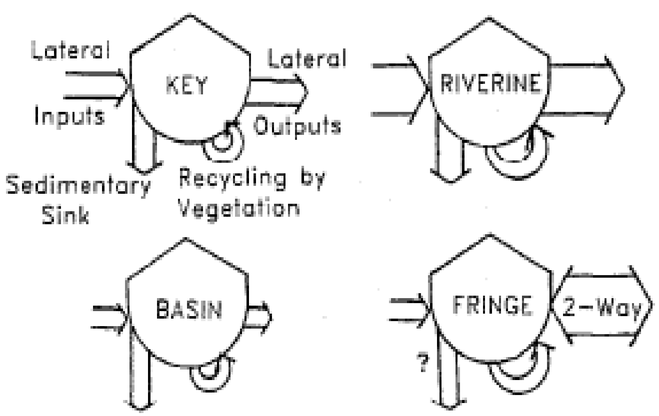


Figure 1. Comparison of a sedimentary elemental cycle in the three wetland categories: riverine, basin, and fringe. Dia-

Brinson's 1993 *Hydrogeomorphic Classification* combined his 1988 adaptation of Lugo & Snedaker's 1974 geomorphologic types with this ternary diagram emphasizing relative water sources to wetlands.

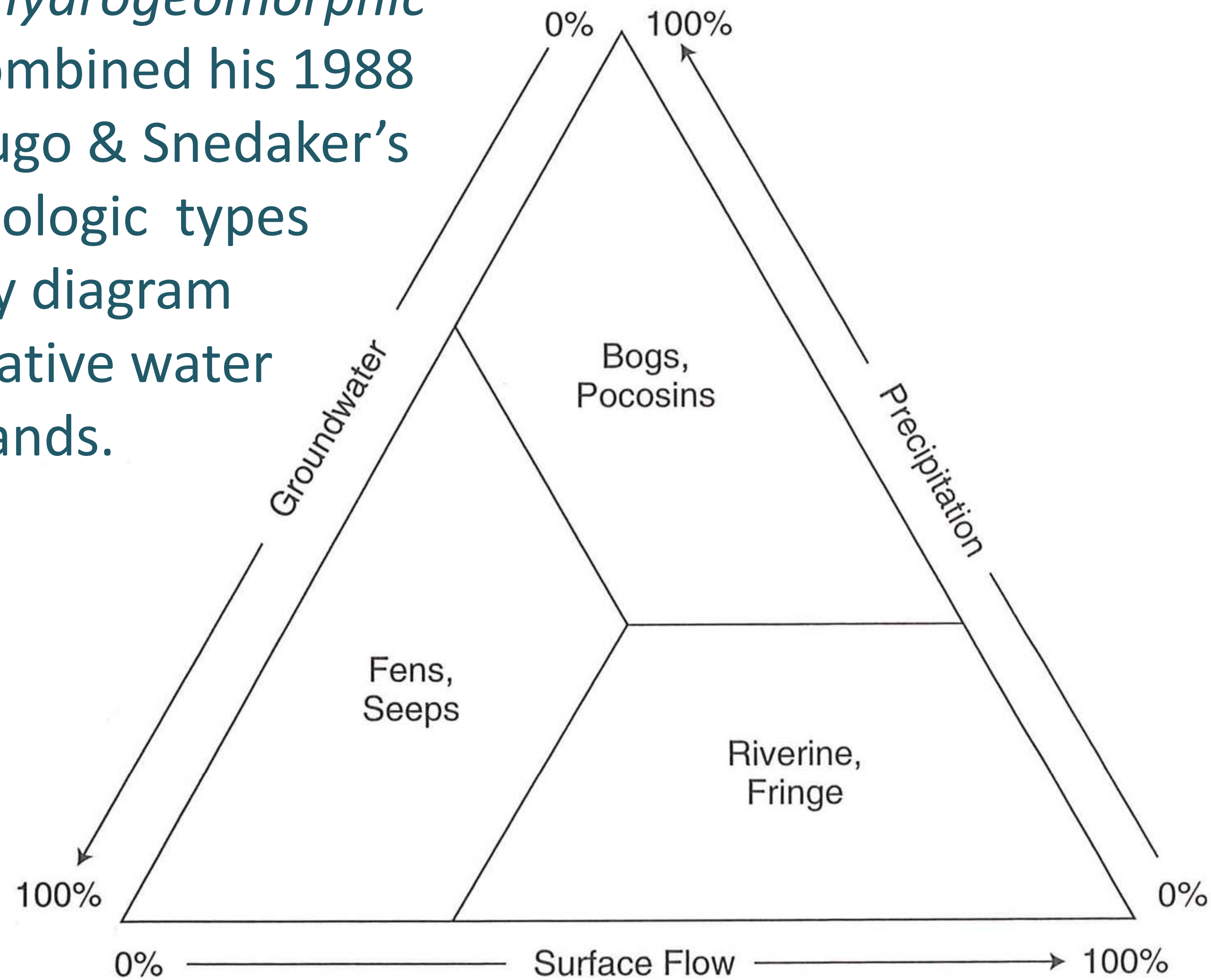
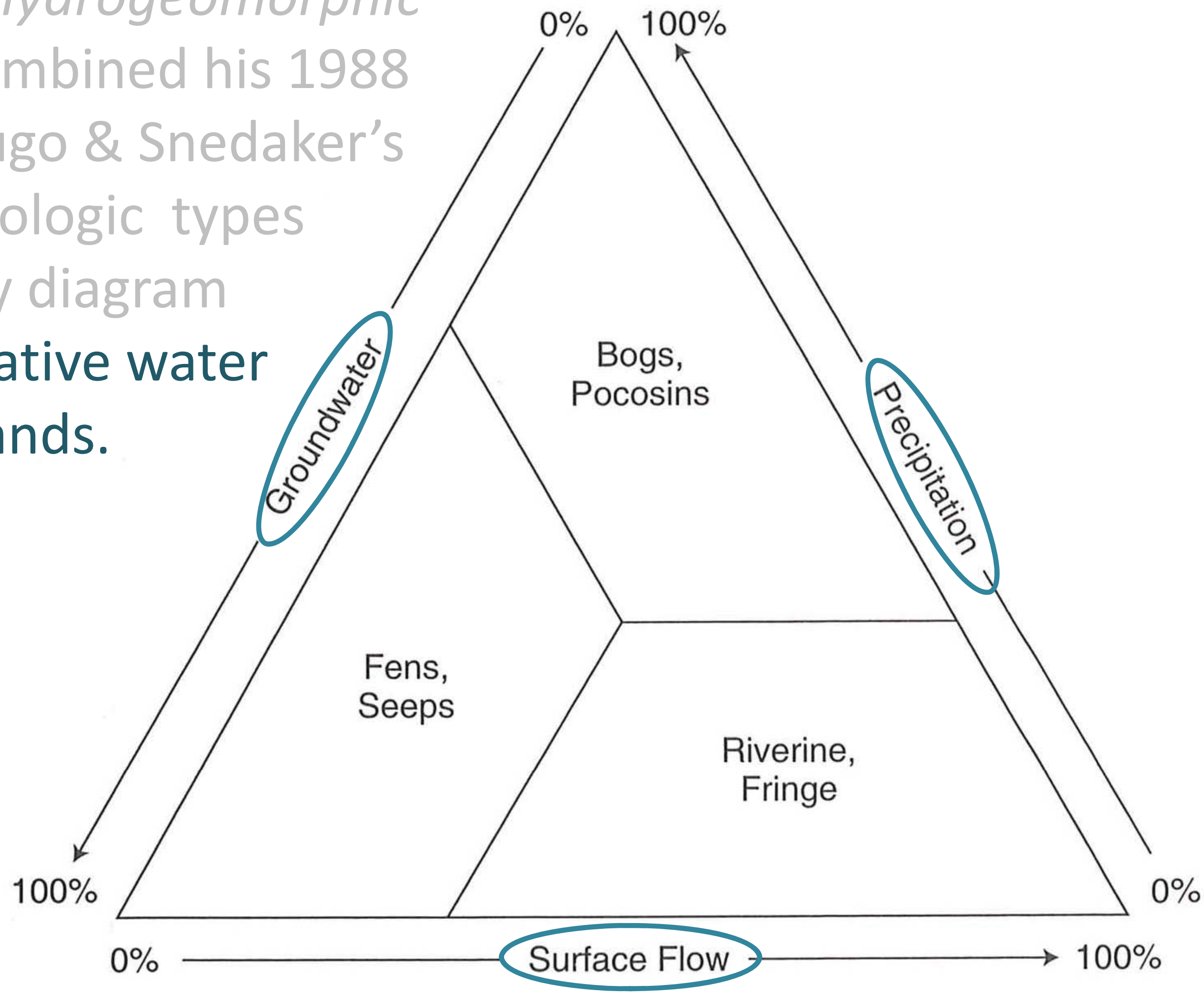


Figure from Brinson (1993) adapted from Zimmerman (1987)

Brinson's 1993 *Hydrogeomorphic Classification* combined his 1988 adaptation of Lugo & Snedaker's 1974 geomorphologic types with this ternary diagram emphasizing **relative water sources to wetlands.**



Pergamon

Geochimica et Cosmochimica Acta, Vol. 58, No. 16, pp. 3353–3367, 1994

0016-7037/94 $6.00 + .00

0016-7037(94)00134-0

Geochemistry and hydrology of a calcareous fen within the Savage Fen wetlands complex, Minnesota, USA

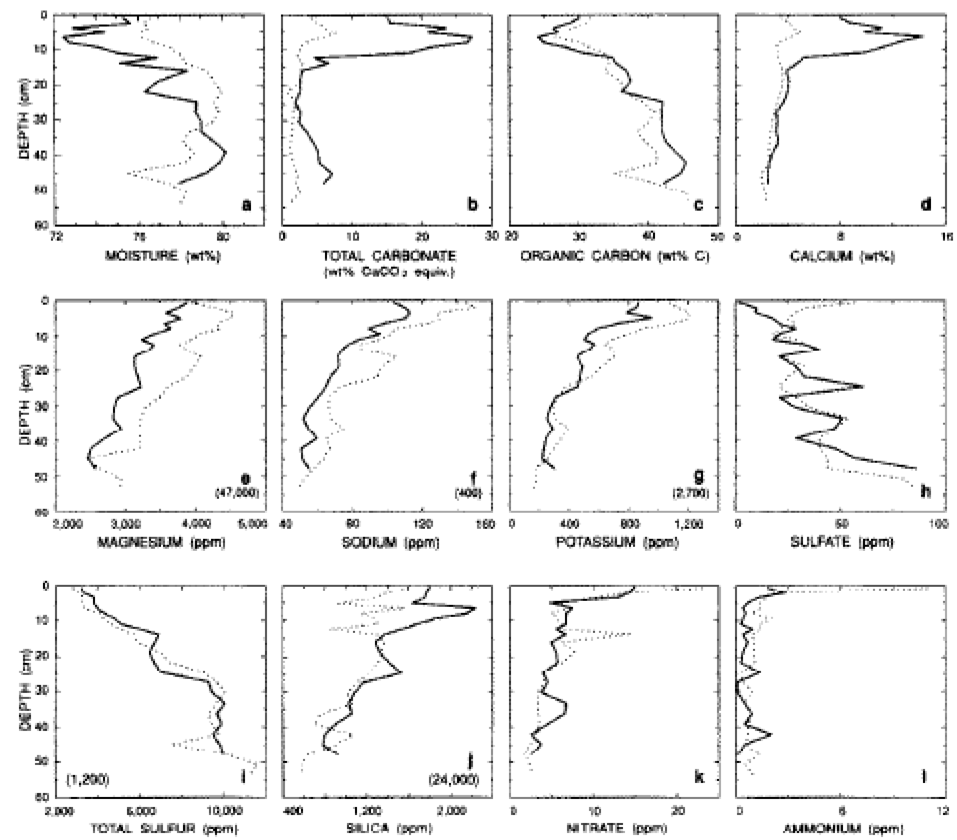
STEPHEN C. KOMOR
US Geological Survey, 2280 Woodale Drive, Mounds View, MN 55112, USA

(*Received October 28, 1993; accepte*

Abstract—Savage Fen is a wetlands complex at the
Valley. The complex includes 27.8 hectares of calc
populations are declining in Minnesota. Water and
studied to gain a better understanding of the hydrolog
water in the fen is a calcium-magnesium-bicarbonate t
composition is the result of interactions among water
and ion exchangers. Shallow groundwater is distinguish
of chloride, sulfate, magnesium, and sodium, and larg
sulfide, and ammonium. Magnesian calcite is the pre
beneath the fen and is an important source and sink
carbon. Calcite concentrations just below the water tab
of organic matter increase the partial pressure of car
to dissolve. Thick calcite accumulations just above th
result from water table fluctuations and attendant c

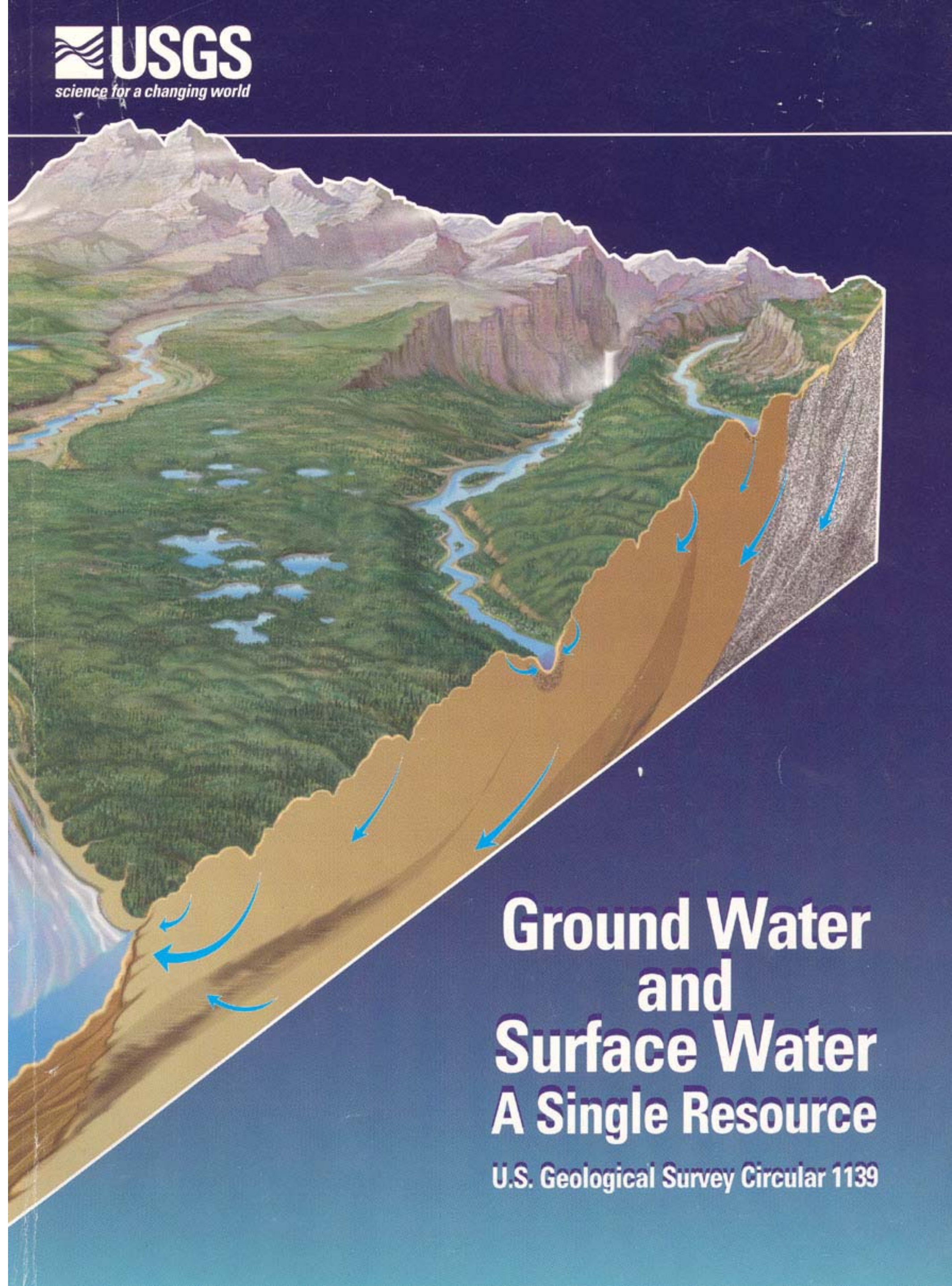
Komor 1994

S. C. Komor



A landmark publication:
Winter, T.C., Harvey, J.W., O.L. Franke, and W.M. Alley. 1999.

Consolidated understanding of the role of ground water in determining the hydrology and chemistry of most aquatic ecosystems.



PROPERTIES OF HYDROGEOLOGIC SETTING

Wetland Position in the Landscape

Geomorphologic Properties of the Watershed

- Surface topography
- Land-surface slope
- Thickness and permeability of the soils
- Composition and hydraulic properties of underlying geologic materials

From Bedford 1996 based on Winter 1988

Ecology, 80(7), 1999, pp. 2151–2169

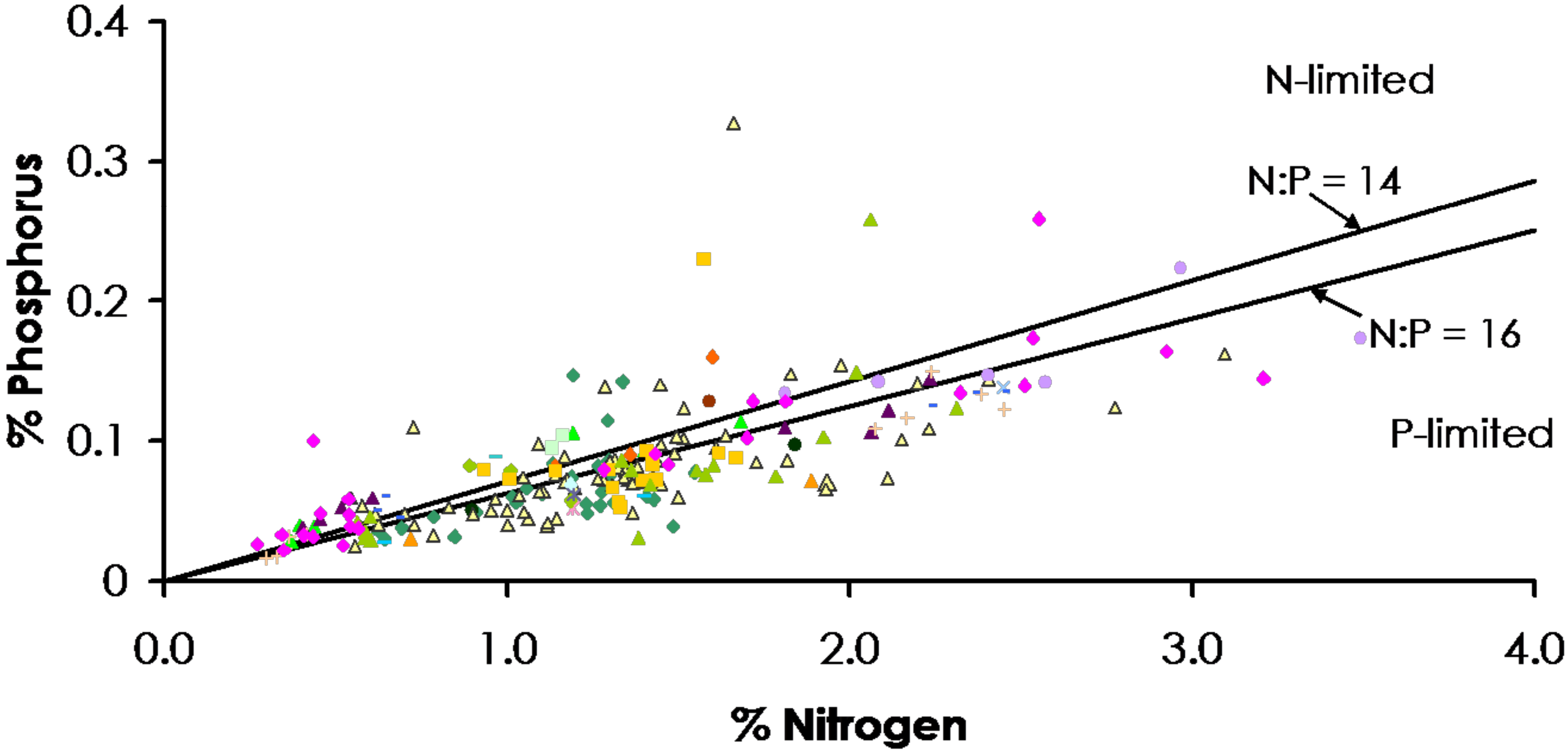
PATTERNS IN NUTRIENT AVAILABILITY AND PLANT DIVERSITY OF TEMPERATE NORTH AMERICAN WETLANDS

