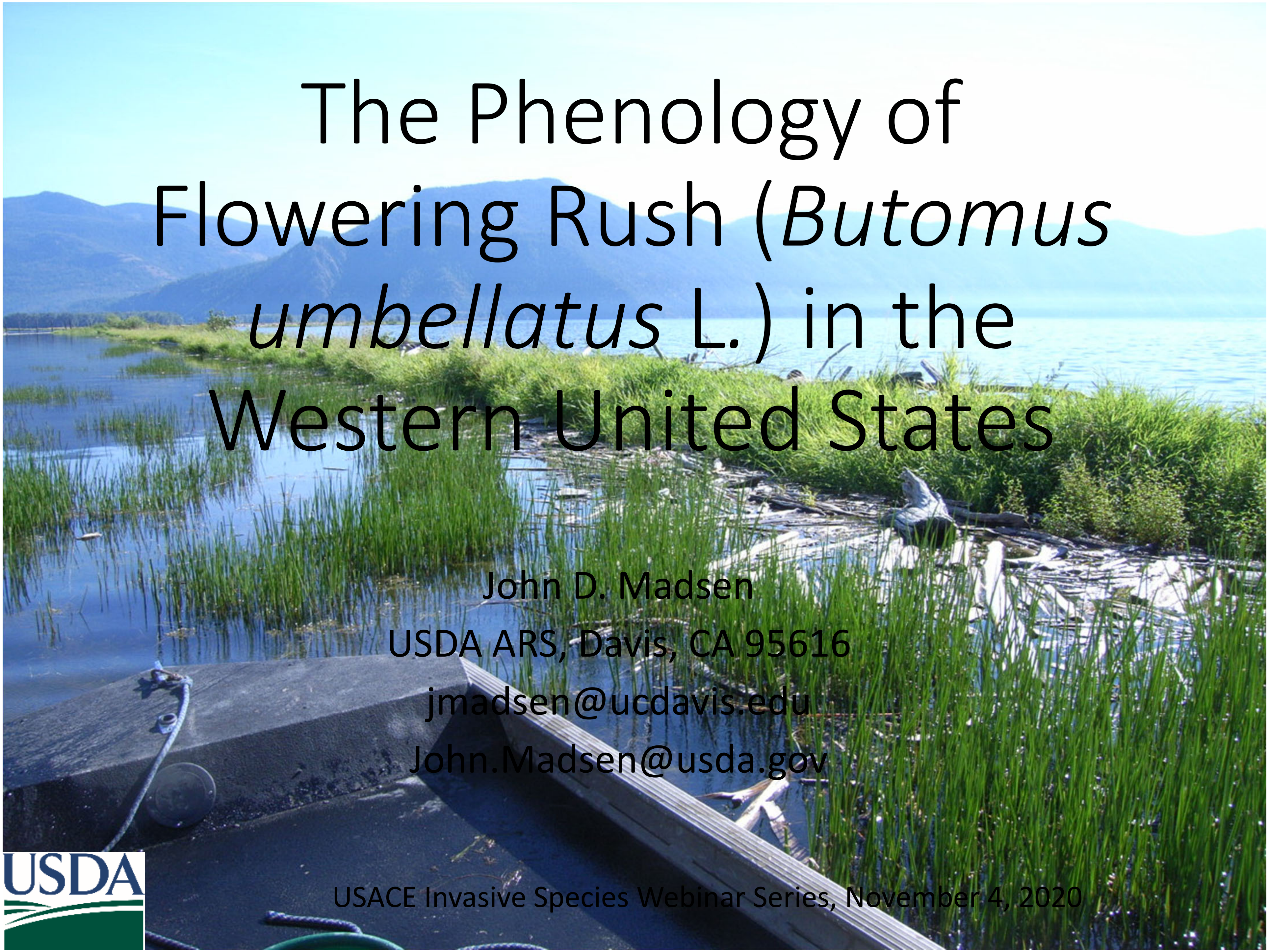


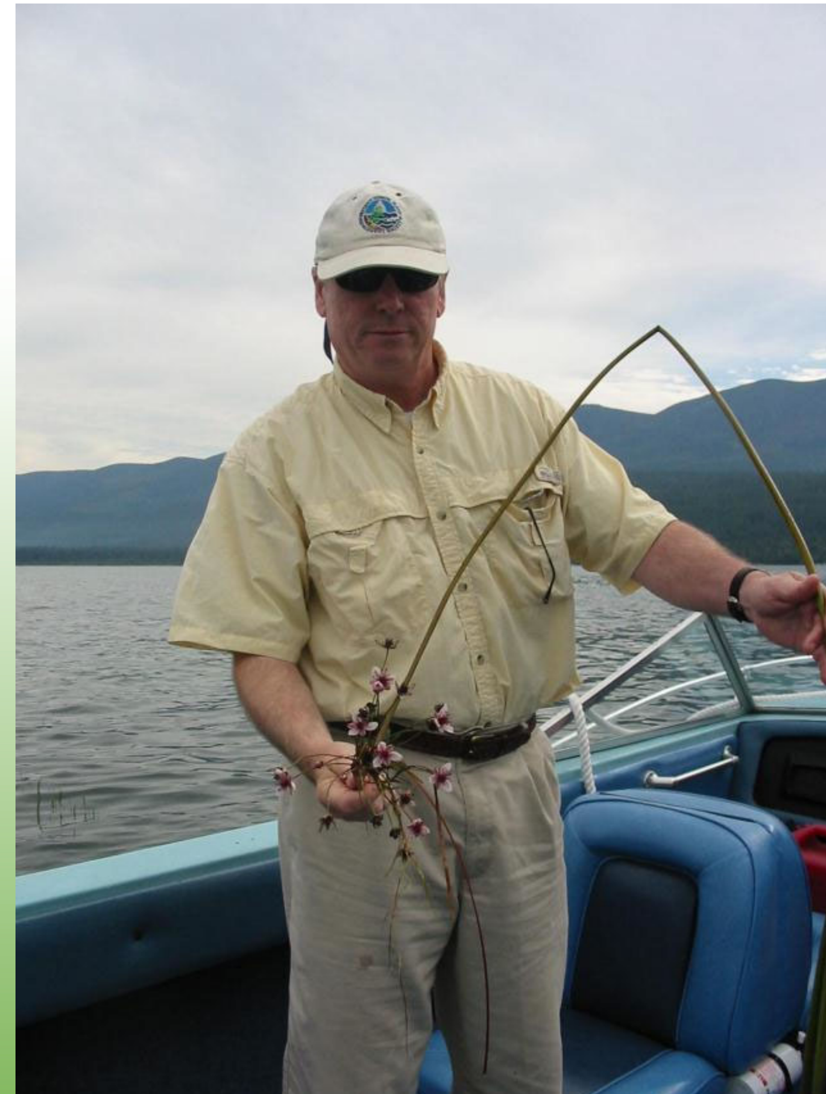
The Phenology of Flowering Rush (*Butomus umbellatus* L.) in the Western United States

John D. Madsen
USDA ARS, Davis, CA 95616
jmadsen@ucdavis.edu
John.Madsen@usda.gov

USACE Invasive Species Webinar Series, November 4, 2020

Flowering Rush (*Butomus umbellatus* L.)

- Long, flexuous or erect leaves growing from a basal rhizome, up to10’ tall
- May grow submersed or emersed in 1 to 10’ water depth, may also grow in moist soil or as facultative wetland plant
- Inflorescence is separate stalk with an umbel of pink flowers; each flower has three petals and three sepals



USDA

Kurt Getsinger, USAERDC – the co-investigator on the phenology work in the West

Monoculture stands

Flowering Rush
(*Butomus umbellatus* L.)

- Introduced from Europe and Asia
- Both a diploid and triploid biotypes
- Diploid biotype undergoes sexual reproduction an produces > 20,000 seeds per plant
- Diploid biotype also produces > 100 of vegetative bulbils per plant and many rhizome buds
- Triploid biotype produces few seeds and relies on vegetative growth for spread

USDA

Diploid vs Triploid

Characteristic		Diploid	Triploid
Flowering and Seed Production		Flowers produce fertile seed	Flowers produce sterile seed
Bulbil Vegetative propagule formed In the inflorescence (Photo by Eckert)		Lots	Rarely, a few
Rhizome Bud Vegetative Propagule formed On rhizome		Lots	Many

Rhizome Buds

Management must be directed at population of rhizome buds:

- ✓Reducing number of rhizome buds
- ✓Preventing the production of new buds

✓Any technology (biological, chemical, mechanical, physical) must address vegetative reproduction

Figure 6A. The rhizome of flowering rush with two rhizome buds, indicated by the yellow arrows. Rhizome buds initiate new shoots and are the main form of vegetative propagation in flowering rush. Photo by J. Madsen, GRI.

Flowering Rush Phenology Objectives

- Identify significant life history stages or structures to target for management
- Identify low points or dynamics in starch storage to facilitate management

Flowering rush shoots sprouting from buds on the rhizome.

Overview of Projects

- Detroit Lakes phenology study with Concordia College
- Davis CA “Common Garden” experiment
    - Three triploid populations grown together in a common environment
- Field sampling for phenology
    - Three sites in Idaho and Montana

Flowering rush growing along a wave break in Pend Oreille Lake, Idaho

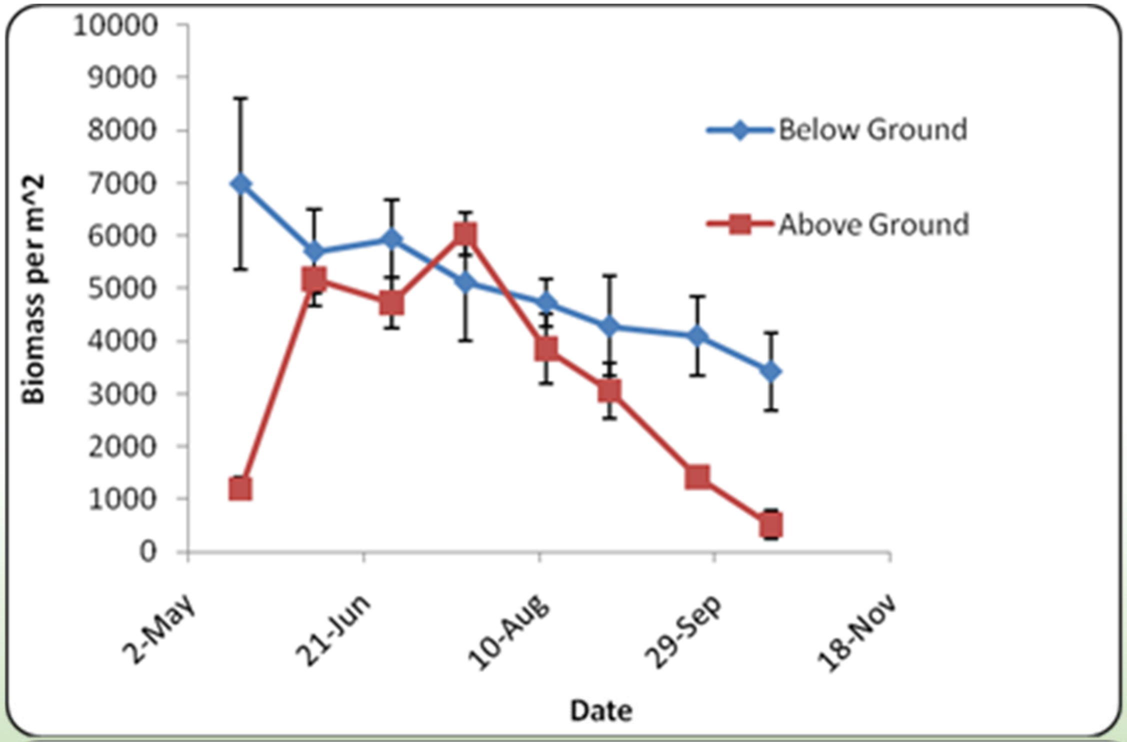
Detroit Lake Phenology Study

- Sampled three sites monthly, May to Nov.
- Twenty samples per site with a 6" core
- Counted rhizome buds, rhizome and shoot biomass
- Mississippi State and Concordia College worked together

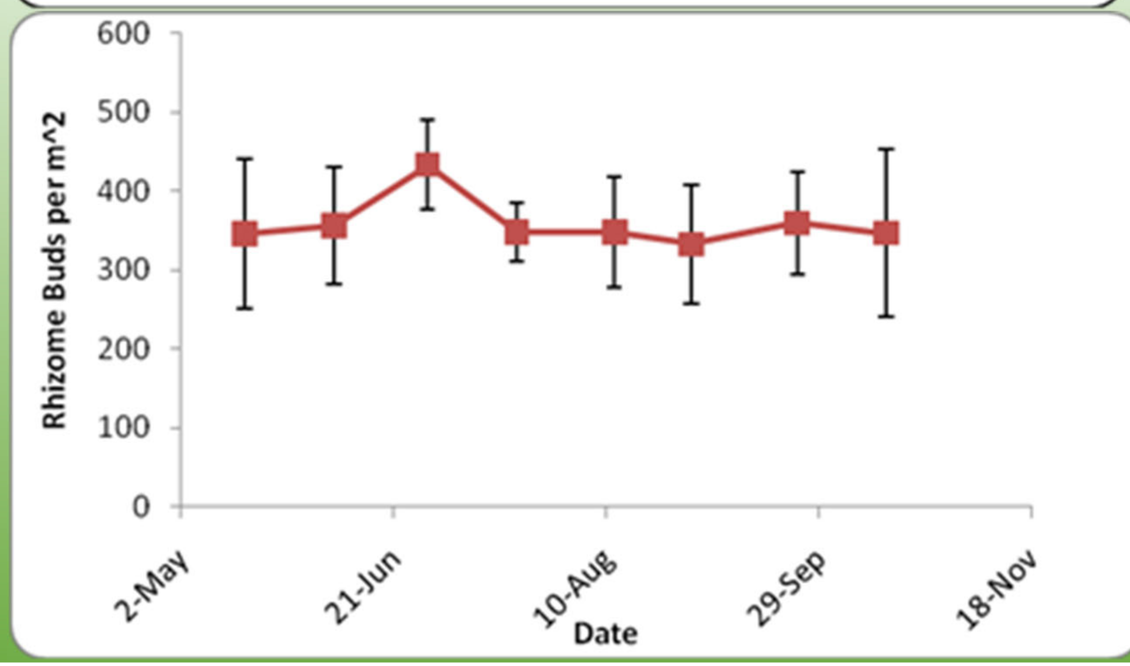
USDA

Phenology

Flowering rush is an herbaceous perennial that grows from May through and dies back in late summer



Flowering rush forms about 350 rhizome buds per square meter – almost 1.5M buds per acre!



