Hydrologic drivers of N-removal and *Phragmites* invasion of Great Lakes coastal wetlands

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Coastal marshes across Great Lakes

- Rich diversity of wetland habitats

Photo: Bill Currie

Coastal marshes across Great Lakes

- Rich diversity of wetland habitats
- Often oligotrophic
- Provide many services, including improving water quality

Photo: Bill Currie

Coastal marshes across Great Lakes

- Invasive *Phragmites australis* is becomes more common in these communties
- Phragmites is common invader in southern half of GL
- Potential to change ecosystem function – e.g. hydrology, wildlife habitat, nutrient cycling

Photo: Christine Angelini

Coastal marshes across Great Lakes

Photo: Bill Currie

Native wetland community, less competition for resources

Photo: Jason Martina

Phragmites australis form dense stands, crowding out native vegetation, especially when resources are abundant

Coastal marshes across Great Lakes

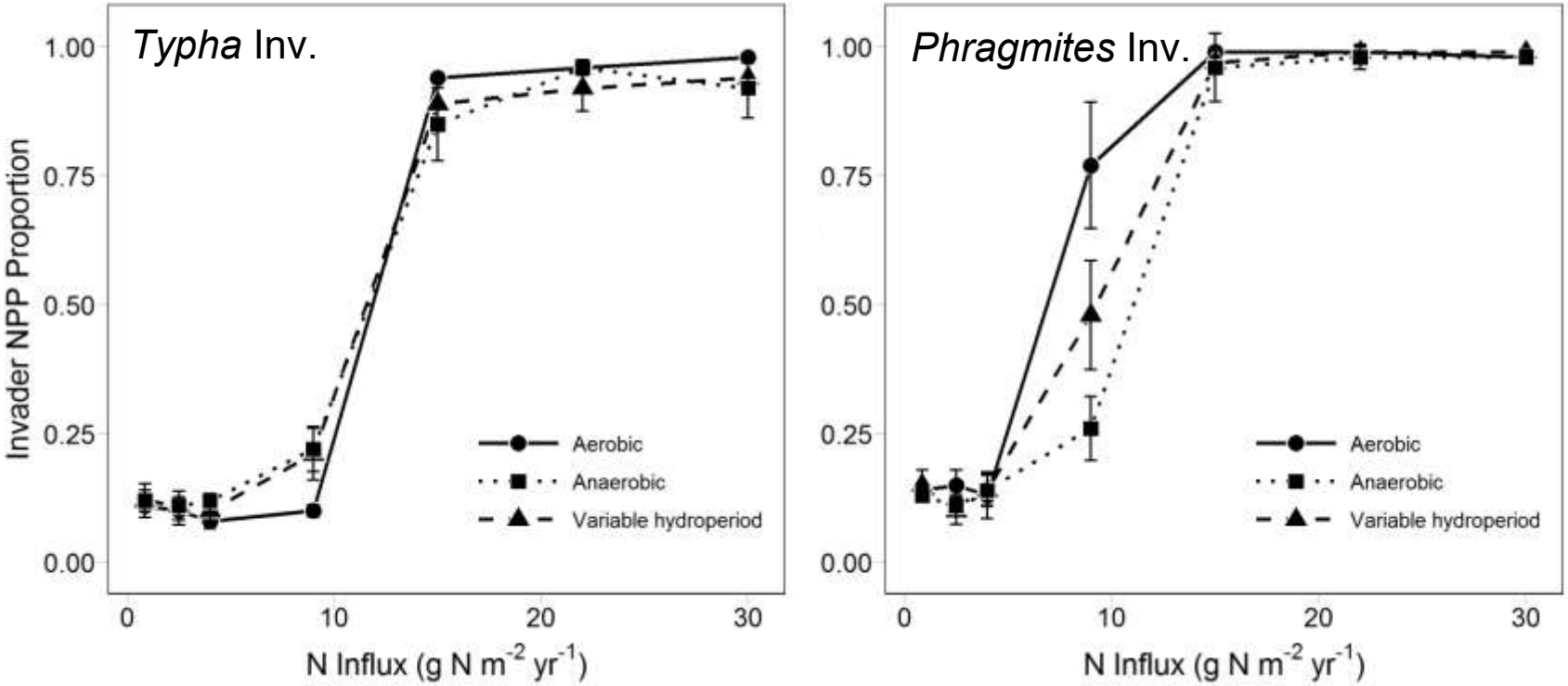
- Ecosystems are shifting with increased inland nutrient loading
- Invasive *Phragmites australis* thrives in disturbed areas with high nutrient loads

Phragmites front encroaching into native marsh

Photo: Sean Sharp

Coastal marsh invasion

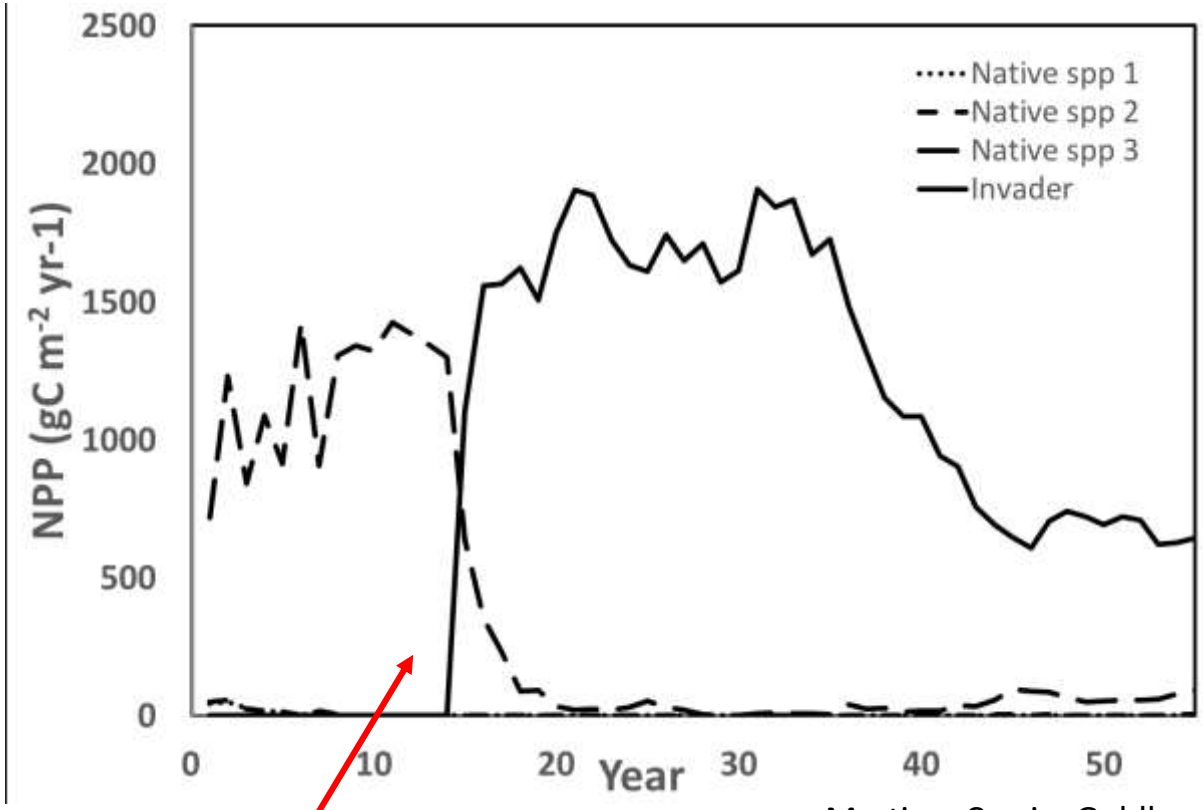
- N-loading known to drive *Phrag* invasion
- Previous studies in our lab show a threshold around 12 gN m^{-2} yr^{-1}



Martina, Currie, Goldberg, Elgersma (Ecosphere 2016)

Coastal marsh invasion

- Phragmites can form stable monoculture in 10 yrs after establishment



Martina, Currie, Goldberg, Elgersma (Ecosphere 2016)

