Implementing direct and fungi-mediated nutrients uptake in a land surface model: insights from a boreal peatland ecosystem

Yaoping Wang[1], Daniel M. Ricciuto[1], Jiafu Mao[1]*, Soren E. Weber[1], Verity Salmon[1], Xiaoying Shi[1], Xiaojuan Yang[1], Natalie A. Griffths[1], Paul J. Hanson[1], Jeffrey M. Warren[1], Colleen M. Iversen[1], Melanie A Mayes[1], Peter Thornton[1]

[1]Environmental Sciences Division and Climate Change Science Institute, Oak Ridge National Laboratory, Oak Ridge, TN, 37830

Motivation

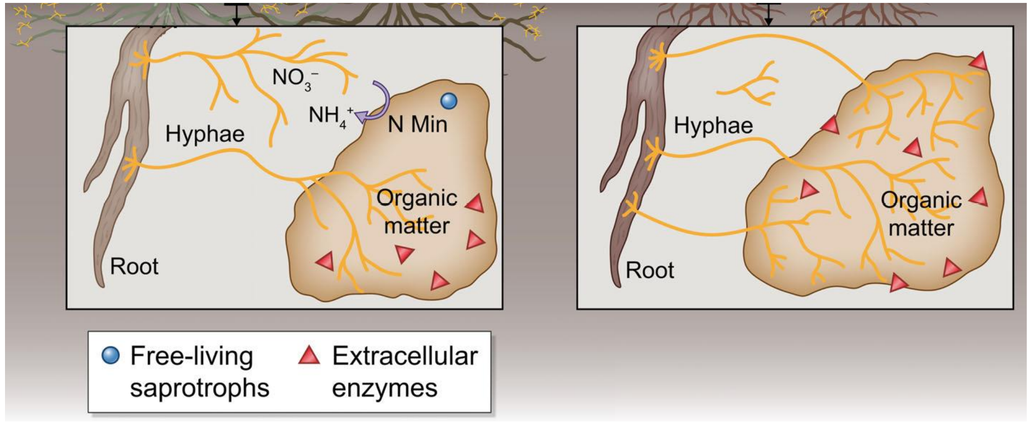
Boreal peatlands store 13-32% of the global soil carbon. Destabilization of this C stock under high-latitude warming can be a major amplifier of the carbon-climate feedback.

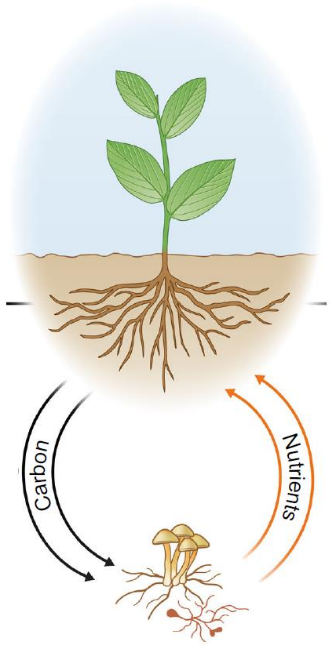
The cold and waterlogged condition creates slow decomposition and low nutrients availability, resulting in slow vegetation growth.

Under nutrient limitation, plants form symbiotic relationship with ectomycorrhizal fungi (EcM) and ericoid mycorrhizal fungi (ErM), which can mine organic nutrients.

Motivation

Plants response to CO_2 fertilization and nutrients availability are affected by fungi association.





Few land surface models/ecosystem models represent this association, and existing studies have not jointly considered EcM and ErM.

Study objective

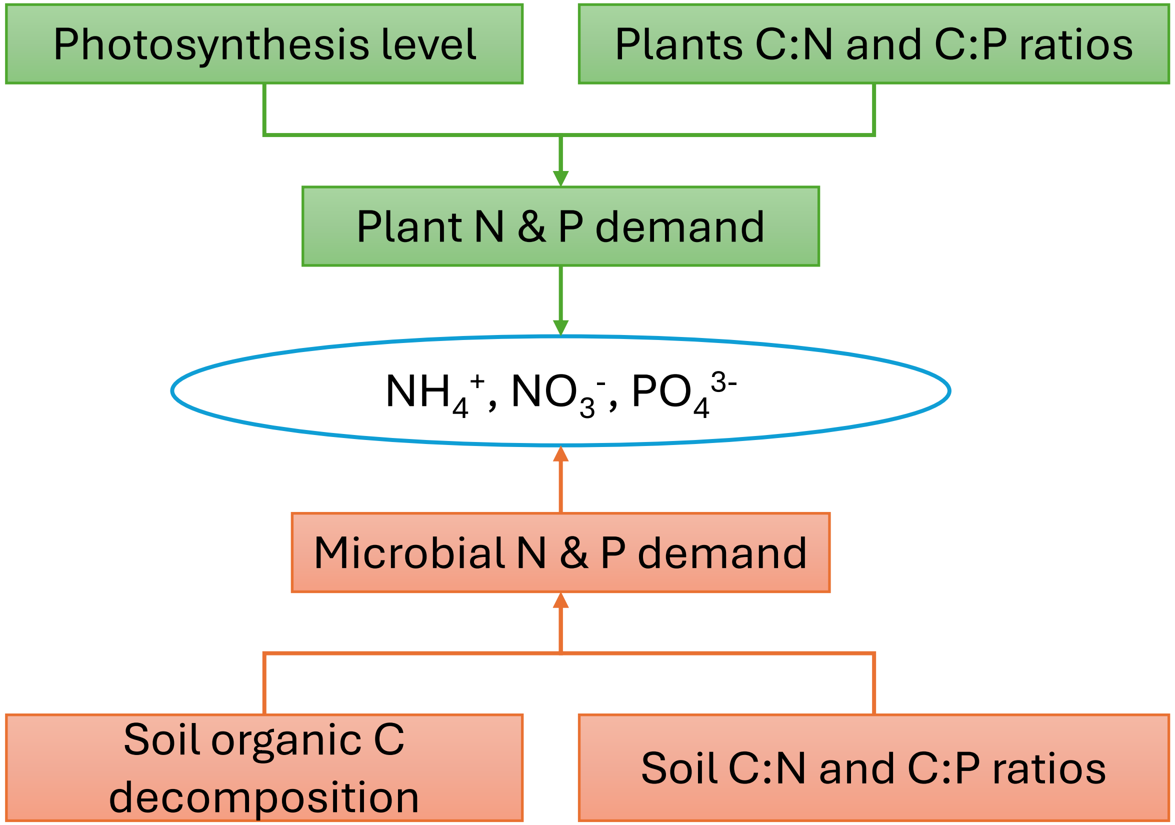
Modify plant nutrients uptake in the ELM-SPRUCE model to implicitly represent EcM and ErM pathways

Analyze modeled ecosystem response to warming and CO_2 addition at the SPRUCE whole-ecosystem warming experiment

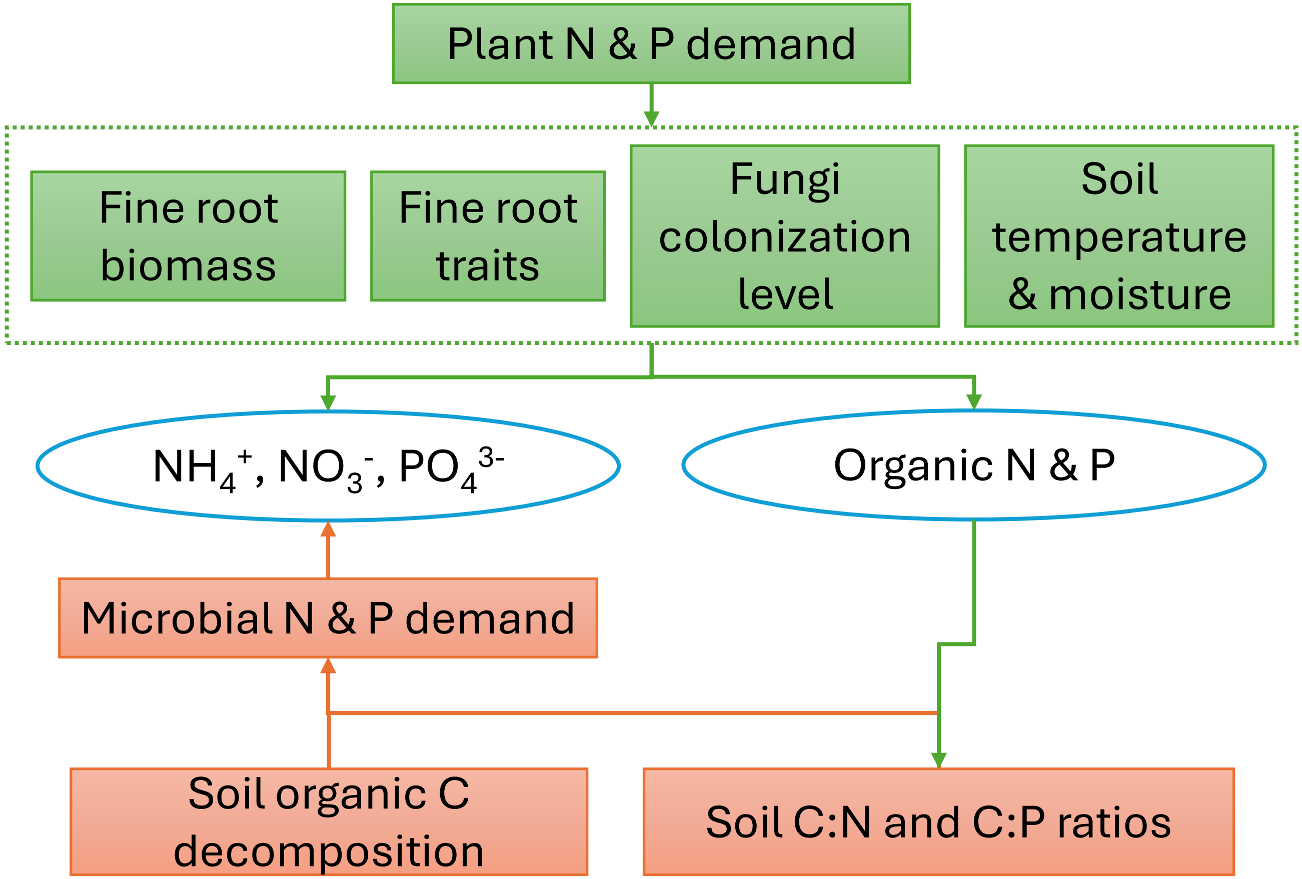
Species	Percentage cover	Fungi association
Black spruce (Picea mariana)	~34%	EcM
Eastern tamarack (Larix laricina)	~14	EcM
Various ericaceous shrubs	~25%	ErM
Sphagnum moss	~25% initially, decline with warming	N/A

Model updates

Default model – mineral nutrients only, demand-driven



Modified model – mineral fine root, mineral fungi, organic fungi uptakes



Simulation experiments

Parameter optimization + structural change

Parameter optimization

$ELM_{default}$ - Default model, default parameters

$ELM_{default,optim}$ - Default model, optimized default parameters

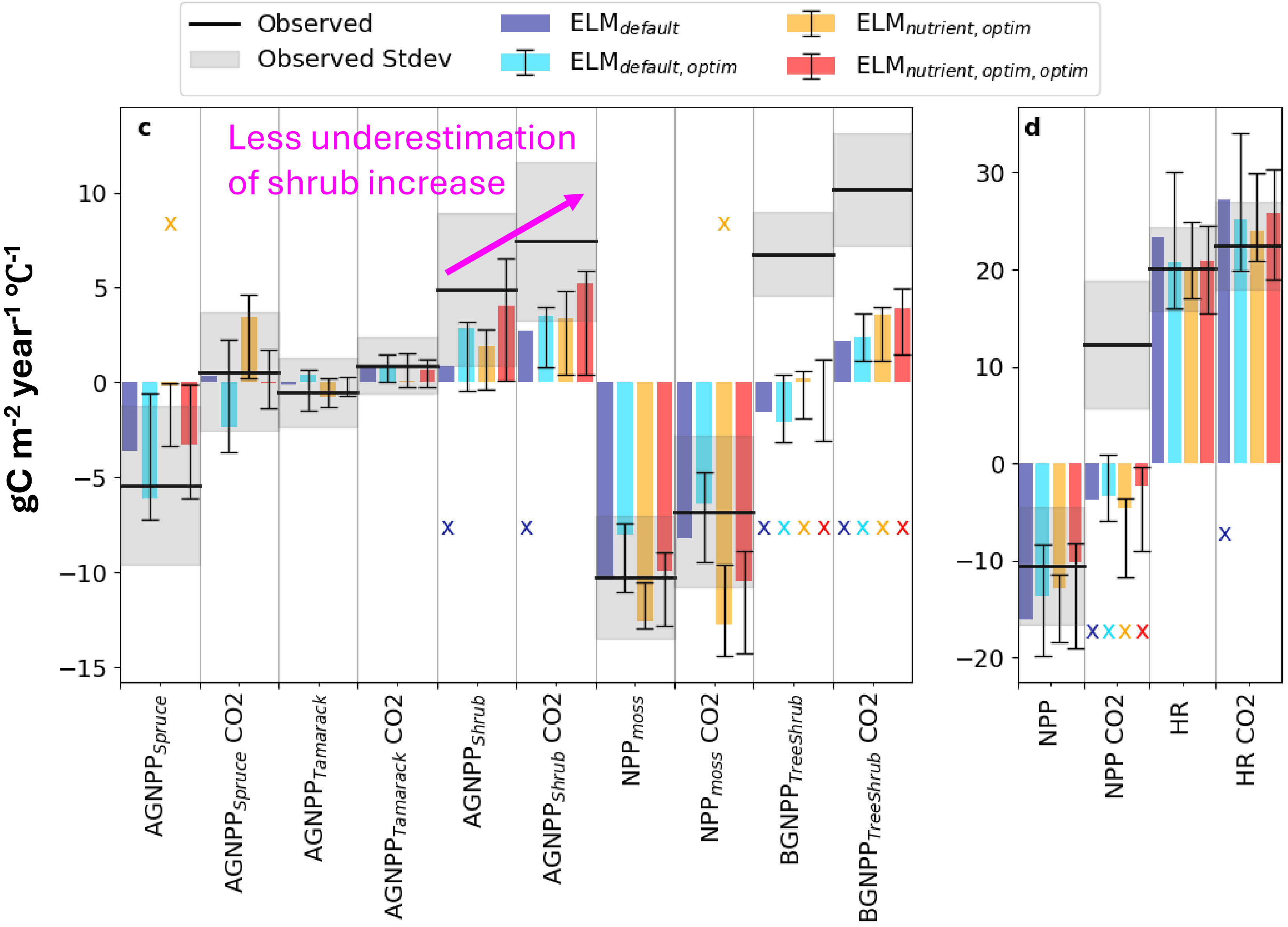
$ELM_{nutrient,optim}$ - Modified model, optimized new parameters