Barbara L. Bedford,[1] Mark R. Walbridge,[2] and Allison Aldous[1]

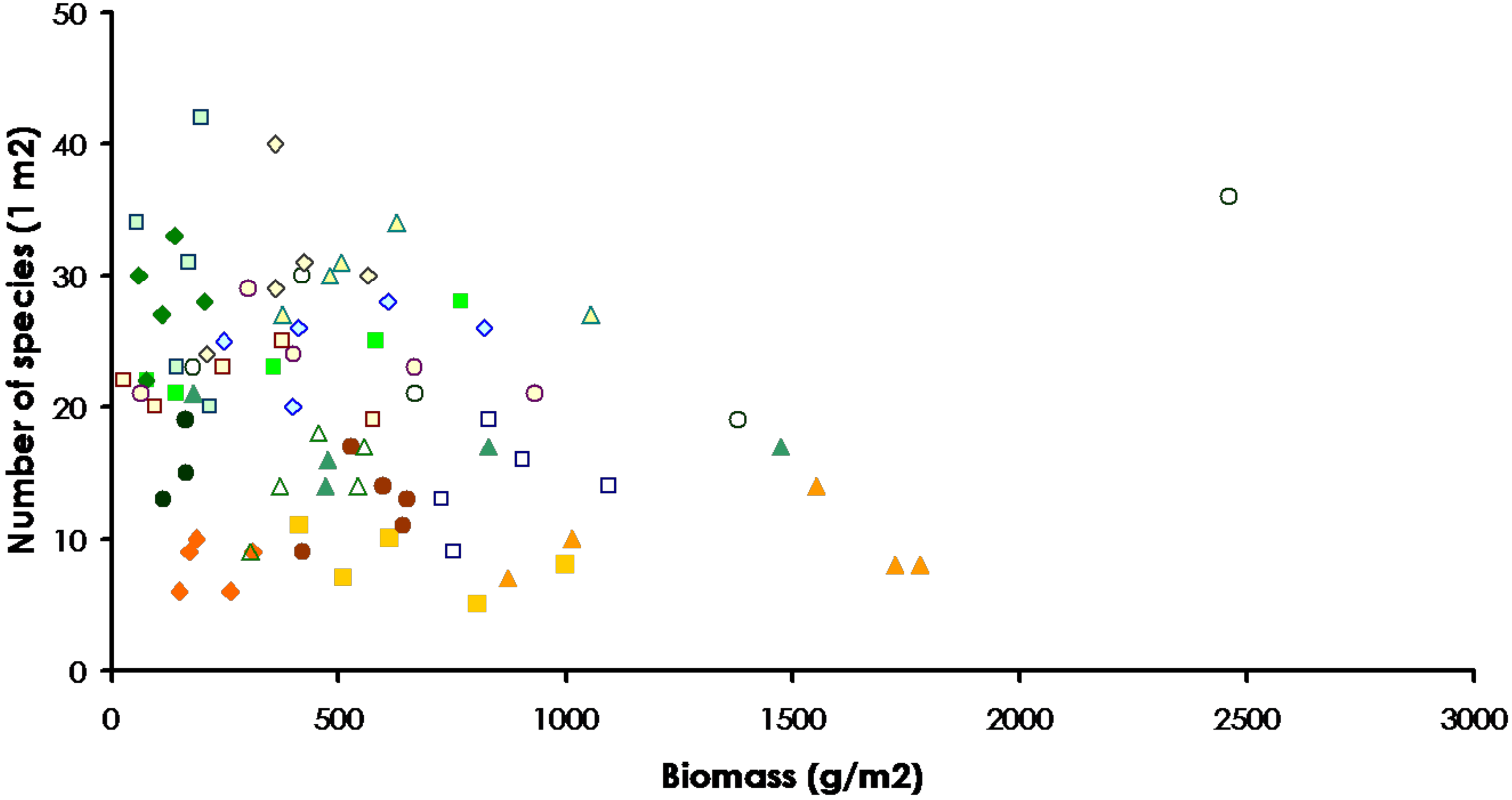
[1]*Department of Natural Resources, Fernow Hall, Cornell University, Ithaca, New York 14853 USA*
[2]*Department of Biology, George Mason University, Fairfax, Virginia 22030-4444 USA*

Abstract. Few wetland studies from temperate North America have related either species richness or plant community composition to any direct measure of nutrient availability, or examined changes in species composition following experimental nutrient additions. Studies of wetlands in western Europe and of other terrestrial ecosystems in North America frequently show that nutrient enrichment leads to changes in species composition, declines in overall plant species diversity, and loss of rare and uncommon species. We therefore used an extensive literature survey and analysis of data on plant species composition, species richness, productivity or standing crop, and C:N:P stoichiometry in plant tissues and surface soils to draw conclusions about the nature of nutrient limitation in temperate North American bogs, fens, marshes, and swamps, and to infer their potential response to nutrient enrichment. We searched all major bibliographic data bases for studies containing such data (through March 1998) and added relevant data from our own ongoing research. We analyzed plant and soil data sets by wetland type and by wetland soil type, and the plant data set also by growth form.

Our fen data showed that many wetlands, and especially rich fens, were P-limited based on tissue N:P ratios



Our fen data showed the typical relationship of biomass to species richness: highest richness at low biomass



Seminar Road Map

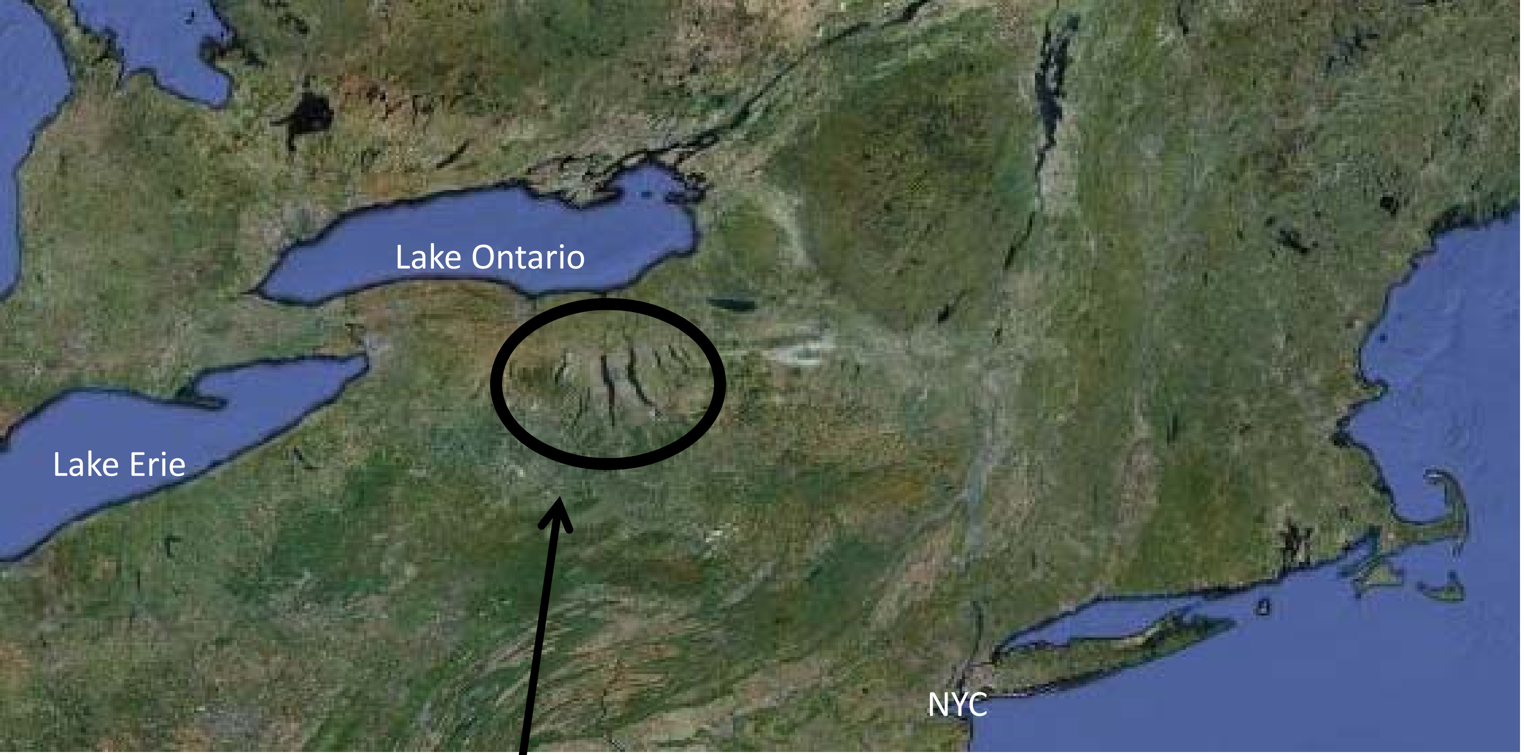
Caveats, biases, and blind spots

An apocryphal & abbreviated history of the infiltration of groundwater hydrology and biogeochemistry into the mind of a wetland plant ecologist

The particular nature of New York’s groundwater-dependent rich fens

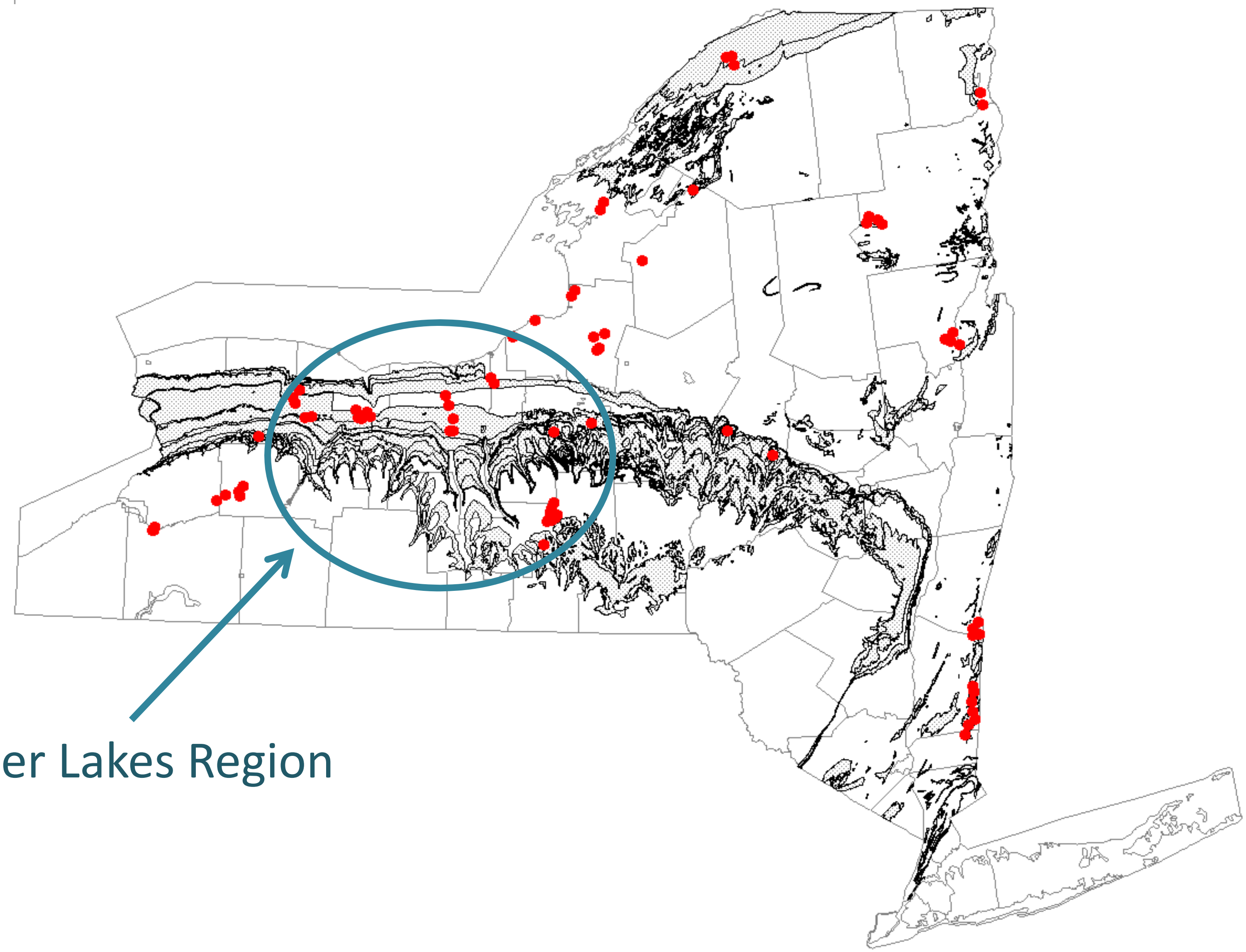
Vegetation response to N and P enrichment

Explaining responses: gradients of Fe, S, P interactions



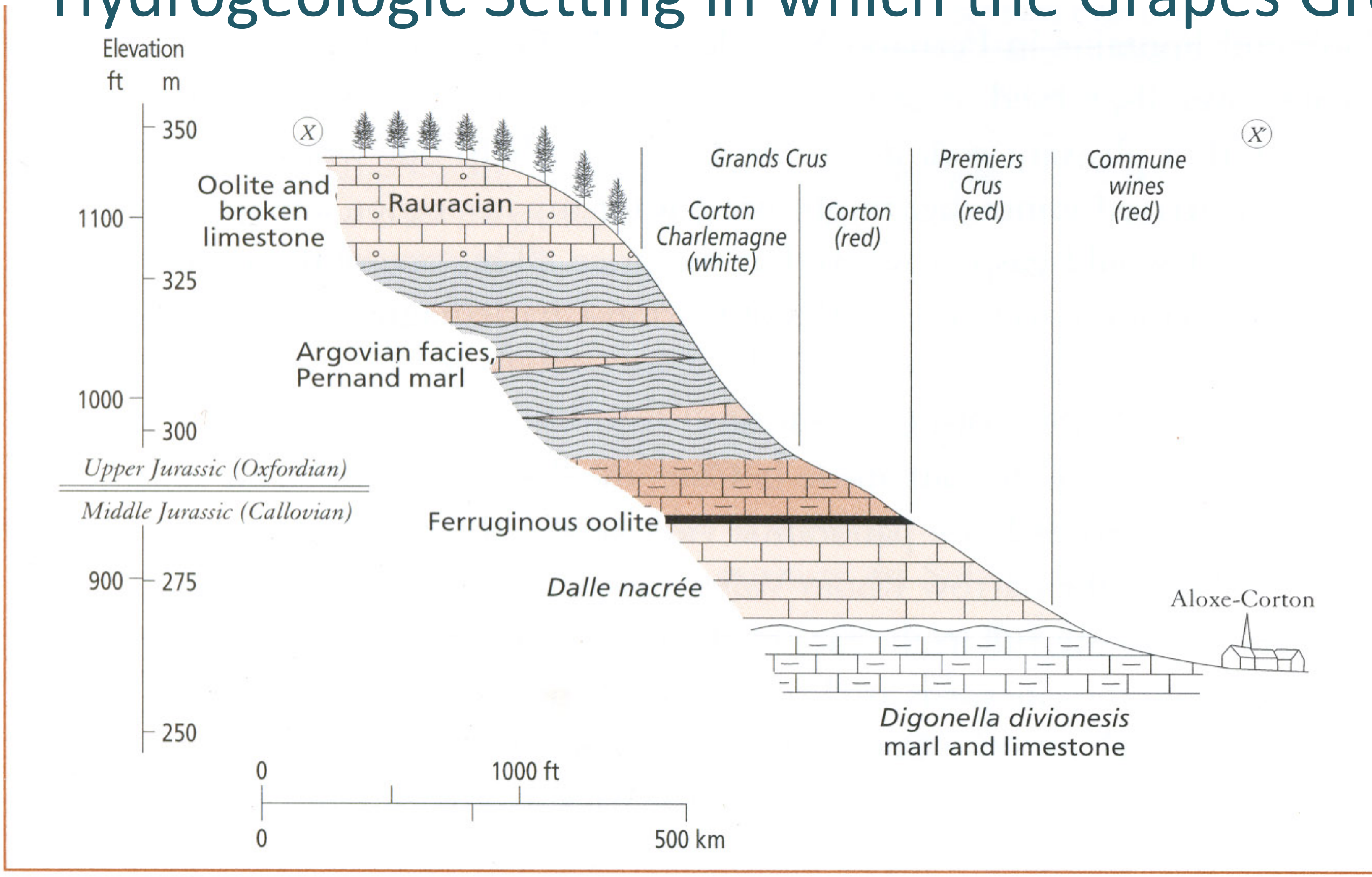
The Finger Lakes Region of NY

Distribution of NY Fens in Relation to Carbonate Bedrock



Finger Lakes Region

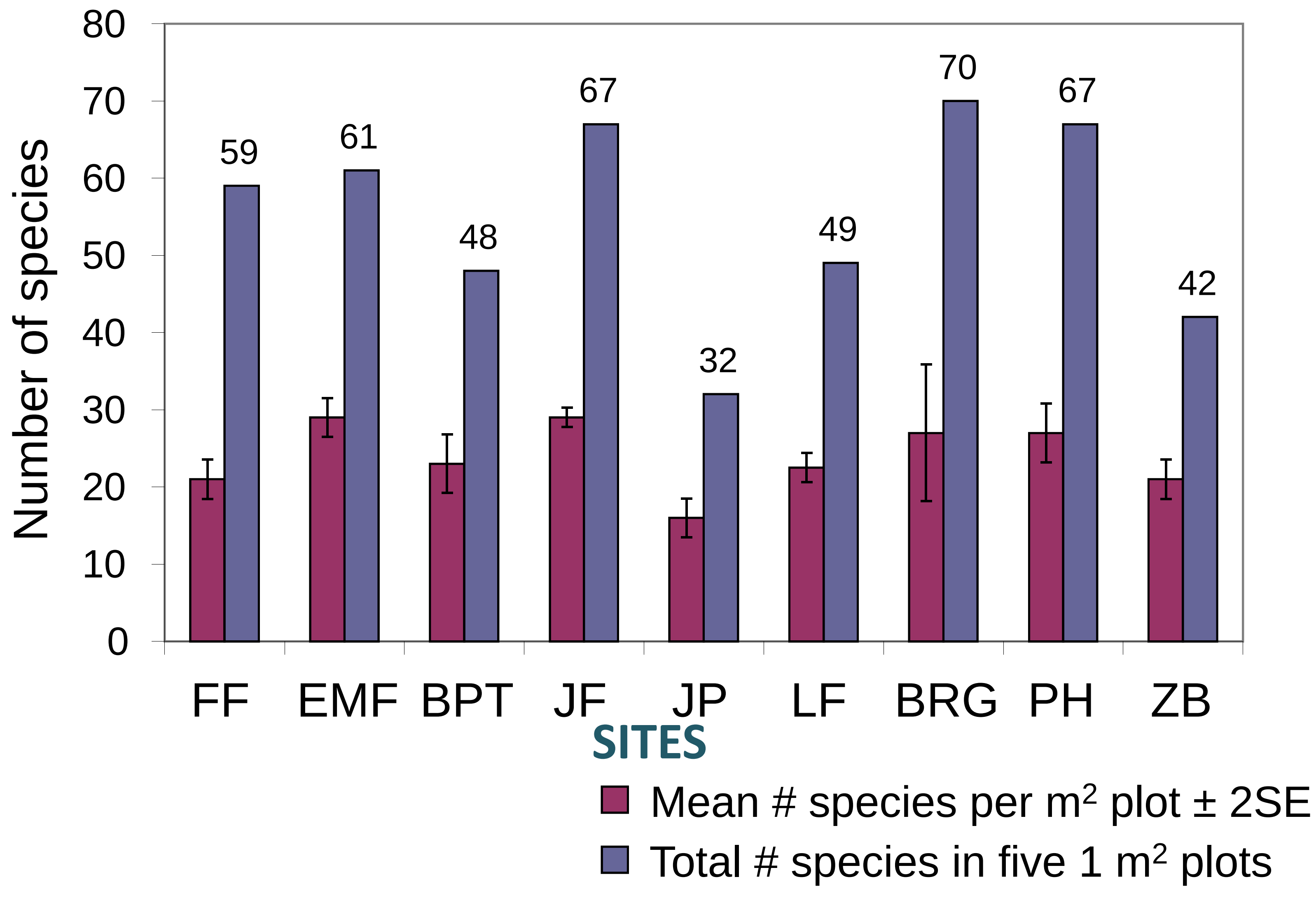
The Quality of Wine Reflects the Hydrogeologic Setting in which the Grapes Grow