Phrag introduced in yr 15

Research Questions

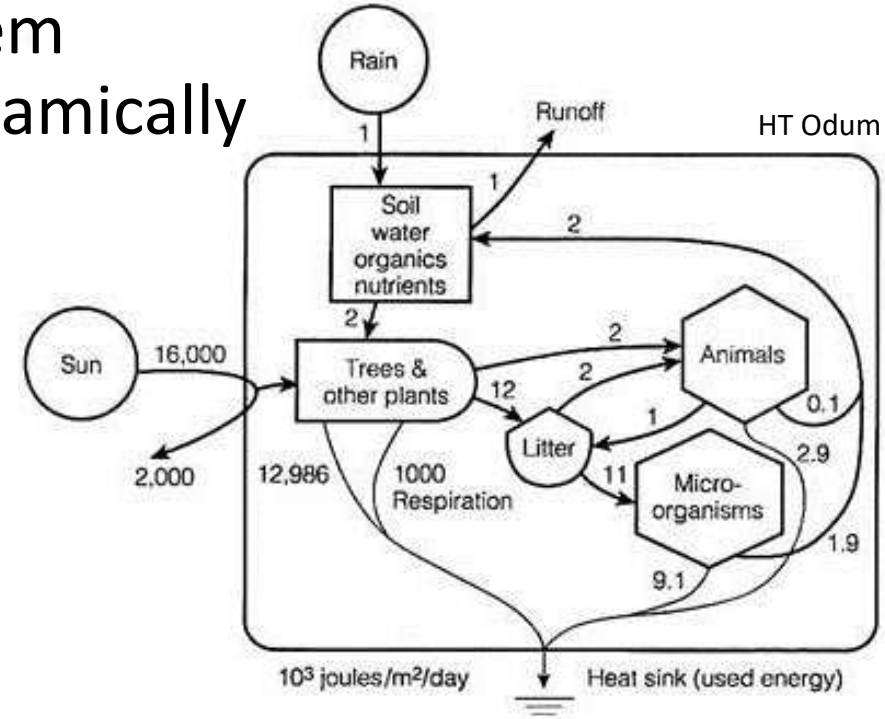
1. How do residence time and hydrologic regime interact to influence *Phrag* invasion?

2. Does this affect N-removal in the form of either plant uptake or denitrification?

Photo: S Sharp

Methods

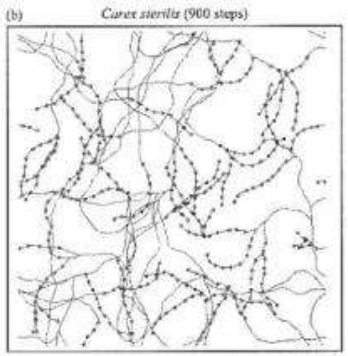
- We used MONDRIAN (Currie et al. 2014), a dynamic simulation model, to address these questions
- Mondrian simulates ecosystem processes iteratively and dynamically



Currie, Goldberg, Martina, Wildova, Farrer, Elgersma (2014, Ecological Modelling)

MONDRIAN

- Clonal reproduction and plant physiology
- Resource competition
- Dynamic ecosystem processes



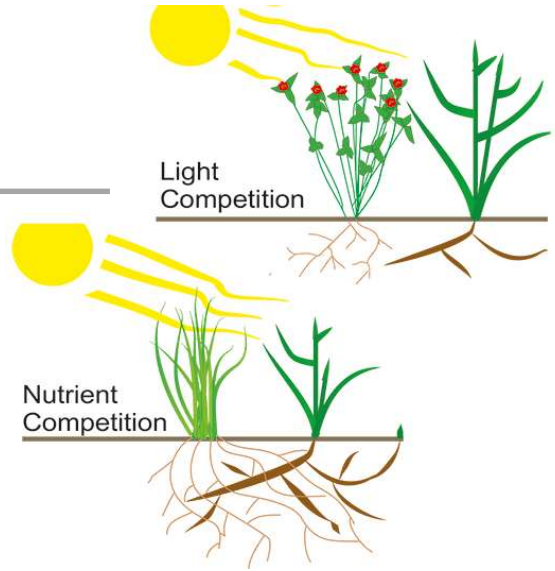
Mondrian spans the **four** main levels of ecological organization:

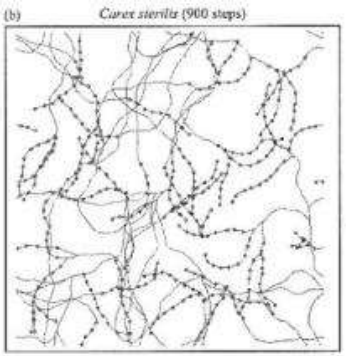
Individual physiology, Population ecology, Community ecology and Ecosystem ecology

MONDRIAN

- Clonal reproduction and plant physiology

- Resource competition





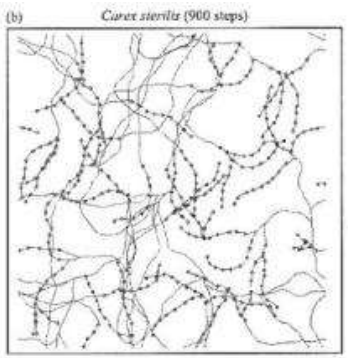
Also, Mondrian spans the **four** main levels of ecological organization:

Individual physiology, Population ecology, Community ecology and Ecosystem ecology

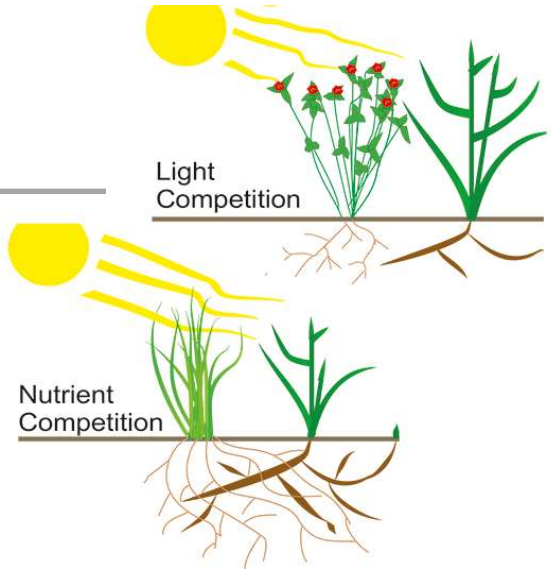
- Dynamic ecosystem processes

MONDRIAN

- Clonal reproduction and plant physiology



- Resource competition



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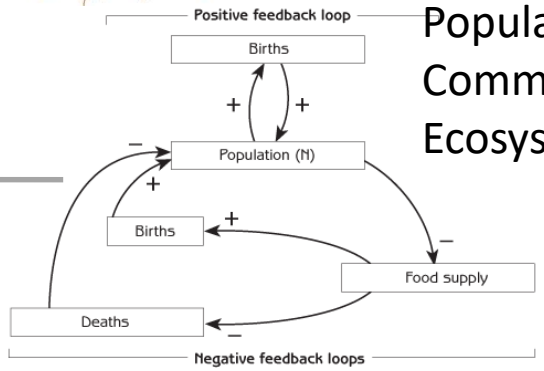
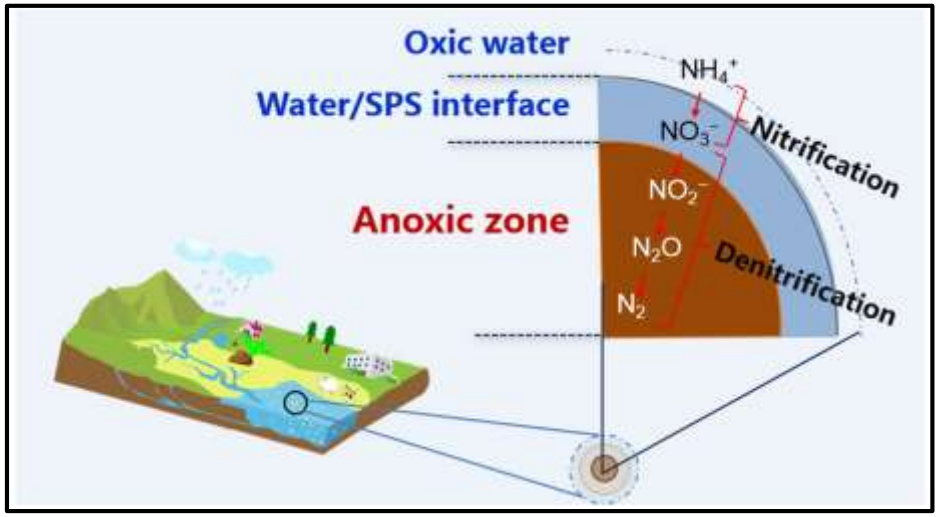