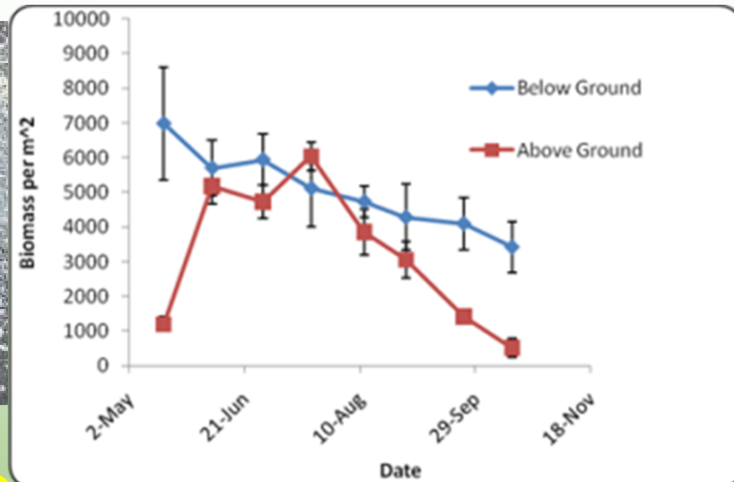
Graphs by Michelle Marko

Detroit Lakes, Minnesota

SUMMER

Leaves

FALL



SPRING

Rhizome Buds Increased

WINTER

Rhizome

USDA

Flowering Rush and Reservoir Operations in the Far West

October – April

May - September

Rhizome Buds

Management must be directed at population of rhizome buds:

- ✓Reducing number of rhizome buds
- ✓Preventing the production of new buds

✓Any technology (biological, chemical, mechanical, physical) must address rhizome buds

Figure 6A. The rhizome of flowering rush with two rhizome buds, indicated by the yellow arrows. Rhizome buds initiate new shoots and are the main form of vegetative propagation in flowering rush. Photo by J. Madsen, GRI.

USDA

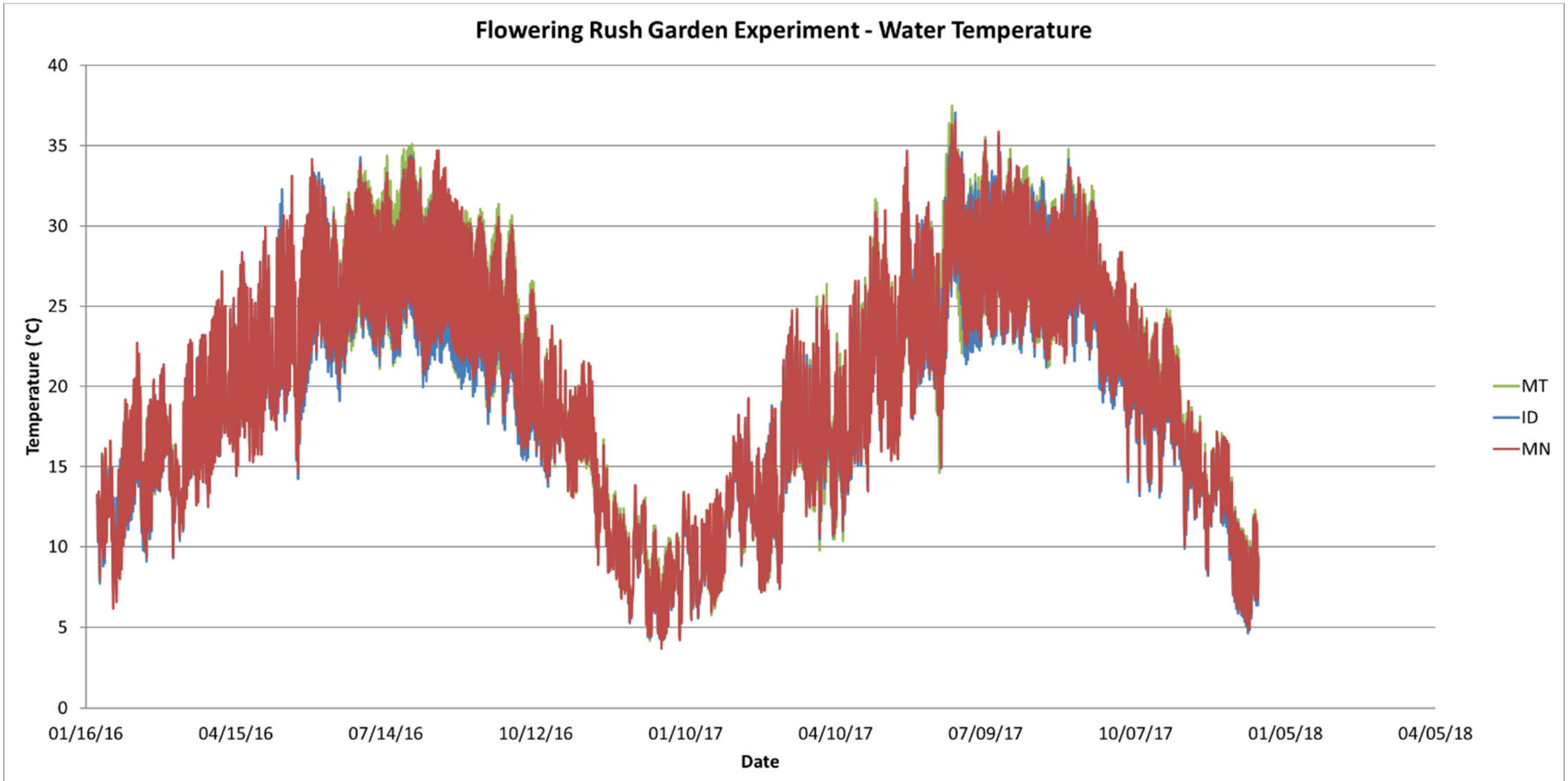
Common Garden Experiment – Davis, CA

- 48 pots of flowering rush planted in each of three vaults for three populations (Minnesota, Montana, and eastern Idaho)
- All are triploid populations
- Height measured weekly
- Two pots per vault harvested each month
- Temperature recorded continuously

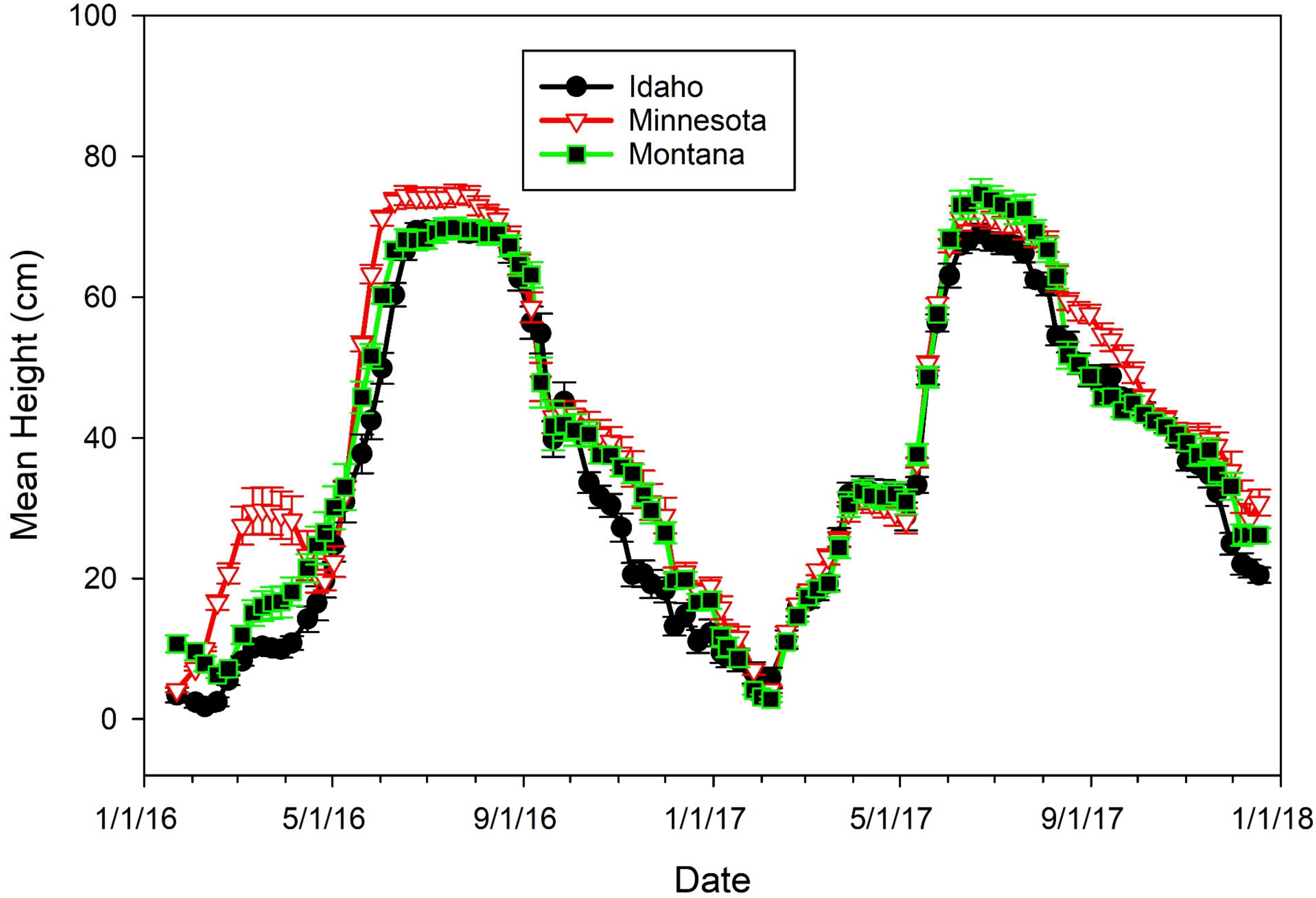
Kurt Getsinger collecting plants for use in the common garden experiment