$ELM_{nutrient,optim,optim}$ - Modified model, optimized default and new parameters

Structural change

Structural change

Validation on temperature sensitivity of C fluxes



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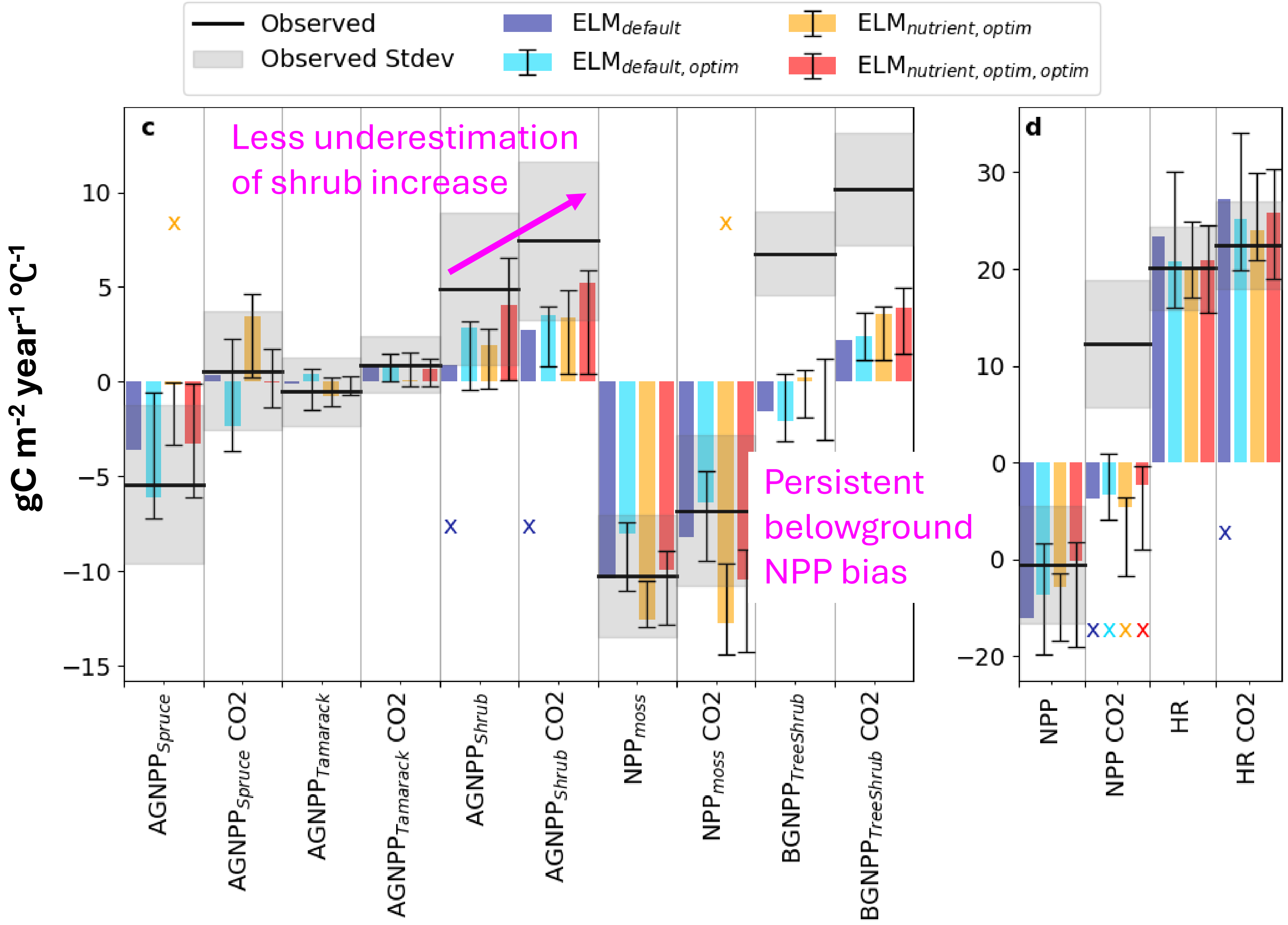
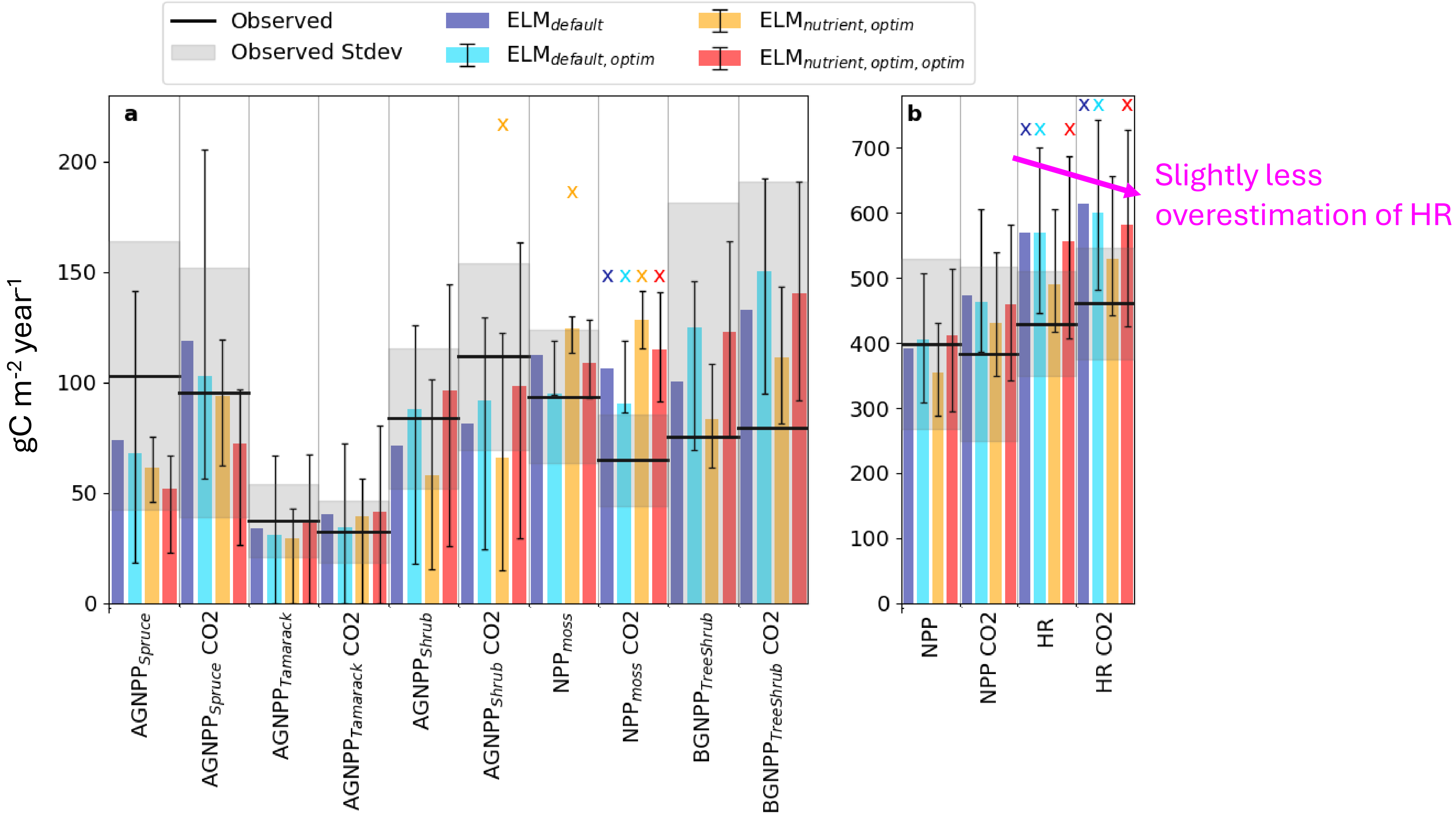
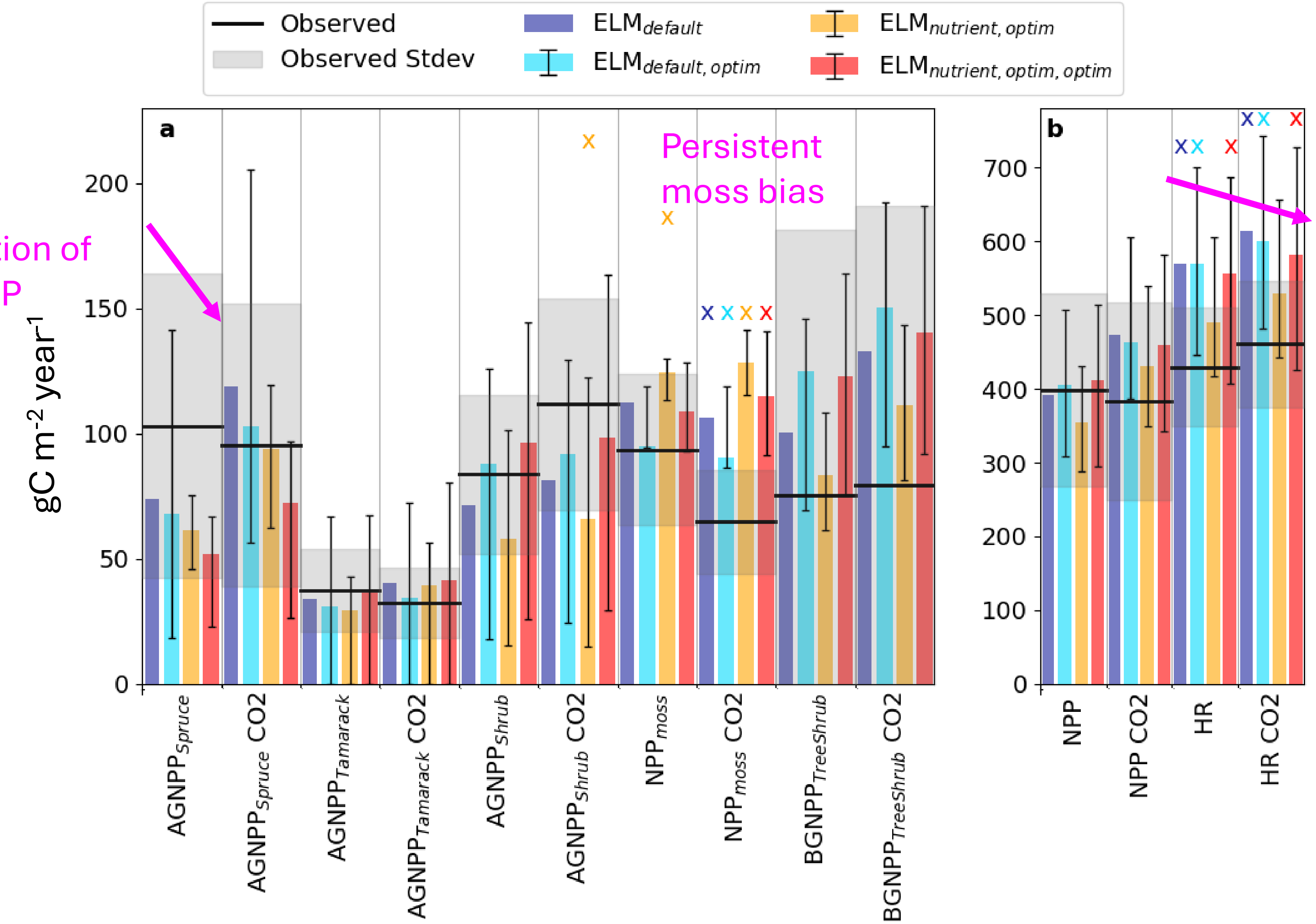