MONDRIAN

- Parameterized w/ field data
- Recent versions introduced clonal branching and coupled nitrification-denitrifcation



Xinghui et al. 2016

Photo: S Sharp

Experimental design: Community and nitrogen

- Species
  - 3 native species
    - *Eleocharis smallii*
    - *Juncus balticus*
    - *Schoenoplectus acutus*
  - Phrag invader
    - *Invades at yr 15 + 20*

Eleocharis smalii

Phragmites australis

Juncus balticus

Schoenoplectus acutus

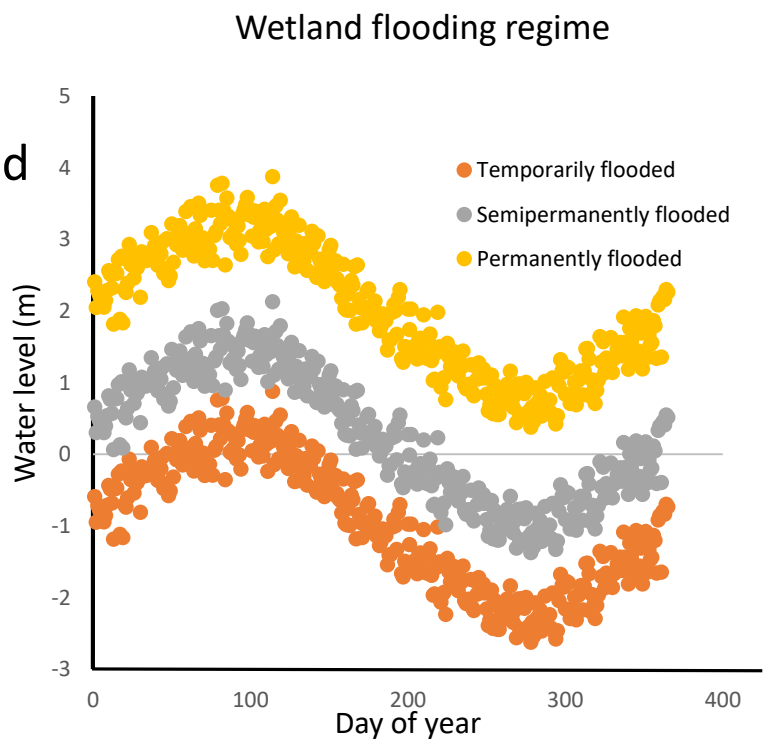
All species parameterized using literature and field data

Invasion

- Natives are allowed to establish for 15 years before invader added in two cohorts 5 years apart
- Propagule pressure = # ind. in cohorts
- Response variables (% Invasion, Total NPP, N cycling) recorded and averaged from years 55 to 60 (new ecosystem stability reached by this time period)

Experimental design: Hydrology

- Hydrology
  - Selected regimes that reflect controlled impoundments and 3 National Wetland Inventory classifications:
    - Permanently, semi-permanently, and temporarily flooded



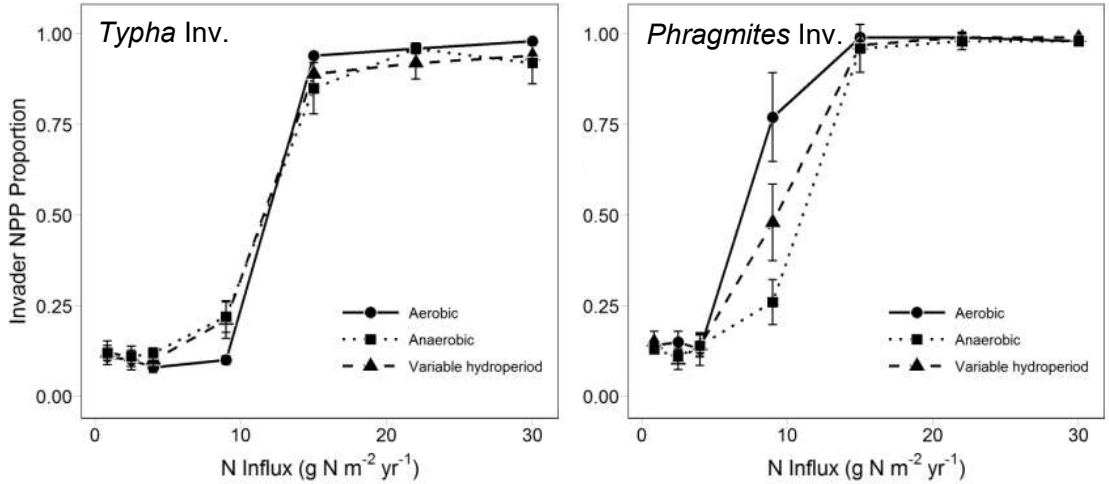
Experimental design: Hydrology

- Hydrology
  - Selected regimes that reflect controlled impoundments and 3 National Wetland Inventory classifications:
    - Permanently, semi-permanently, and temporarily flooded

- Flushing and residence time
  - High (10 days – retention pond)
  - Medium (100 days – Saginaw Bay)
  - Low (1000 days – Lake Erie)

Experimental design: Community and nitrogen

- Nitrogen loading (includes NH_4 and NO_3)
  - Background levels (4 gN m^{-2} yr^{-1})
  - Invasions threshold (12 gN m^{-2} yr^{-1})
  - Typical loading rates of LP (20 gN m^{-2} yr^{-1})
  - High loading rates of LP (30 gN m^{-2} yr^{-1})



Experimental design: Model simulations

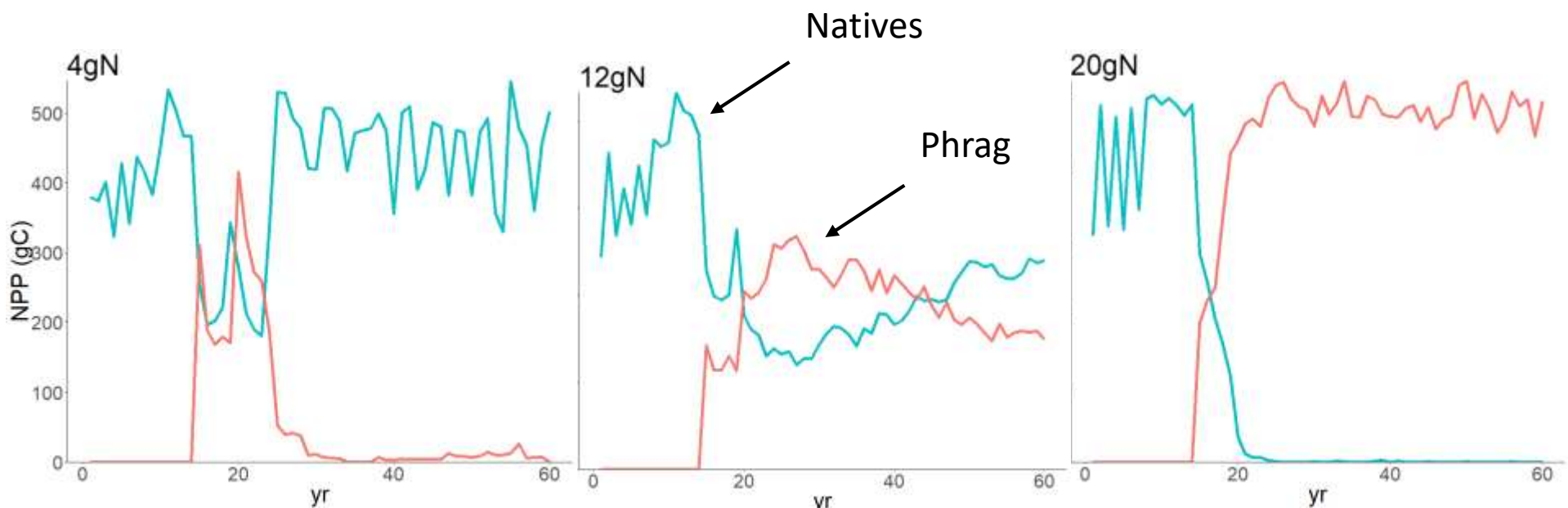
- **Community composition**: Natives only and with invasive Phrag (high and low propagule pressure)
- **N loading:** Constant N Loading – 4.0, 12.5, 20.0, 30.0 g N m^{-2} yr^{-1}
- **Hydrology**: constant -15 cm and 30 cm depth in reference to the mineral soil surface, 3 seasonal fluctuations (permanent, semipermanent, temporarily
- **Water residence time:** 10 days, 100 days, 1000 days
- 3 stochastic reps
- 540 fully factorial total simulation runs
- Simulation ran for 60 years