USDA

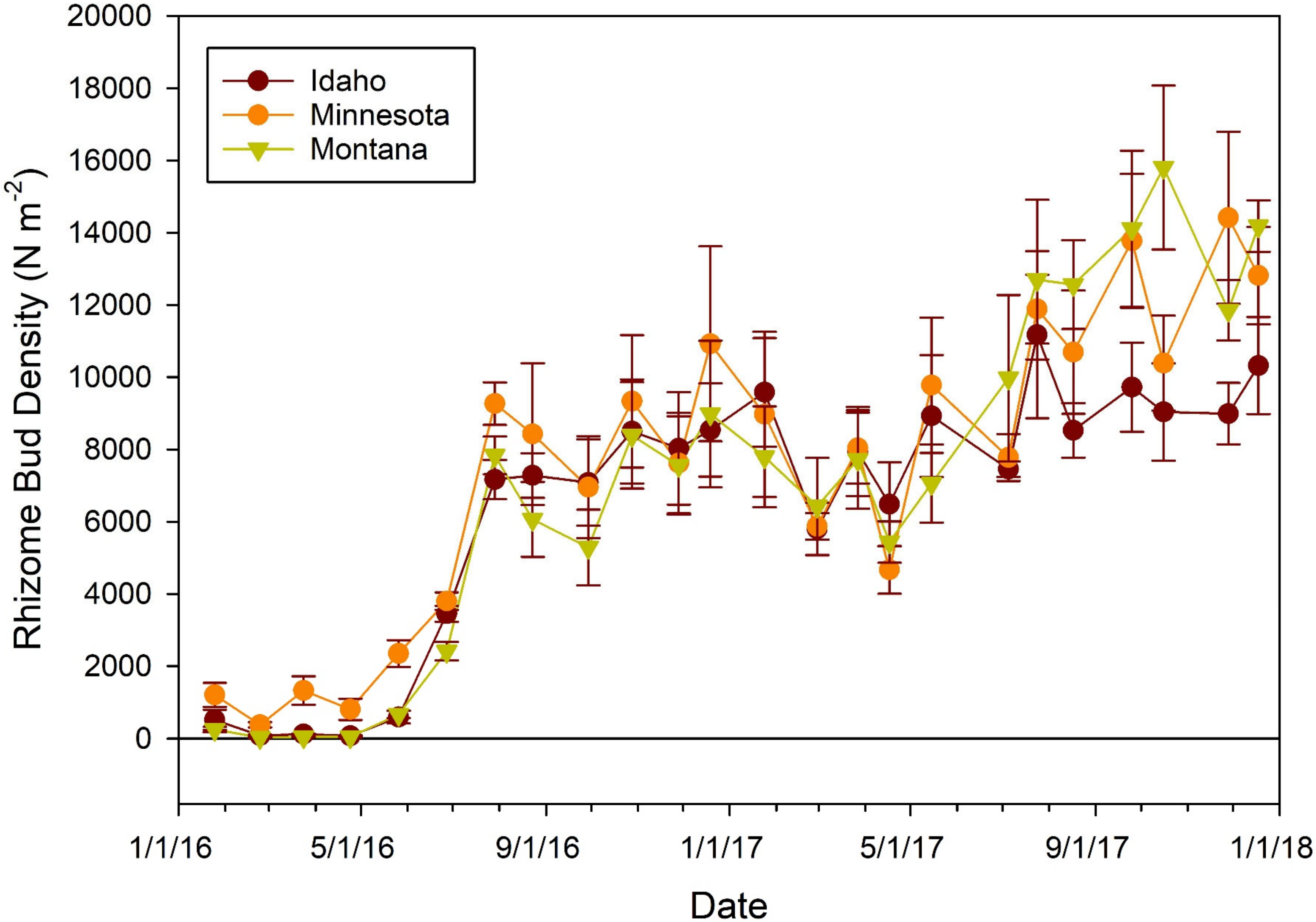
Vault Water Temperature



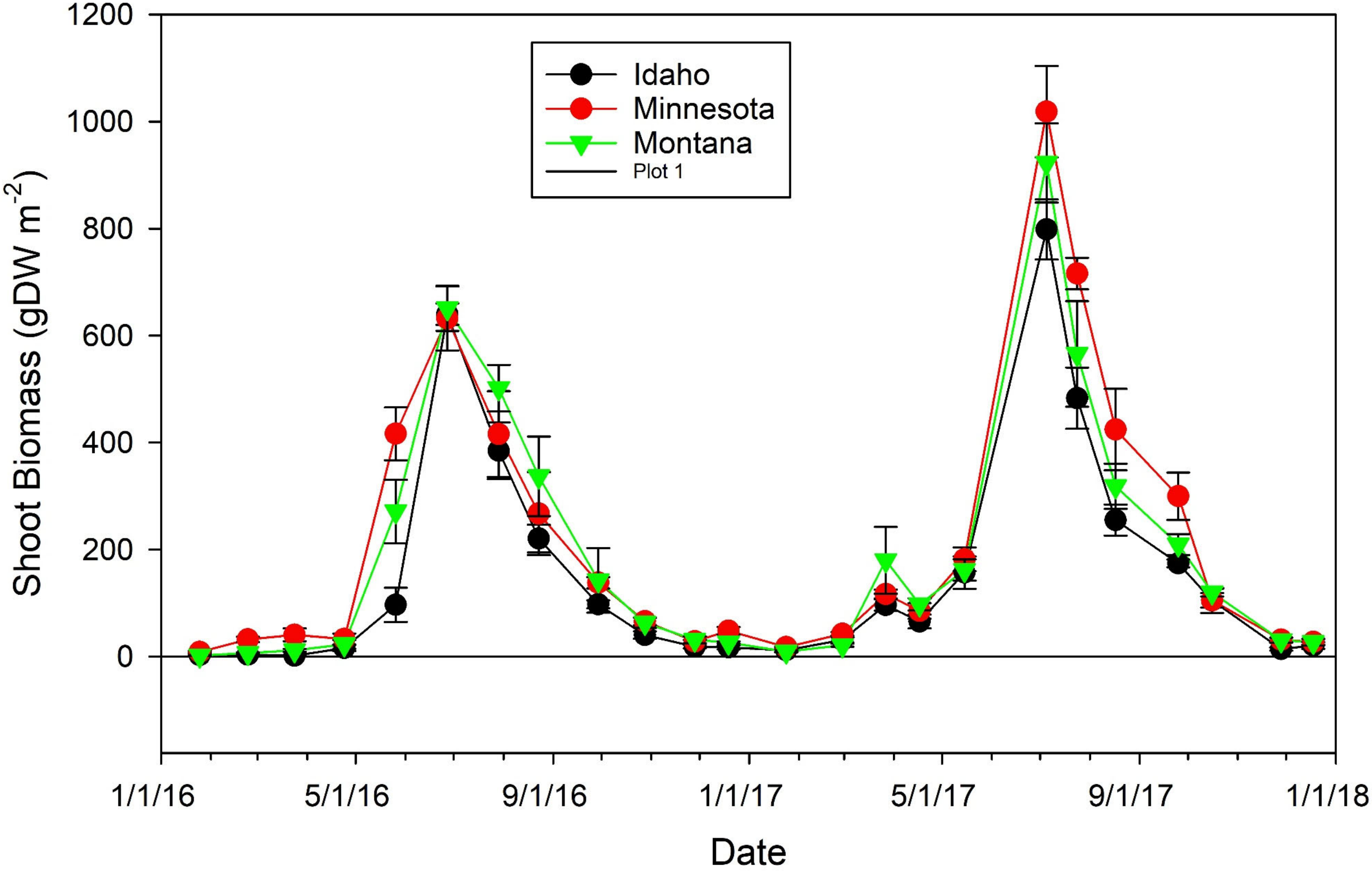
Weekly Shoot Height



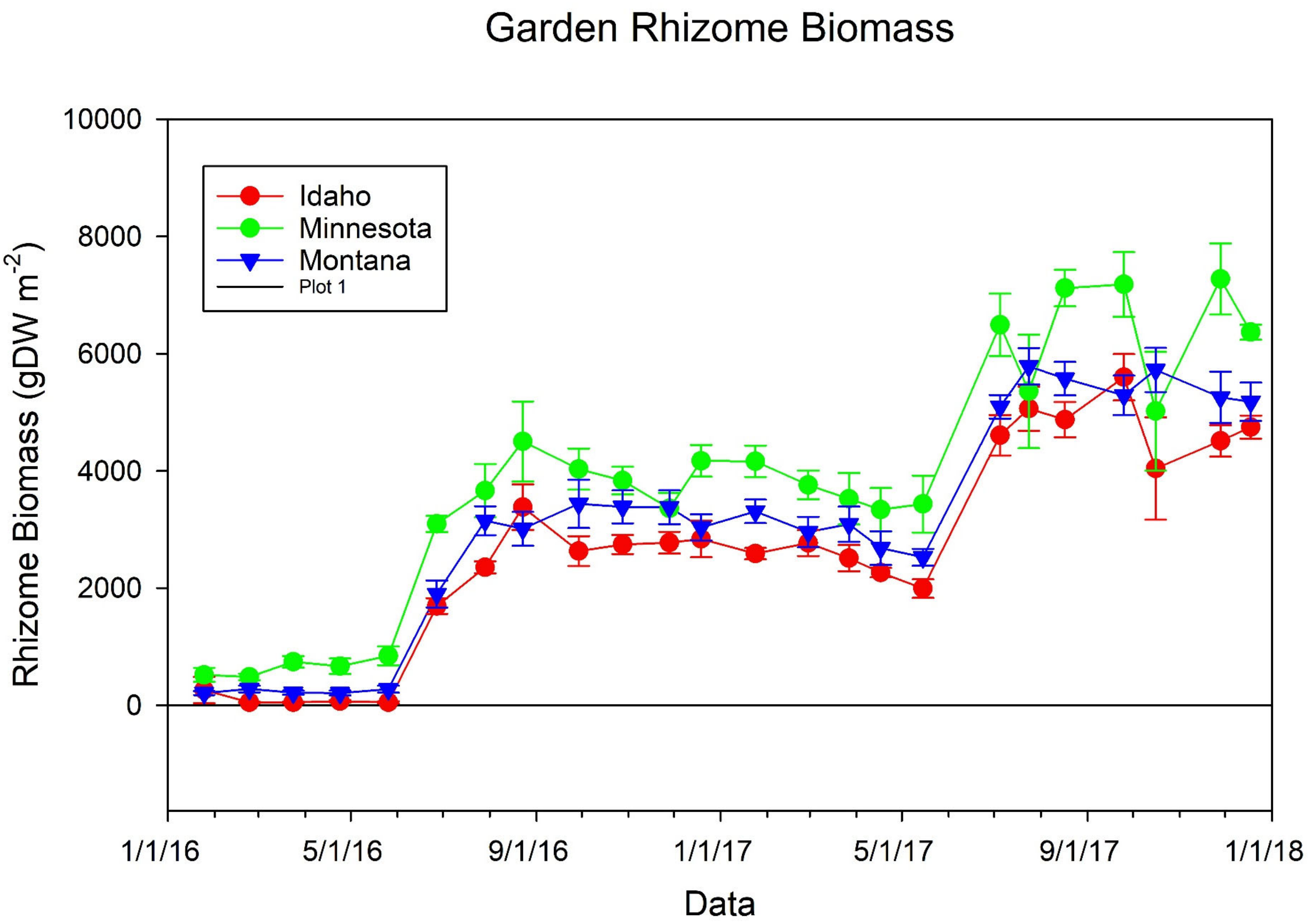
Garden Experiment Bud Density



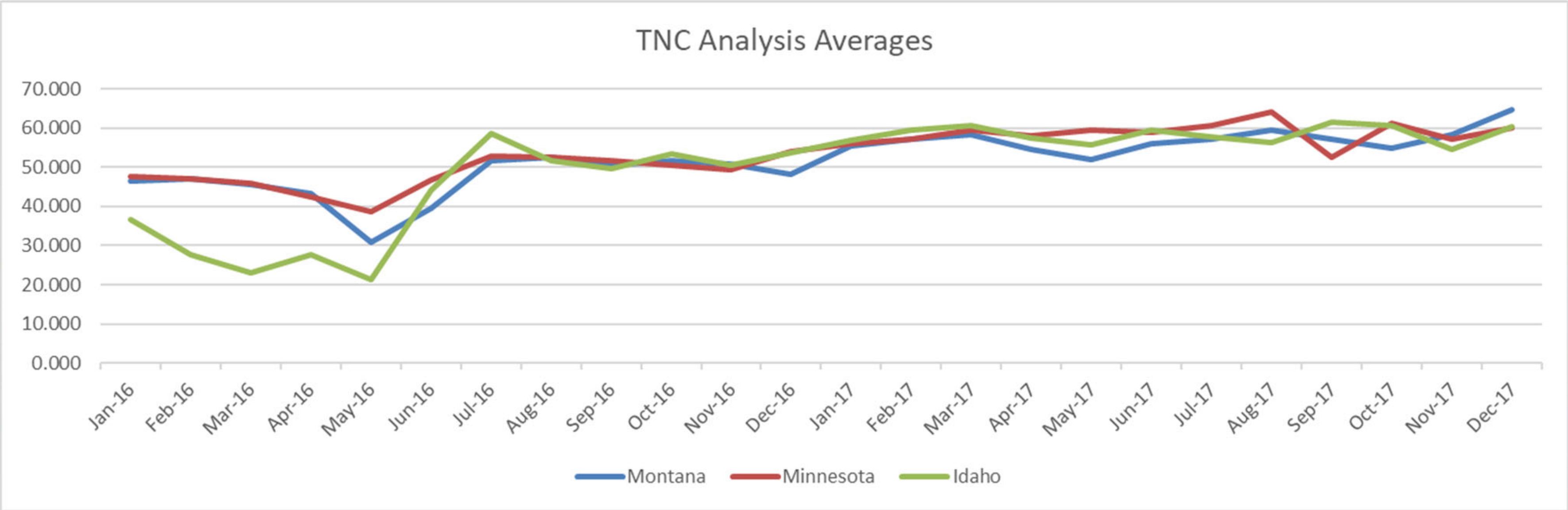
Garden – Shoot Biomass

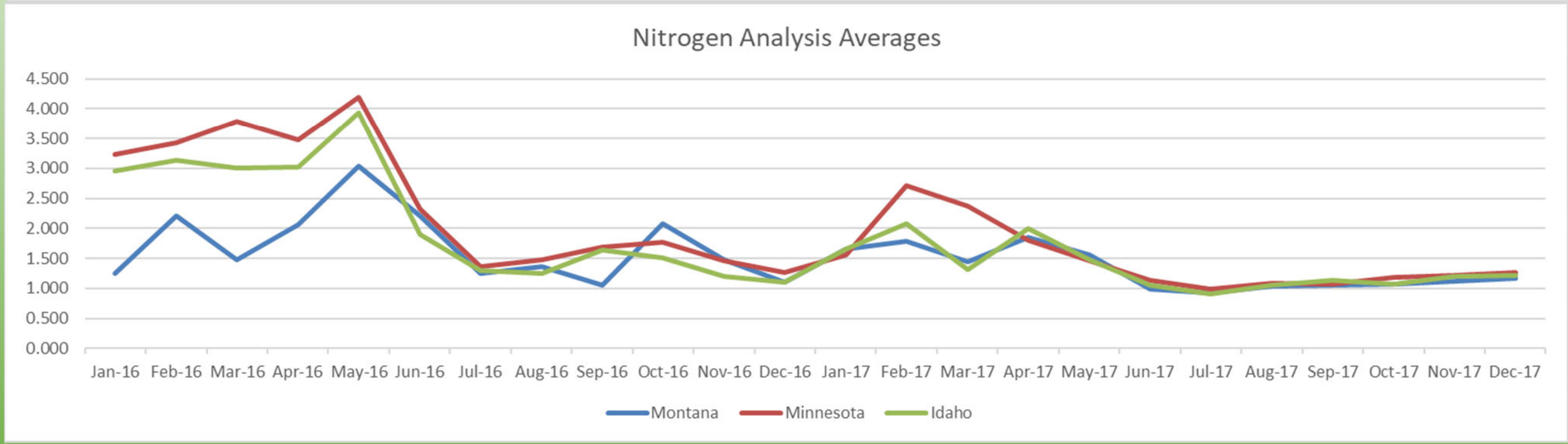


Rhizome Biomass



Rhizome TNC and Nitrogen



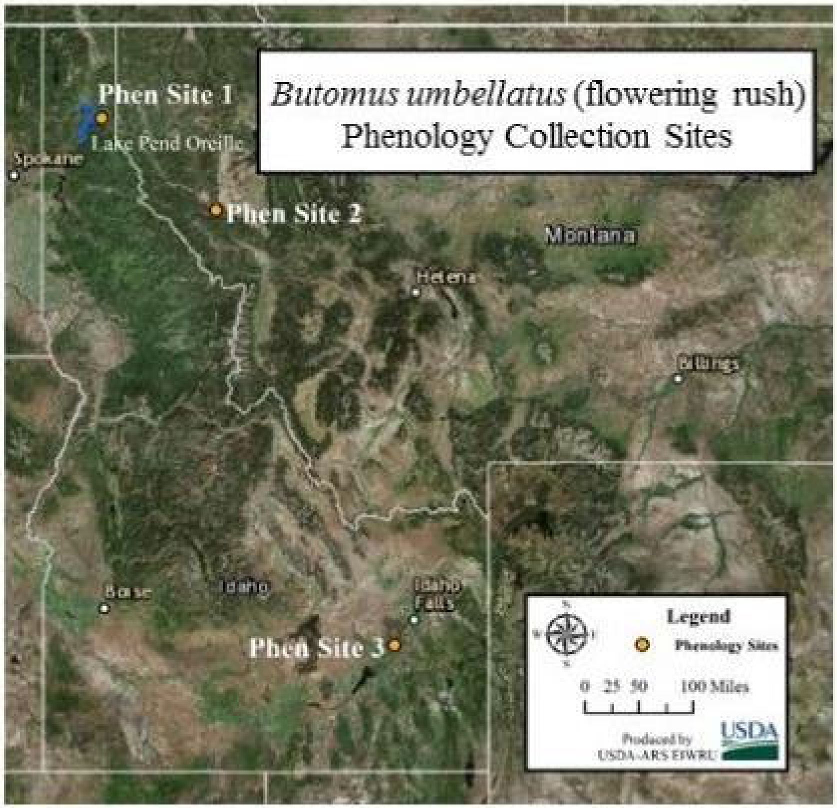


Common Garden Experiment Summary

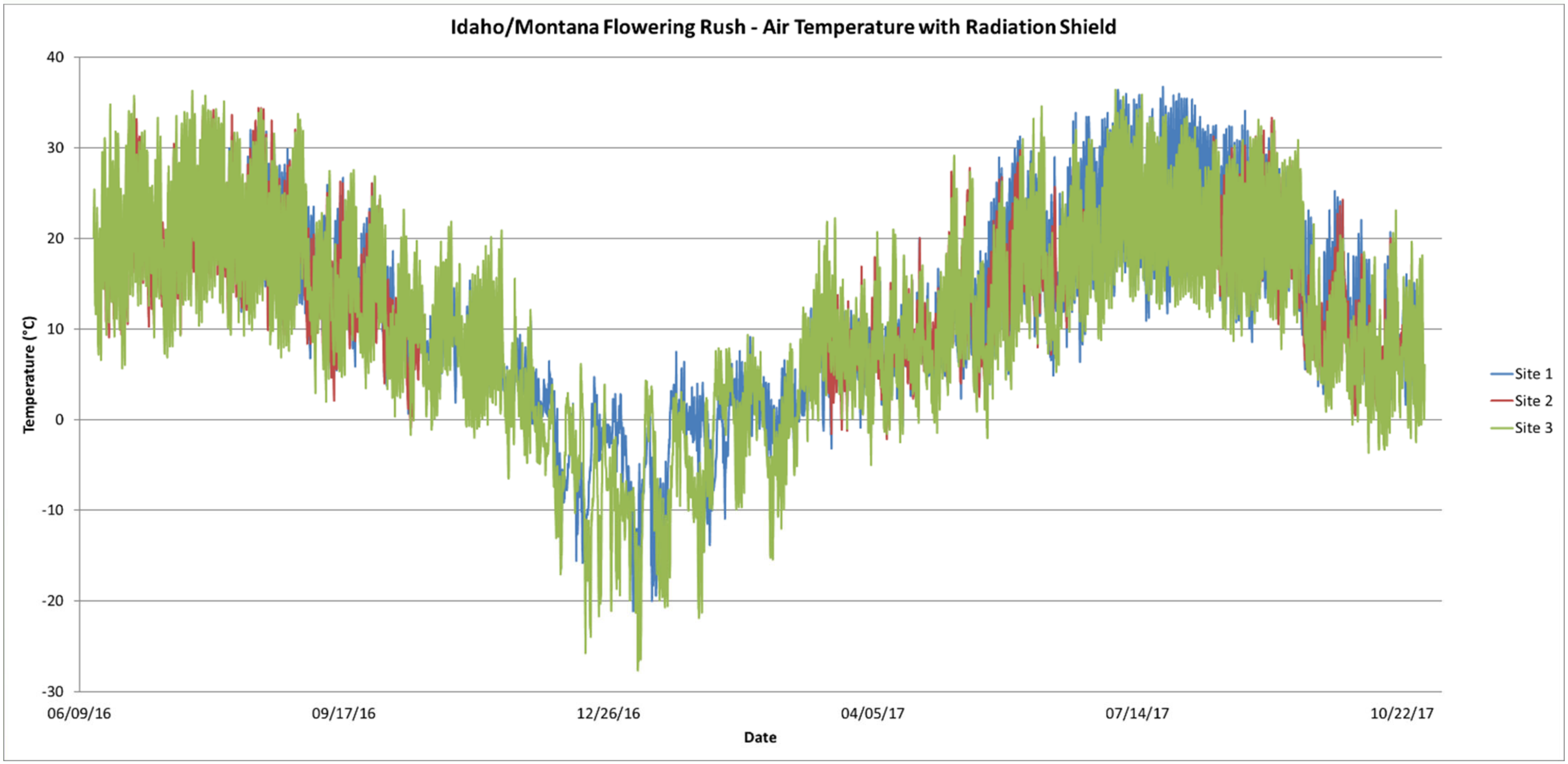
- Shoot elongation started when water temperature was 15C
- Shoot biomass had a brief peak at 600 (2016) to 1,000 (2017) gDW m^2
- Rhizome biomass increased from one year to next
- Performance of the three triploid populations was identical

Field Sampling – Idaho, Montana

- Samples collected in three sites
  - 1 – Pend Oreille Lake, ID
  - 2 – Kookoosint Boat Launch, Flathead River, MT
  - 3 – Rose Pond, Blackfoot, ID
- 20 biomass samples collected per time
- April, June, Aug, Oct 2016 and 2017