Validation on mean C fluxes



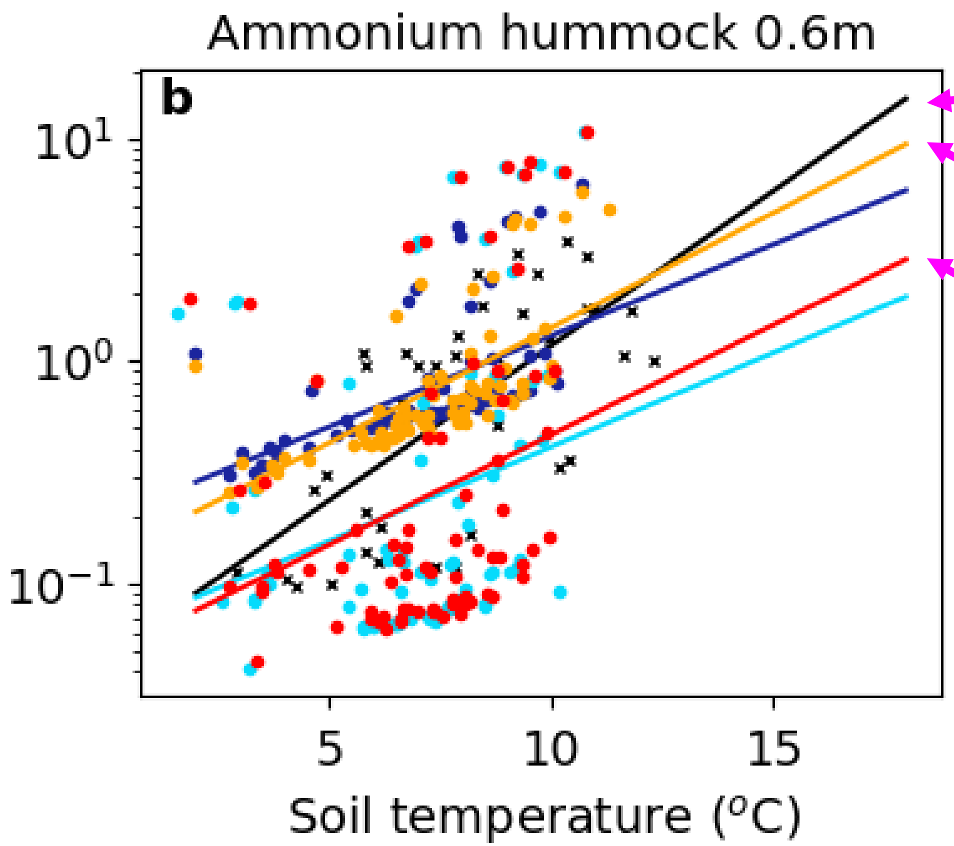
Validation on mean C fluxes

More underestimation of spruce AGNPP



Slightly less overestimation of HR

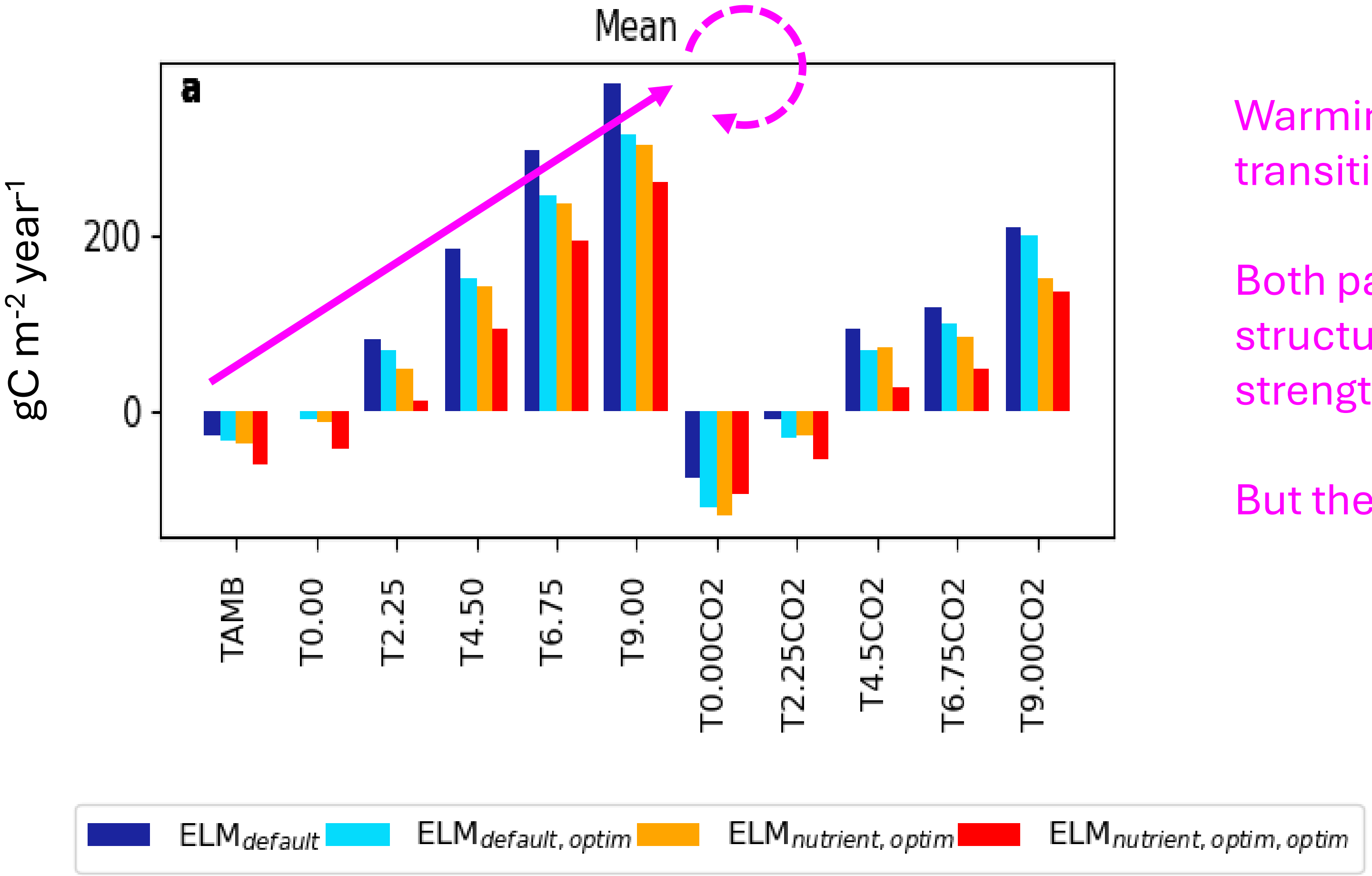
Qualitative validation between resin-exchange nutrients and net mineralization



Observed slope is very large

Structural modification reduces the underestimation of response to warming

Implication for net ecosystem exchange

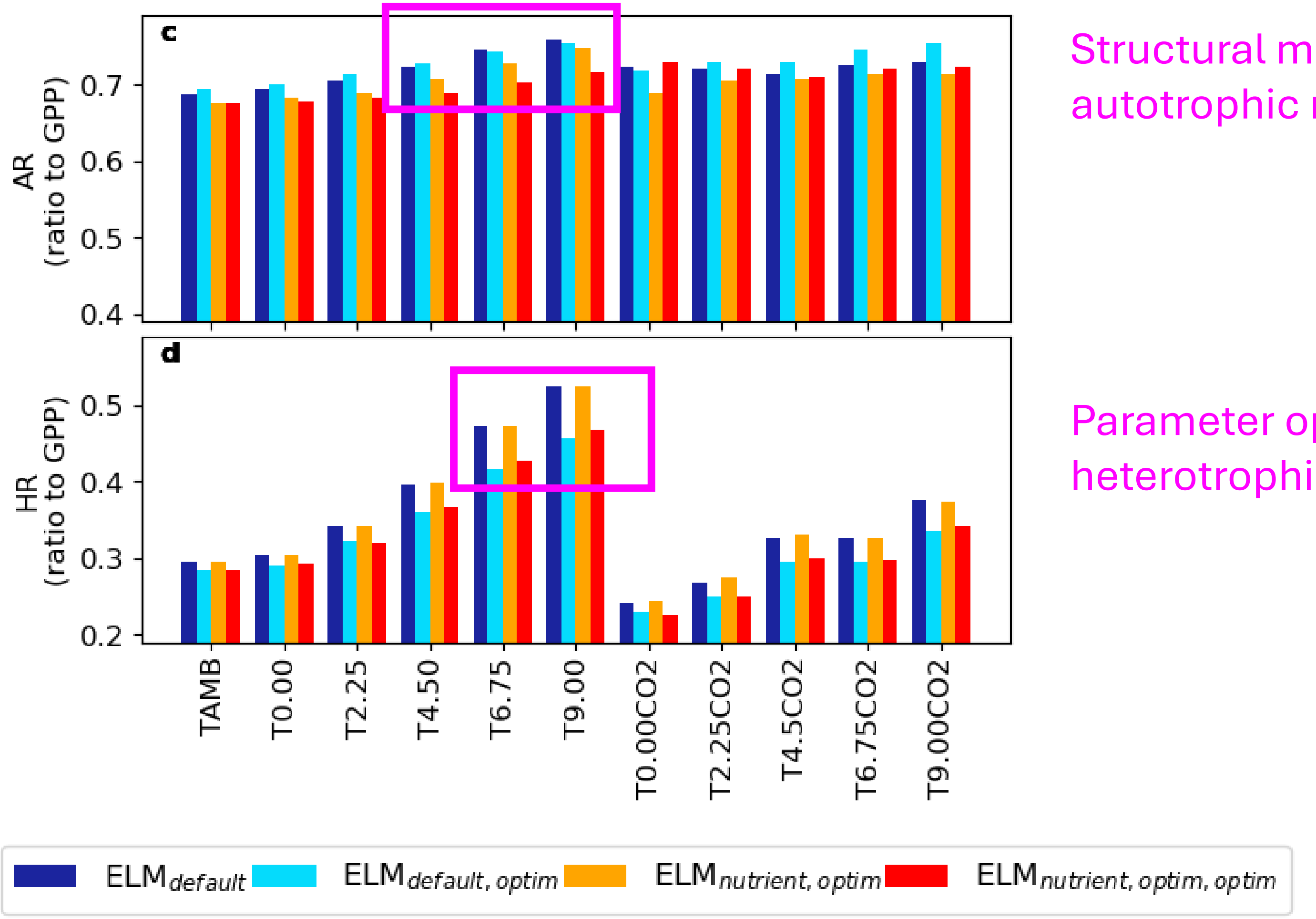


Warming induces sink-to-source transition

Both parameter optimization and structural modification reduce the strength of this transition

But the mechanisms are different

Explanation for net ecosystem exchange

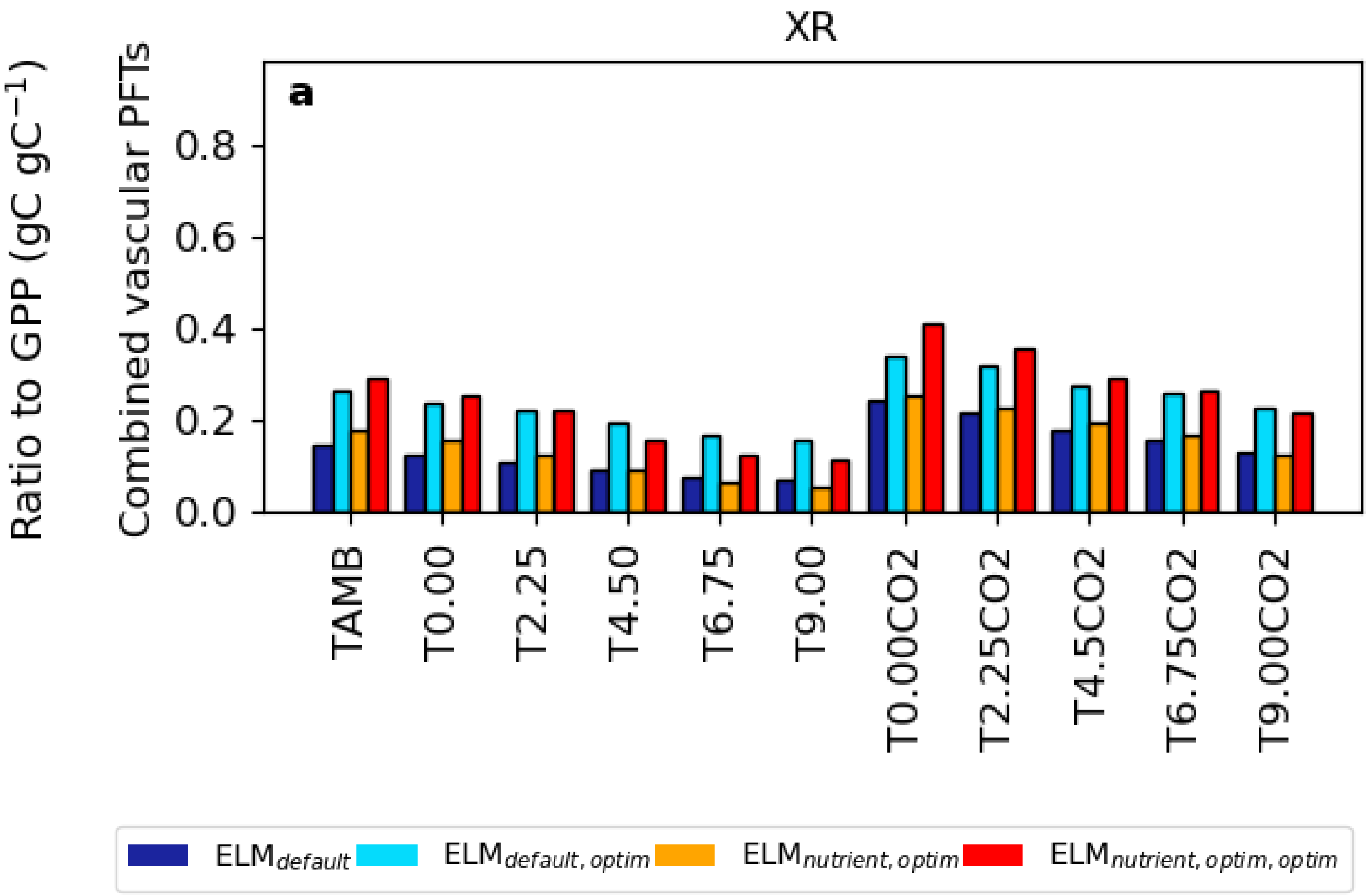


Structural modification reduces autotrophic respiration

Parameter optimization reduces heterotrophic respiration

Explanation for net ecosystem exchange

Parameter optimization increases excess respiration (XR), which is caused by nutrients limitation