Results – Invasion

- All results from low propagule pressure
- Invasion scenario along N-loading gradient
- Invader introduced yr 15 and again at yr 20

- 3 invasion scenarios:

Does not establish *Coexists* *Dominates*

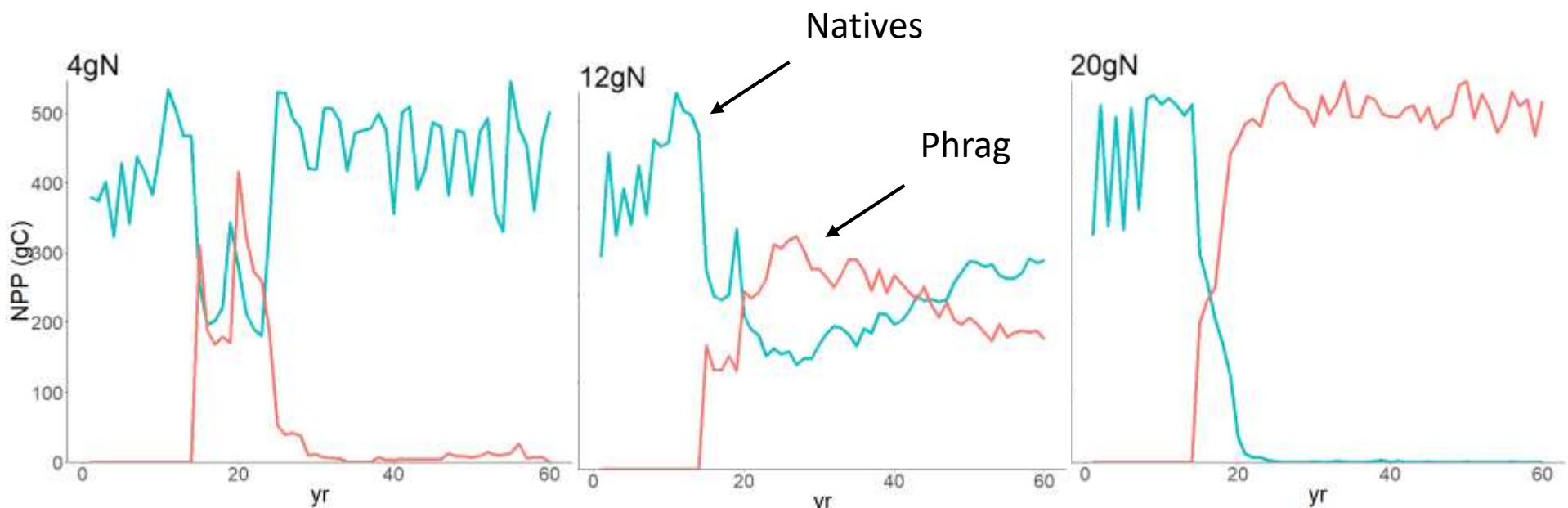


Results – Invasion

- *Steady state reached after several years*
- *Programmed death causes regular dips as 'generations' die*
- *A myriad of factors can change this threshold*

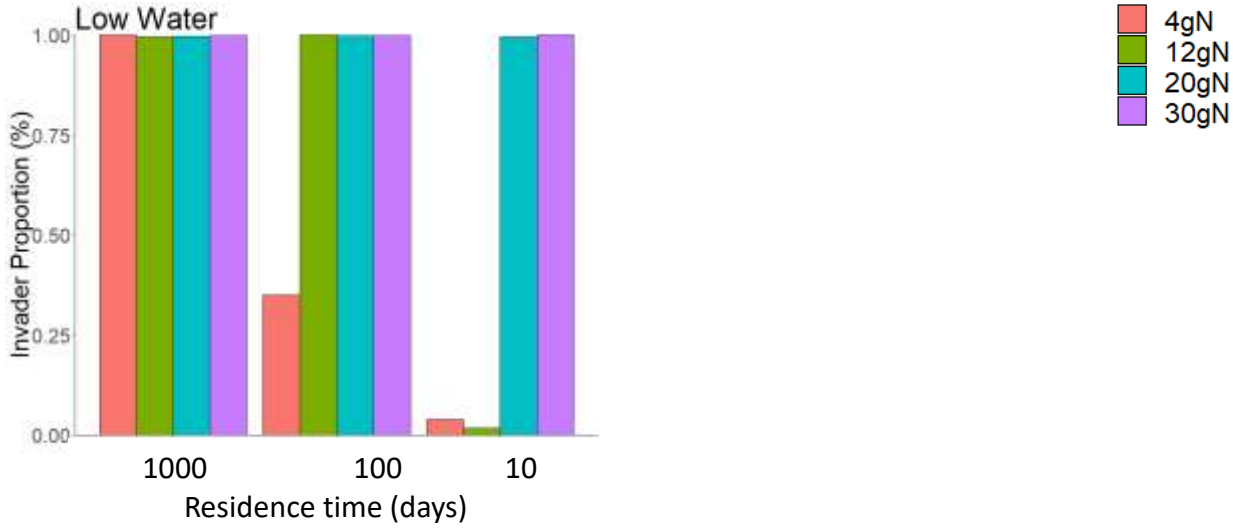
- 3 invasion scenarios:

Does not establish *Coexists* *Dominates*



Results – Invasion last 5 yrs

- **Constant low water (15cm below surface)**
  - Phrag does well in low water conditions, higher flushing
  - High residence time can also induce invasion, even with low N-loading