Air Temperature



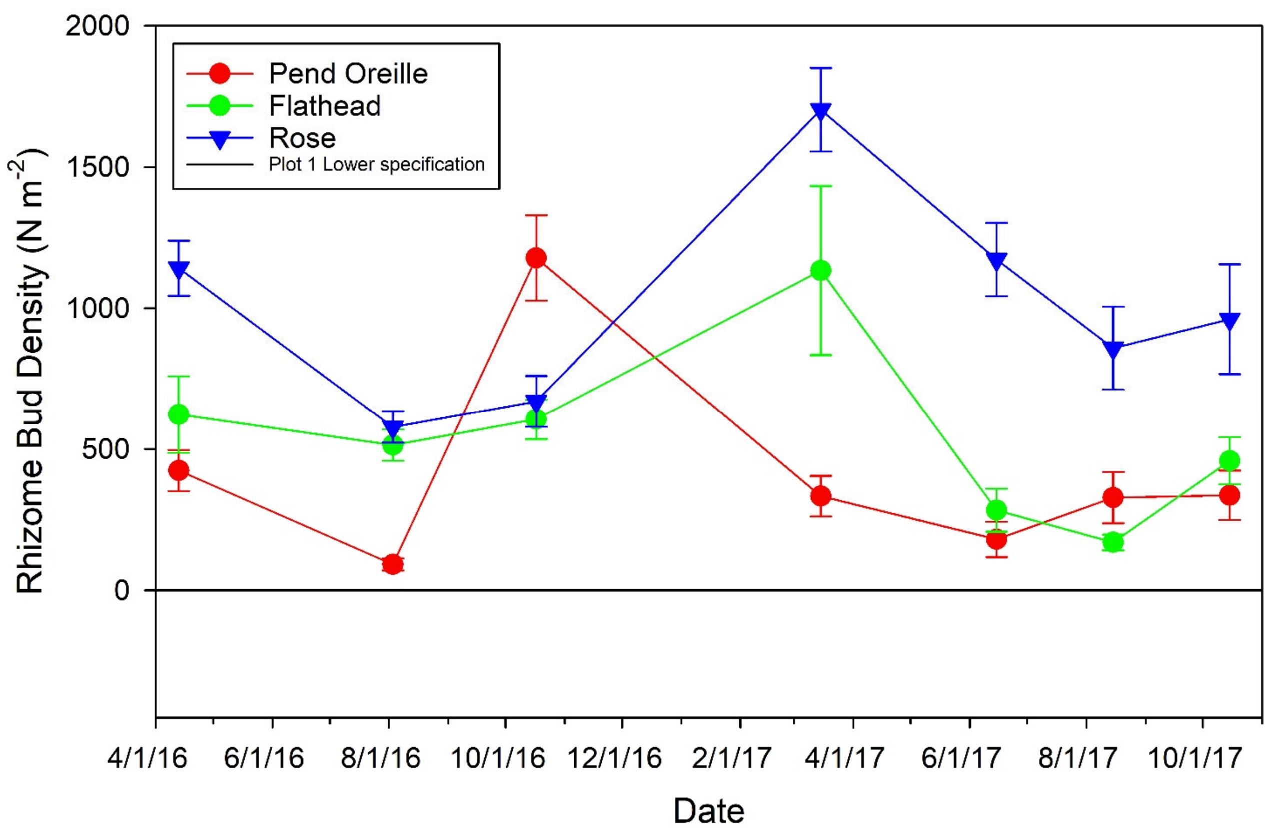
Field – Bud Density

Bud density ranges from 200 to 1,700 buds per square meter

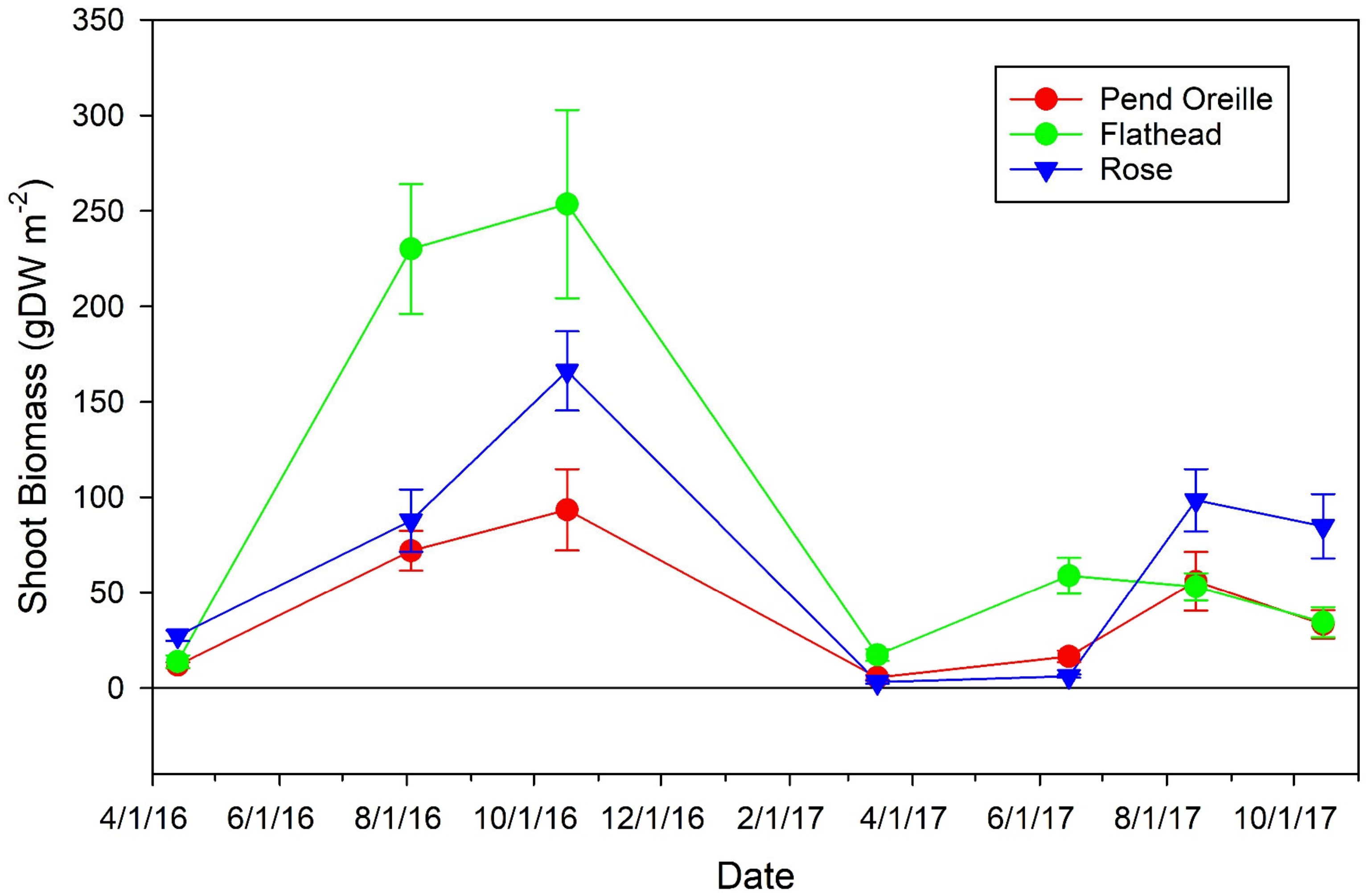
Translates to .5 to 5 million buds per acre

Buds "consumed" when shoots sprout, generated in August

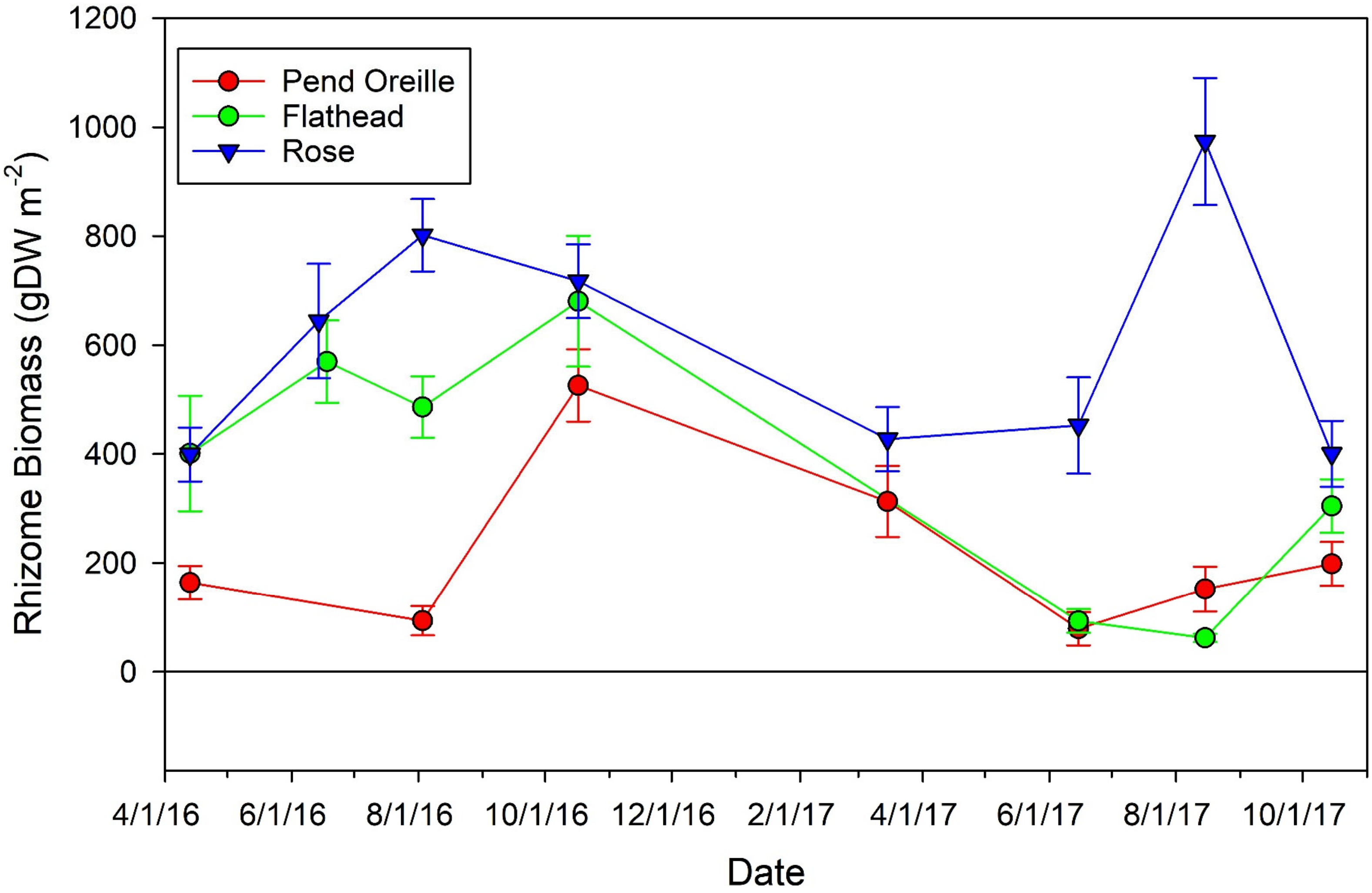
Management to prevent bud formation or destroy sprouting buds



Field – Shoot Biomass



Field – Rhizome Biomass



Phenology Summary

- Phenology studies the life history, seasonal growth, and carbohydrate storage patterns of target aquatic weeds
- The important life stage of flowering rush is the rhizome bud
- Management should exploit either preventing bud formation, depleting existing rhizome buds, or both

Acknowledgements

- Support from USDA ARS Aquatic Weed CRIS and USAERDC Chemical Control of Flowering Rush work unit
- Detroit Lake work funded by Pelican River Watershed District, and working with Dr. Michelle Marko of Concordia College
- Assistance from Christy Morgan and John Miskella, USDA ARS Biological Technicians
- Chase Youngdahl and Brad Bluemer (Retired), Bonner County Weed Dept
- Thomas Woolf, formerly of ISDA
- Dan Eldredge, Bingham Co Weed Dept
- Jeff Pettingill, Bonneville Co Weed Dept


Chase Youngdahl, Tom Woolf, John Madsen, Brad Bluemer at Clarks Fork Delta


Jeff Pettingill and Dan Eldredge

Contact Information

Dr. John D. Madsen

USDA ARS ISPHRU

UC-Davis, Plant Sciences,

Mail Stop 4

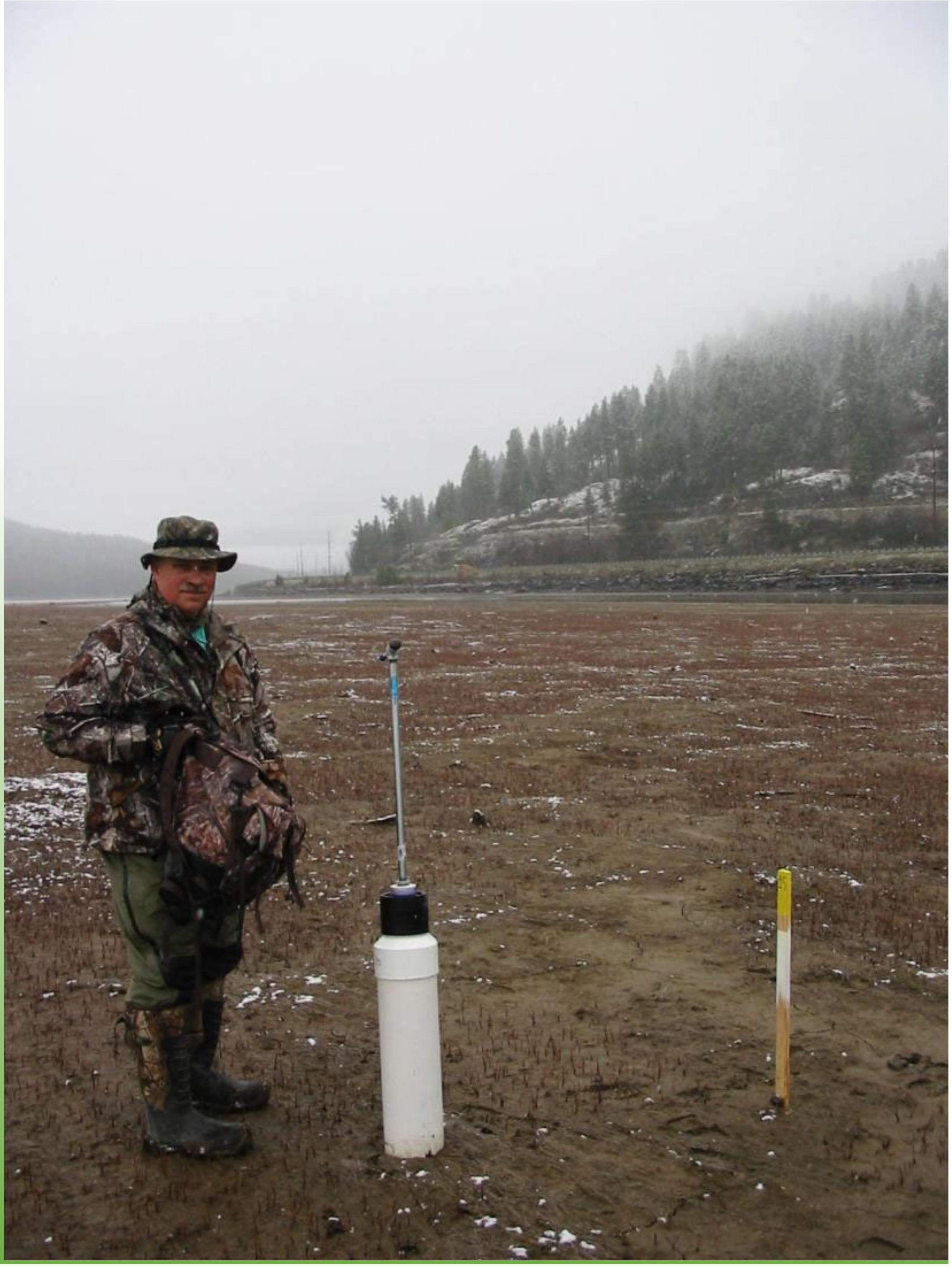
274 Robbins Hall

Davis, CA 95616

jmadsen@ucdavis.edu

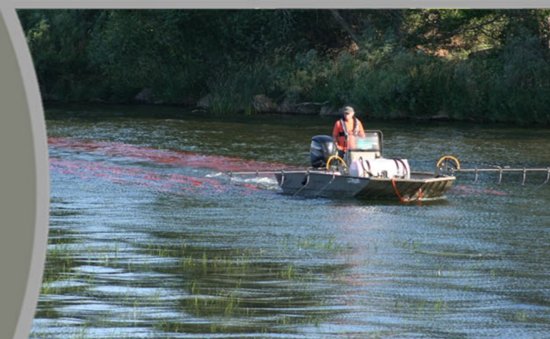
john.madsen@usda.gov

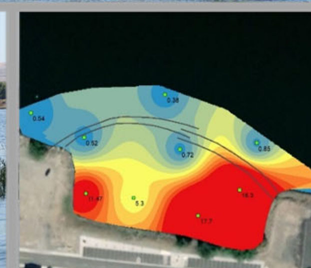
Ph. 530-752-7870



Management of Flowering Rush in Hydrodynamic Systems: Water Exchange Processes and Herbicide Contact Time