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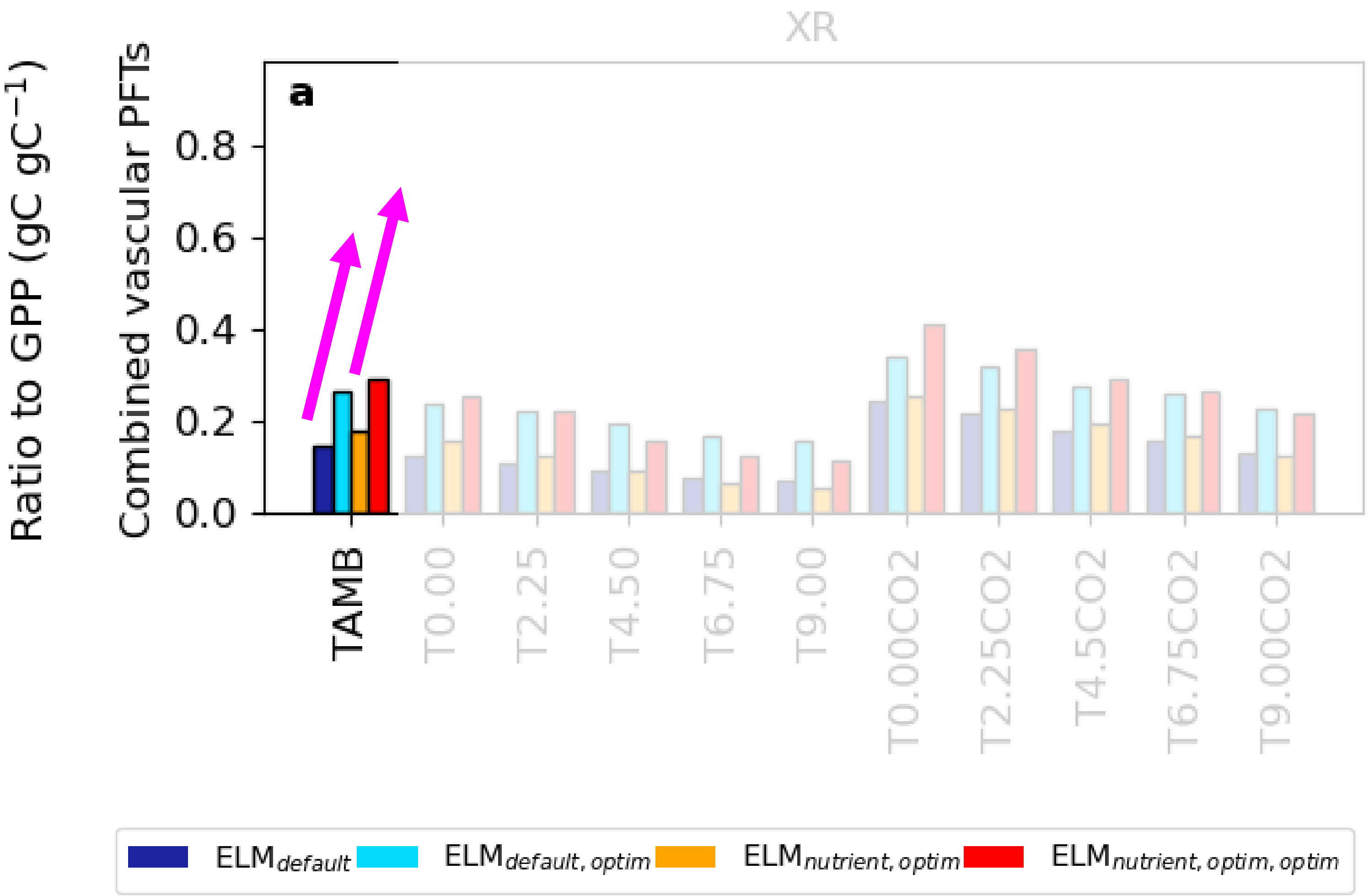
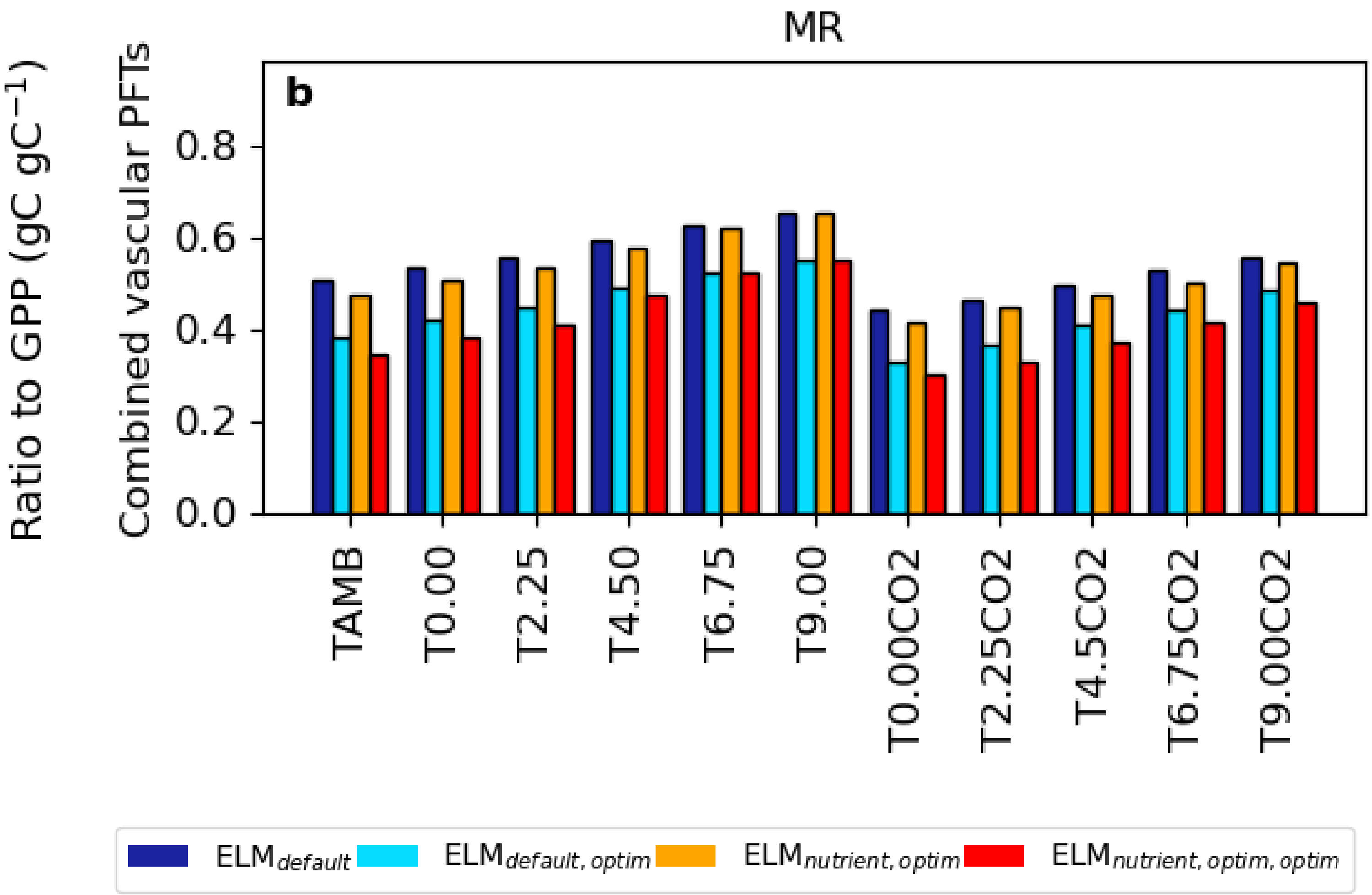


Explanation for net ecosystem exchange

Parameter optimization decreases maintenance respiration (MR) by changing base rate and Q10



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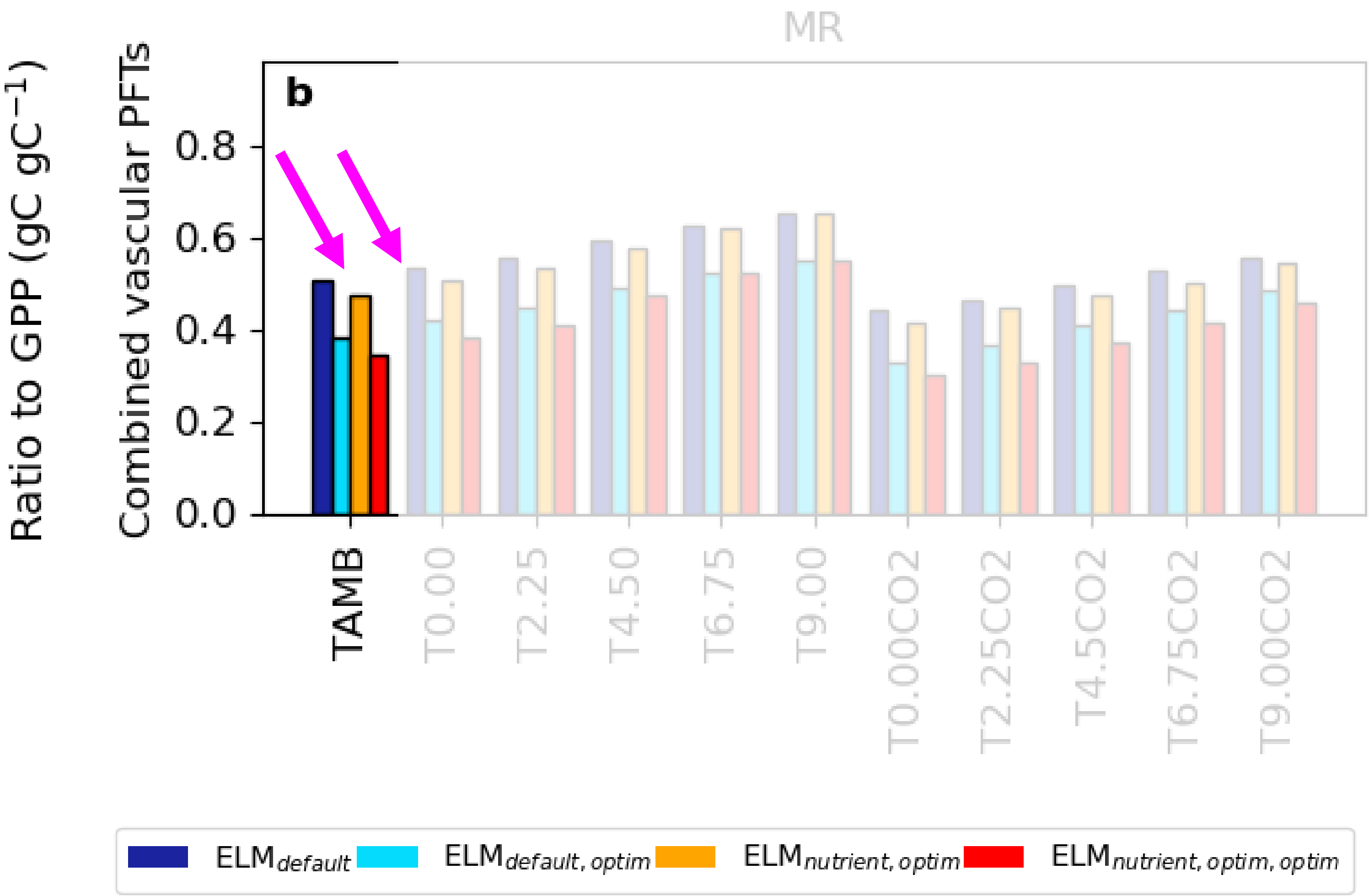
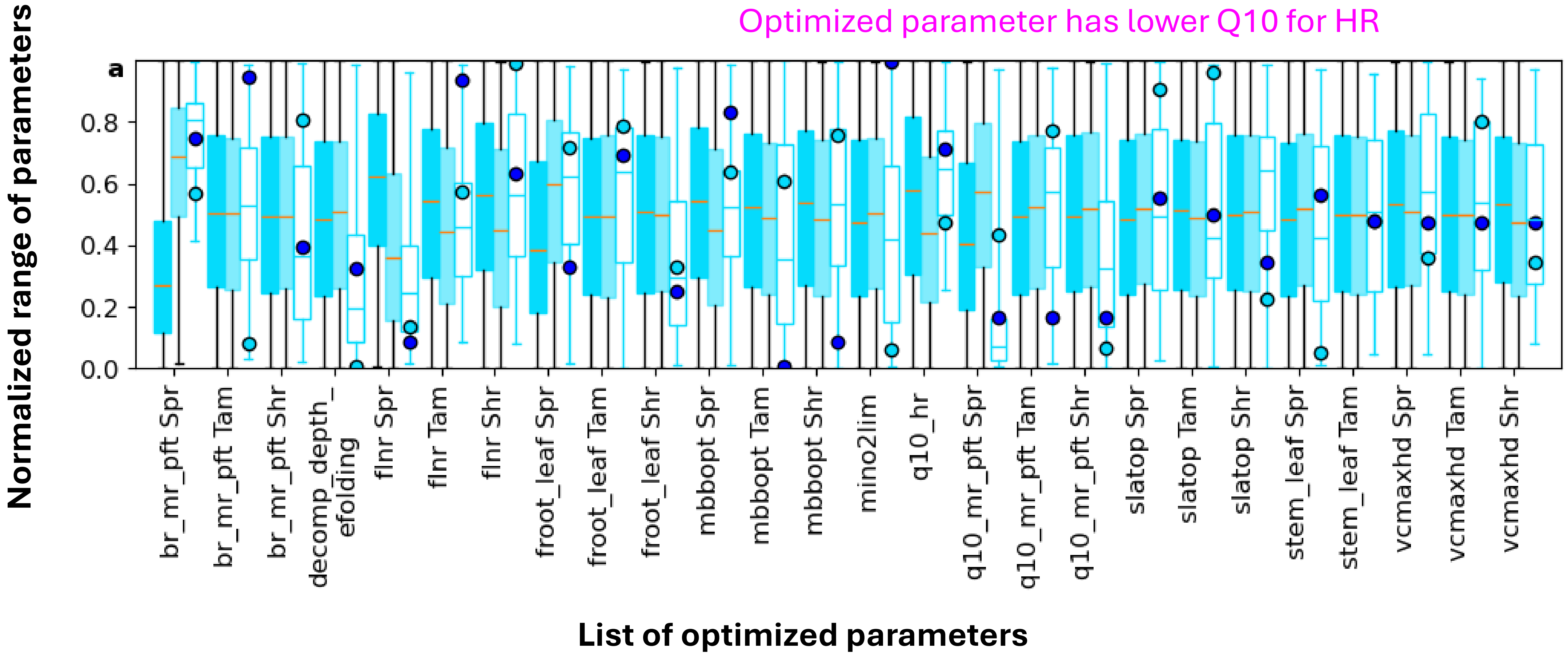