Results – Invasion last 5 yrs

100% Phrag

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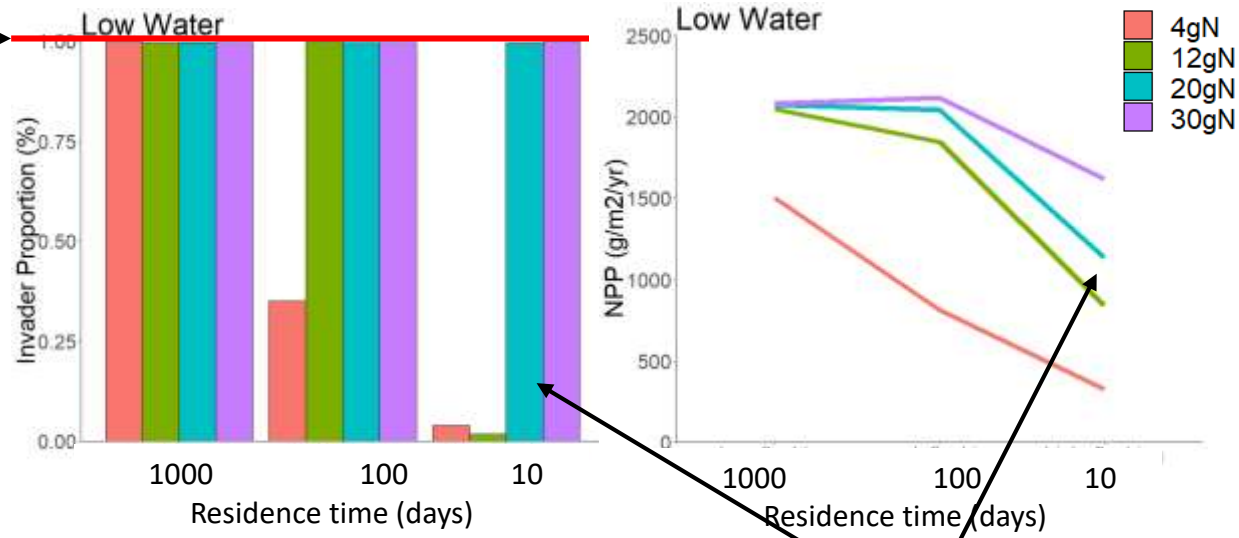
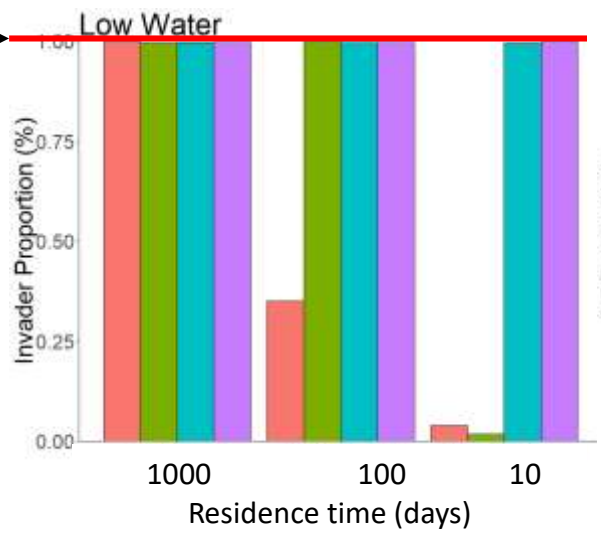


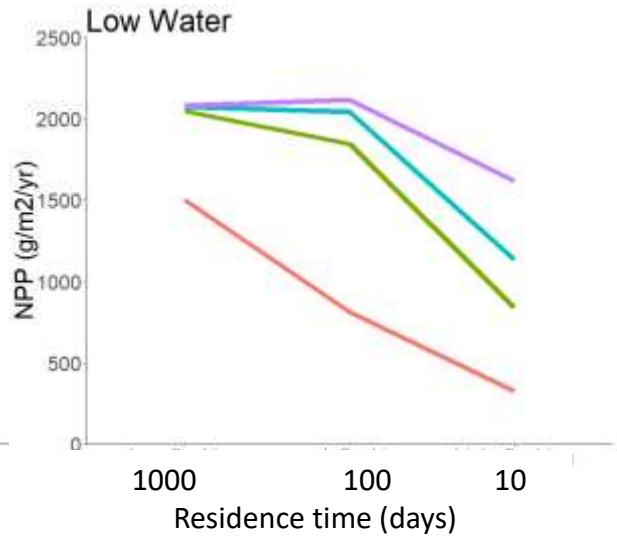
- More Phrag=more NPP
- Although it still dominates in high flushing+20N, it is much less productive

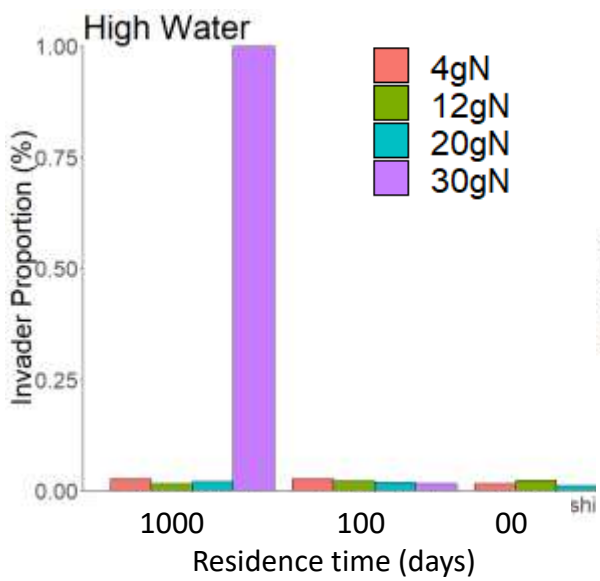
Results – Invasion last 5 yrs

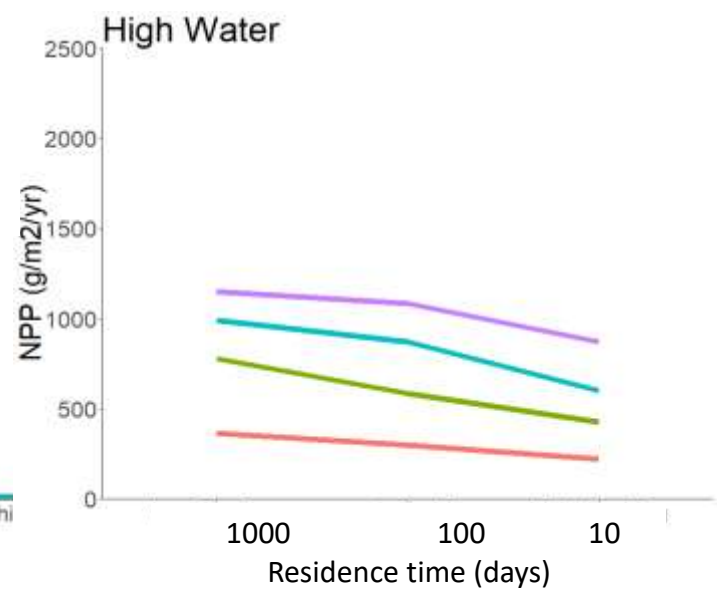
100% Phrag →

- **Constant low water (15cm below surface)**
  - Phrag does well in low water conditions, higher flushing
- **Constant high water (30cm above surface)**
  - Productivity is slowed in flooded conditions, freeing resources for natives



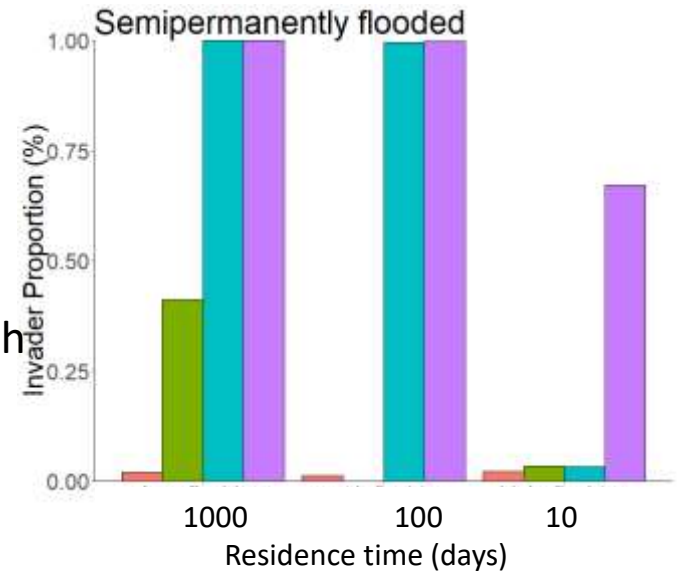


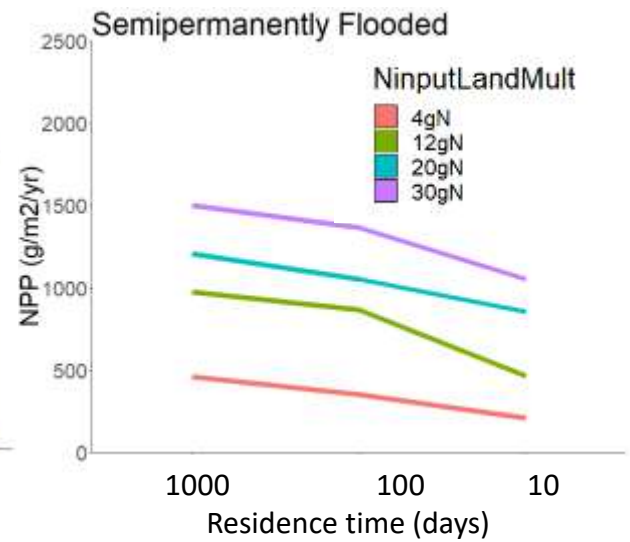




Results – Invasion last 5 yrs

- Seasonal spring flooding
  - High flushing rates control invasion
  - Natives can establish