BURGUNDY: PARADE OF CAP-ROCK SCARPS

Taken from *Terroir* (1998) by James E. Wilson

Species Diversity in New York Rich Fens



New York's Rich Fen Flora

Number of vascular species = 440

Total NY vascular flora = 3200

Number of non-vascular species = 77

Total NY bryophytes = ~ 620

Total number of species = 517


Ben Wolfe

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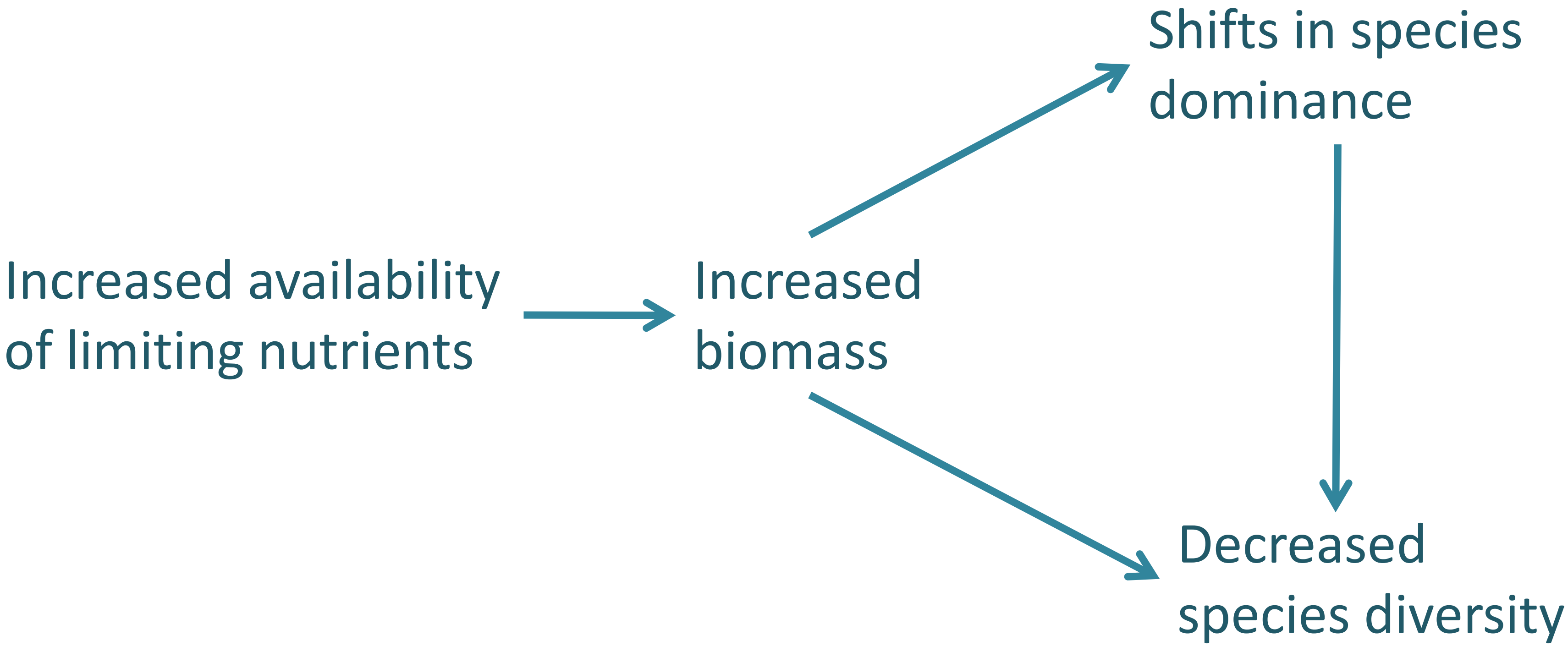
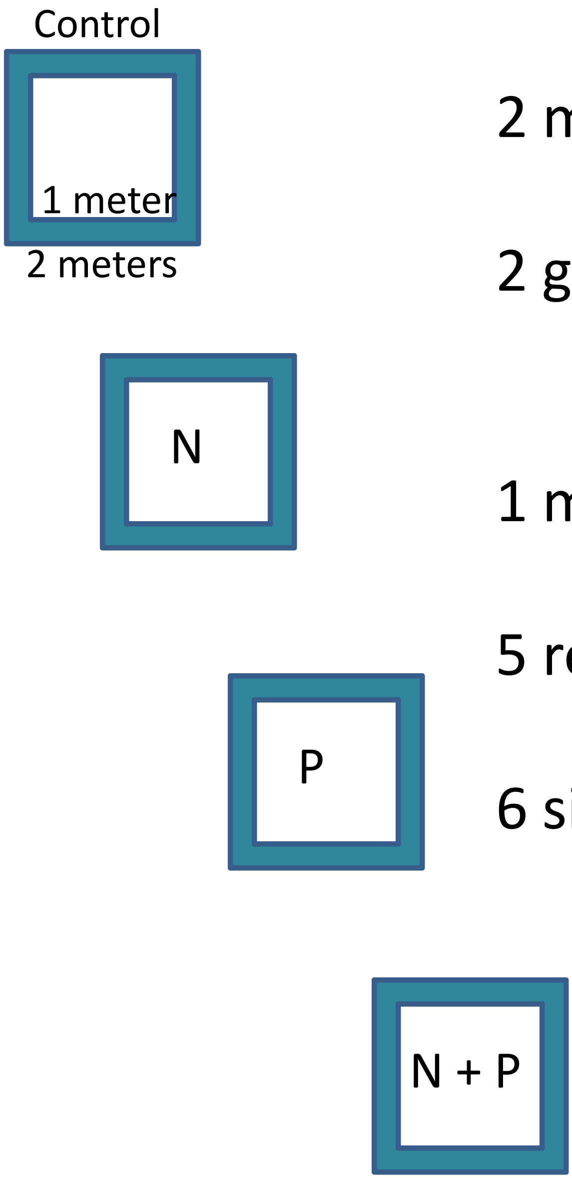
Hypothesized relationship between nutrient enrichment and plant species diversity



Design of Experimental Nutrient Enrichment



2 m x 2 m plots fertilized

2 g P/m2, 6 g N/m2 – applied in two equal doses each year

1 m x 1 m internal plots used for measurements

5 replicates each site

6 sites

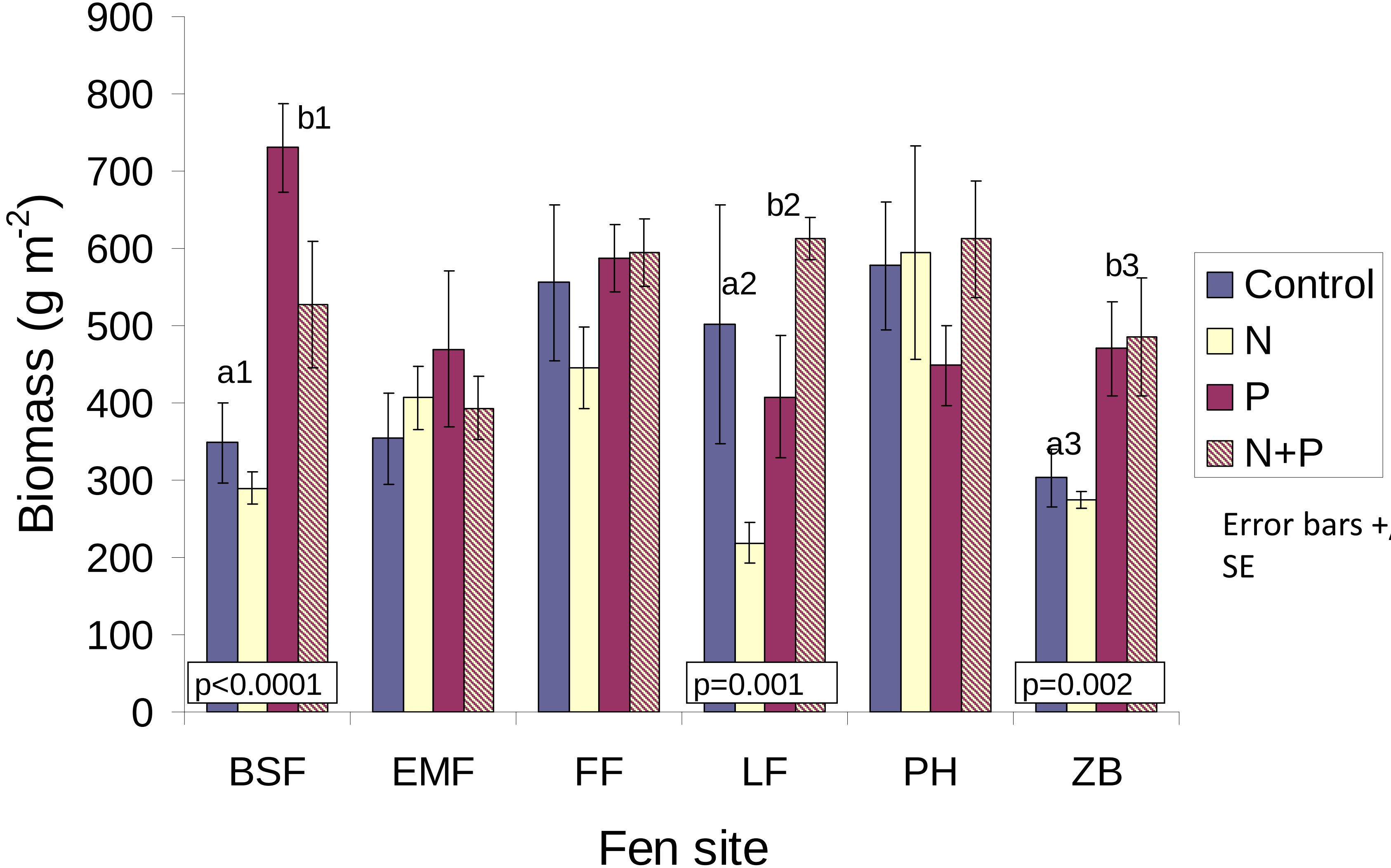
2 of the sites received 3 additional P treatments: an organically bound P, Ca-P, and Fe-P

Belle School Fen fertilization experiment after 6 years of treatment

Control plot

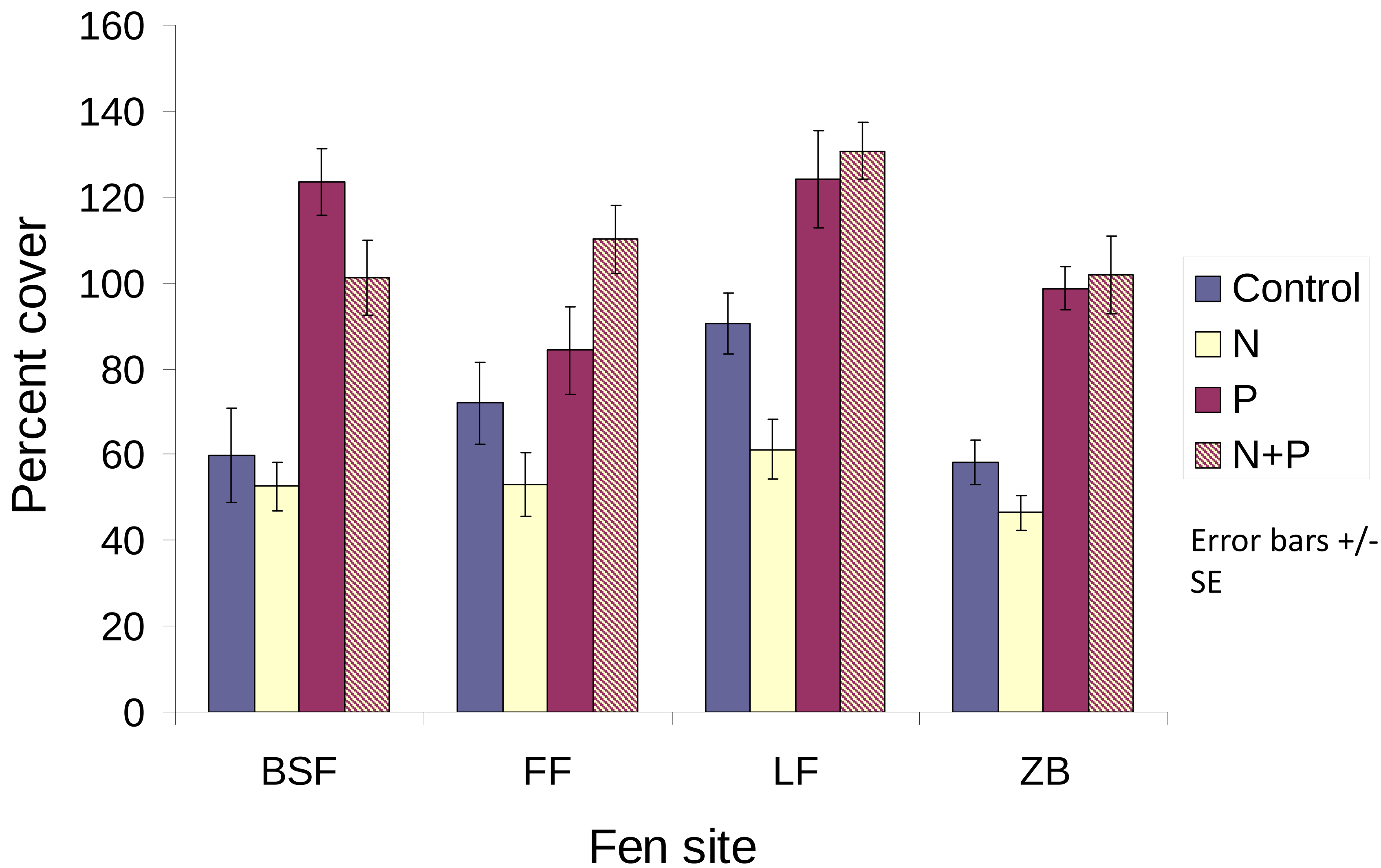
P fertilization plot

Biomass increased in only three sites in response to fertilization, after four years of treatment

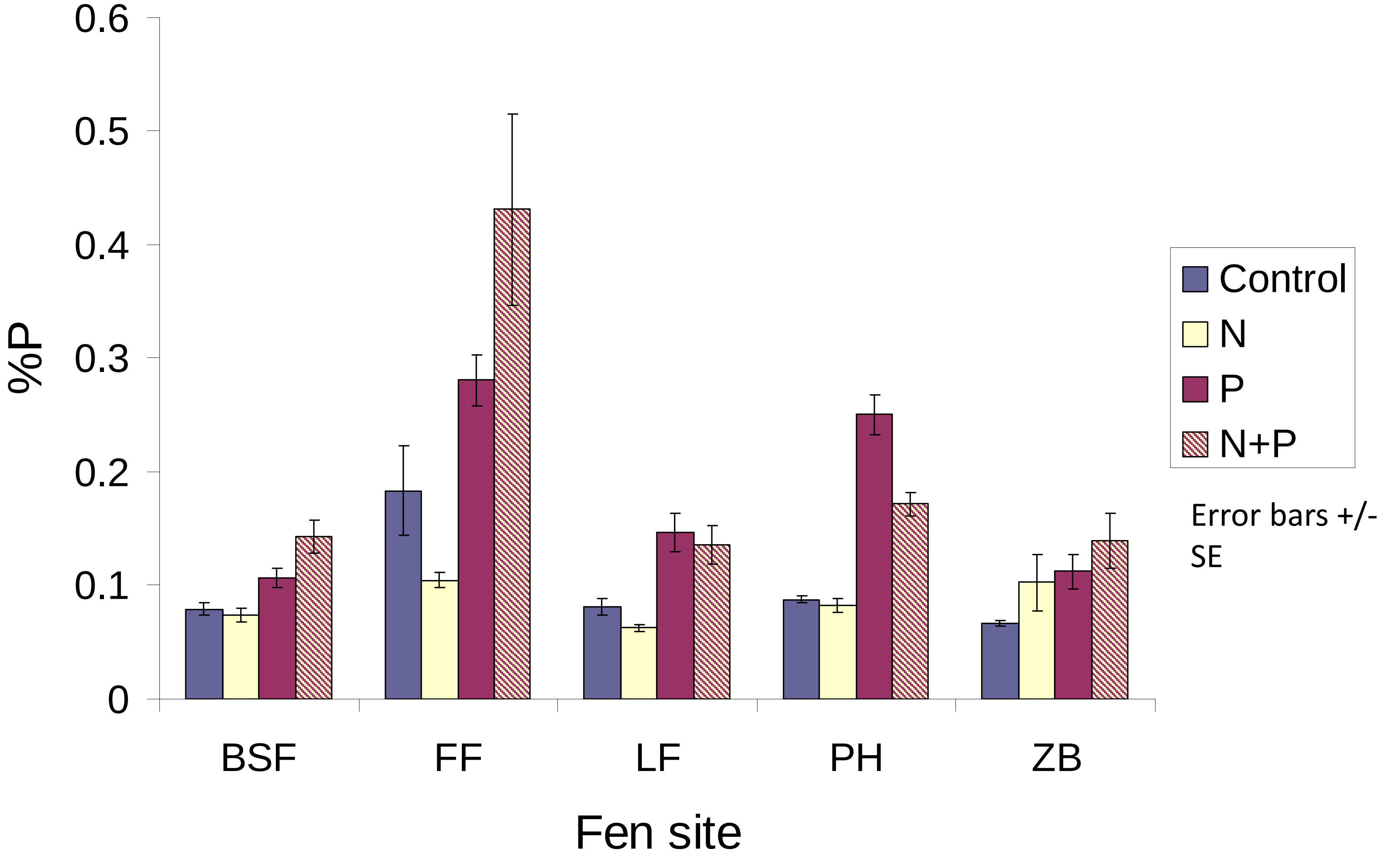


Error bars +/- SE

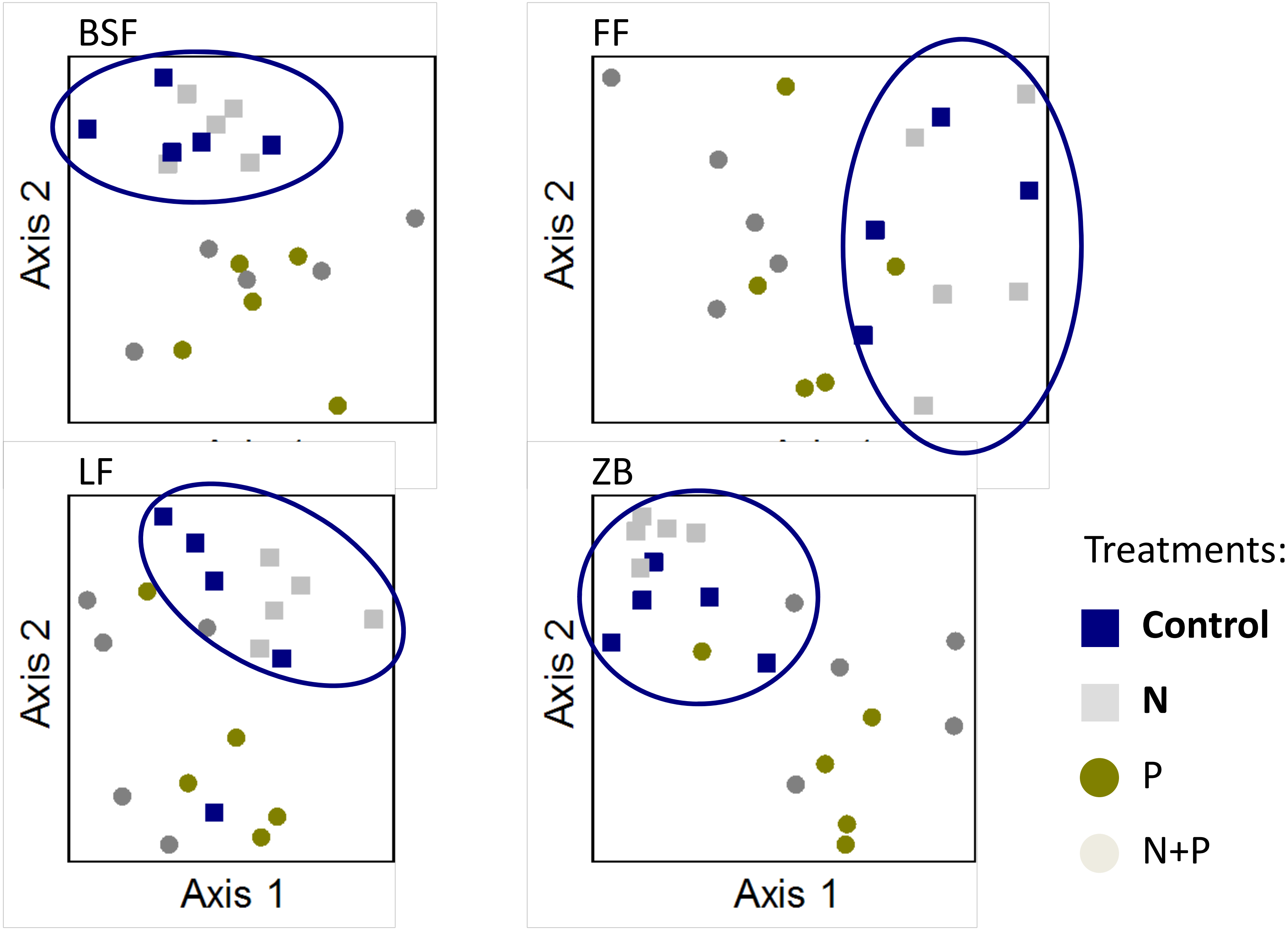
Total vascular cover increased significantly after nine years of fertilization, 2000-2008