Explanation for net ecosystem exchange

Optimized parameter has lower Q10 for HR



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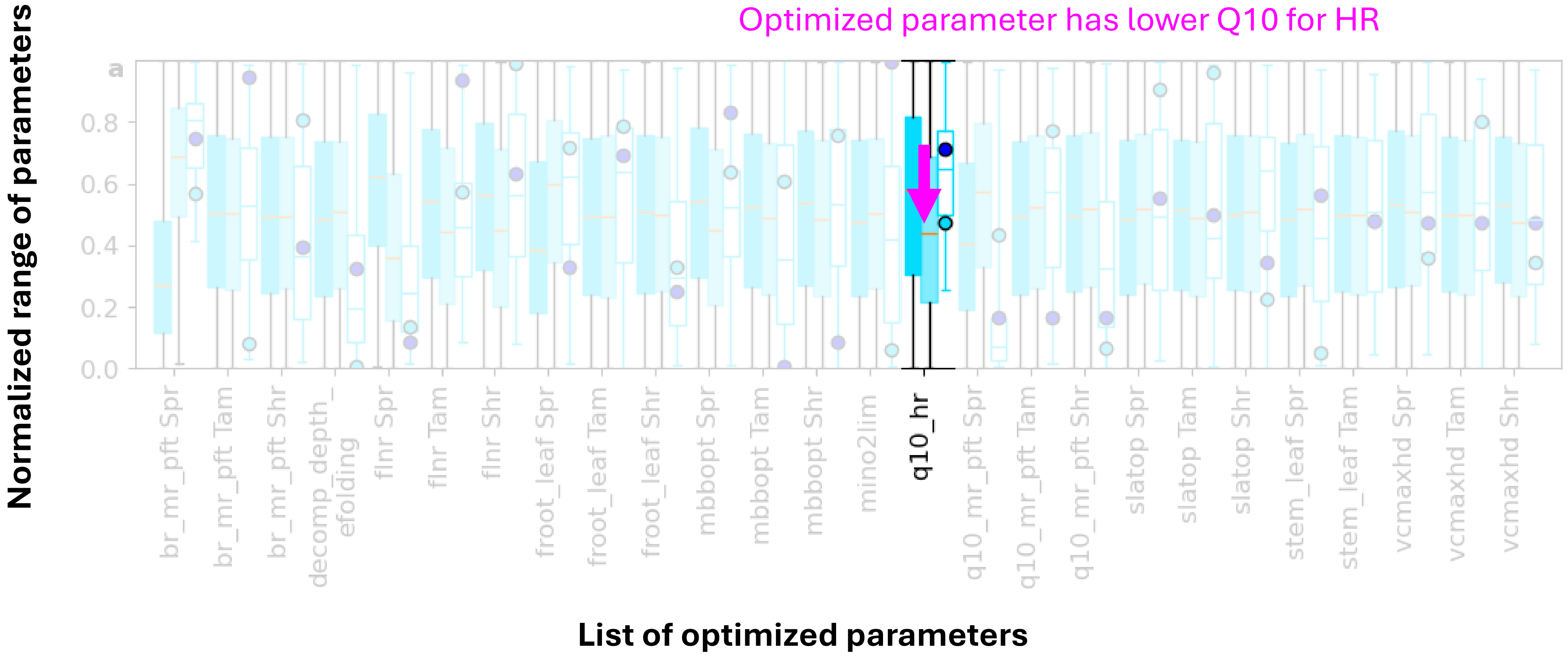
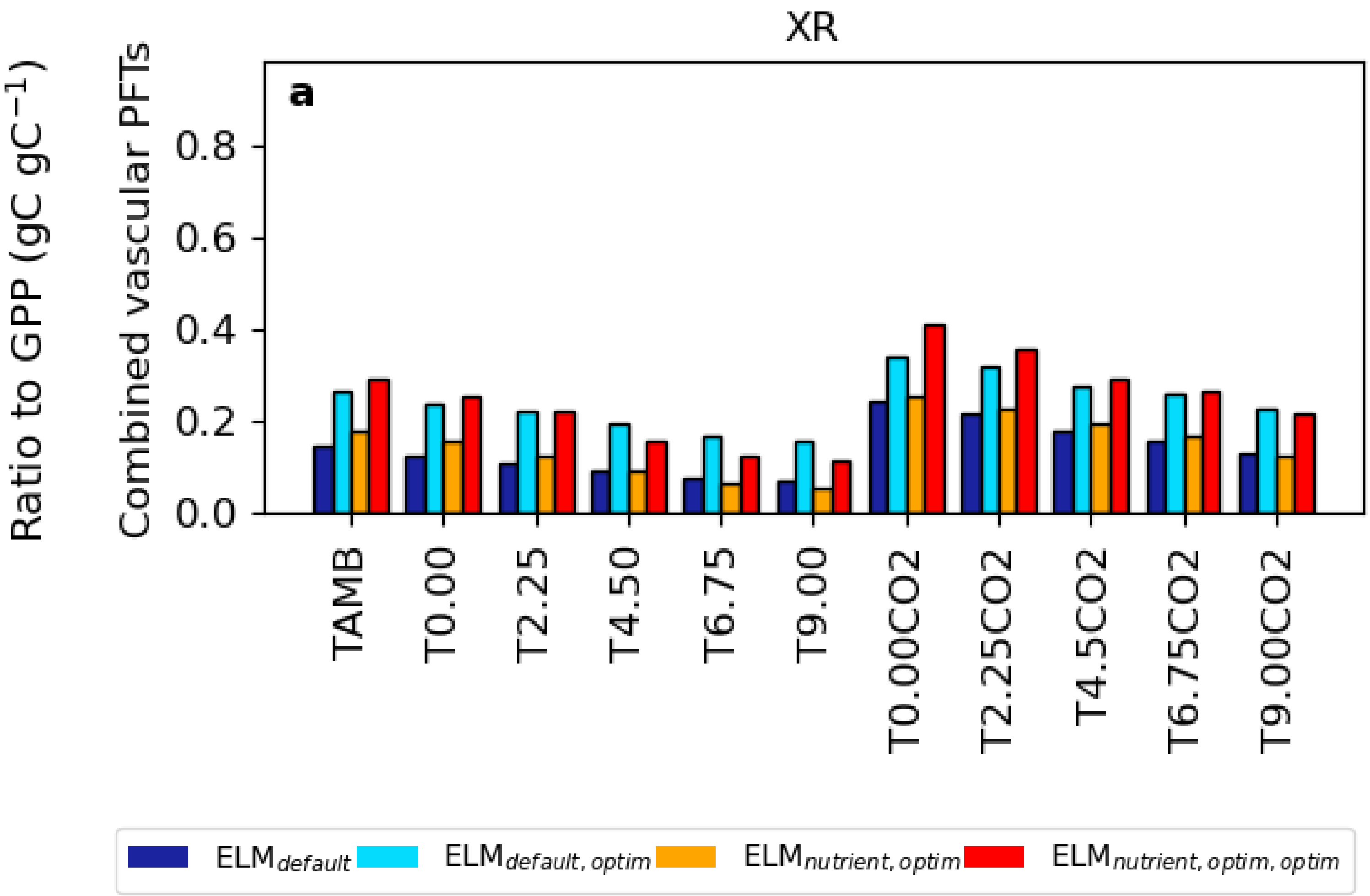


Explanation for net ecosystem exchange

Structural modification causes XR to decline more from coldest to warmest chambers



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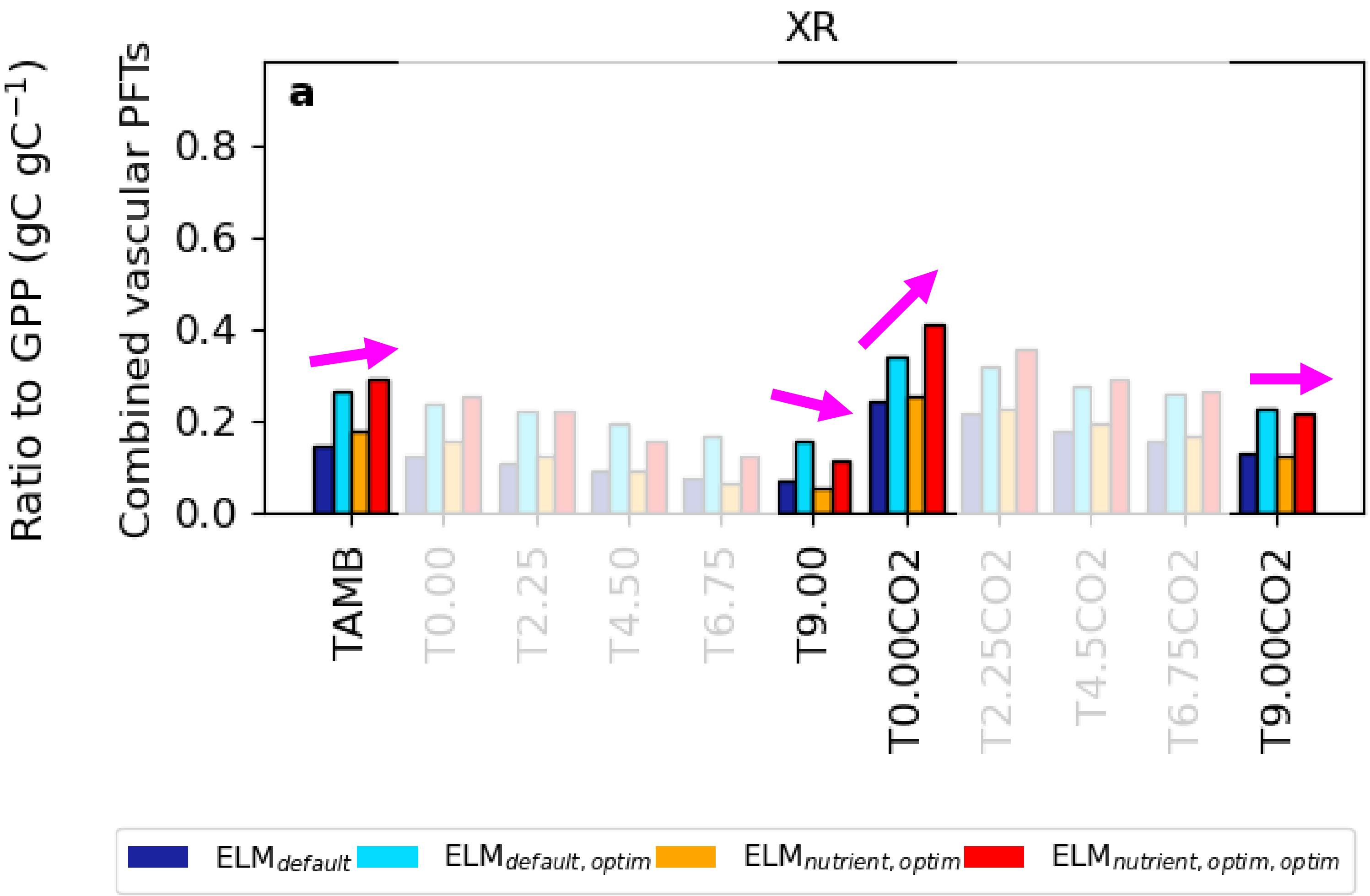
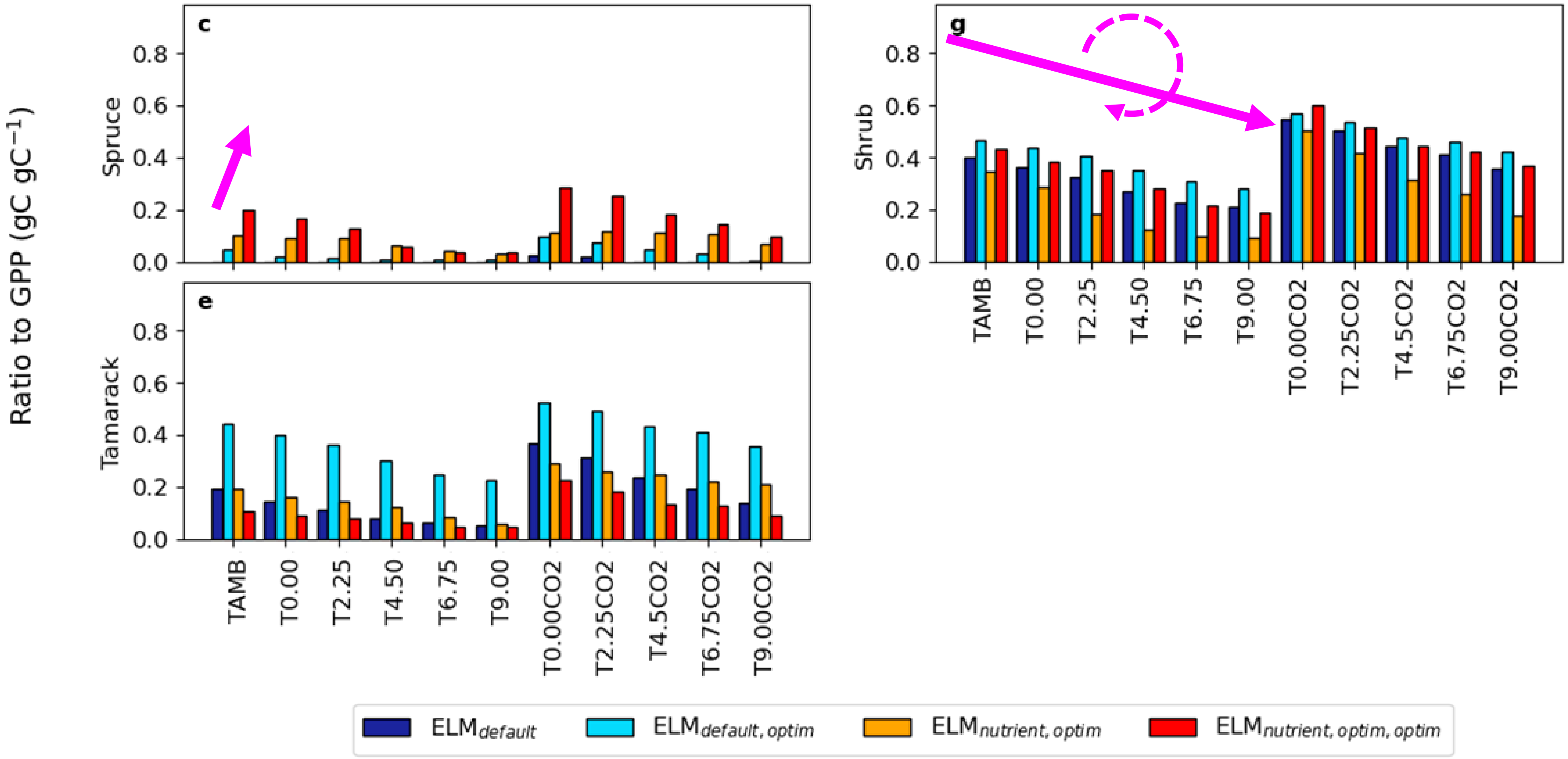