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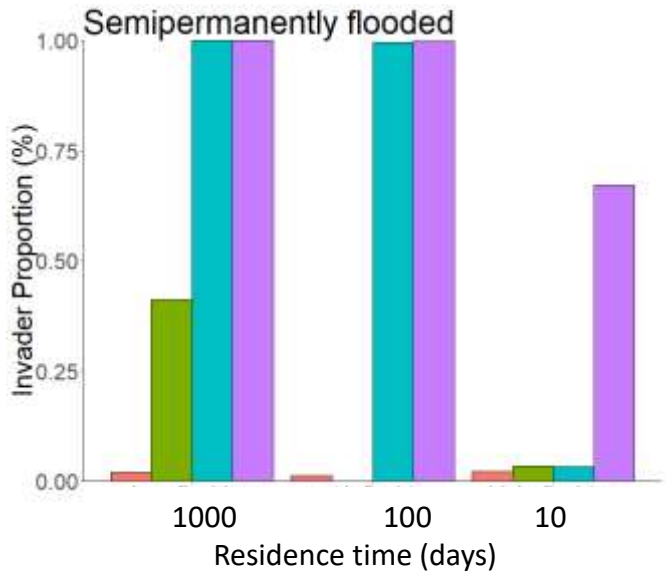
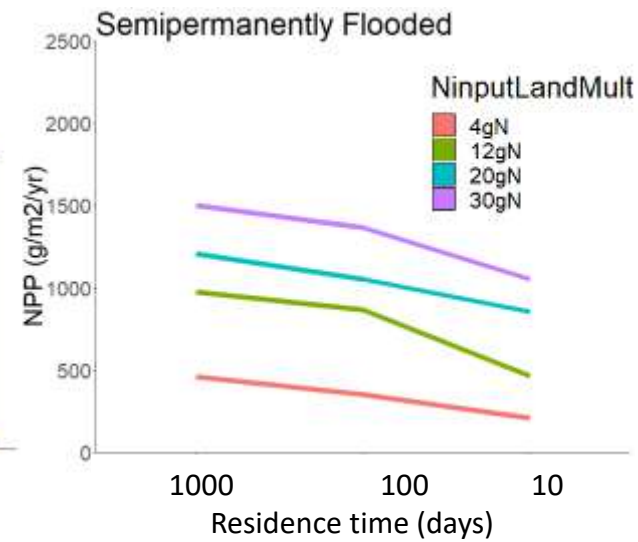
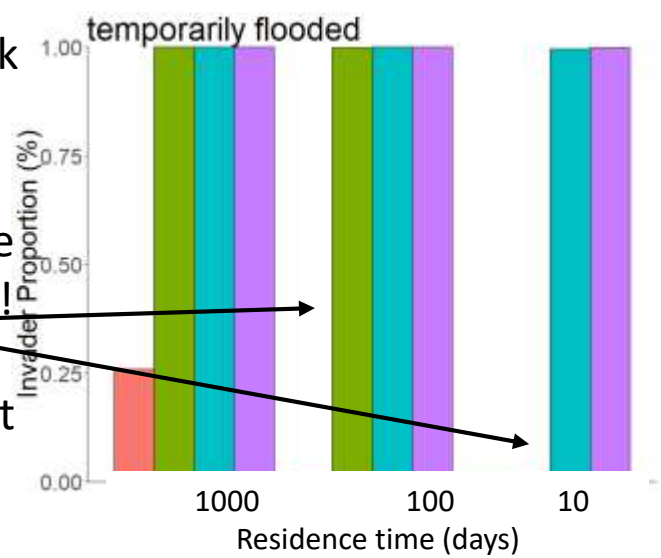


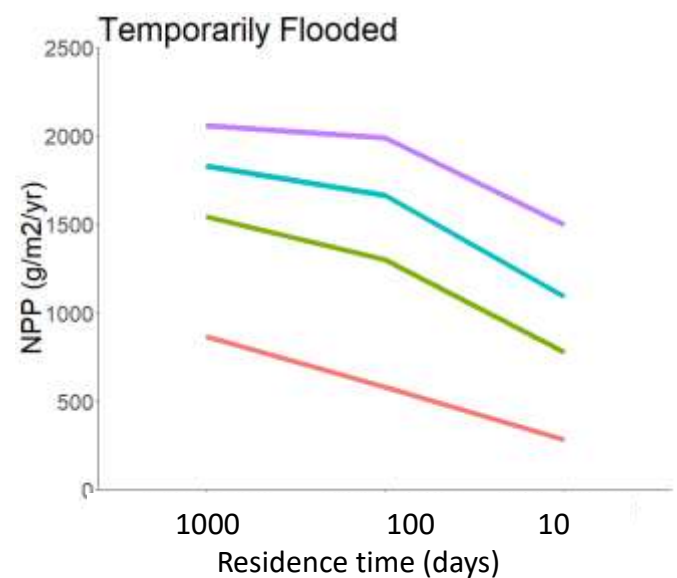


- Only flooded during peak water flow

Flushing rates can equal the impact of N-load reduction!

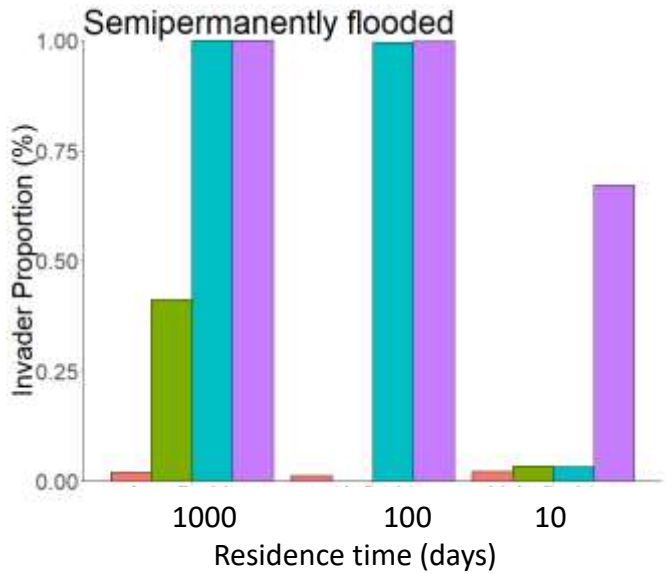
…however, you're really just kicking the can down the watershed