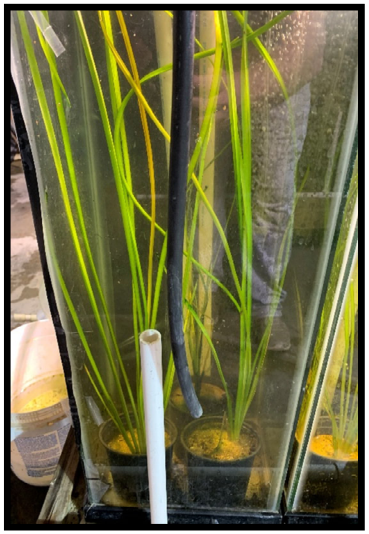


Bradley T. Sartain PhD
US Army Engineer Research & Development Center
Environmental Laboratory
Vicksburg, MS

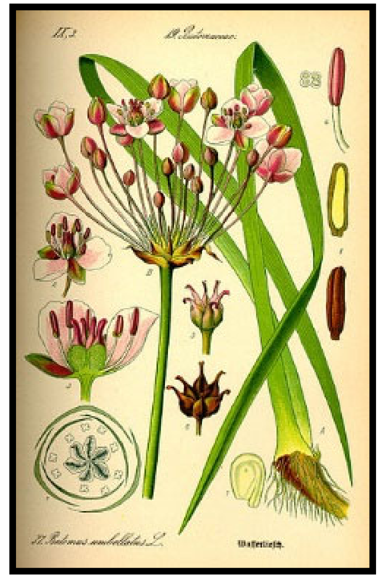
ERDC
Engineer Research and Development Center
Innovative solutions for a safer, better world
US Army Corps of Engineers®
U.S.ARMY®

Outline:

1. Introduction
   - Problem
   - Site Description
2. Water Exchange Evaluations 2018
   - Materials and Methods
   - Results
3. Small Scale Herbicide Trial
4. Herbicide Treatment 2019-2020
   - Water Exchange
   - Herbicide efficacy
5. Conclusions
6. Ongoing and Future Research

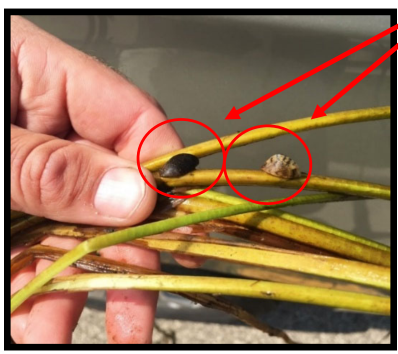


Problem: Flowering rush continuing to expand across the northern U.S. and Southern Canada



Negative impacts to

- Native plant communities
- Fish & wildlife habitat
- Water use
- Promote establishment/spread of other invasive species

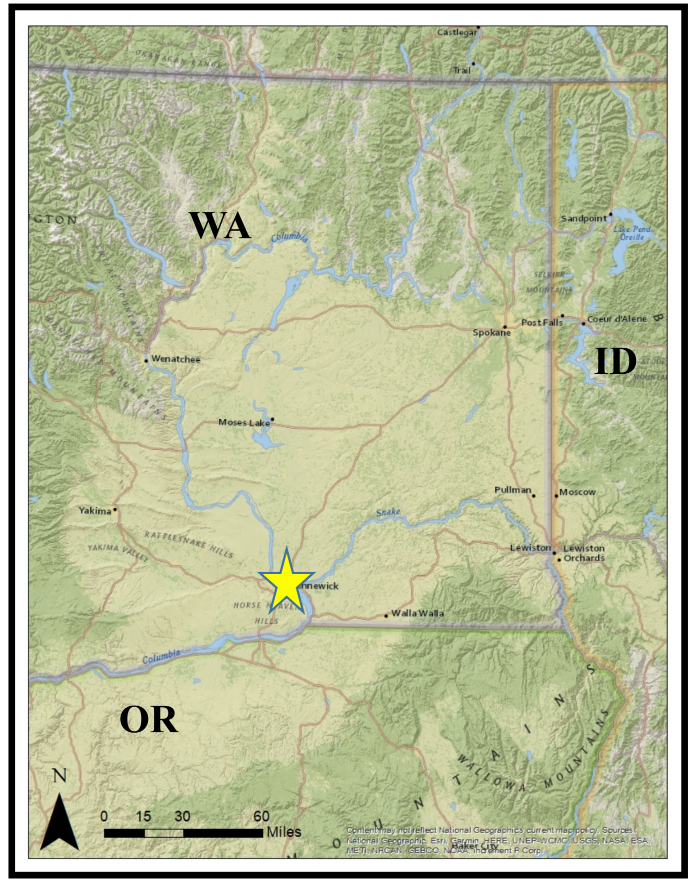


Increase substrate availability for invasive mussels

Increase invasive fish habitat

Study Site: Columbia River, Kennewick, WA

- McNary Pool / Lake Wallula
- Priest Rapids Dam (upstream)
- McNary Dam (downstream)
- Drainage area: 214,000 sq mi
- Flowering rush first documented in 2008



Water Exchange Evaluations: 2018

Unrestricted Flow

- High, moderate, low flow sites
- No barriers/curtains

Bubble Tubing

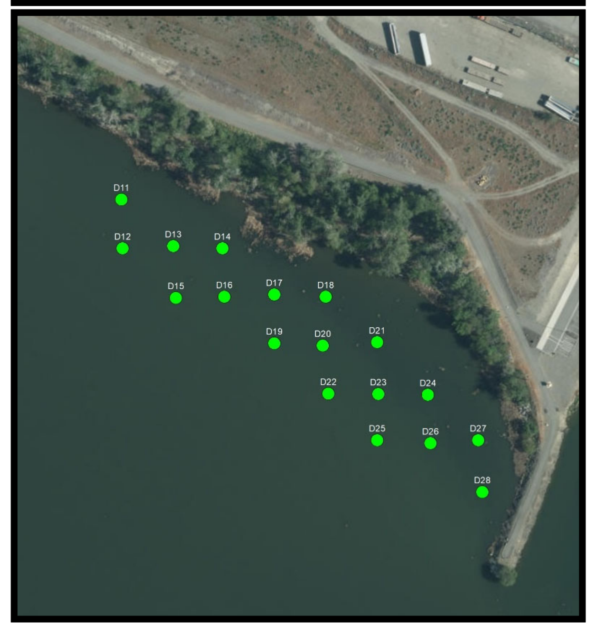
- First evaluation of Bubble Tubing®
- Clover Island "The Notch"
- Multiple configurations

Port of Pasco/Osprey Point

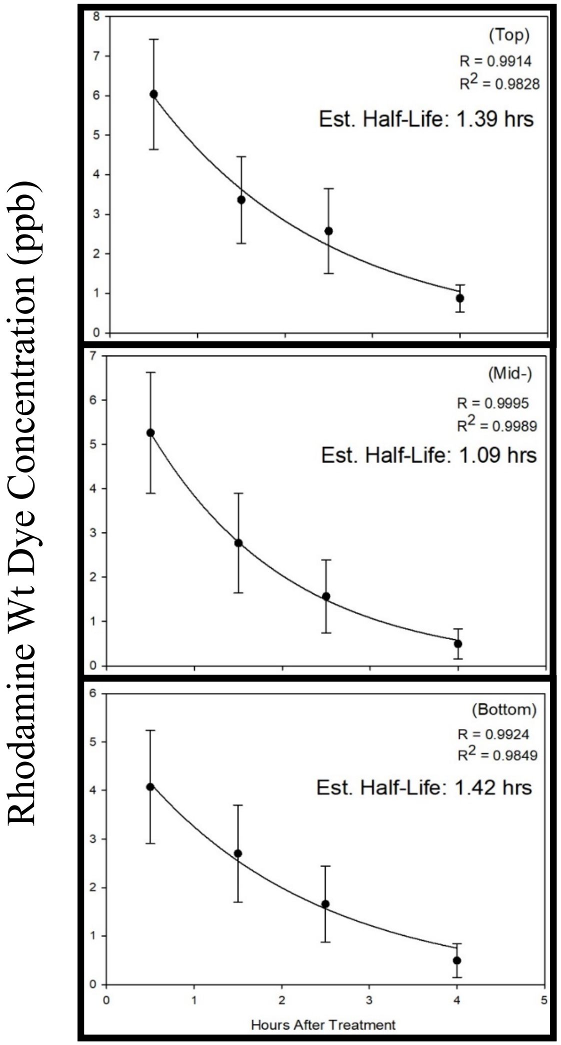
- Largest site evaluated ~7.5 acres
- Extends along the shoreline parallel to the main river channel
- Average depth 5.6’
- Rip rap shoreline and small peninsula on the downstream end
- Flowering rush occurrence >80%

Materials and Methods

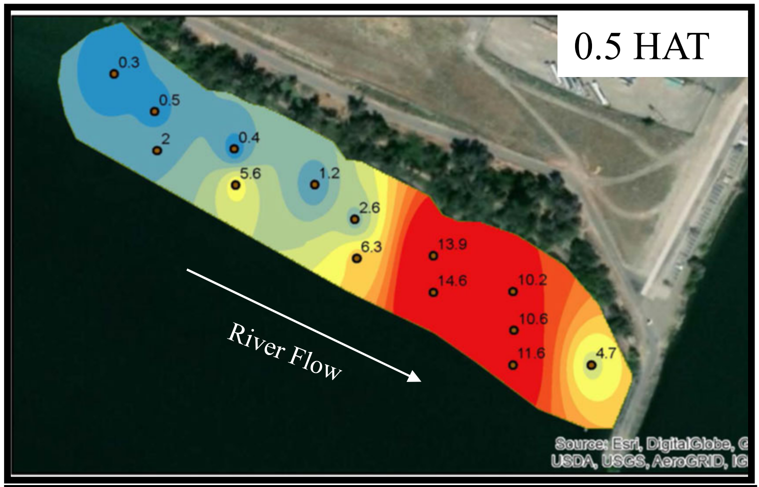
- Rhodamine WT dye
- Target concentration 10 µg/L
- Dye measurements at pre-determined points and time intervals
- Dye applied August 25, 2018
- McNary Dam discharge during treatment and sampling 184-185 kcfs

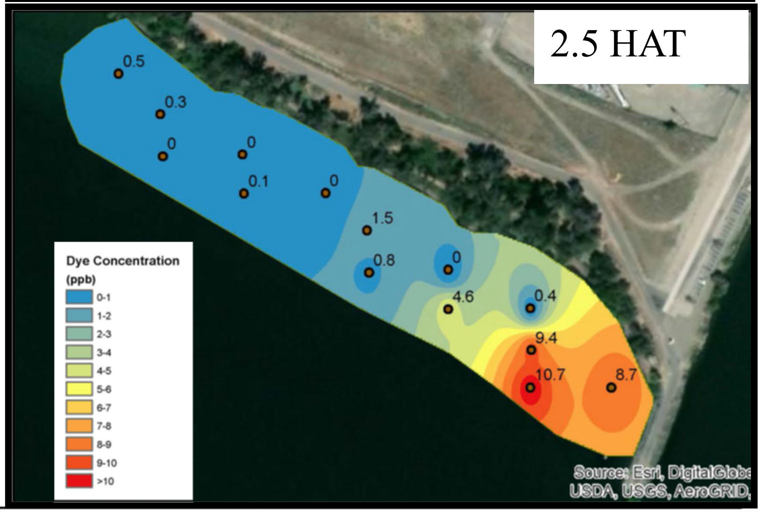


Water Exchange Results



Whole Plot RWT
Half-life: 1 hr 20 min





Small Scale Herbicide Trials

Treatments

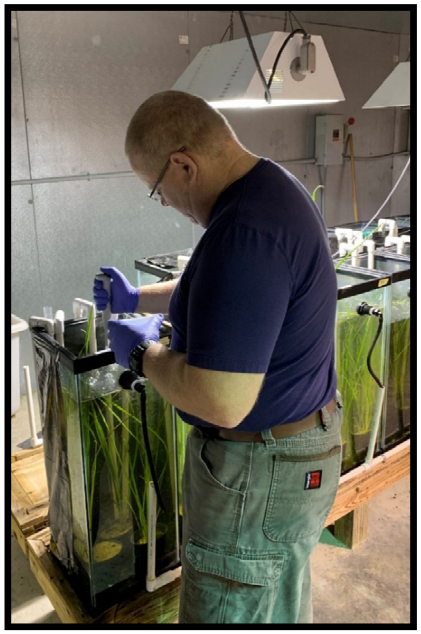
- Non-treated control
- Diquat (0.37 ppm)
- Endothall (5 ppm)
- Diquat + Endothall (0.36 ppm + 1.8 ppm)