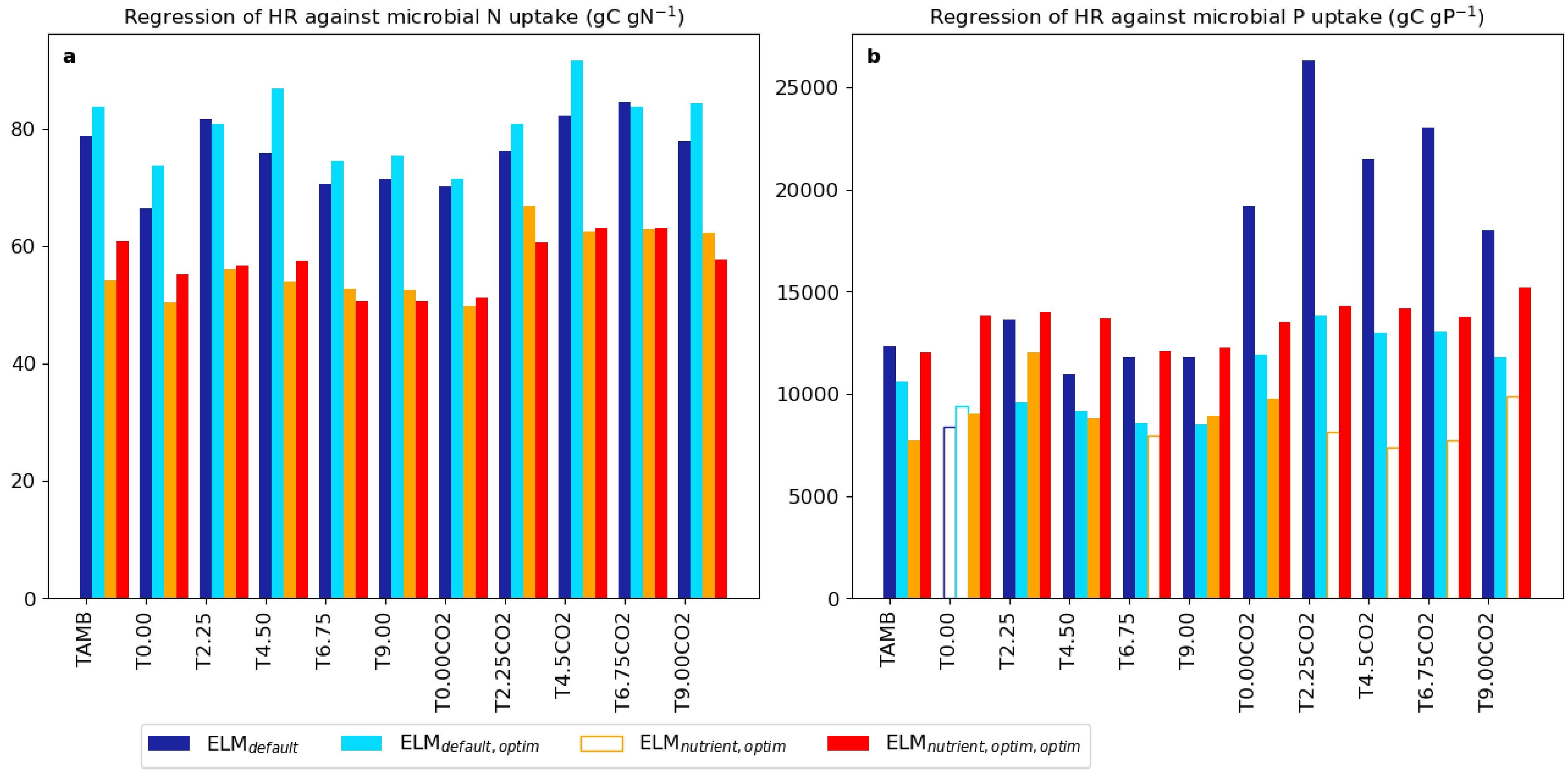
Explanation for net ecosystem exchange

Structural modification changes the inter-PFT competition relationships on nutrient limitation



Explanation for net ecosystem exchange

Structural modification creates greater N limitation on soil organic matter decomposition



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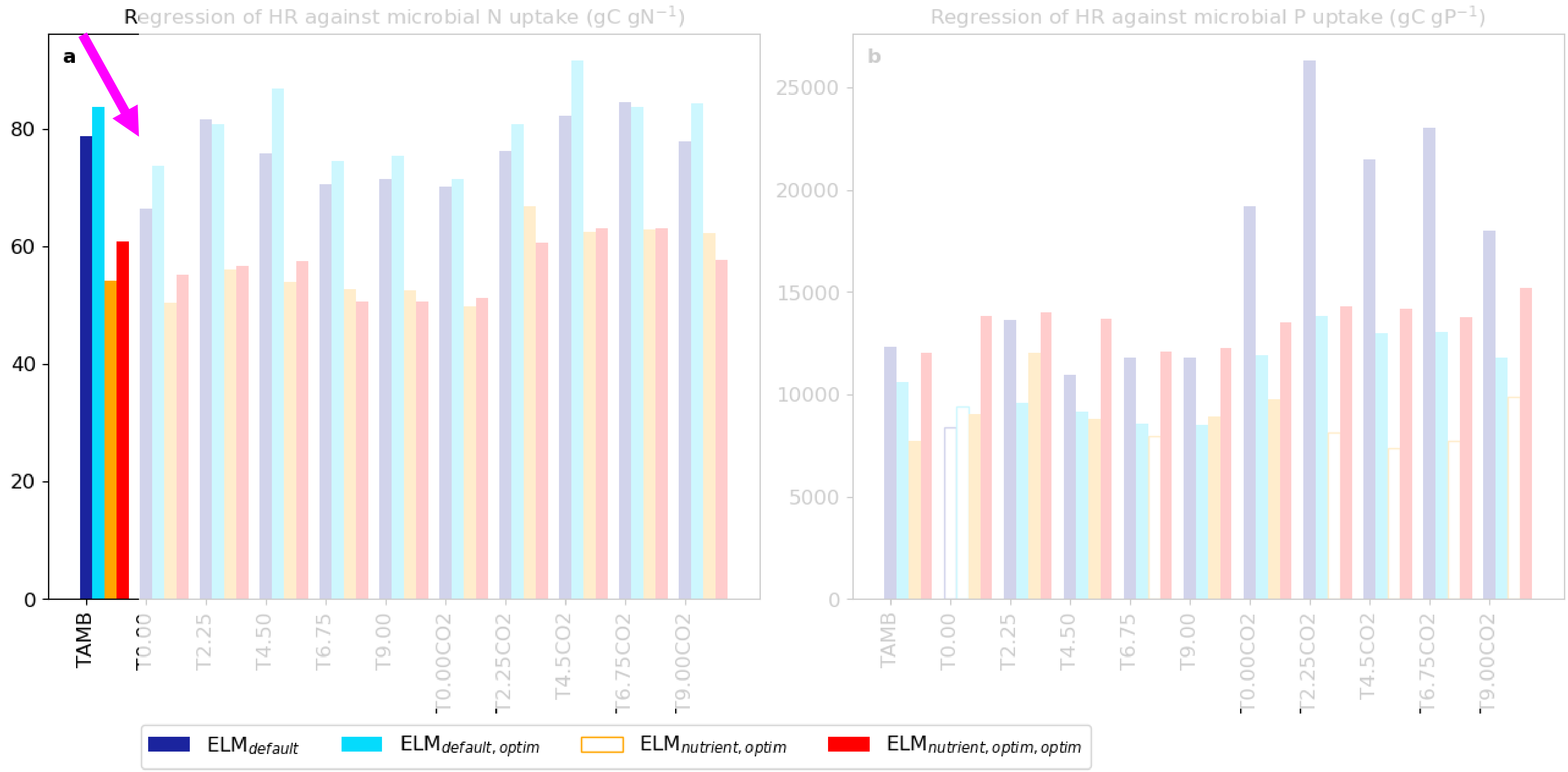
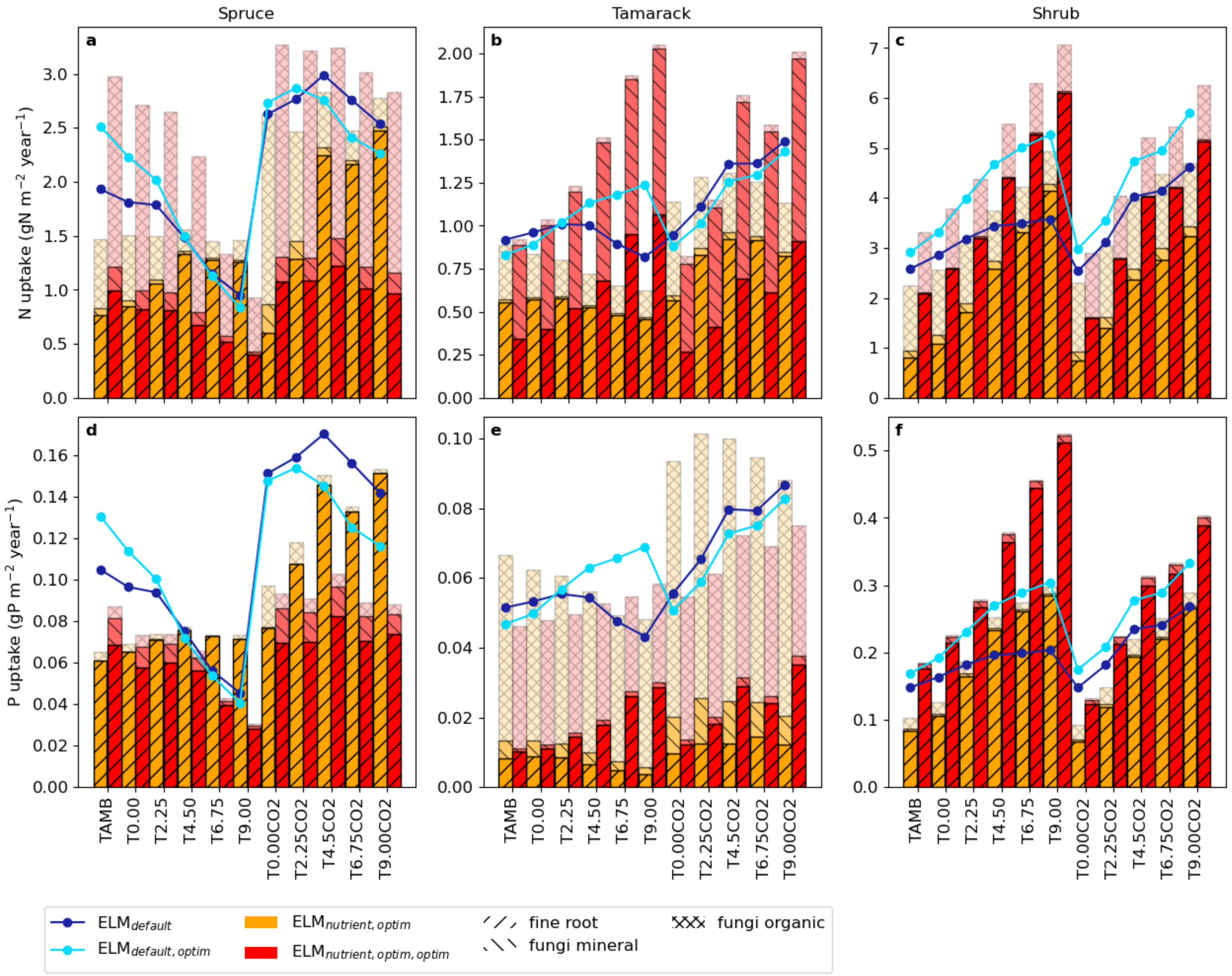


Nutrient uptake diagnostics

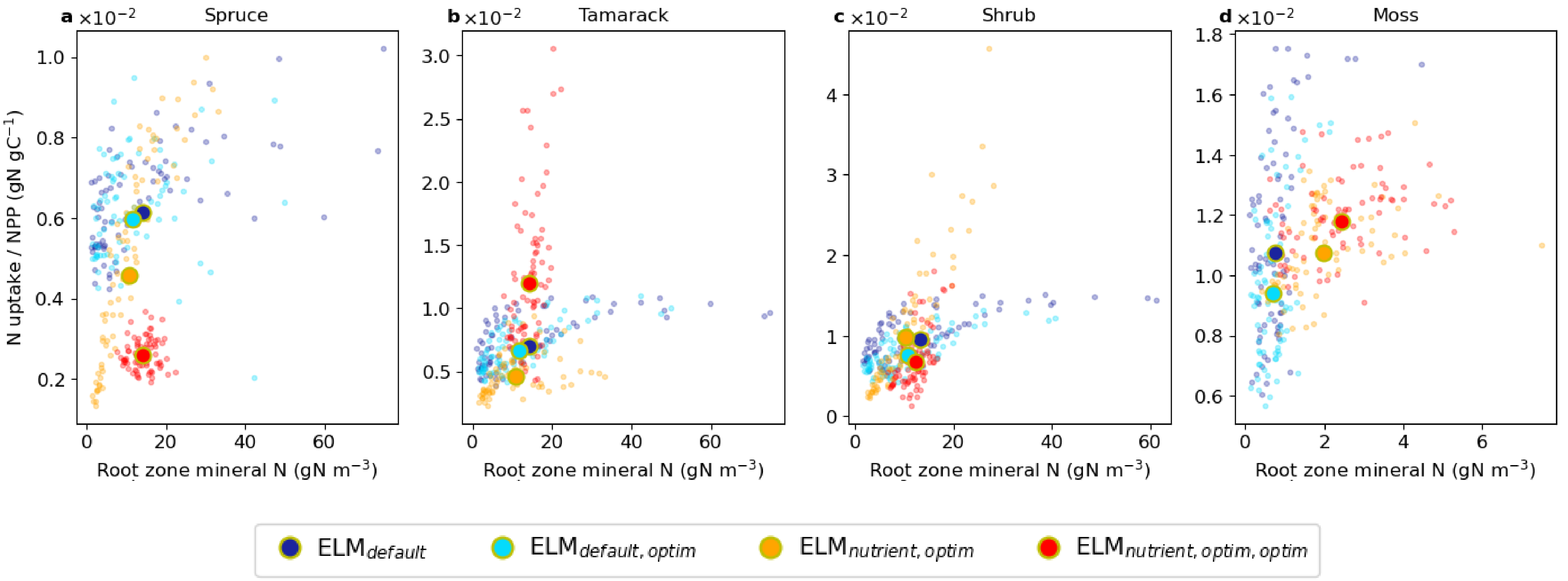
Percentage organic nutrients uptake via fungi is a sizeable fraction of total uptake