Plants showed significant responses to fertilization as indicated here by tissue P in composite forb species

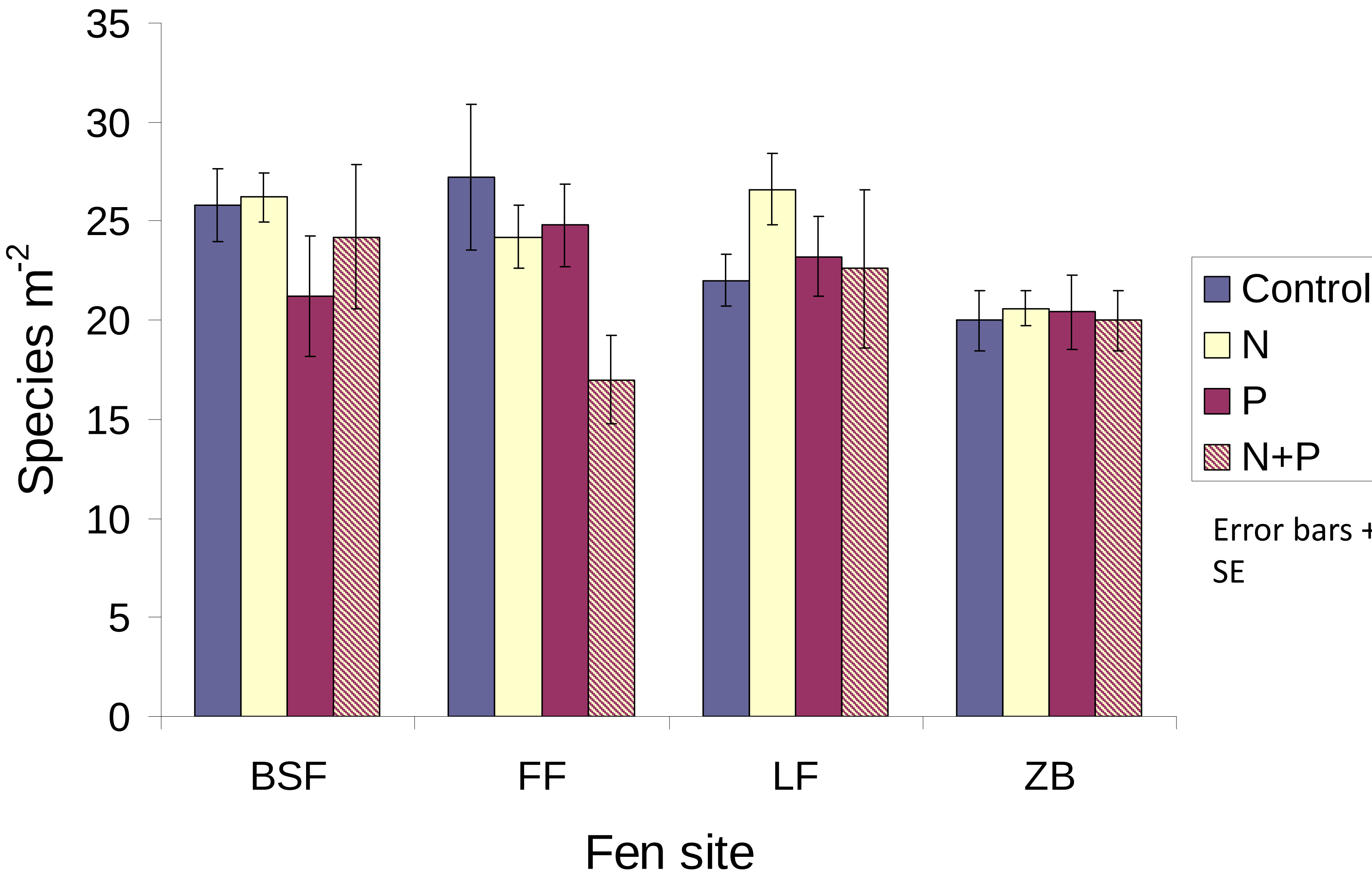


NMS ordination of species composition showed that P treatments differed significantly from both controls and N treatment



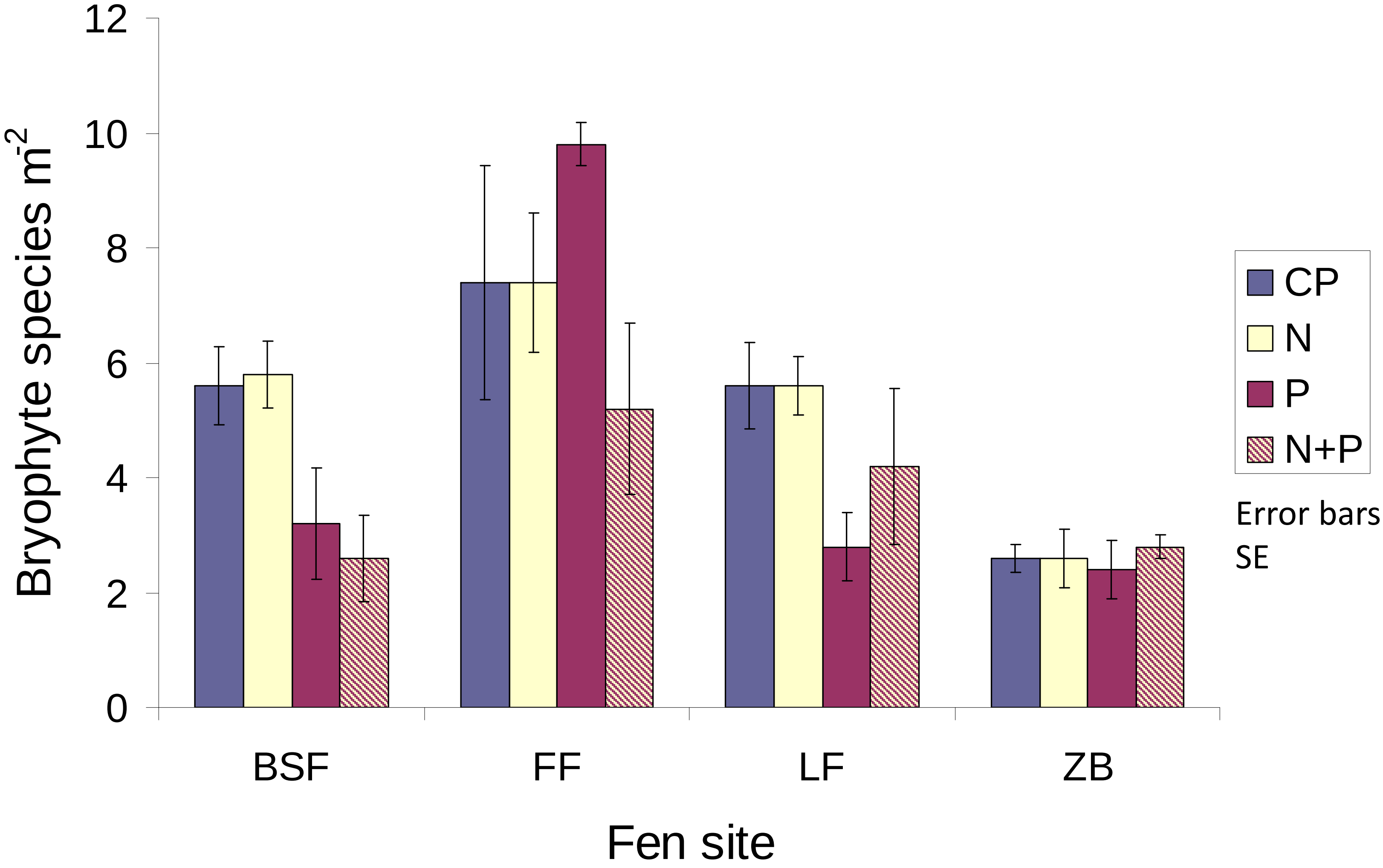
BUT . . .

Virtually no response of total species density after nine years of fertilization, 2000-2008



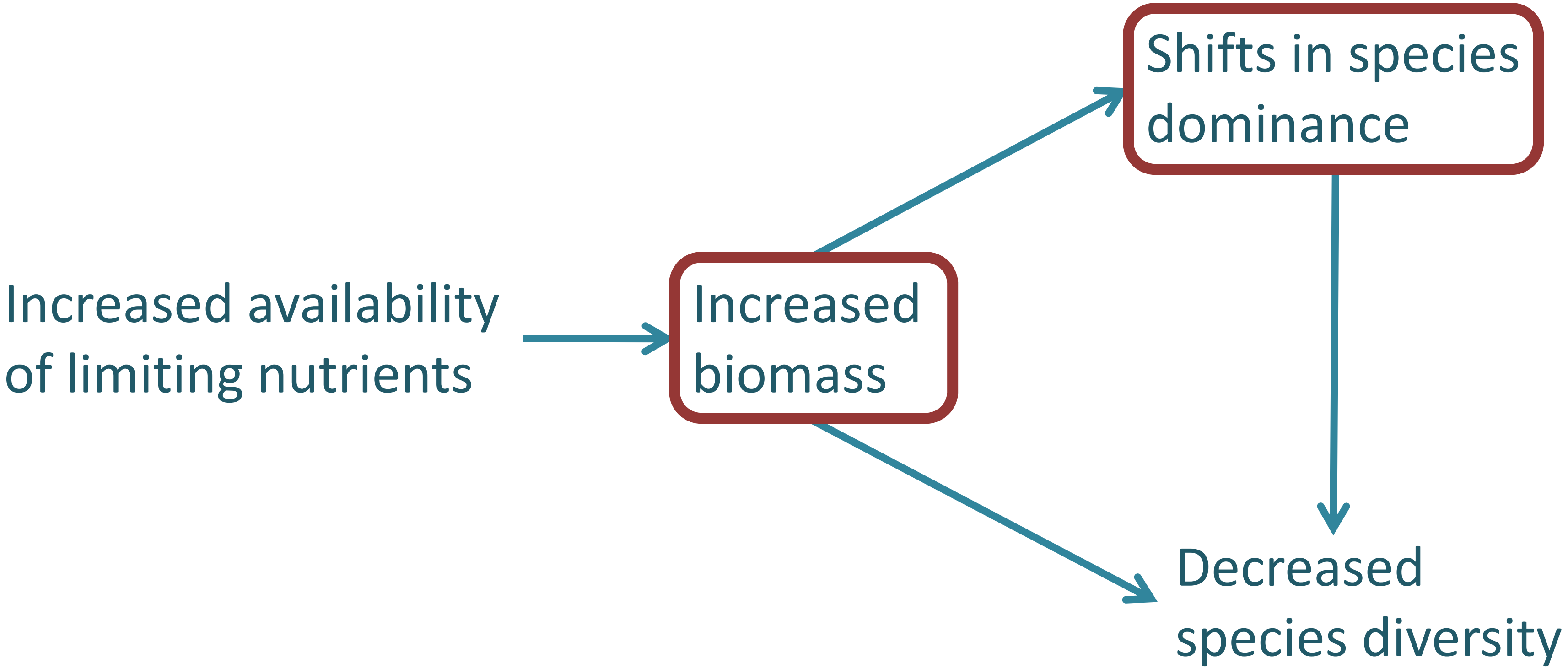
Error bars +/- SE

Response of bryophyte species density to fertilization varied by site, after nine years of fertilization



Error bars +/- SE

Observed relationship between nutrient enrichment and plant species diversity



Vol 437|22 September 2005|**doi:10.1038/nature03950** **nature**

LETTERS

Endangered plants persist under phosphorus limitation

Martin J. Wassen[1]*, Harry Olde Venterink[2]*, Elena D. Lapshina[3]† & Franziska Tan

Nitrogen enrichment is widely thought to be responsible for the loss of plant species from temperate terrestrial ecosystems. This view is based on field surveys and controlled experiments showing that species richness correlates negatively with high productivity[1,2] and nitrogen enrichment[3]. However, as the type of nutrient limitation has never been examined on a large geographical scale the causality of these relationships is uncertain. We investigated species richness in herbaceous terrestrial ecosystems, sampled along a transect through temperate Eurasia that represented a gradient of declining levels of atmospheric nitrogen

(fens, bogs and fluvial marshe
temperate Eurasia (51–57° N
transect from the Netherla
Poland (23° E) to western Si
resents a gradient of decli
deposition, from high in t
60 kg N ha^{-1} yr^{-1}), to much l
to very low in Siberia (<5 k
recorded species richness of
gered species (using the Du

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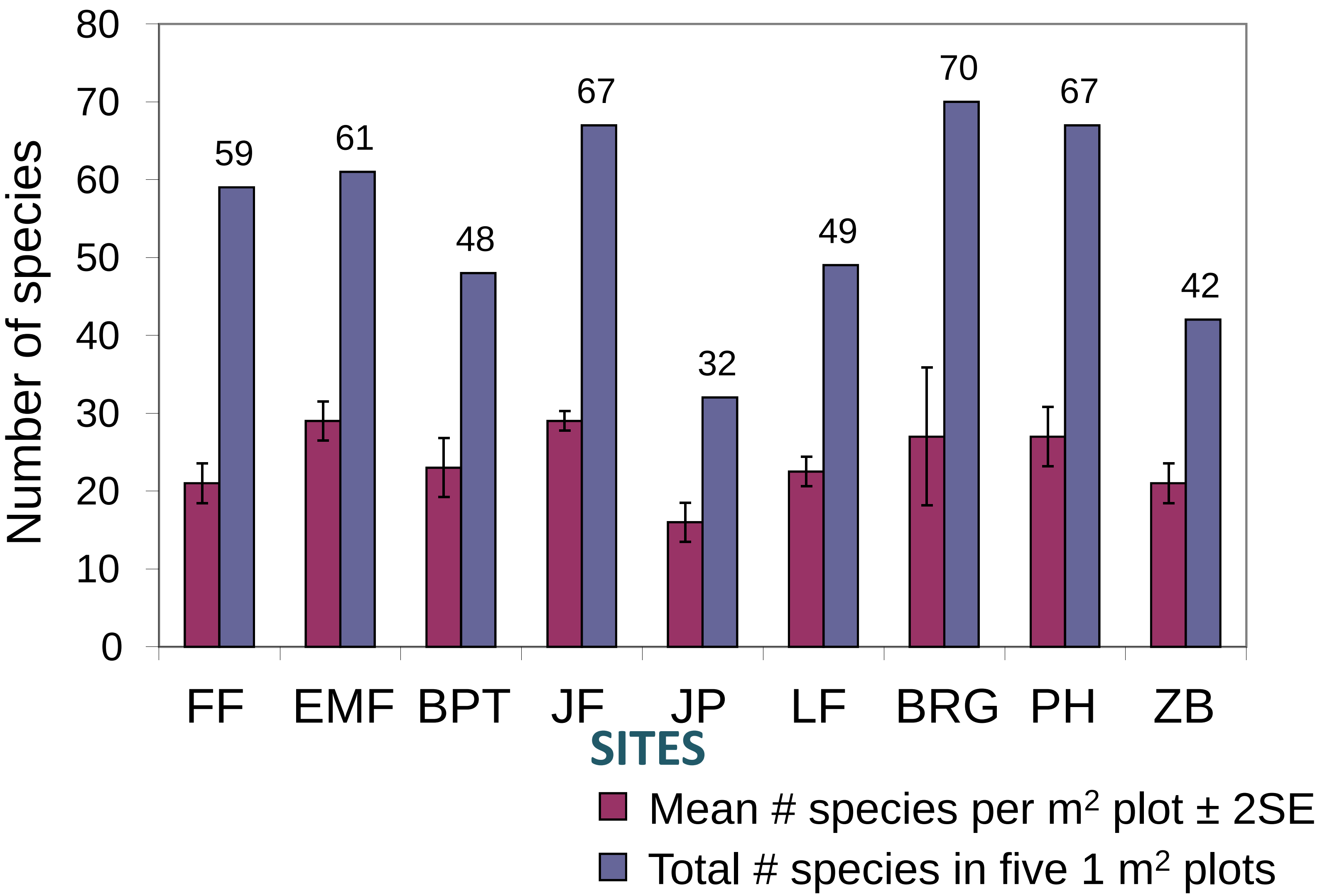
Species Diversity in New York Rich Fens
~ 80 % in the *beta* component

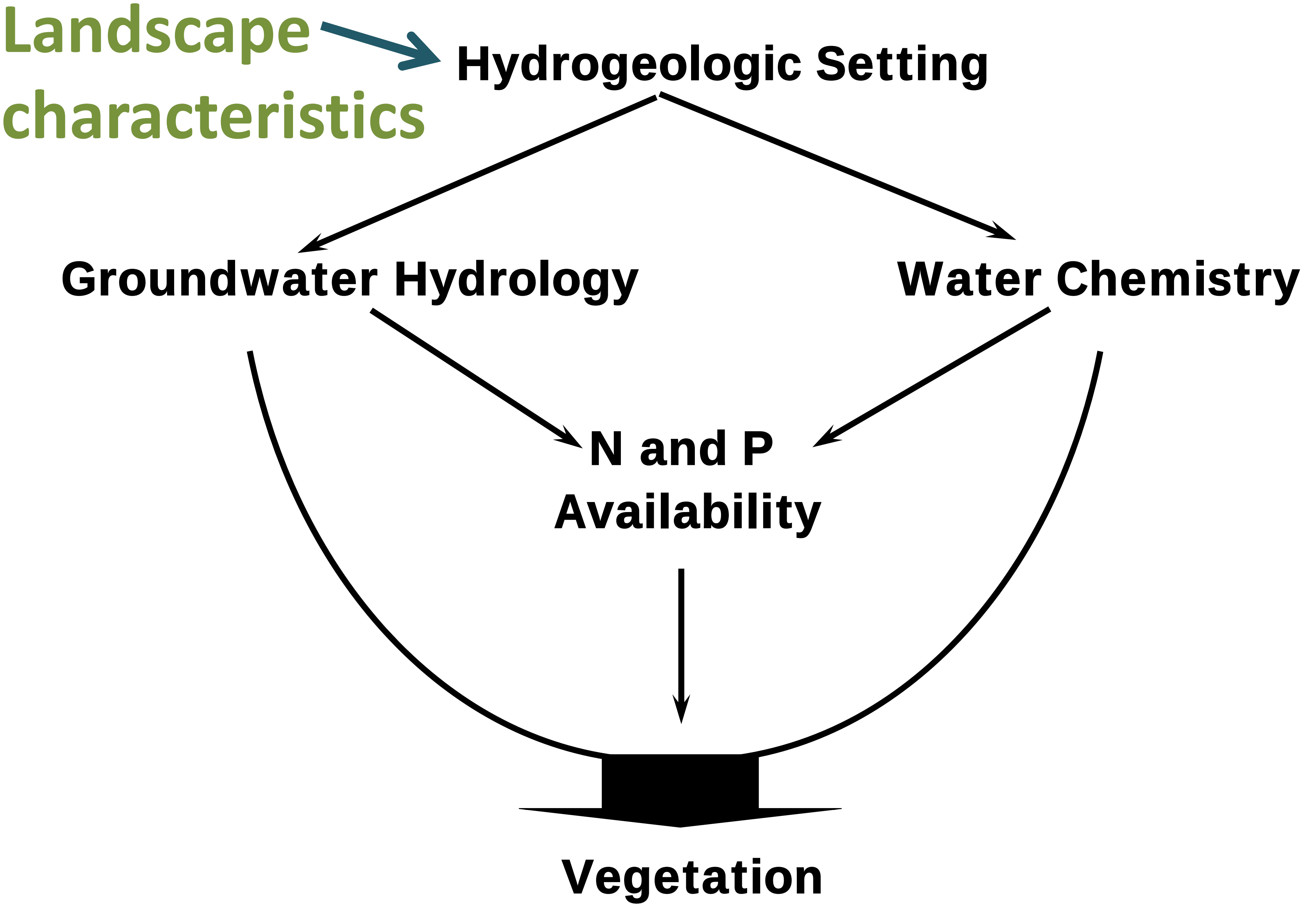


The Nature of New York's Rich Fens

- Groundwater-fed
- Saturated but not flooded
- pH > about 6.0
- Peat or carbonate substrate
- Base-rich
- Rich in dicot herbs and brown mosses
- High calcium, bicarbonate or sulfate
- Many rare plant species

Occur in a landscape of mixed agriculture and forest

Receive N, P, S from agriculture, N and S from atmosphere


Landscape characteristics
Hydrogeologic Setting
Groundwater Hydrology
Water Chemistry
N and P Availability
Vegetation

Groundwater carries the chemical "signature" of the soils, glacial deposits, or bedrock through or over which it moves.