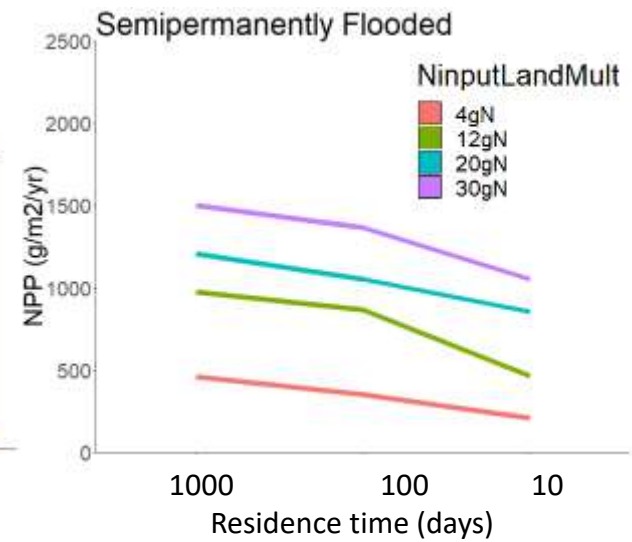




Results – Invasion last 5 yrs

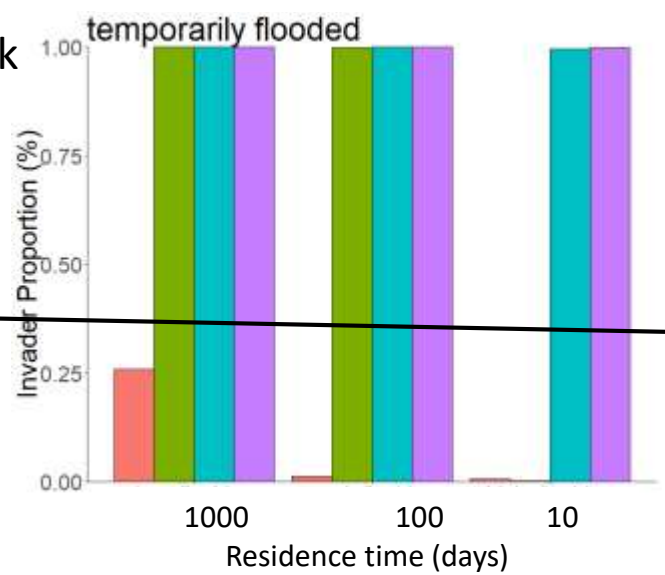
- Seasonal spring flooding

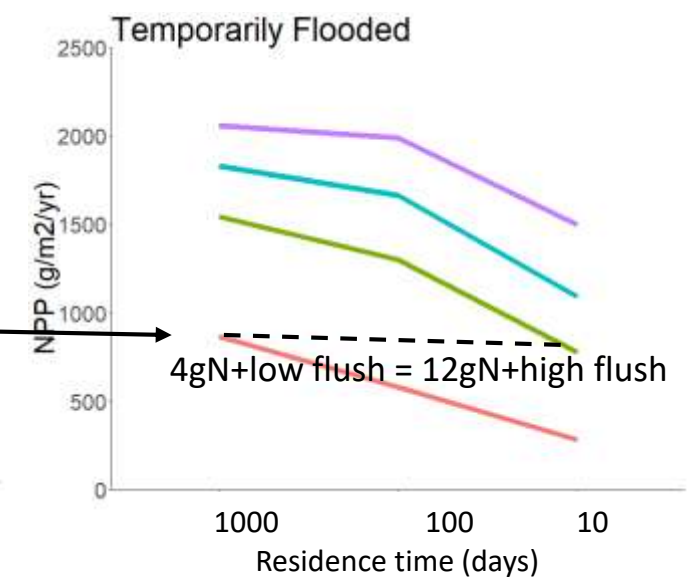




- Only flooded during peak water flow

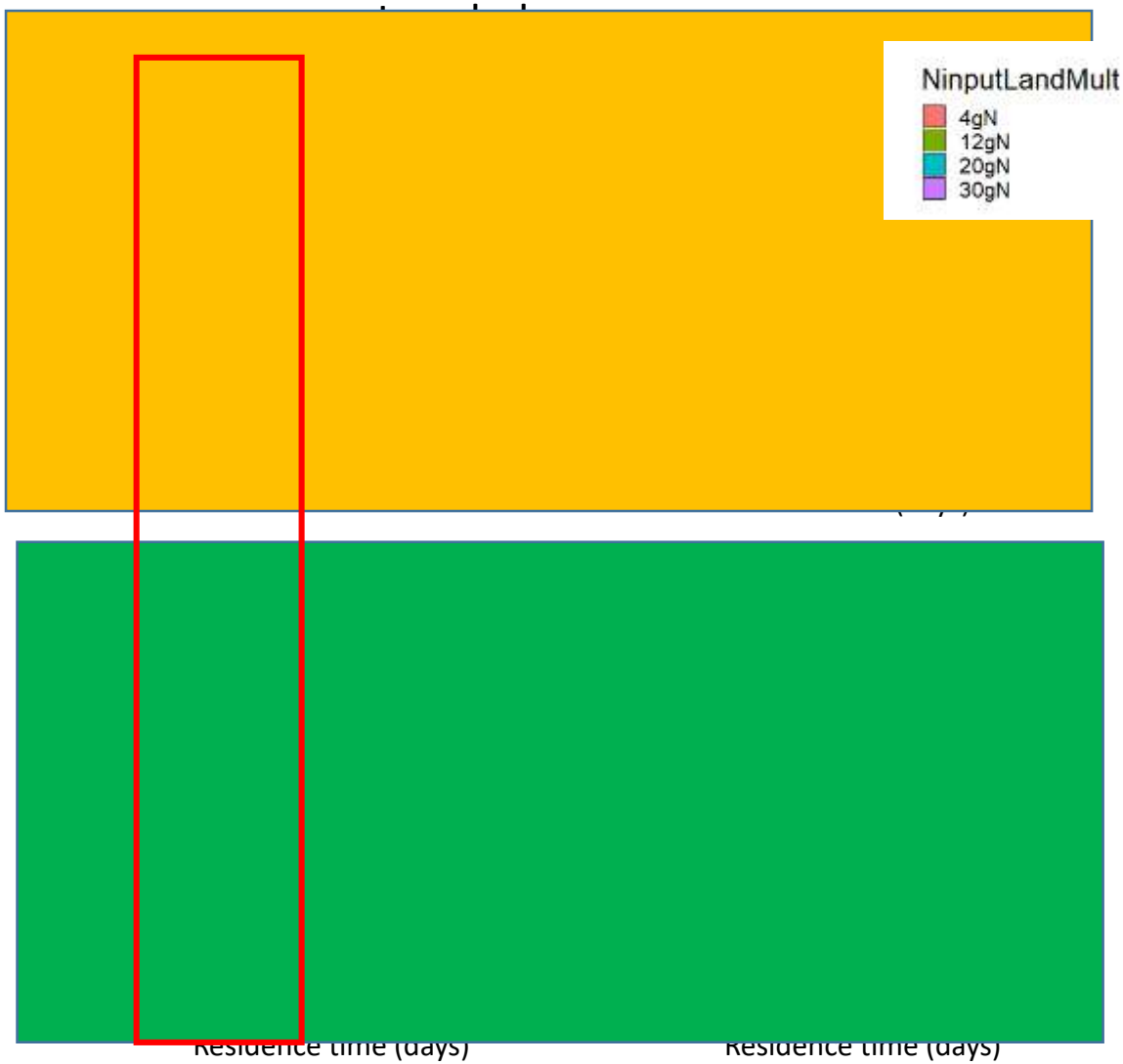
Some scenarios give same ecosystem service (productivity) with no invasion!