Spruce becomes more P-limited in the modified model, explaining the underestimation



Nutrient uptake diagnostics

New model has less defined saturation point in uptake kinetics



Conclusions

With new implicit fungal uptake scheme, ELM-SPRUCE

- better simulates the growth of ErM-associated shrub and net mineralization response to warming
- underestimates the EcM-associated spruce tree due to P limitation
- persistent bias in the non-vascular *Sphagnum* moss and belowground response to warming

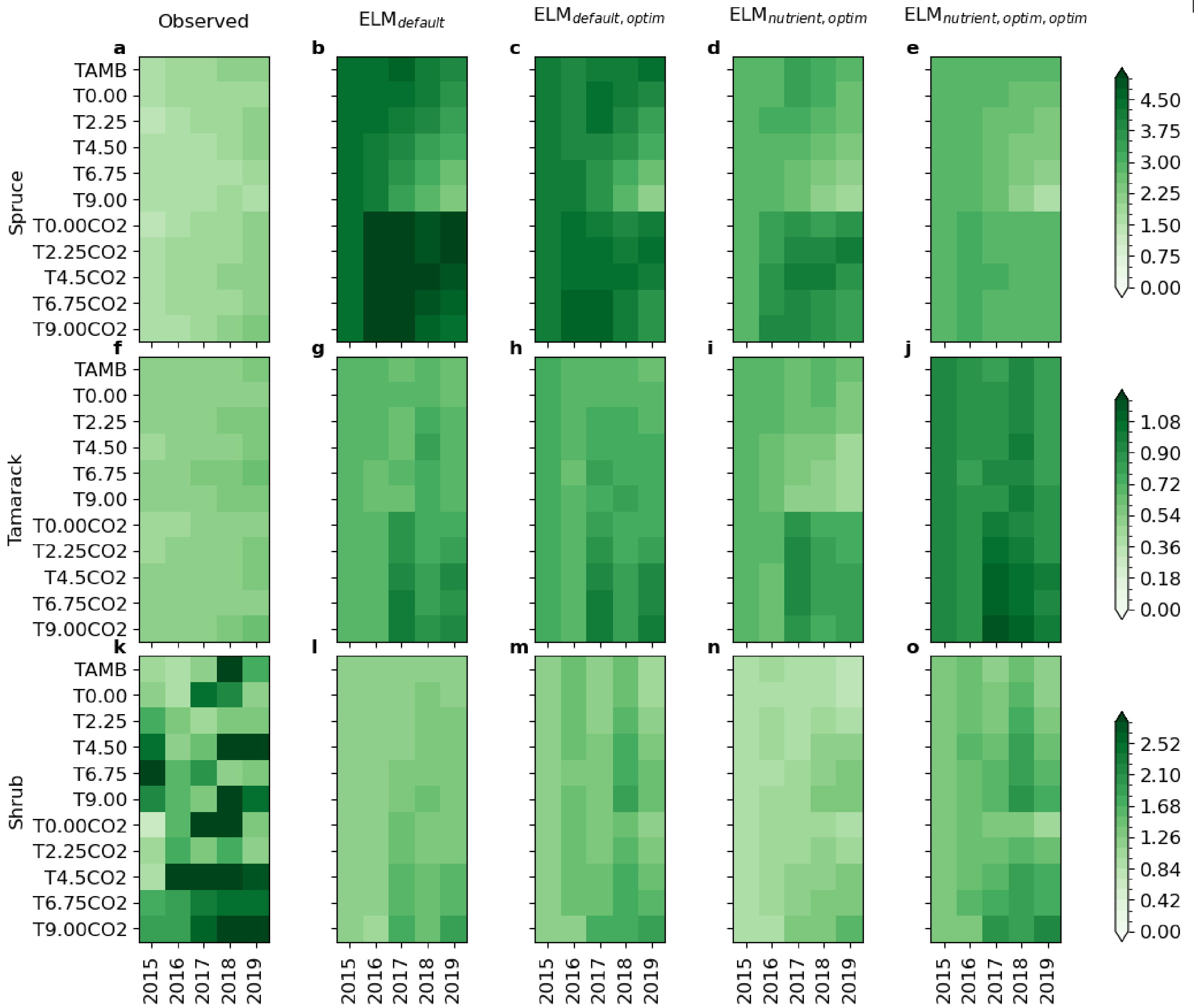
Structural modification changes the inter-PFT nutrients competition

- overall, reduces plant excess respiration due to N limitation in the warmest chambers
- mitigates sink-to-source transition under warming

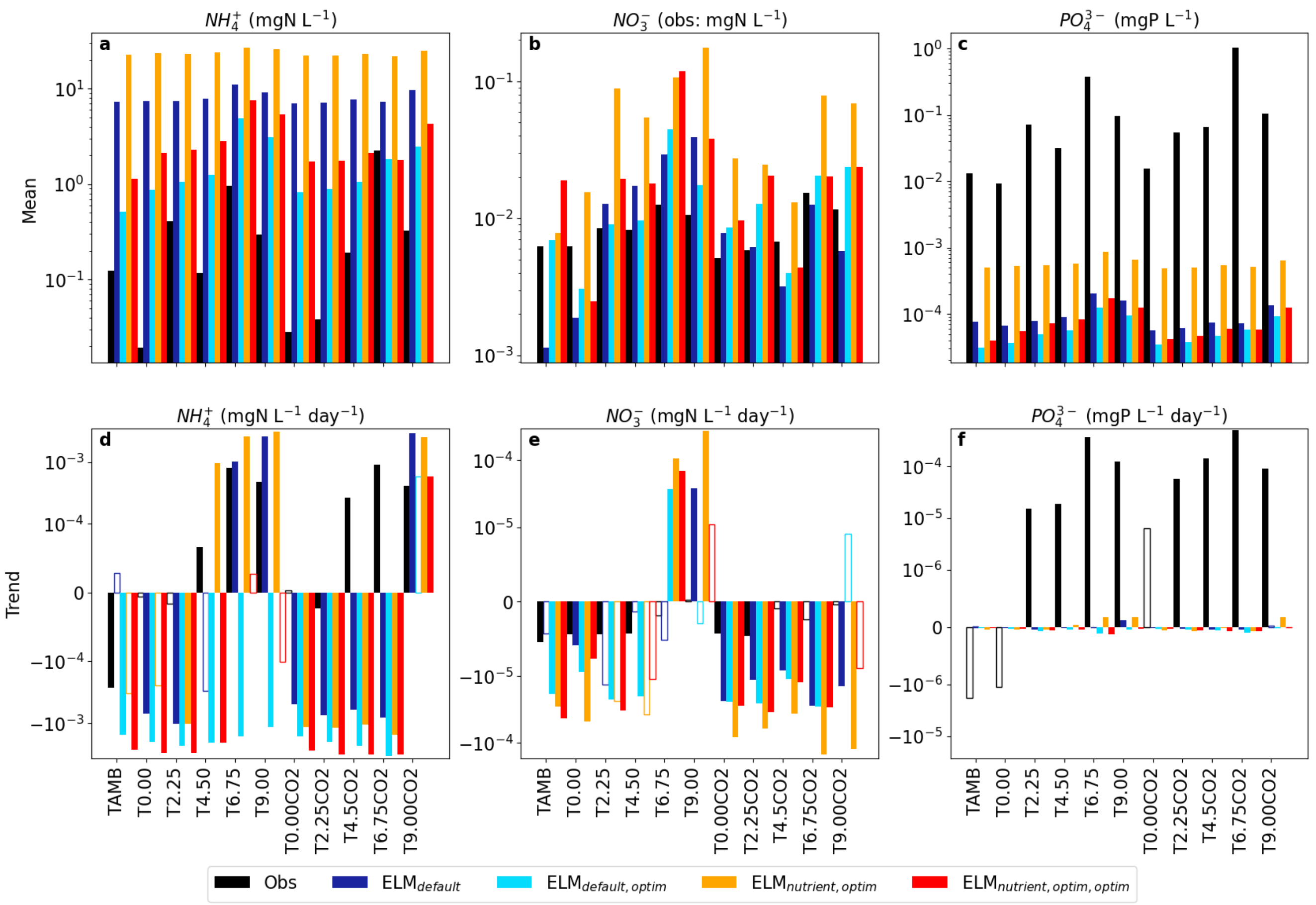
Validation data on total nutrients uptake, fungal uptake percentages and uptake kinetics will help improve the model in the future

Back up slides

Validation on observed annual maximum LAI



Validation on pore water nutrients



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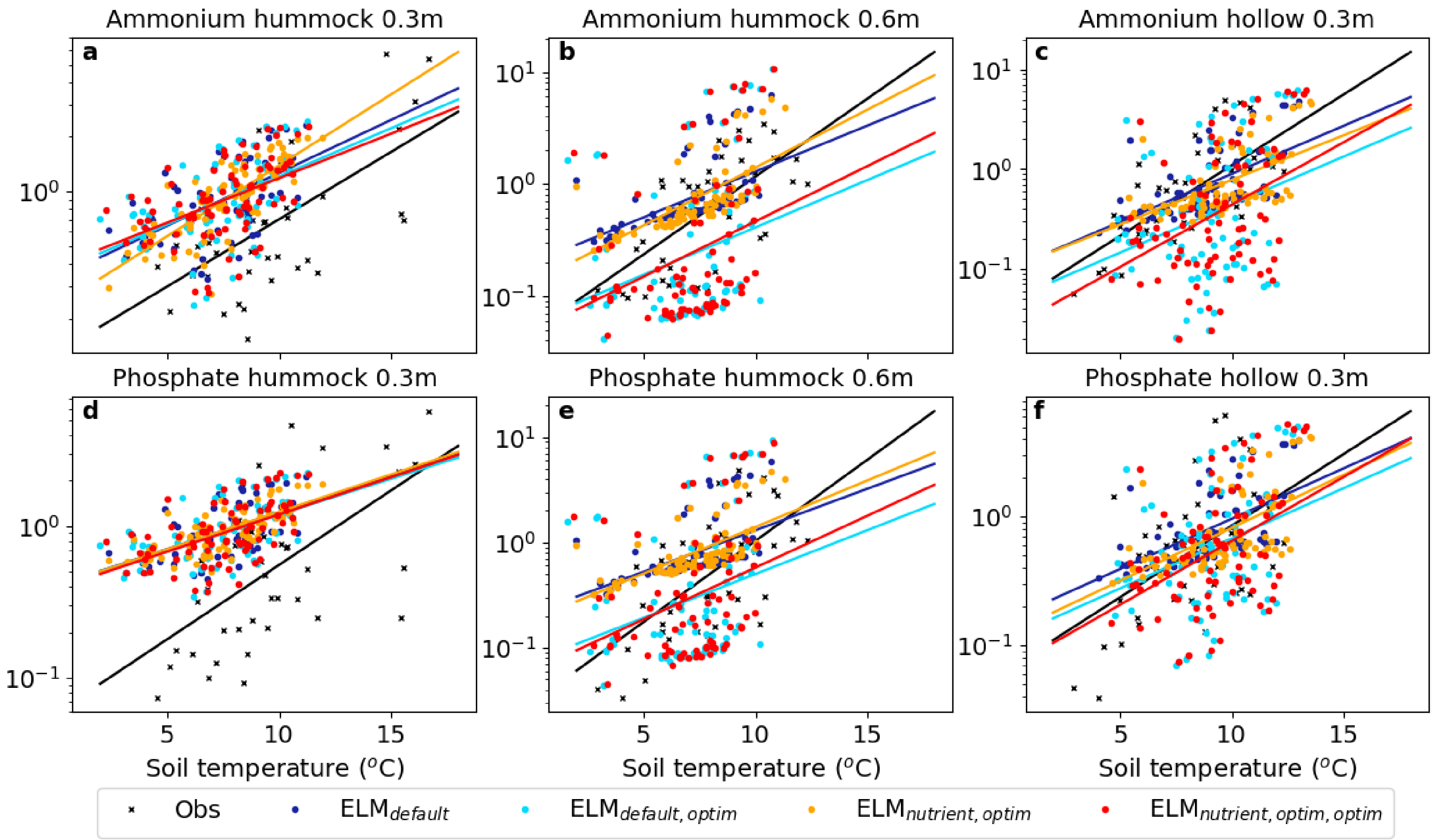
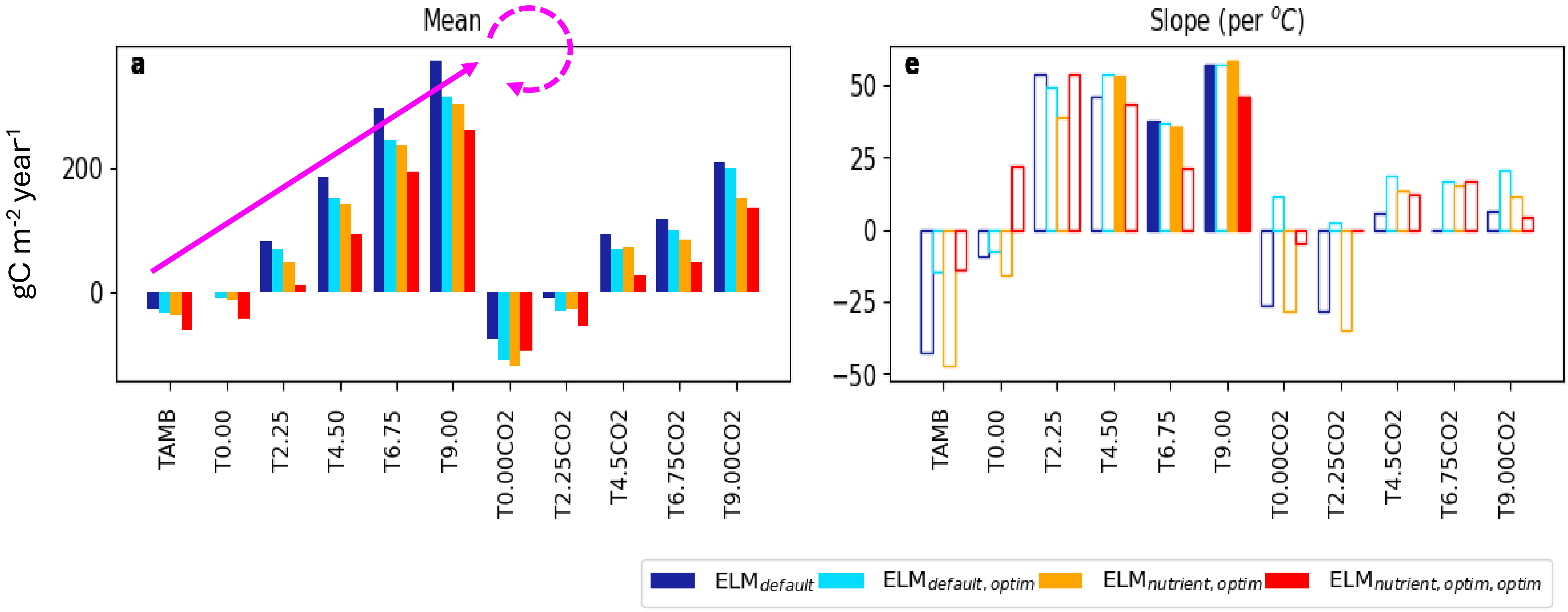