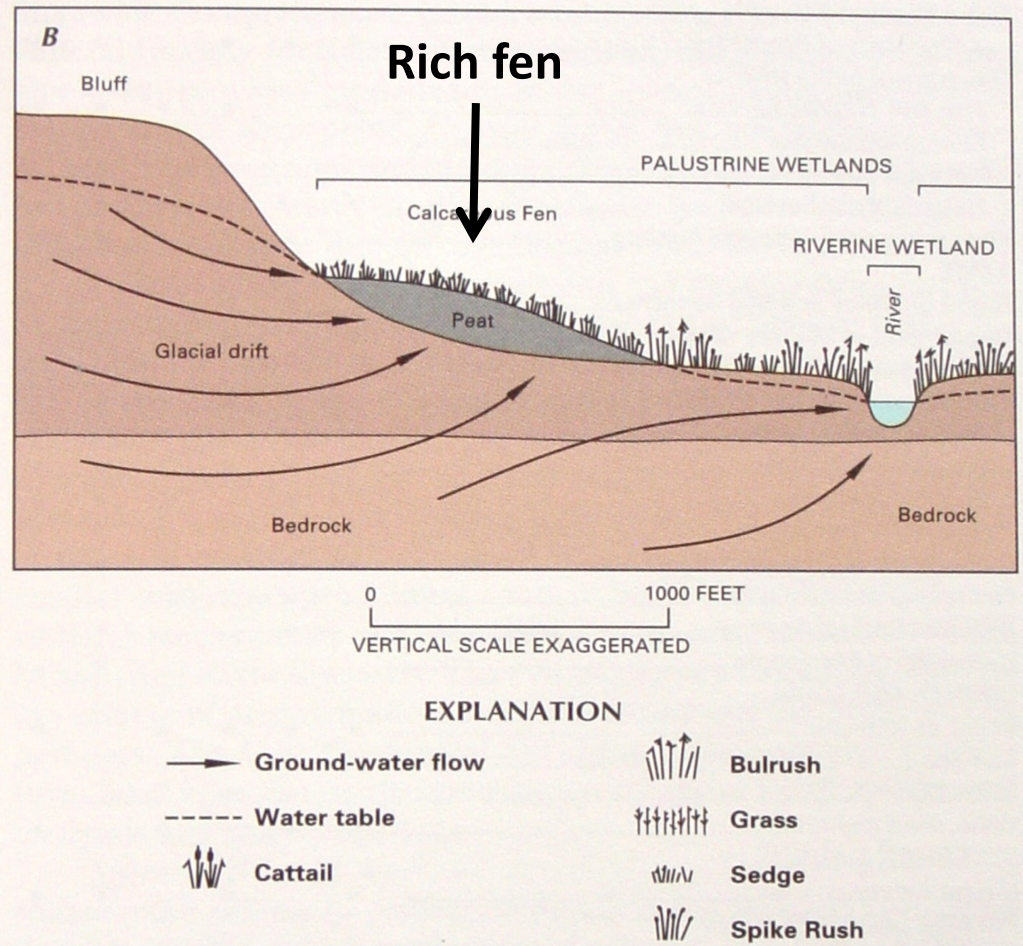
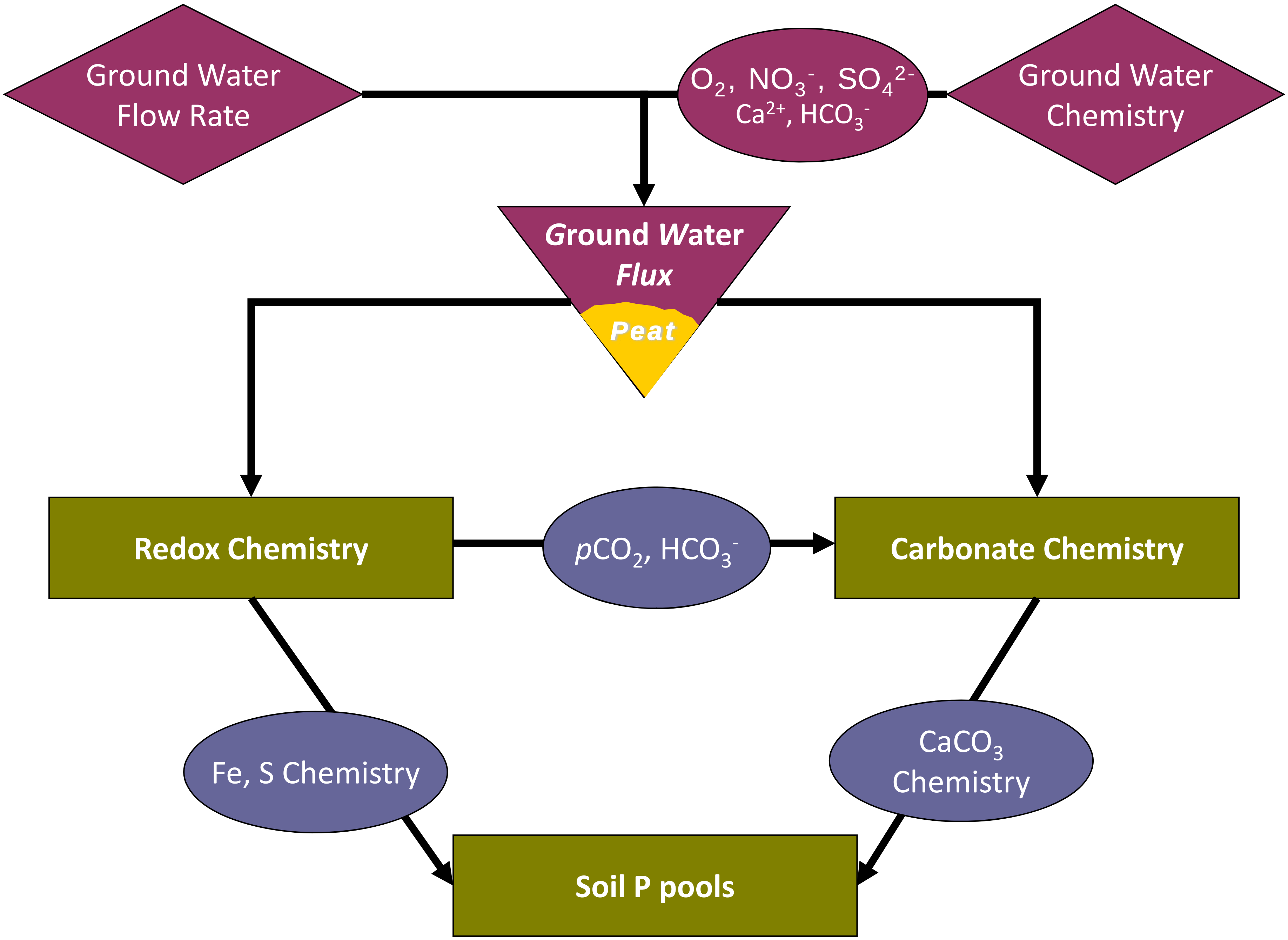
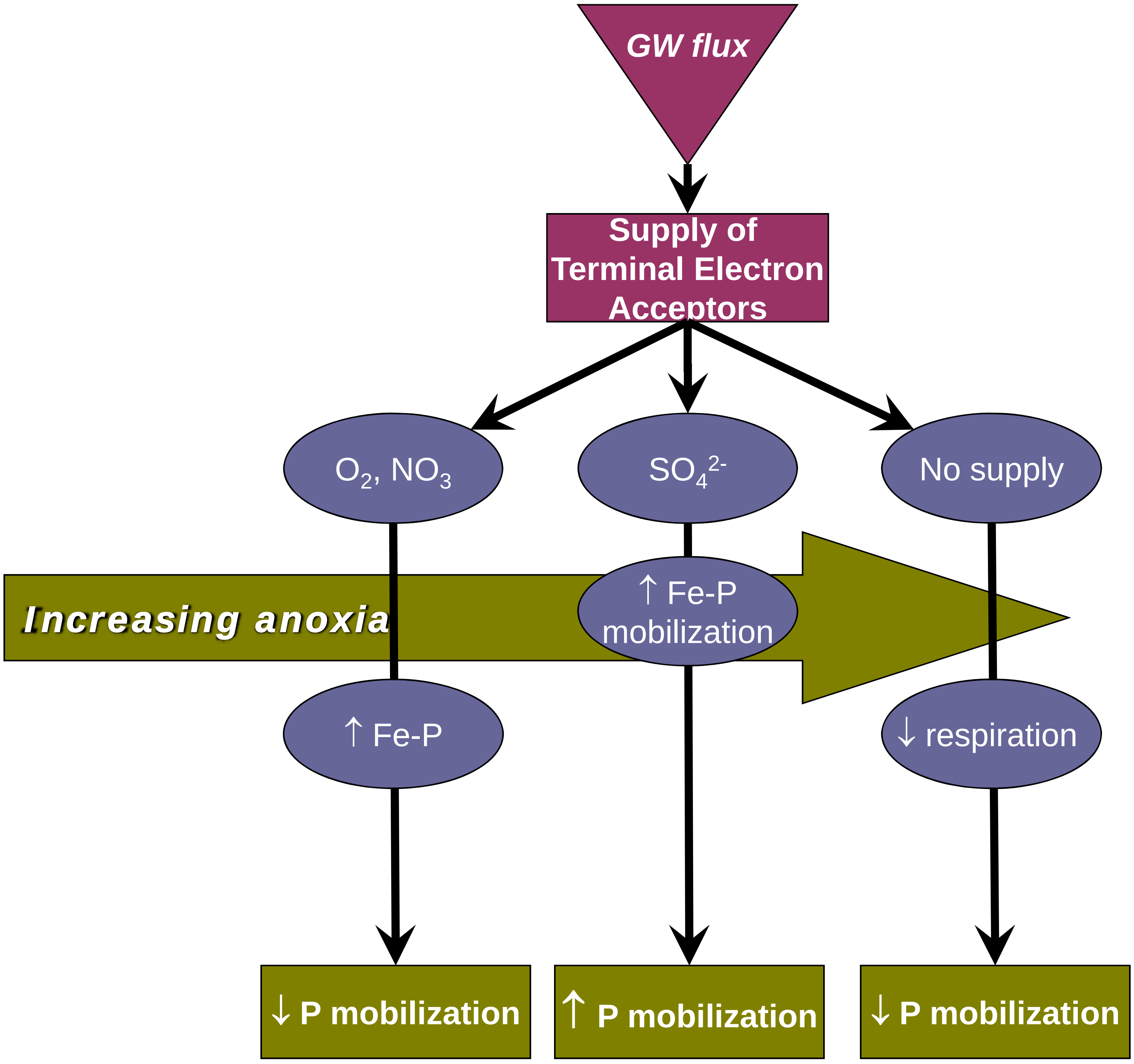


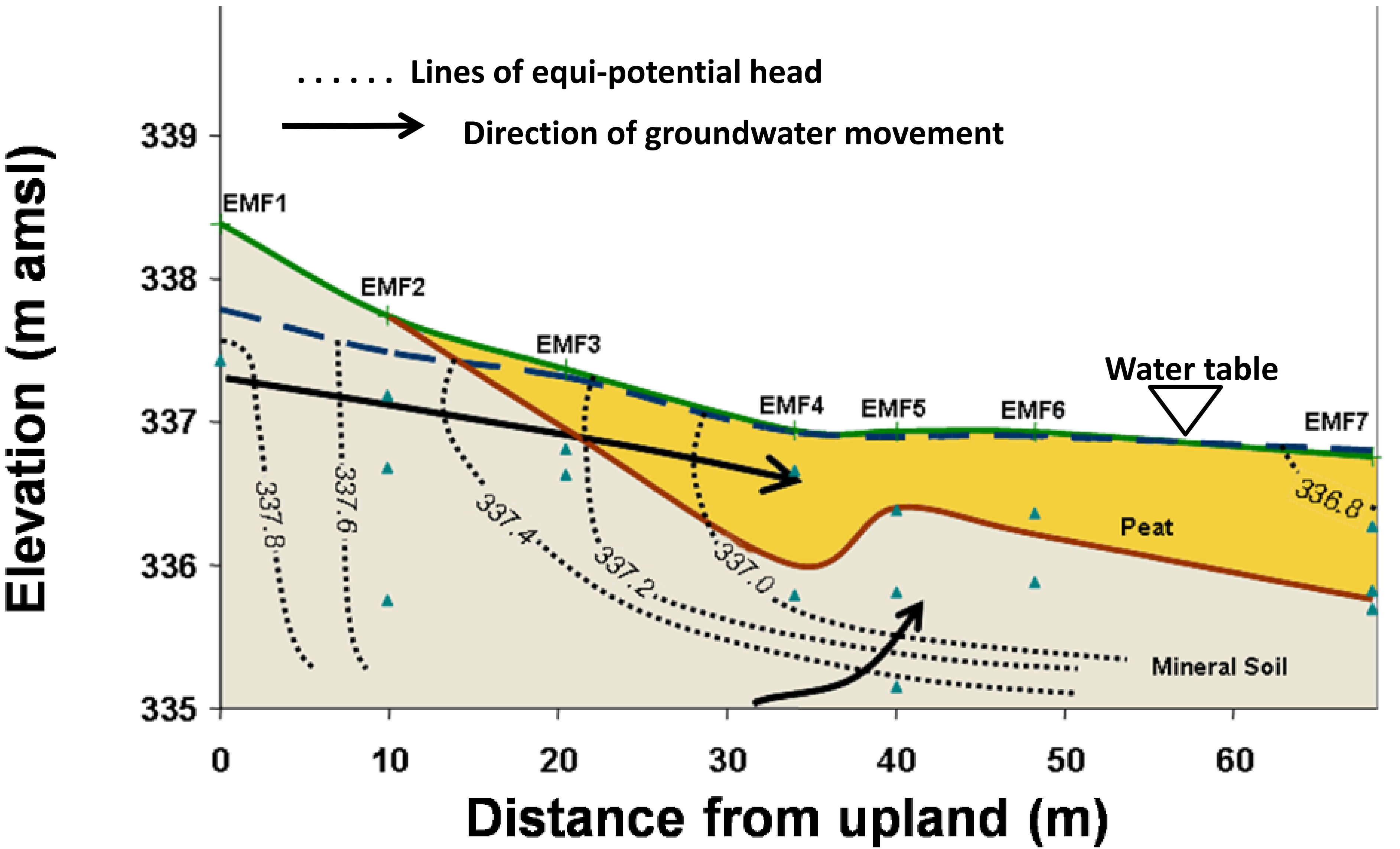
Figure 3. Hydrologic interaction between wetlands and ground water. ***A***, Conceptual ground-water discharge and recharge in a wetland. ***B***, Conceptual ground-water flow under a calcareous fen in the Minnesota River Valley.

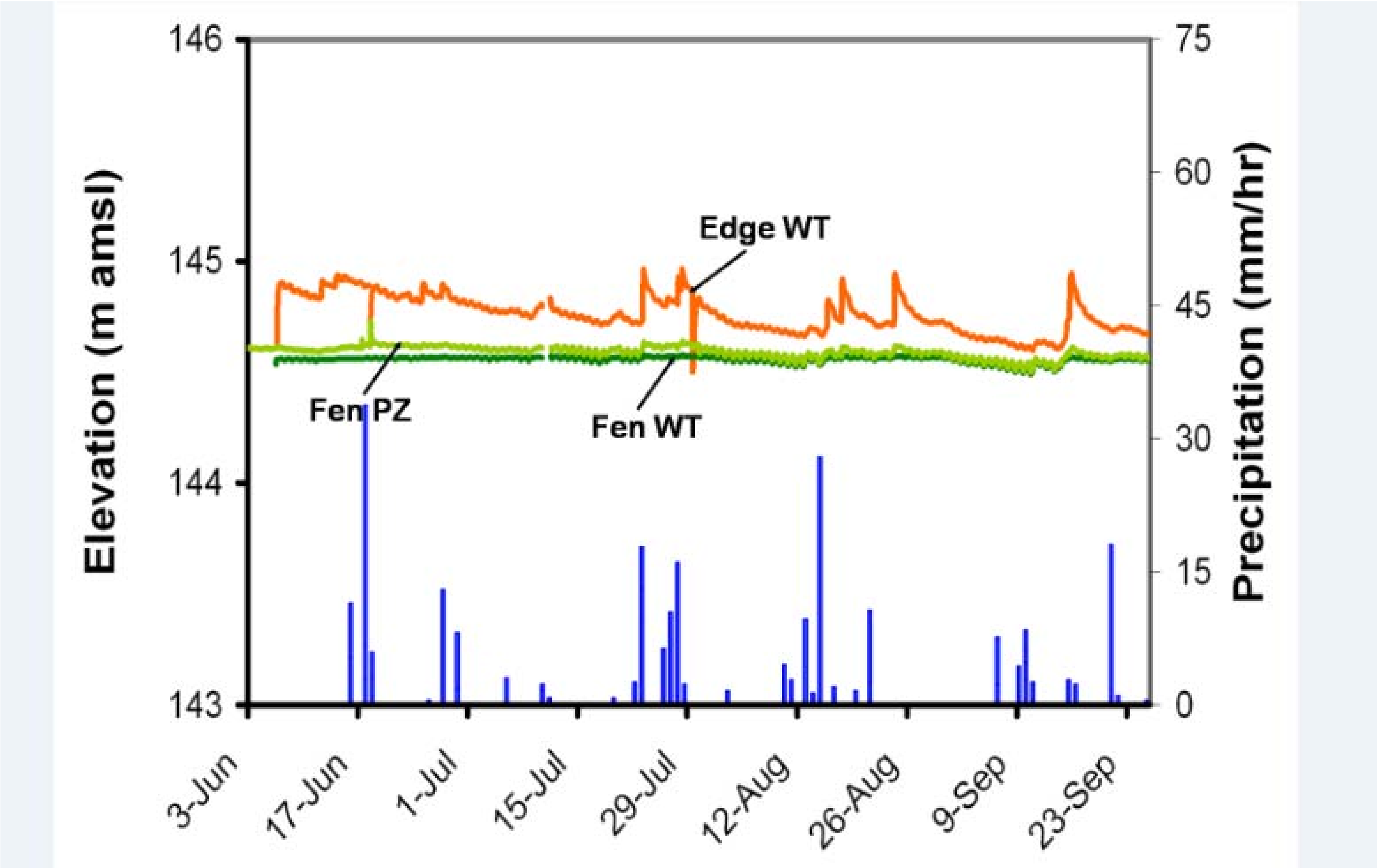
From Winter and others (1999) based on Komor 1994)


Ground Water
Flow Rate
O_2, NO_3^-, SO_4^{2-}
Ca^{2+}, HCO_3^-
Ground Water
Chemistry
Ground Water
Flux
Peat
Redox Chemistry
$p$$CO_2$, HCO_3^-
Carbonate Chemistry
Fe, S Chemistry
$CaCO_3$
Chemistry
Soil P pools


GW flux
Supply of Terminal Electron Acceptors
O_2, NO_3
SO_4^{2-}
No supply
Increasing anoxia
↑ Fe-P mobilization
↑ Fe-P
↓ respiration
↓ P mobilization
↑ P mobilization
↓ P mobilization