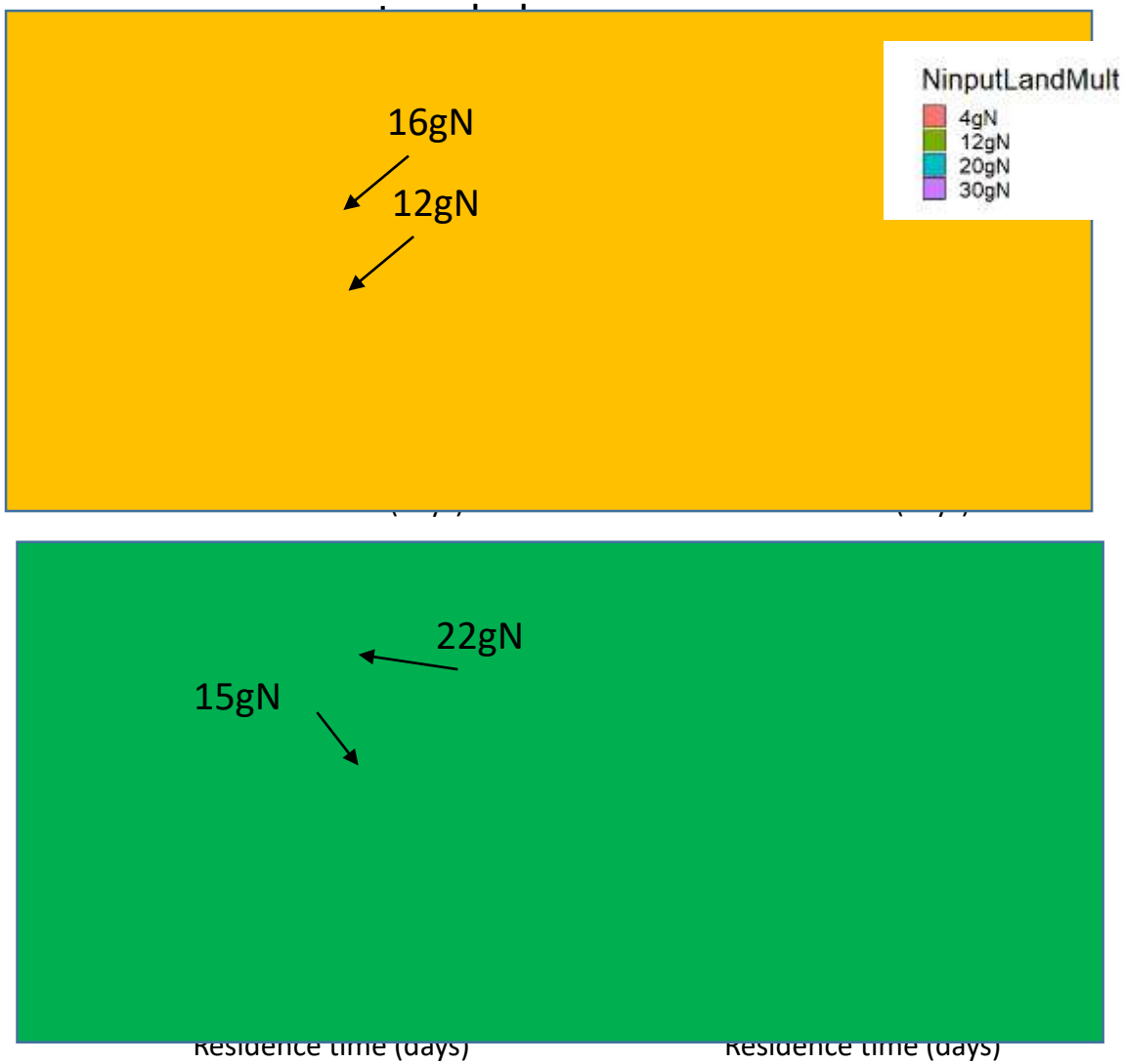
Results – Denitrification and N-retention

- Same denitrification potential with low flushing
- Phrag ***temporarily removes nitrogen***, but is still labile, can re-enter the watershed



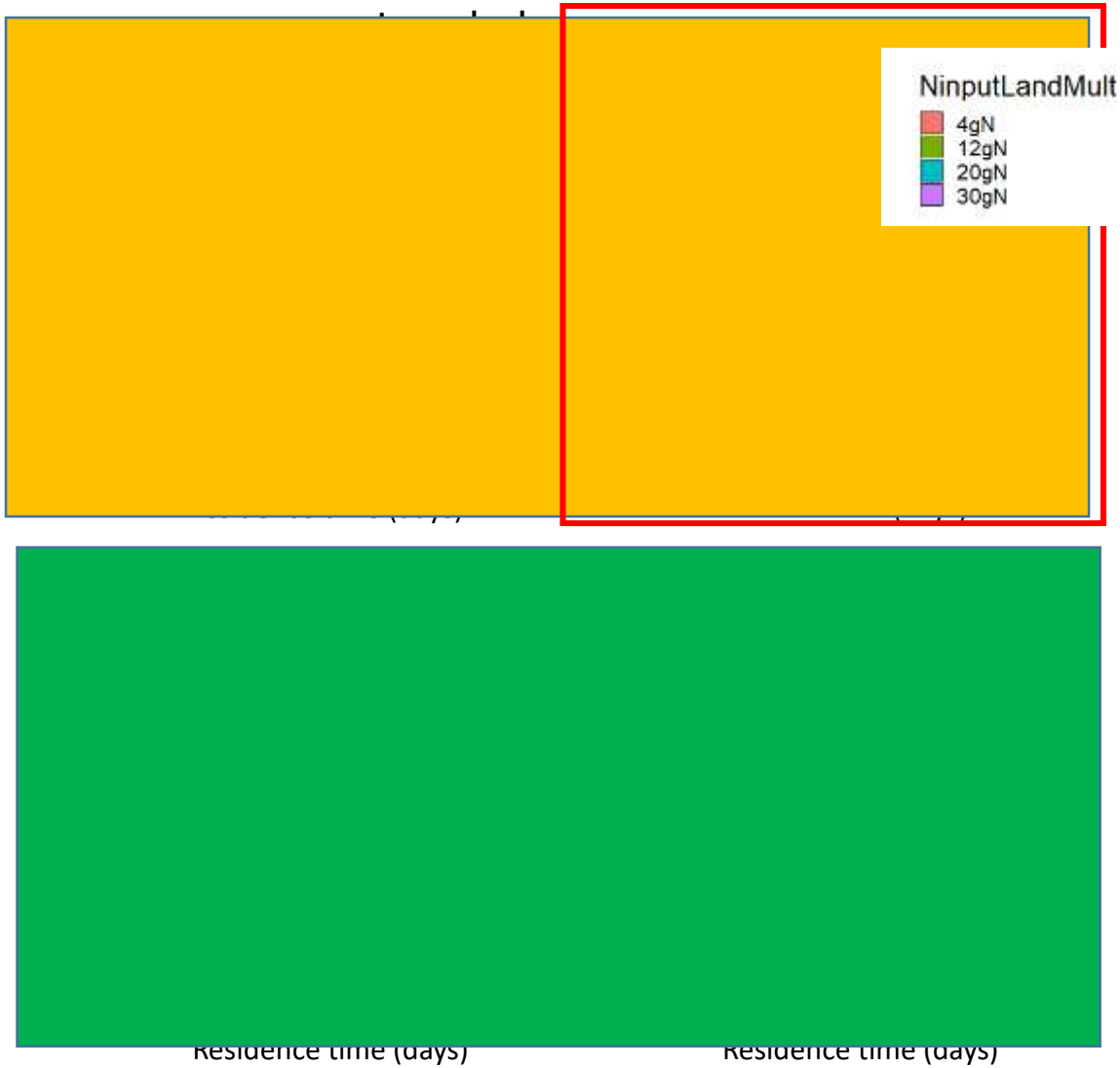
Results – Denitrification and N-retention

- Same denitrification potential with low flushing
- Phrag ***temporarily removes nitrogen***, but is still labile, can re-enter the watershed
- More potential for DeNTRF in native communities in lower flushing scenarios
  - ~5gN more per year with high N and higher flushing



Results – Denitrification and N-retention

- Interesting that DNTR can be so high in rarely flooded wetlands
- However, with no standing water in Temporarily Flooded, saturated soil can still dentrify



Summary

- High N loading causes invasion, but high residence time can trigger invasion even under low N regime
- Low residence time can reduce invasion risk at the cost of less nitrogen removal
- Denitrification (more perm N-removal) greatest without invasion

Future directions

- Combining MONDRIAN with a regional watershed model to identify hotspots for invasions
- Simulated future predicted scenarios of water regime, including early, smaller flow peaks and even seasonally shifted peaks
- Using MONDRIAN to inform restoration strategies for planting natives, including planting densities required under different hydrology and nutrient regimes

MONDRIAN free for use!

- Mondrian is now available for download
  - Mondrian 4.0, in a zip file with the executable code and examples of input files.
  - Go to current projects at williamcurrie.net.
  - Detailed 70-page user guide included

Questions?

MONDRIAN available at williamcurrie.net.

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Fred A. and Barbara M. Erb Family Foundation

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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Results – Denitrification and N-retention

- N retention = 1-[N hydro exp + N detrital export/N influx]
  - >0 = Export less than influx; some N retained
  - <0 = more N exported than enters
  - 0 = In = Out
- Some interaction at 4gN and low flushing