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

Sean J Sharp\(^1\)*, Kenneth Elgersma\(^2\), Jason Martina\(^3\), William S Currie\(^1\), Deborah E Goldberg\(^1\)

\(^1\)University of Michigan  
\(^1\)University of Northern Iowa  
\(^1\)Texas A&M University  

*Presenter: Sean J Sharp, PhD, Postdoctoral fellow  
seanjsharp@gmail.com
Coastal marshes across Great Lakes

• Rich diversity of wetland habitats
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 becoming more common in these communities

• Phragmites is a 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

Native wetland community, less competition for resources

*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

Photo: Sean Sharp

Phragmites front encroaching into native marsh
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

\[\textit{Phrag}\] introduced in yr 15

Martina, Currie, Goldberg, Elgersma (Ecosphere 2016)
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?
Methods

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

• Resource competition

• Dynamic ecosystem processes

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

Individual physiology, Population ecology, Community ecology and Ecosystem ecology
• Parameterized w/ field data

• Recent versions introduced clonal branching and coupled nitrification-denitrification

Photo: S Sharp

Xinghui et al. 2016
Experimental design: Community and nitrogen

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

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

![Wetland flooding regime](image-url)

- Day of year
- Water level (m)

Wetland flooding regime

- Temporarily flooded
- Semipermanently flooded
- Permanently flooded
• 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

![Graph showing invasion scenarios](image)
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

- **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

- More Phrag = more NPP
- Although it still dominates in high flushing + 20N, it is much less productive
Results – Invasion last 5 yrs

- 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
Results – Invasion last 5 yrs

- Seasonal spring flooding

- 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!

4gN+low flush = 12gN+high flush
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 denitrify
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.

seanjsharp@gmail.com
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