Implication for net ecosystem exchange

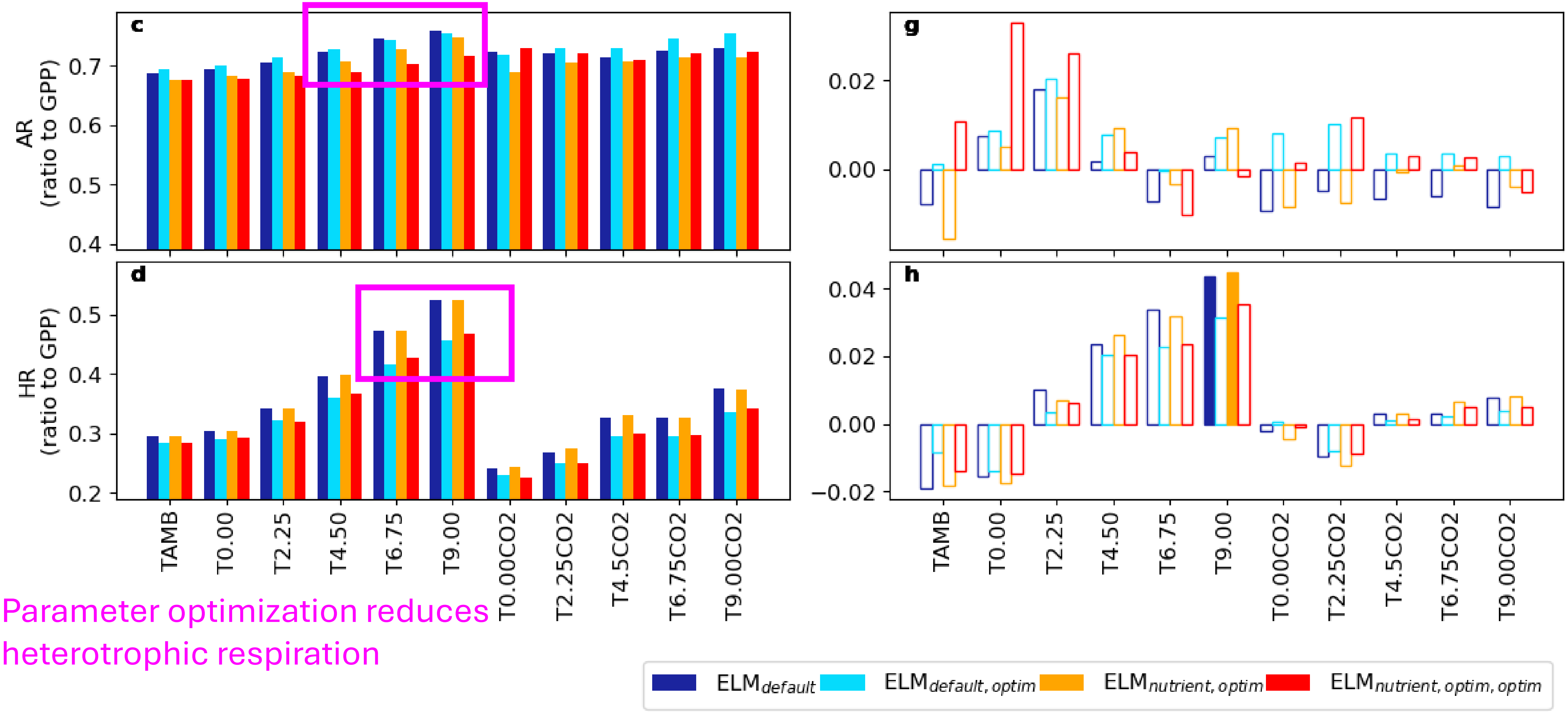
Warming induces sink-to-source transition

Parameter optimization and structural modification reduces the strength of this transition



Implication for net ecosystem exchange

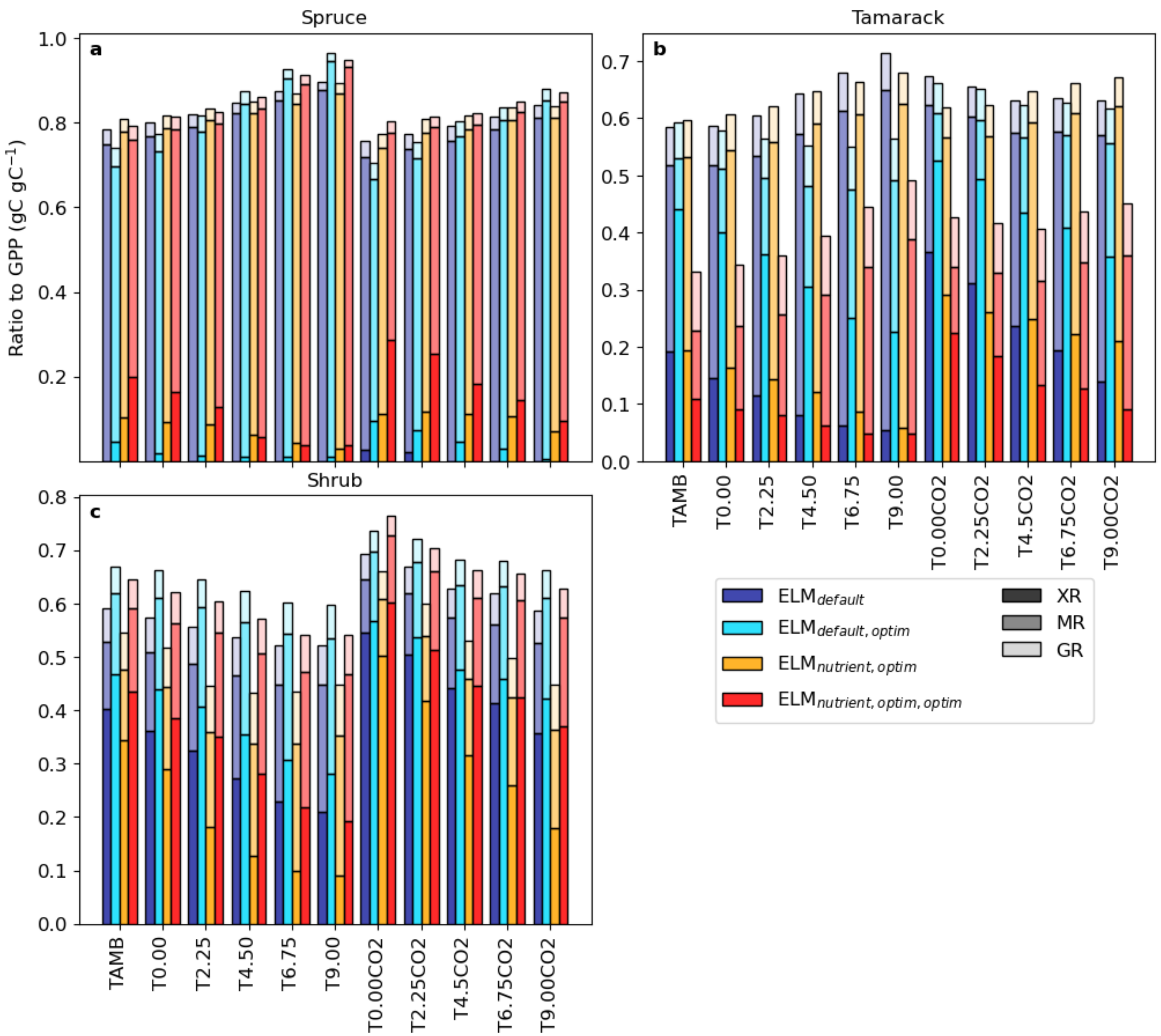
Structural modification reduces autotrophic respiration



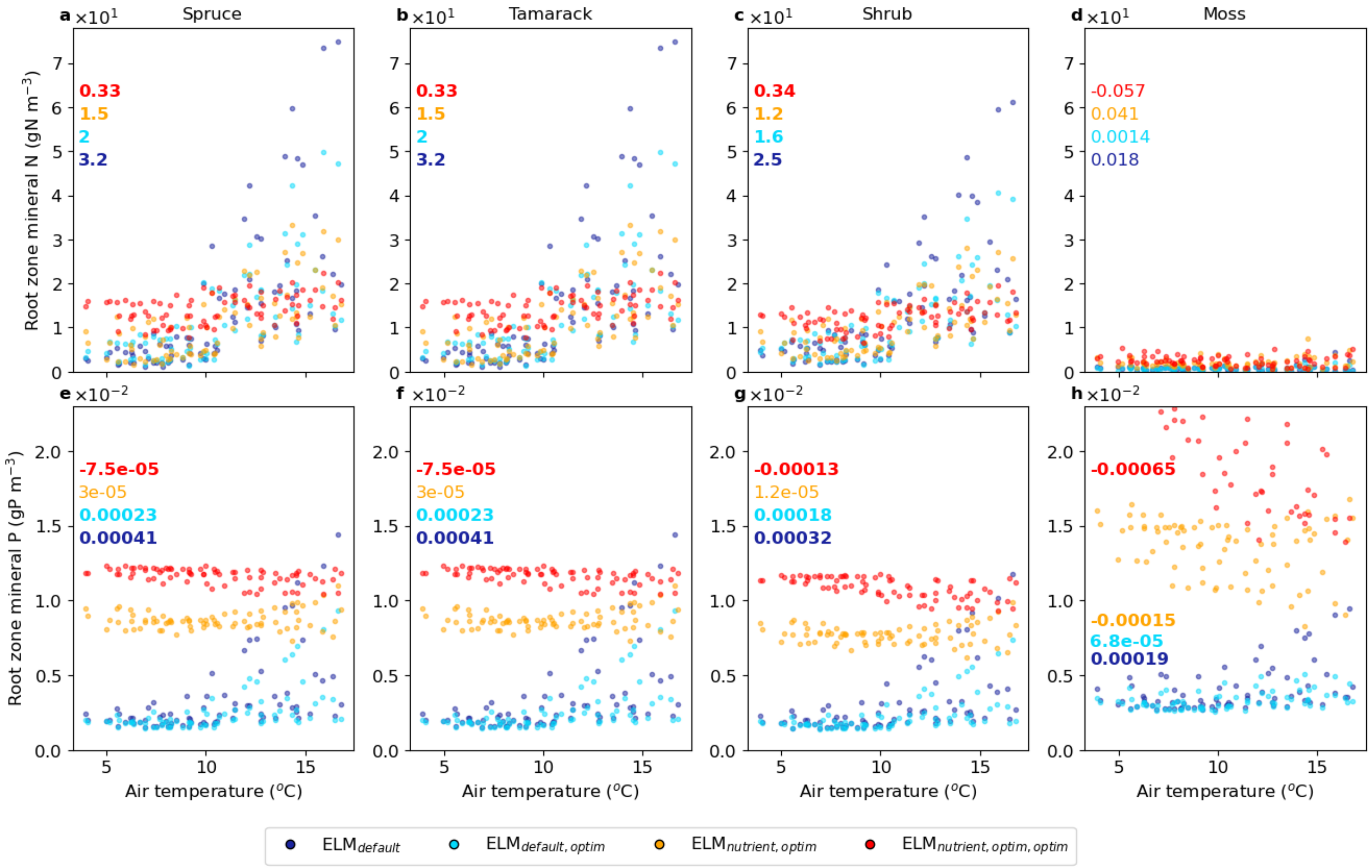
Parameter optimization reduces heterotrophic respiration

Explanation for net ecosystem exchange

Structural modificati s limitation



Moss is accessing more P in modified model



Phosphorus uptake kinetics