Exposure Times

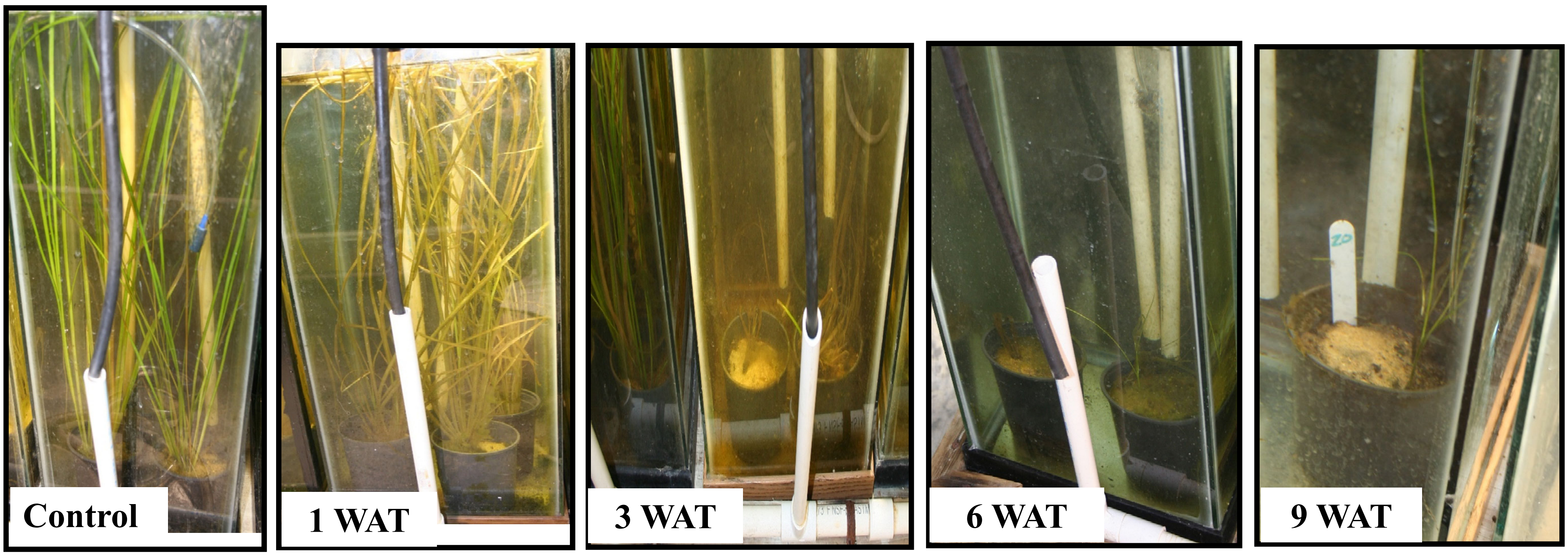
- 3 hour
- 6 hour
- 12 hour

Harvest

- 4 WAT
- 8 WAT
- 12 WAT



- All treatments resulted in loss of shoot vigor 2 DAT
- Visual ratings ≥ 70% control of shoot biomass 3 WAT
- No notable differences observed between treatments or exposures



Small Scale Herbicide Trial Results

	Dry weight biomass g per m^2 (Percent Biomass Reduction Compared to the Reference)					
	4 WAT		8 WAT		12 WAT	
	Rhizome	Shoot	Rhizome	Shoot	Rhizome	Shoot
Reference[a]	165.8 ± 39.6	78.6 ± 21.8	283.8 ± 85.0	58.9 ± 24.3	231.5 ± 102.3	42.4 ± 16.1
Main Effect Factor						
Herbicide[b]						
Diquat	59.9 ± 8.5 ns (64 ± 5%)	3.4 ± 0.8 ns (96 ± 1%)	50.0 ± 9.5 ns (82 ± 4%)	2.2 ± 0.5 ns (96 ± 1%)	34.1 ± 9.2 ns (85 ± 4%)	1.5 ± 0.6 a (96 ± 2%)
Endothall	58.6 ± 10.3 ns (65 ± 6%)	6.0 ± 1.9 ns (92 ± 3%)	53.6 ± 10.8 ns (81 ± 4%)	8.5 ± 3.3 ns (85 ± 6%)	42.5 ± 9.8 ns (82 ± 4%)	8.8 ± 3.2 b (79 ± 8%)
Diquat + Endothall	57.3 ± 12.1 ns (65 ± 7%)	2.3 ± 0.8 ns (97 ± 1%)	47.0 ± 10.2 ns (83 ± 4%)	3.1 ± 1.4 ns (95 ± 2%)	30.7 ± 7.9 ns (87 ± 3%)	1.5 ± 0.5 a (97 ± 1%)
Exposure Time						
Three Hours	56.7 ± 10.6 ns (66 ± 6%)	3.9 ± 1.2 ns (95 ± 2%)	54.7 ± 9.6 ns (81 ± 6%)	3.9 ± 1.3 ns (93 ± 2%)	48.3 ± 11.6 ns (79 ± 5%)	5.7 ± 2.4 ns (87 ± 6%)
Six Hours	65.8 ± 10.6 ns (60 ± 6%)	5.3 ± 1.8 ns (93 ± 2%)	37.9 ± 8.2 ns (87 ± 3%)	1.5 ± 0.7 ns (97 ± 1%)	33.0 ± 6.6 ns (86 ± 3%)	2.6 ± 1.2 ns (94 ± 3%)
Twelve Hours	53.3 ± 9.7 ns (68 ± 6%)	2.6 ± 0.8 ns (97 ± 1%)	58.0 ± 11.9 ns (80 ± 4%)	8.5 ± 3.3 ns (85 ± 6%)	26.0 ± 7.4 ns (89 ± 3%)	3.5 ± 2.4 ns (92 ± 6%)

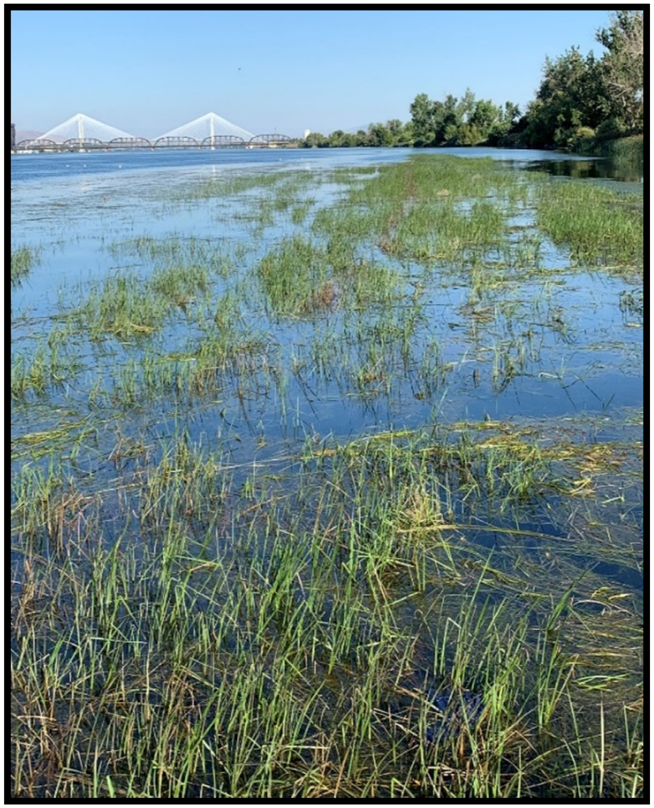
[a] Reference data were not included in the statistical analysis.
[b] Data for each main effect factor are pooled over all levels of the other factor. Means within a column for each main effect factor followed by the same letter are not significantly different based on LSMEANS mean separation test (α=0.01); n = 21.

- No Herbicide x Exposure Interaction or exposure time effect (α=0.01)
- Shoot biomass 12 WAT significant herbicide effect
- Diquat or products containing diquat provided significantly better control of flowering rush shoots 12 WAT

Water Exchange & Herbicide Evaluation 2019

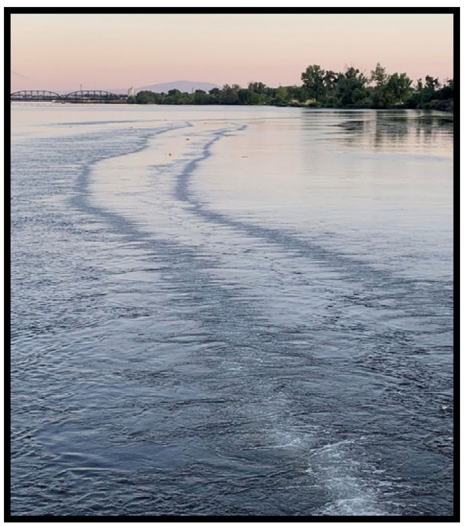
Port of Pasco/Osprey Point

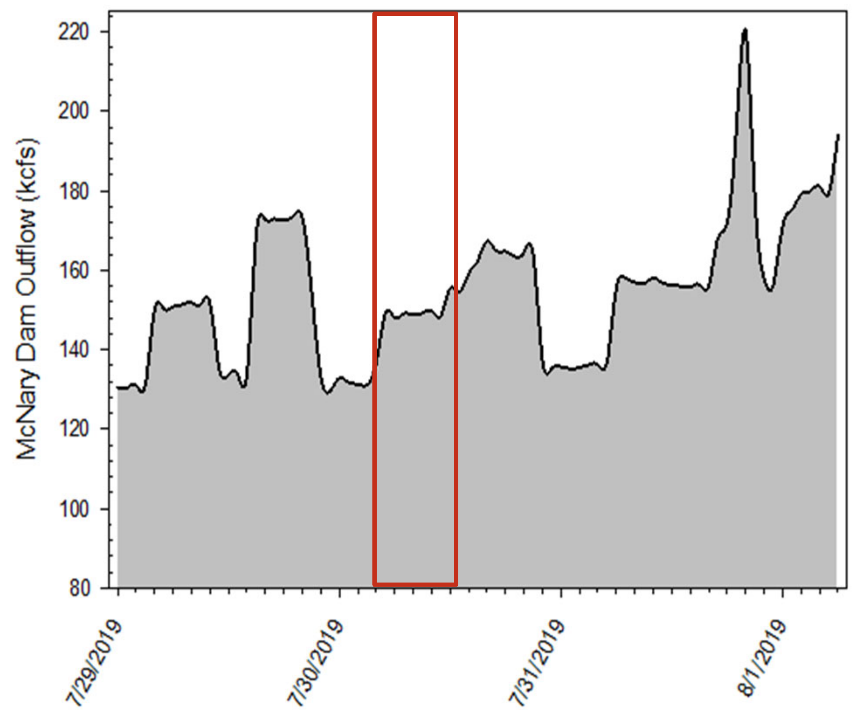
- Water exchange data from 2018
- Ease of access for Bubble Tubing deployment
- Large stand of flowering rush
- Site reduced from original 7.5 acres to 4.5 acres