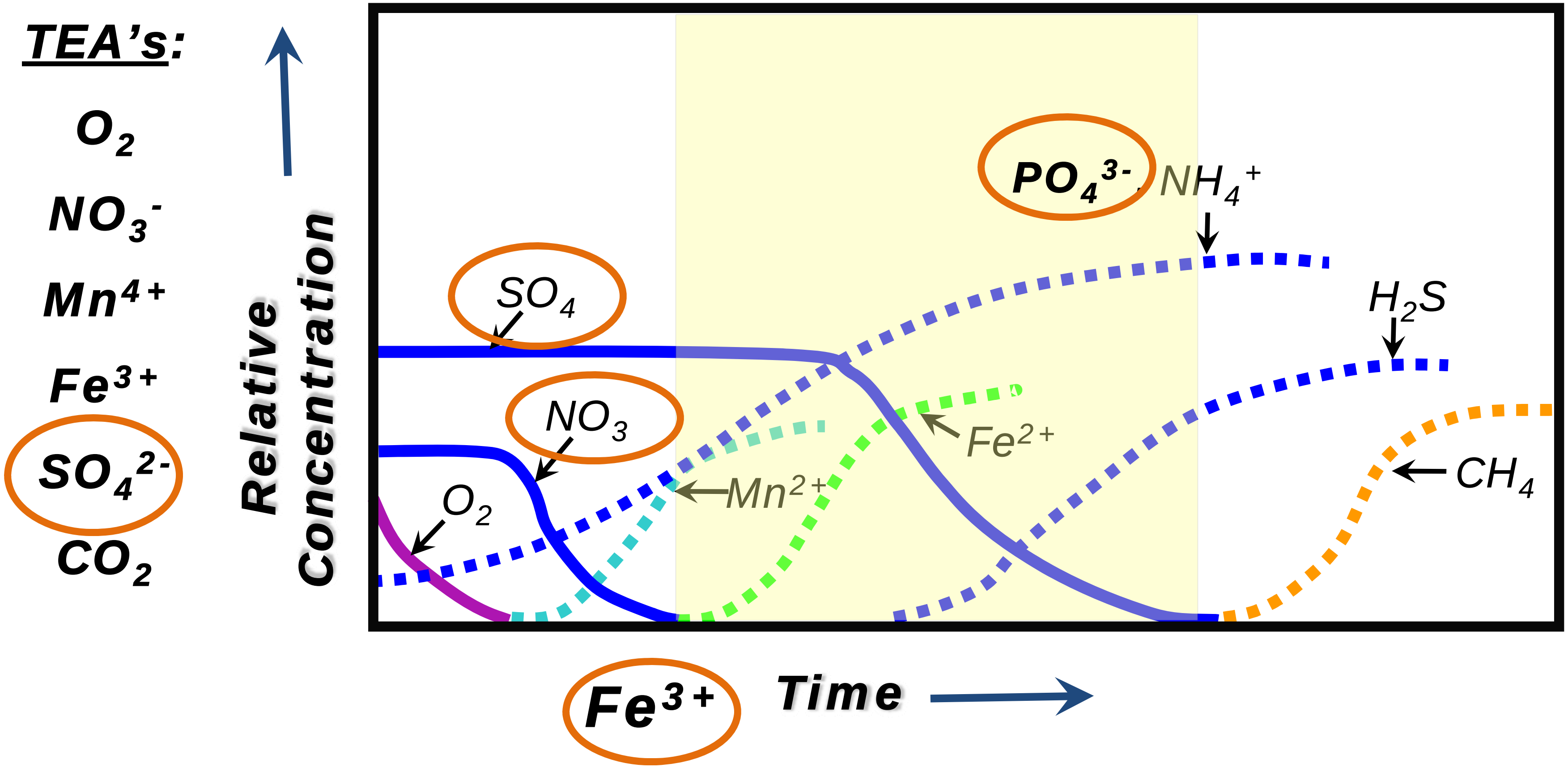
Locations of well clusters along a gradient of groundwater flow in East Malloryville Fen, New York





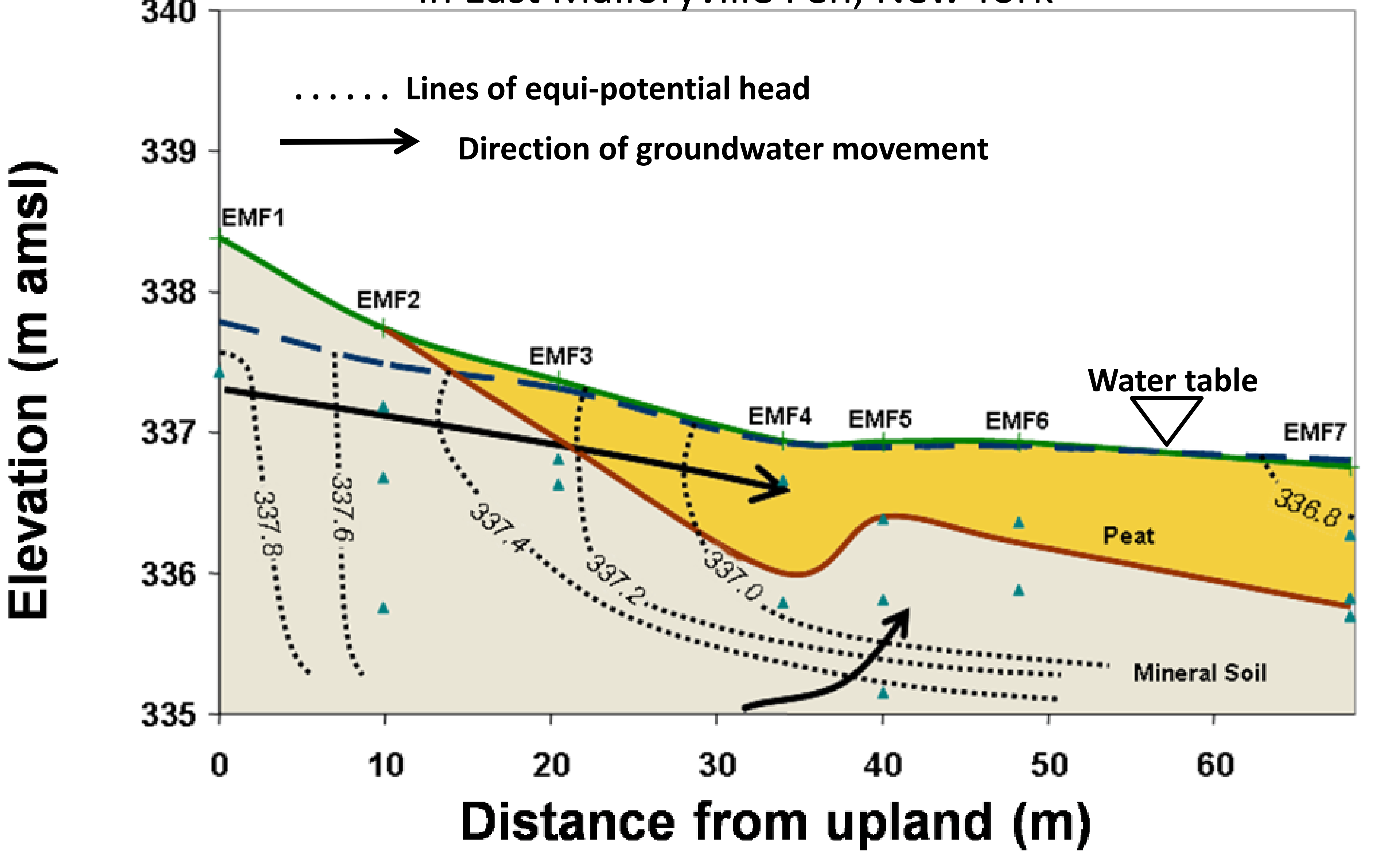
Groundwater discharge to fens maintains the water table near the soil surface and within a 10 cm range

Ground water supplies electron acceptors (TEA's) that control biogeochemical reactions **leading to increased P availability**



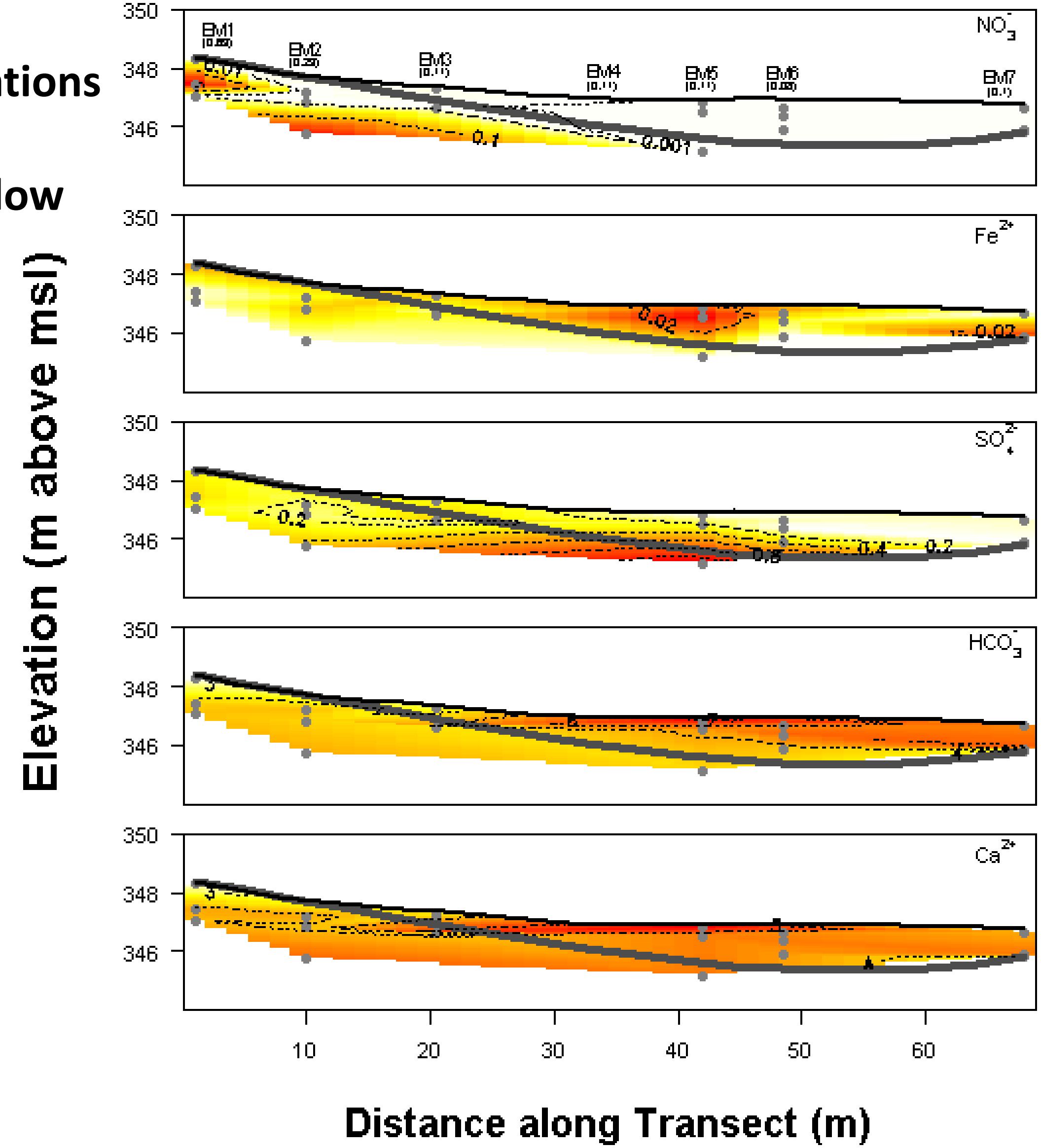
Modified from Mitsch & Gosselink 2000

Locations of well clusters along a gradient of groundwater flow in East Malloryville Fen, New York



Patterns and chemistry of groundwater flow create gradients in pore water chemistry across the fen

Highest concentrations in bright orange, lowest in pale yellow



Nitrate

Reduced iron

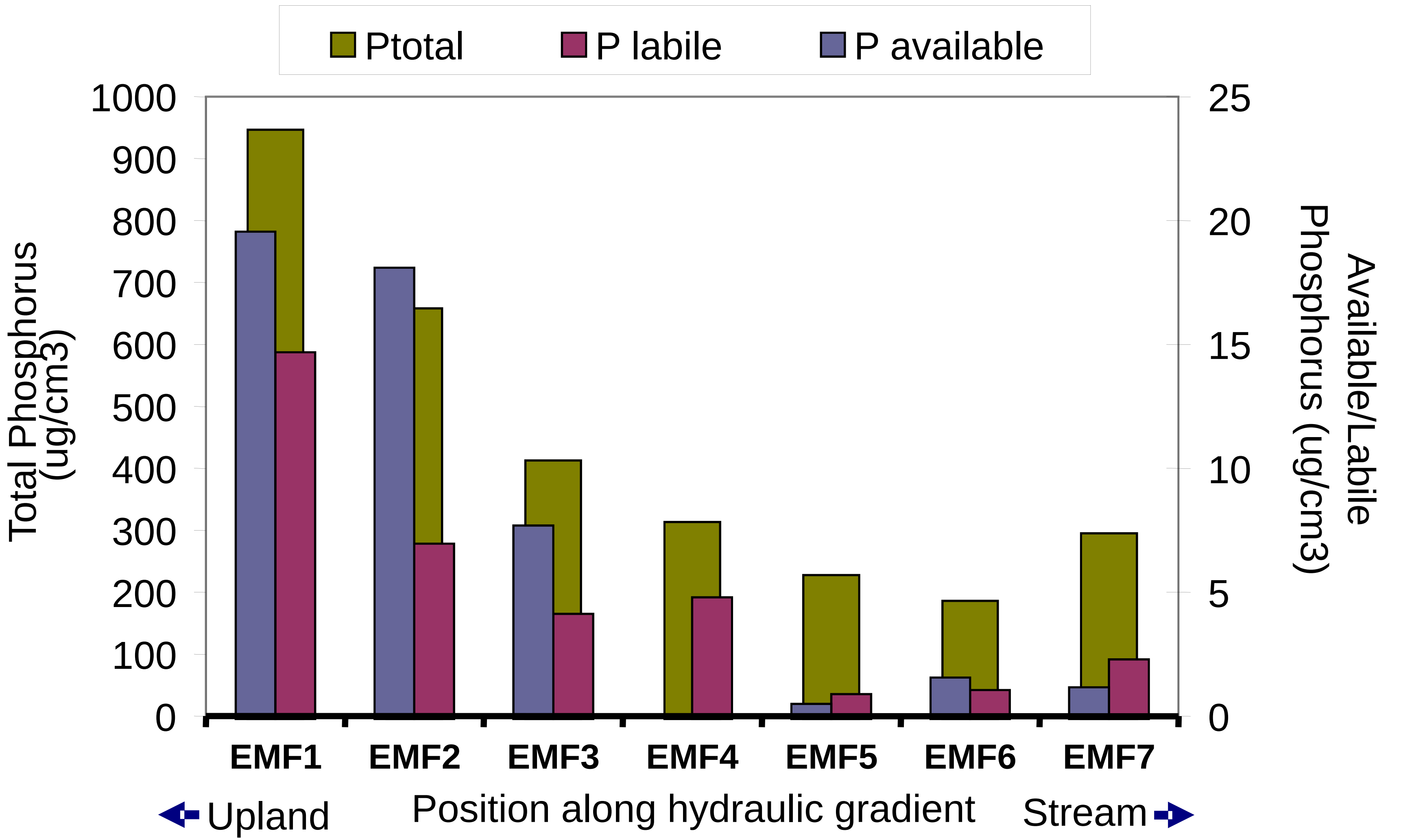
Sulfate

Bicarbonate

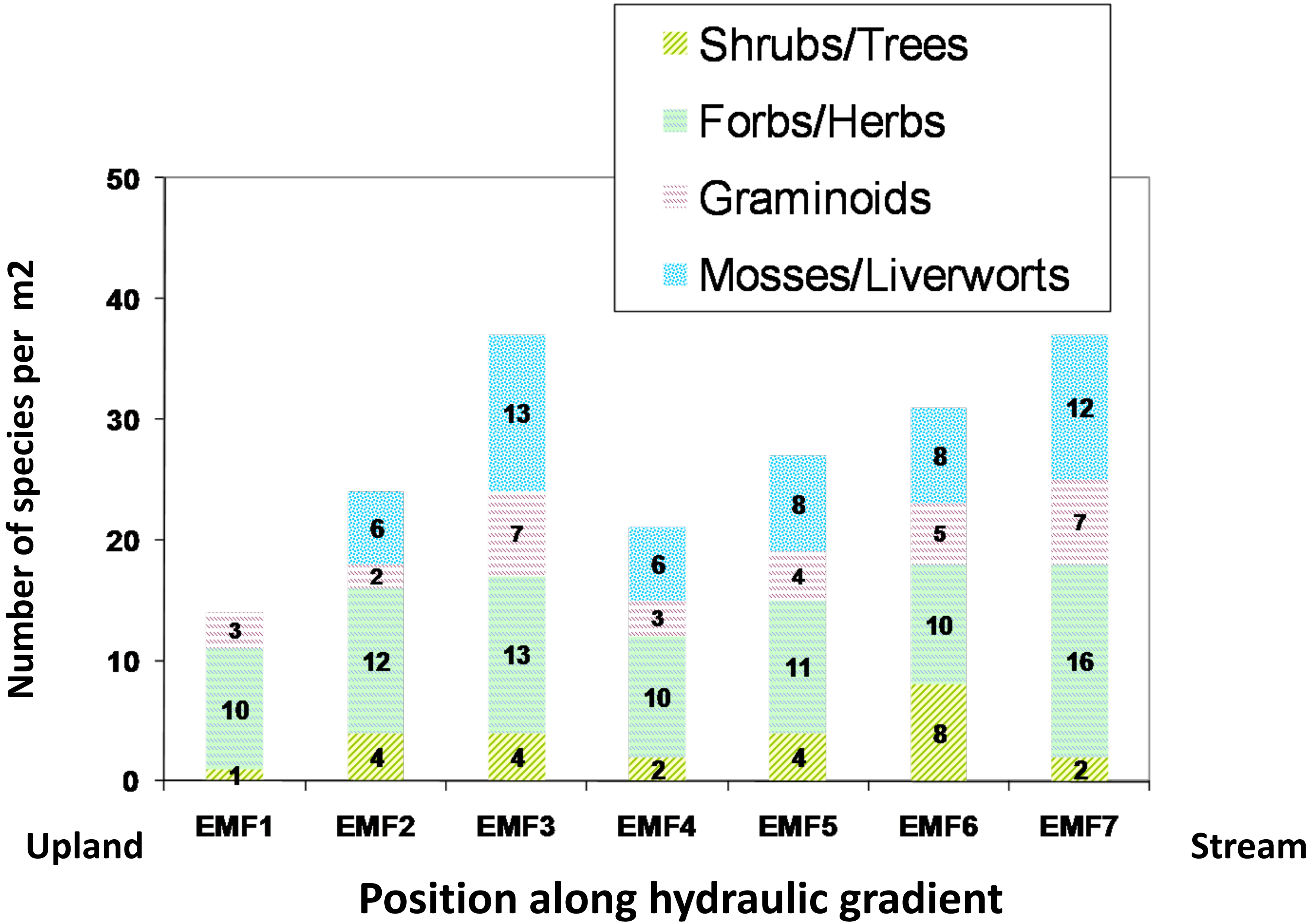
Calcium ion

East Malloryville Fen

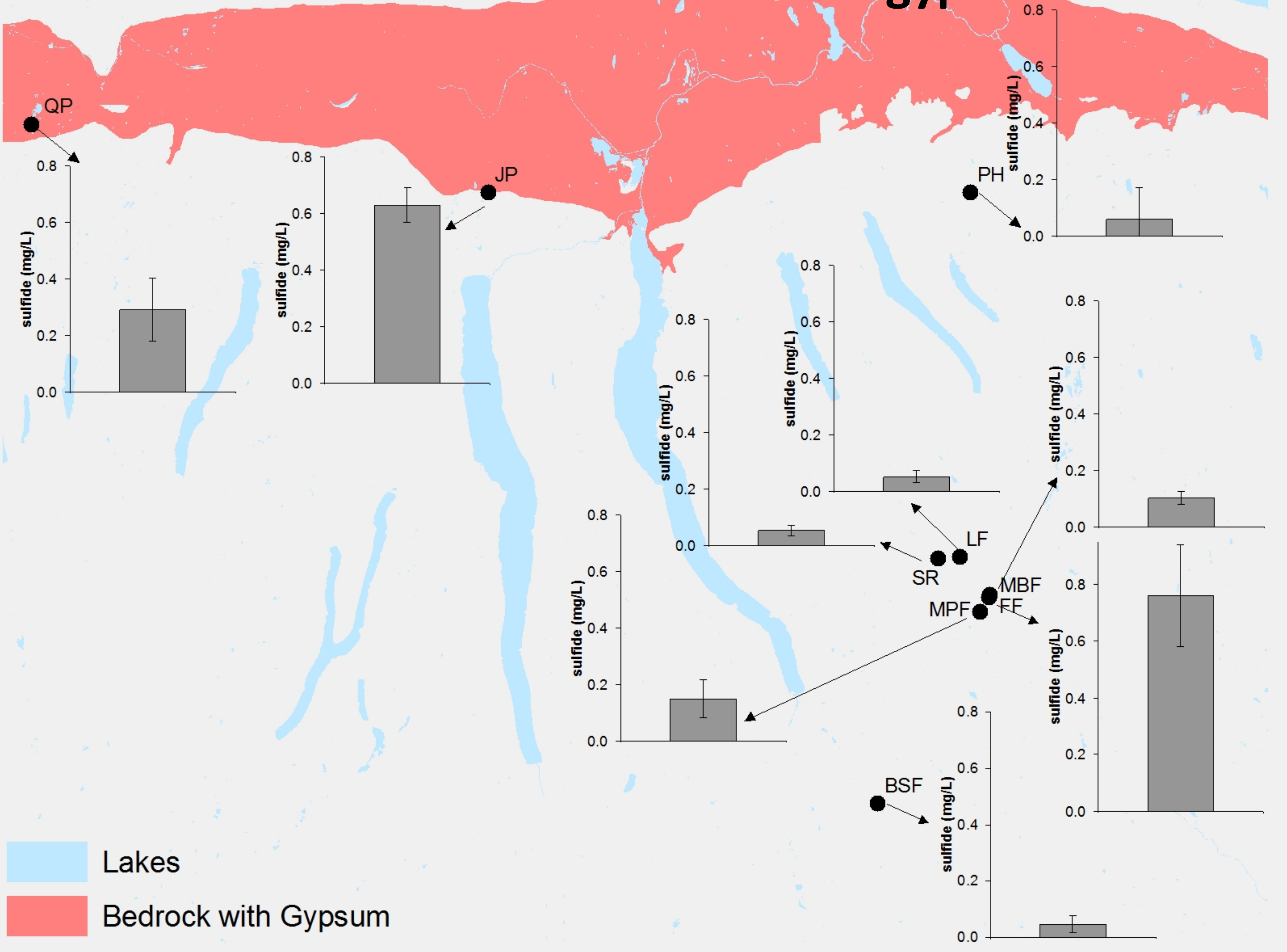
Consequently, available soil phosphorus content decreases along the groundwater flow path in East Malloryville Fen



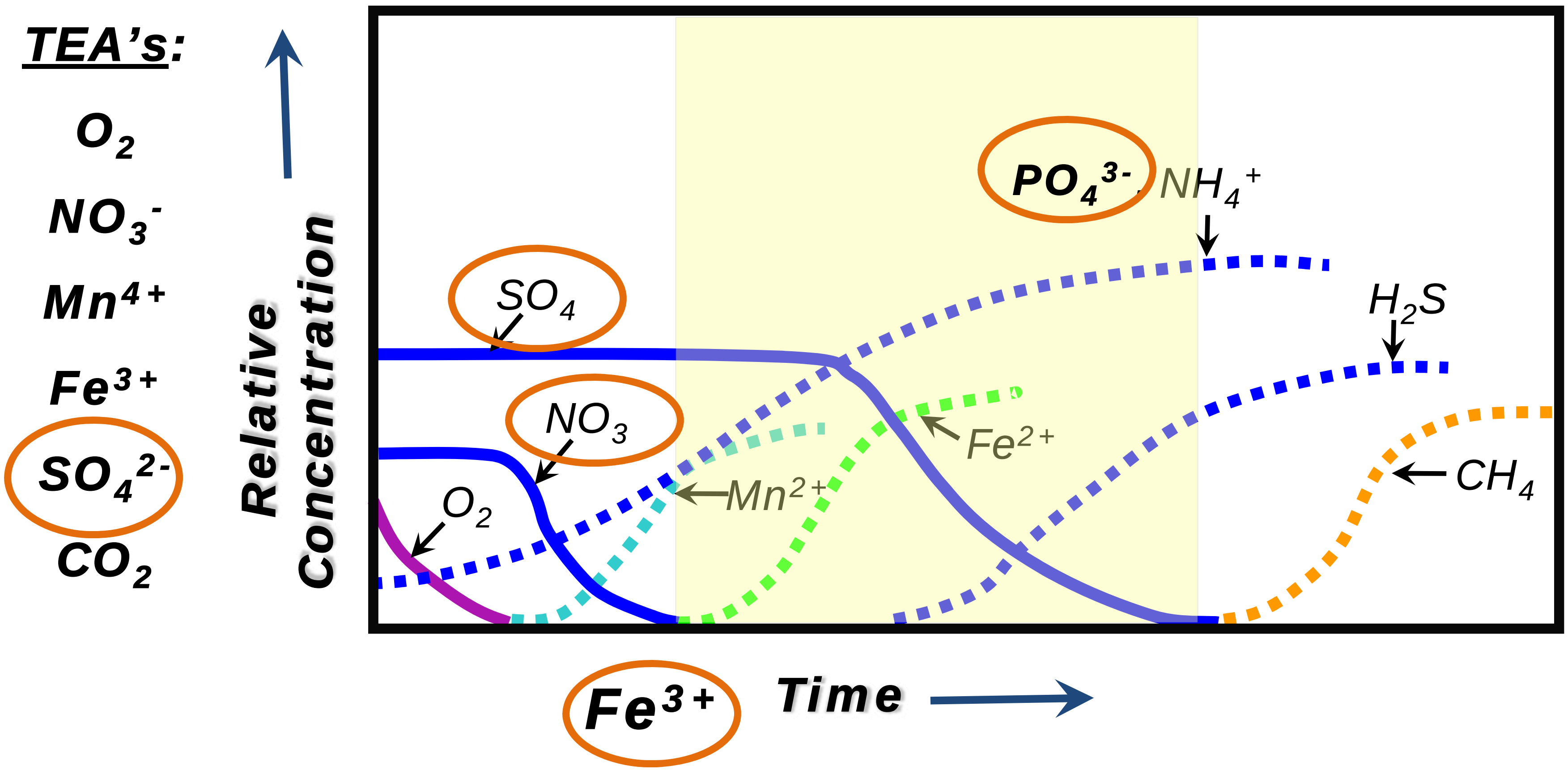
Number of species along the gradient reflect P availability



Sulfide levels in NY fens in relation to gypsum bedrock

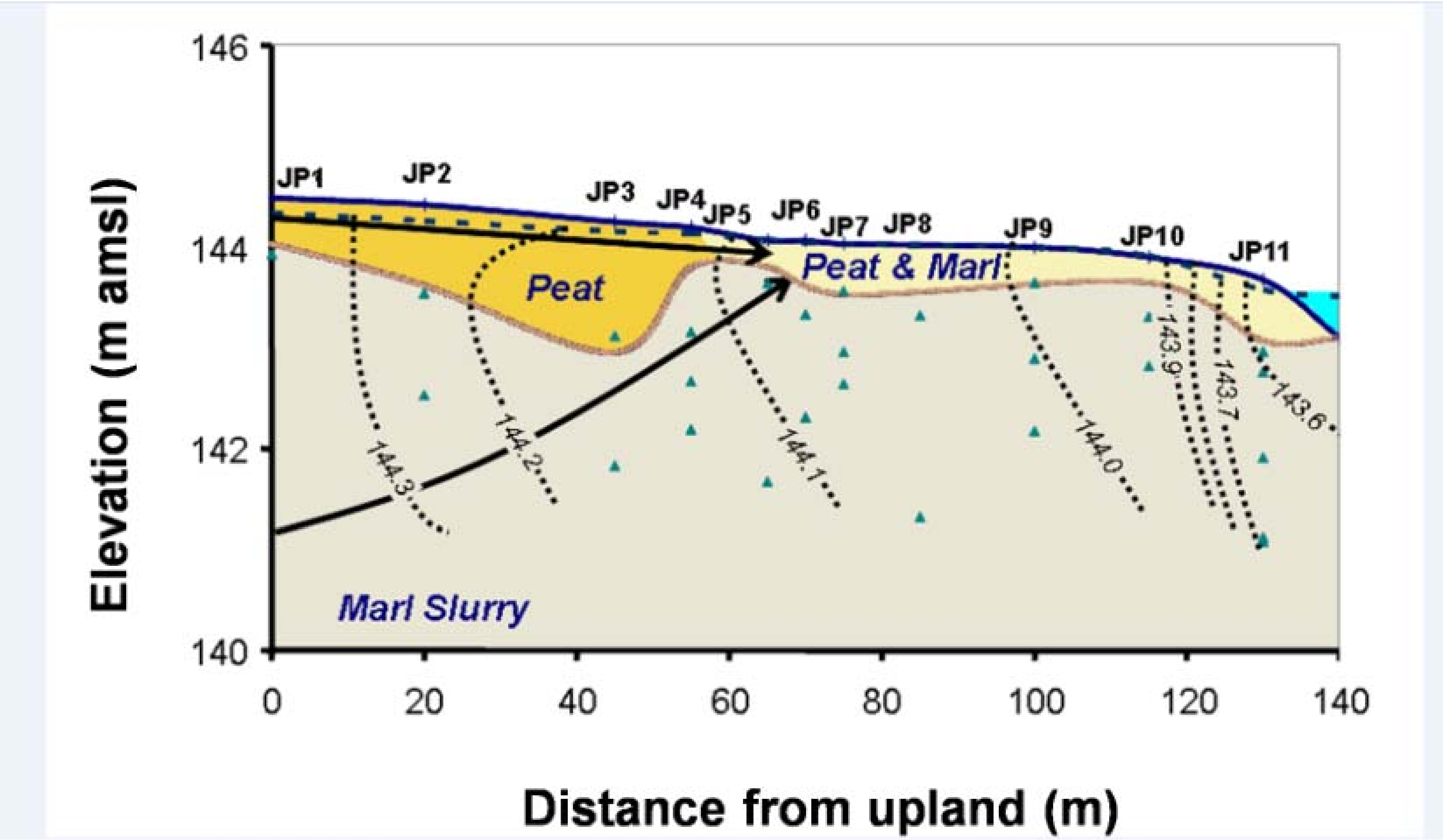


Ground water supplies electron acceptors (TEA's) that control biogeochemical reactions **leading to increased P availability**



Modified from Mitsch & Gosselink 2000

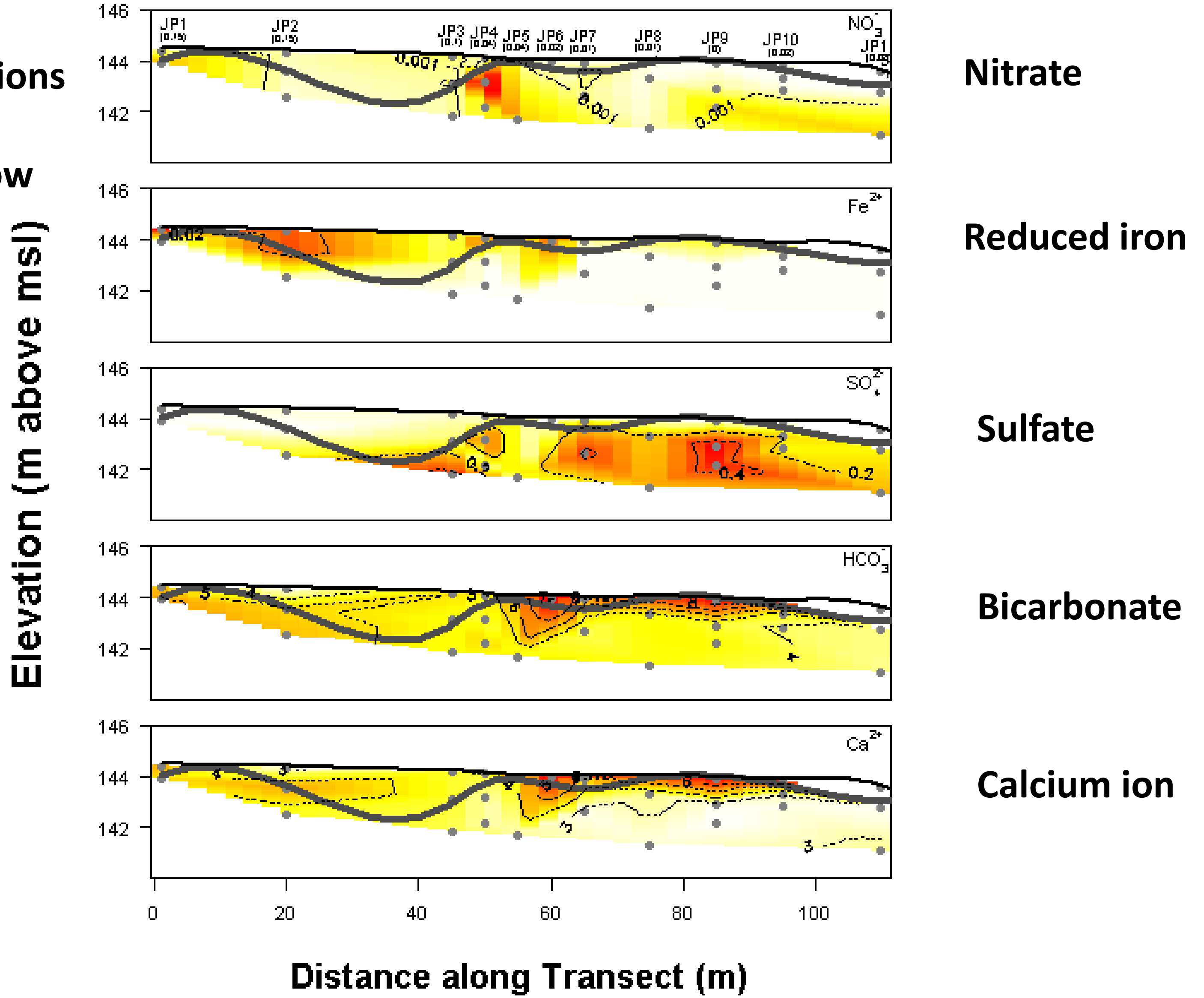
Locations of well clusters along a gradient of groundwater flow in East Junius Pond Fen, New York



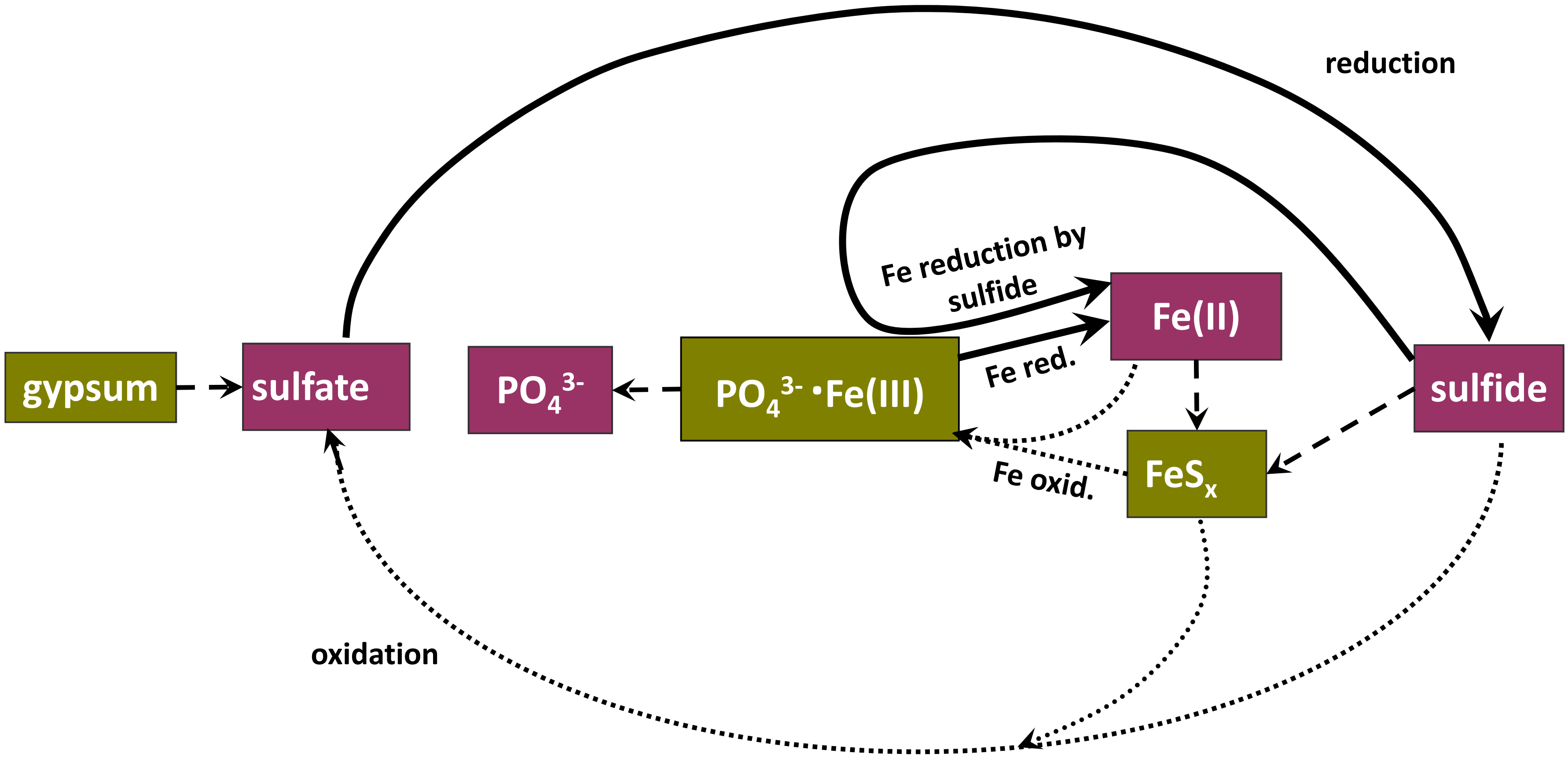
Groundwater flow paths and composition of subsurface geologic materials determine water chemistry in fens.

Gradients in pore water chemistry at Junius Pond Fen

Highest concentrations in bright orange, lowest in pale yellow



Sulfate derived from gypsum bedrock affects plants through effects on P availability and sulfide production.

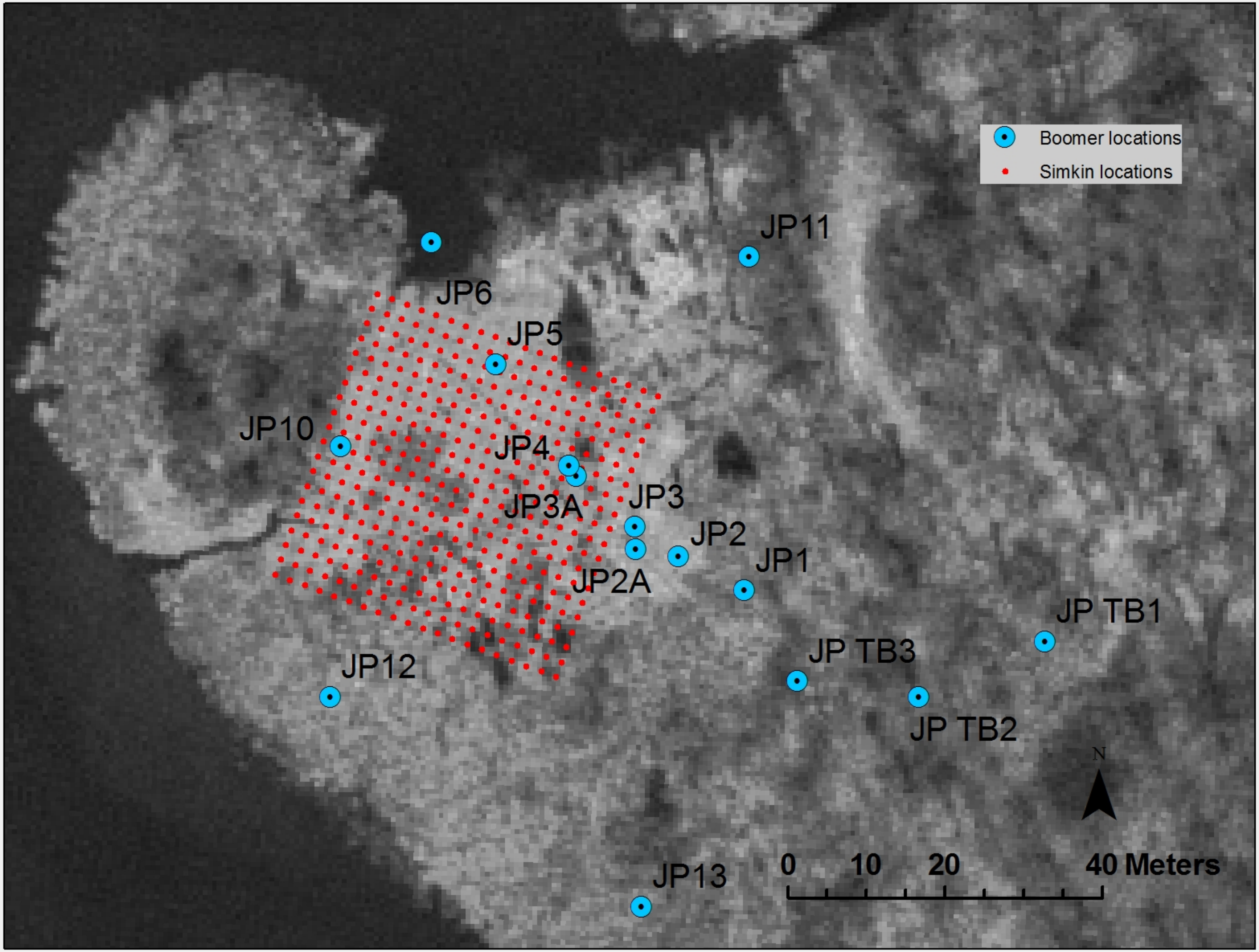


Green = solid phase

Plum = aqueous phase

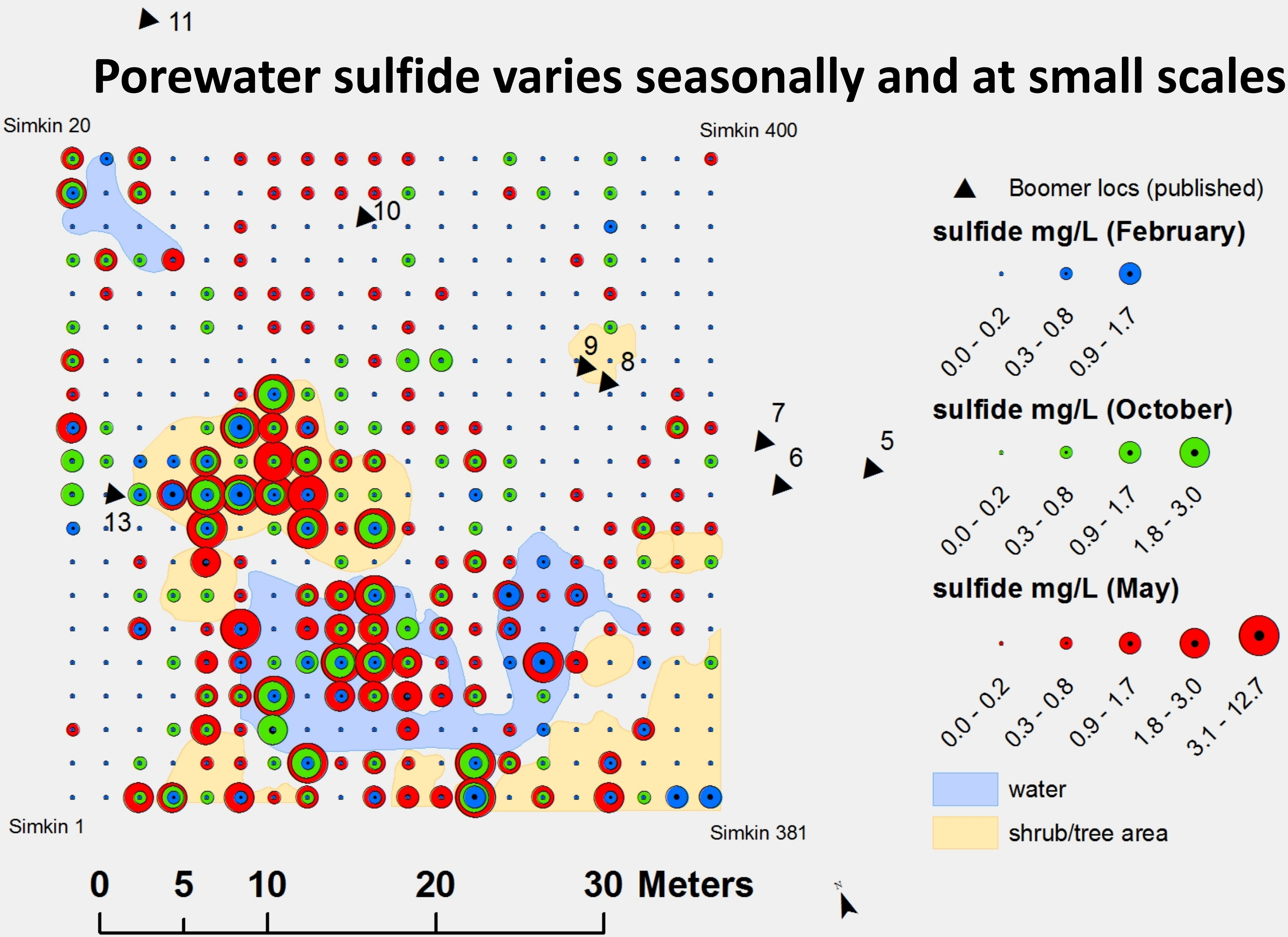
Solid lines = reduction

Dashed lines = oxidation

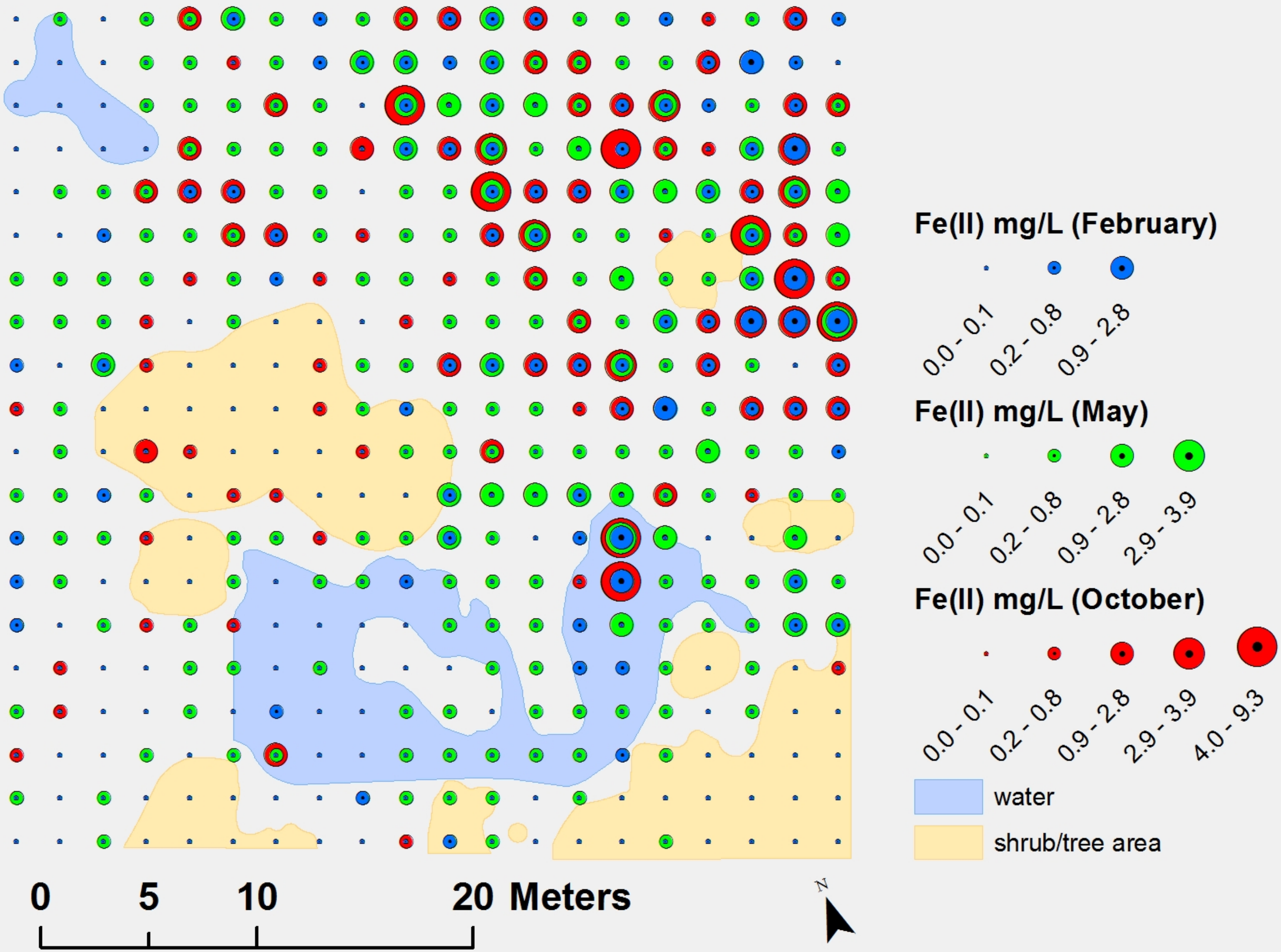


Boomer locations
Simkin locations
JP11
JP6
JP5
JP10
JP4
JP3A
JP3
JP2
JP1
JP2A
JP TB1
JP TB3
JP TB2
JP12
JP13
N
0 10 20 40 Meters

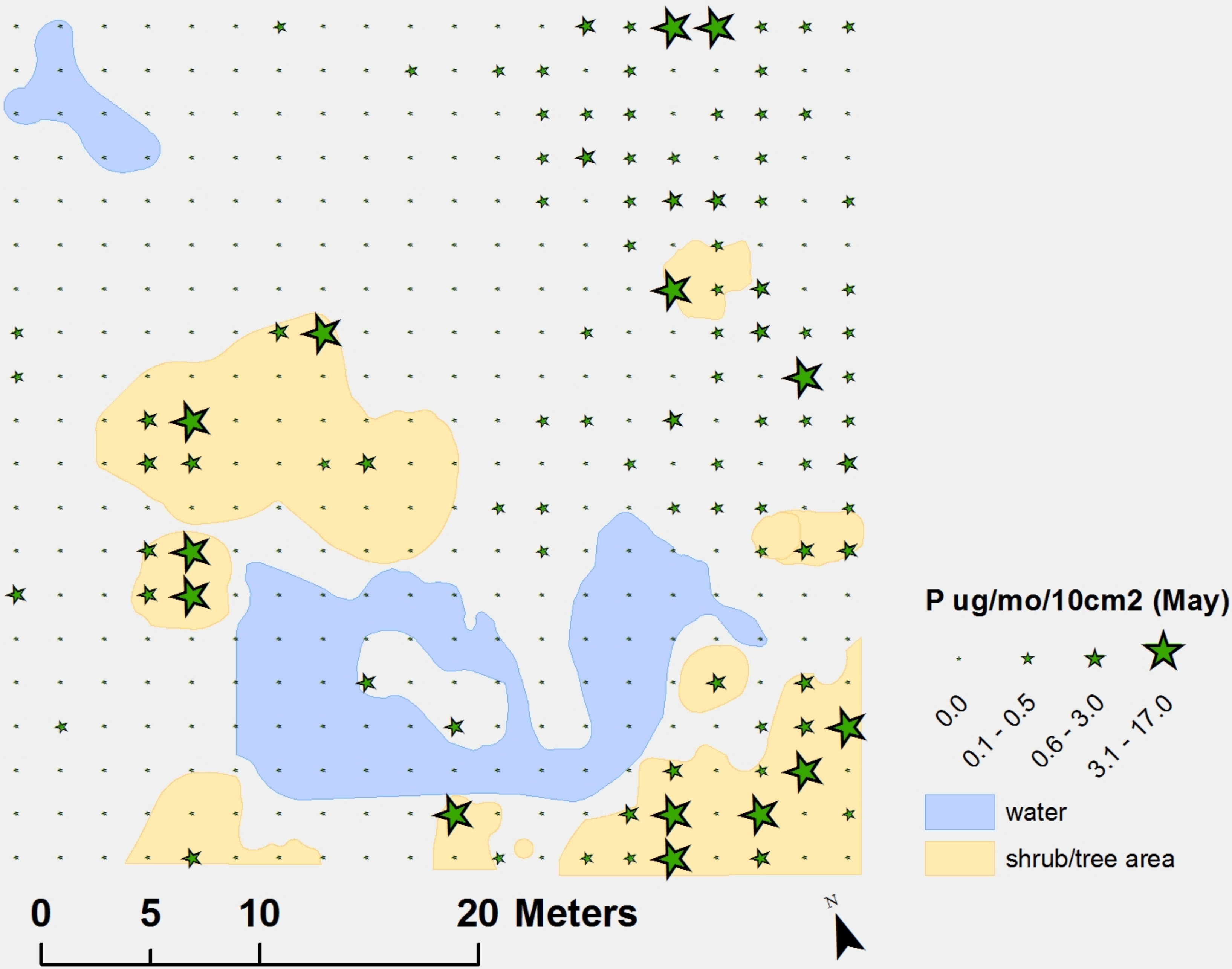
Porewater sulfide varies seasonally and at small scales

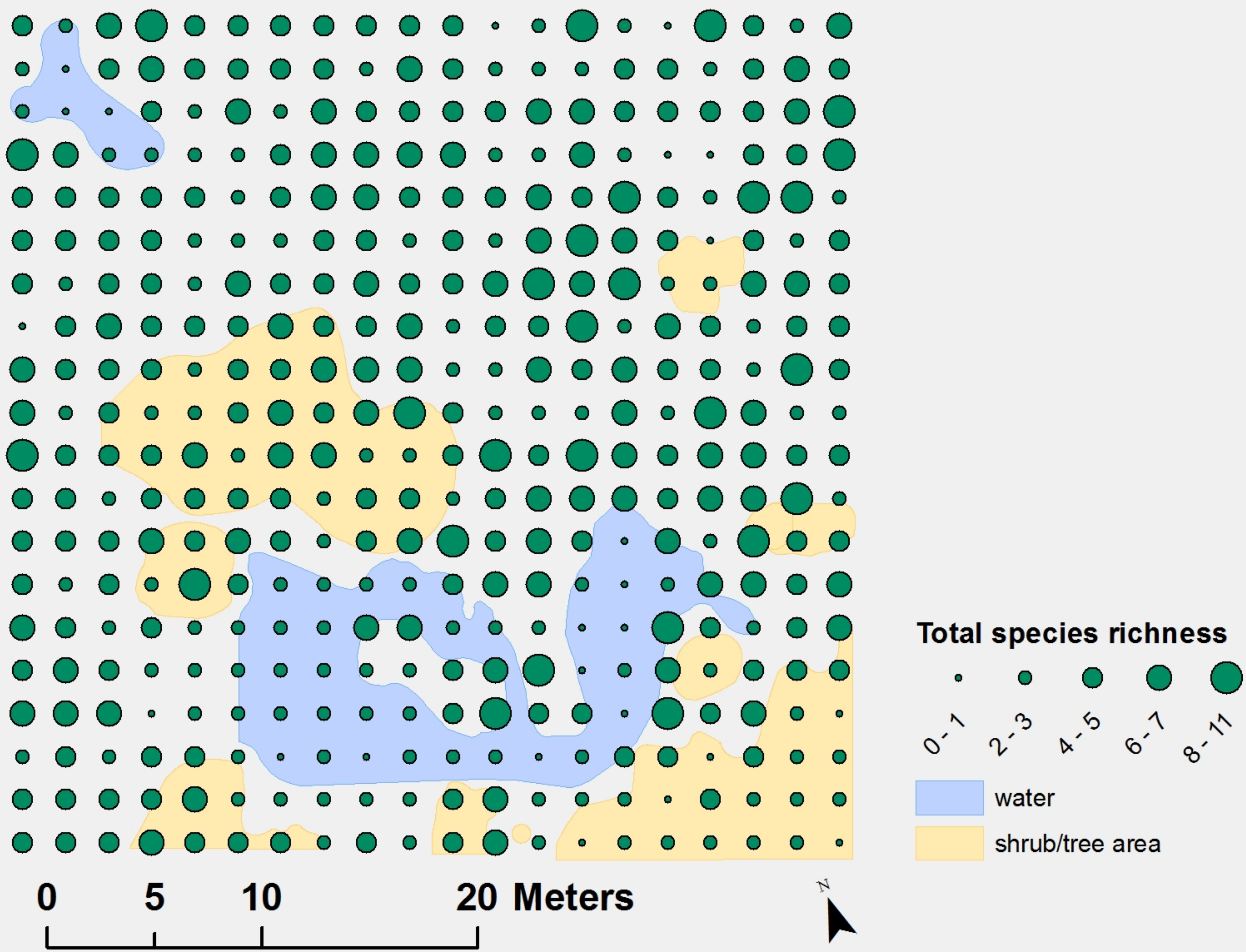


Reduced iron in porewater also varies seasonally, spatially



Resin P varies is relation to the S and Fe




Total species richness
0 - 1
2 - 3
4 - 5
6 - 7
8 - 11
water
shrub/tree area
0
5
10
20 Meters
N

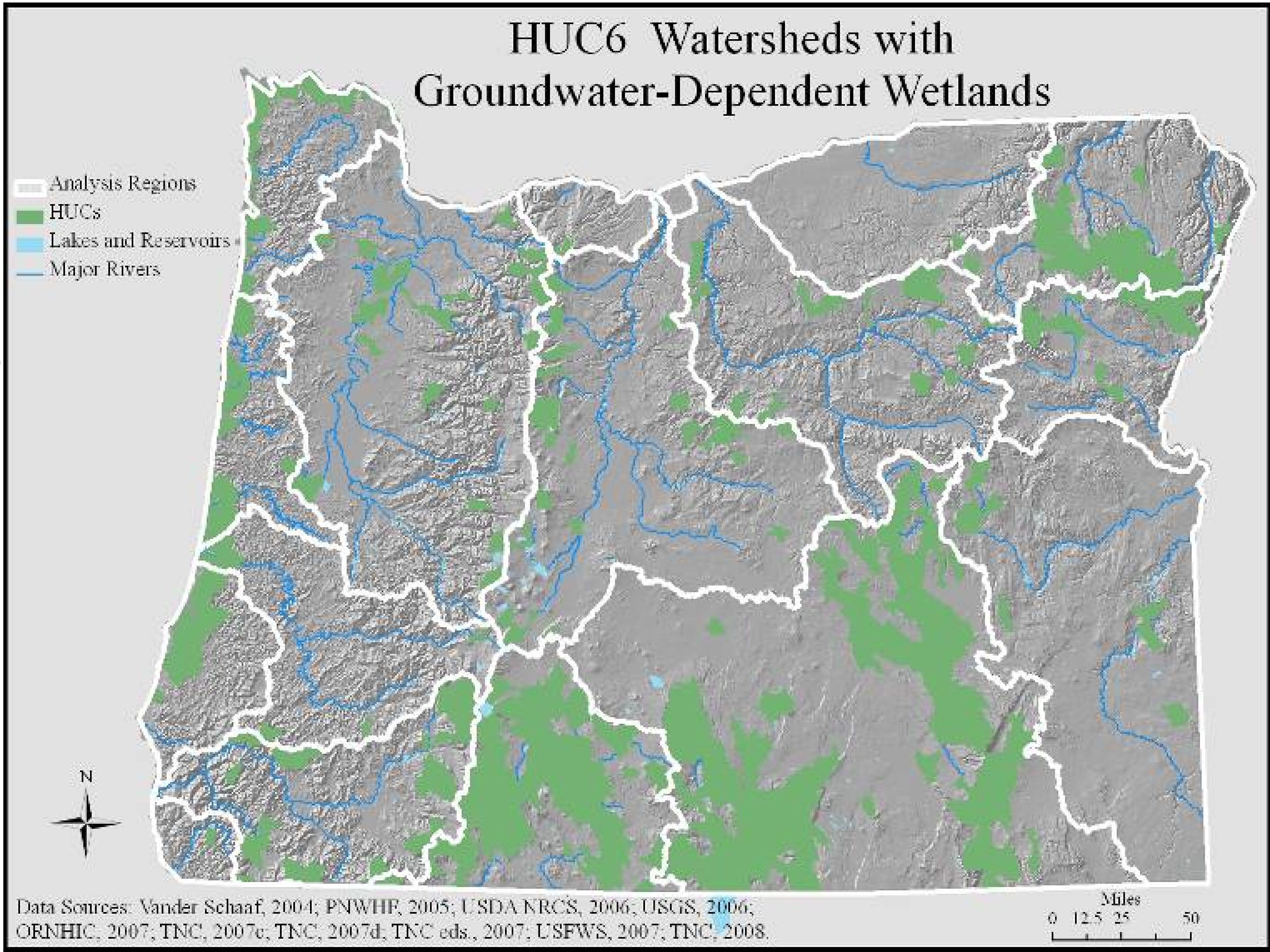
Groundwater Dependent Wetlands

Courtesy Allison Aldous, TNC Oregon

Contains a fen

OR

Groundwater-dependent wetlands >1% of HUC6 area



Wisconsin Wetlands Association

Wetland Alert!

Assembly Hearing on Groundwater Bill

Your testimony is needed

March 26, 2010

Dear Barbara,

An important groundwater protection bill (SB 620/AB 844) is working its way through the legislature. The Assembly Natural Resources Committee is holding a hearing on the bill next Wednesday, March 31st at 9:00 a.m. in Madison. Testimony from citizens and scientists is needed to demonstrate that there is strong public support, and an ecological imperative, for the sustainable management of Wisconsin's groundwater resources. Read on for details about the bill and how you can help get it passed.

In This Alert

- How and why to speak up for groundwater protection
- About the Groundwater Protection Act
- Does the bill improve protections for wetlands?

How and why to speak up for groundwater protection

Though groundwater is critically important to Wisconsin's industries, it also provides clean drinking water for Wisconsin's communities and vital inputs

“Conclusions”

Ground water integrates terrestrial and aquatic systems

Ground water creates chemical gradients that profoundly affect biogeochemical cycles

Groundwater effects on wetland biogeochemistry affect plant species composition and diversity at the landscape, site, within site levels

Temporal and spatial heterogeneity created by ground water make fertilization experiments hard to interpret

We are not done yet!