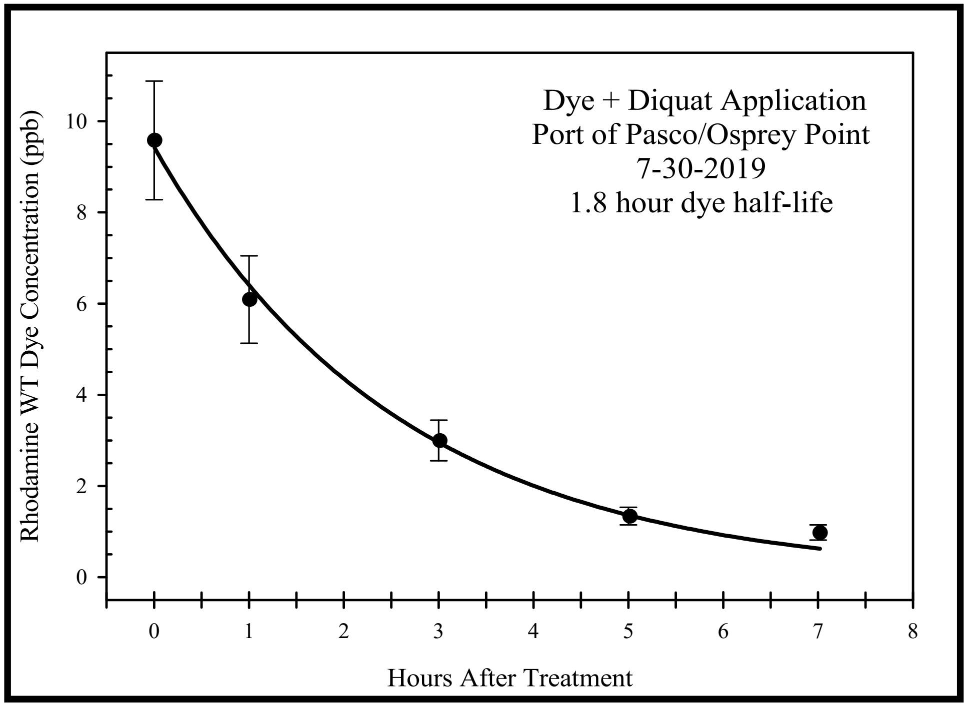
Herbicide + Dye Treatment 2019

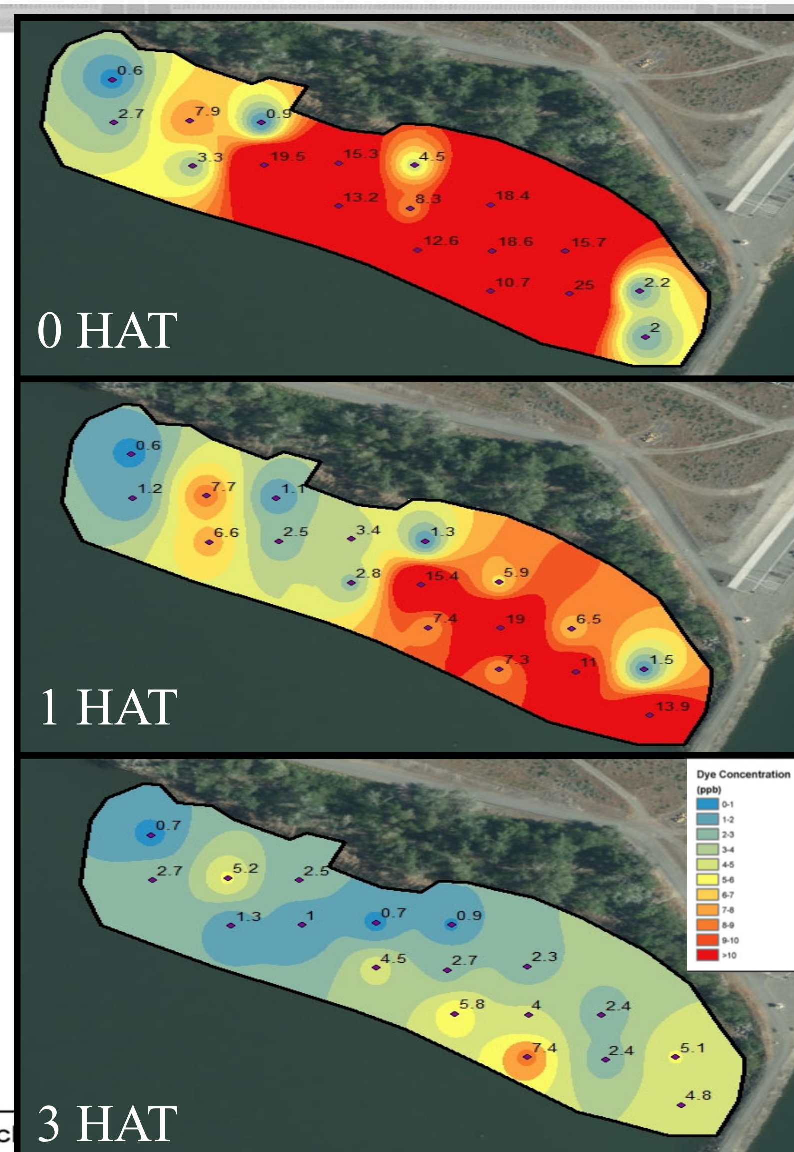
- Diquat + RWT dye applied 30 July, 2019 at 0400 hrs
- Double Bubble Tubing around the treatment plot
- McNary Dam discharge averaged 149 kcfs





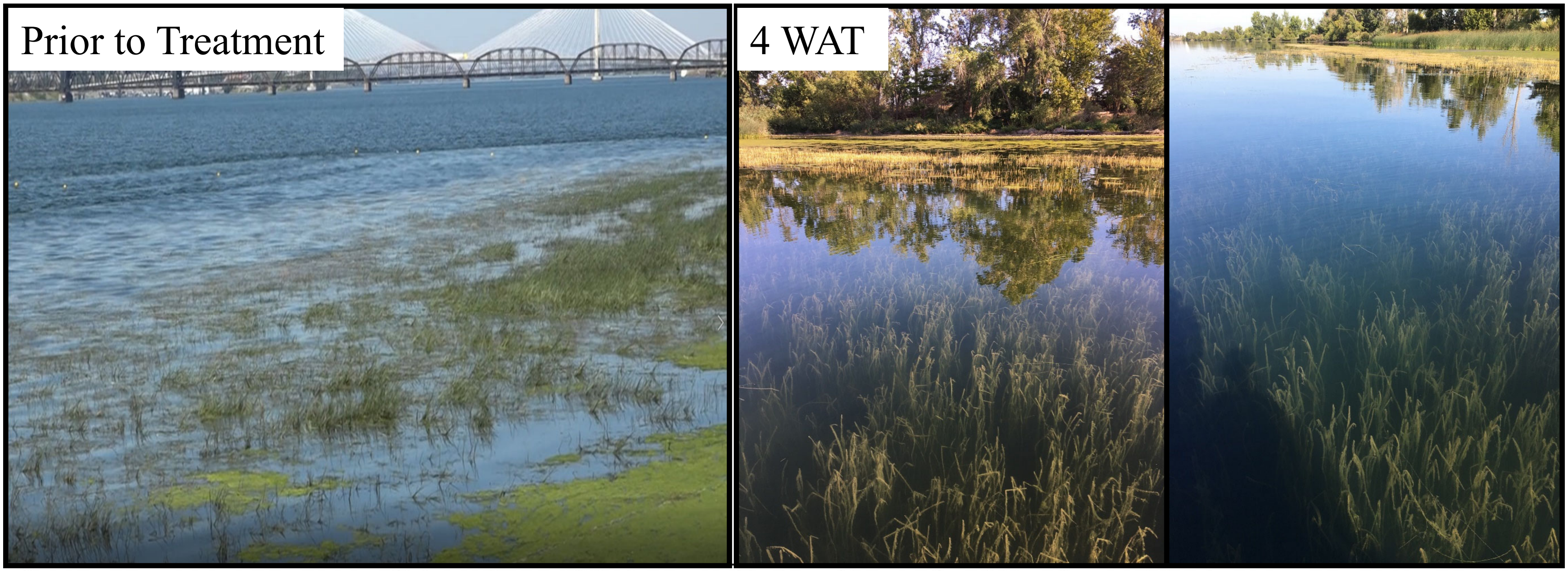
Water Exchange 2019





Herbicide Efficacy –Results

- Flowering rush injury visible by 2 DAT
- Survey conducted at 4, 8, 10, & 52 WAT



Herbicide Efficacy 52 Weeks After Treatment

- Minimal emergent plants present
- Flowering Rush % occurrence ~90%


Prior to Treatment 2019

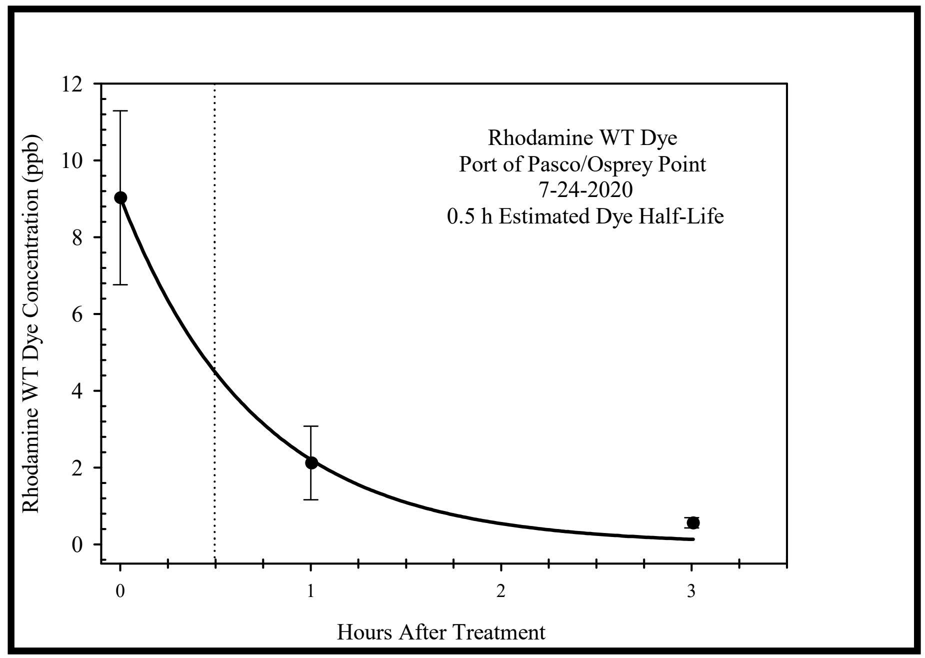

Prior to Treatment 2020

Water Exchange/Herbicide Evaluations 2020

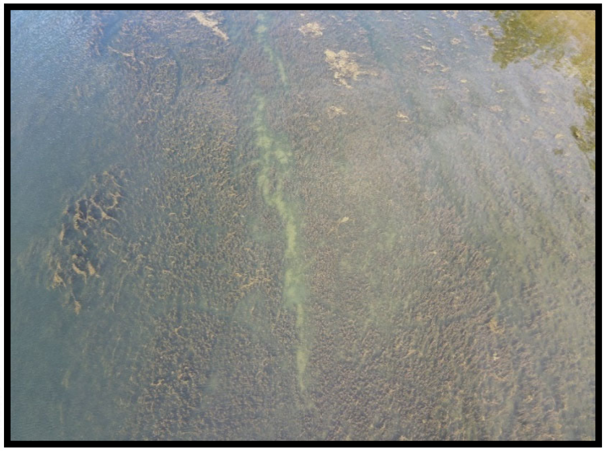
- Follow up Diquat + RWT dye treatment
- Applied: 24 July 2020, 0630 hours
- McNary Dam discharge 185 kcfs
- No bubble curtain included

Water Exchange Results

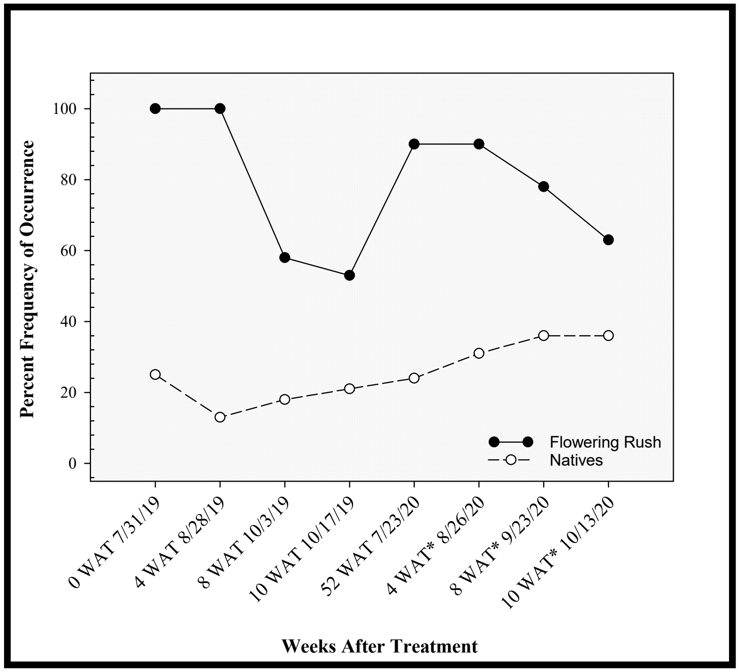
- Estimate dye half-life: ~30 min
- McNary Dam discharge 35,000-40,000 cfs greater than 2019
- No bubble curtain
- Lack of emergent flowering rush biomass



4 Weeks After 2nd Treatment



Change in percent frequency of occurrence over time



- Flowering rush frequency of occurrence decreased following 2019 and 2020 treatments
- Native plant frequency occurrence (*C. demersum, H. dubia, E. canadensis, Potamogeton spp.*) slightly increased

Conclusions of 2019-2020 Field Work

- 2019 diquat treatment effective at controlling emergent/submersed flowering rush shoots
- 52 WAT flowering rush occurrence was 90%, however minimal to no emergent plants were present
- Follow up treatment applied in 2020
- Water exchange more rapid in 2020 (30 min) vs. 2019 (1 h 45min)
- 2020 treatment resulted in significant injury of flowering rush shoots and decrease in frequency of occurrence 8 WAT

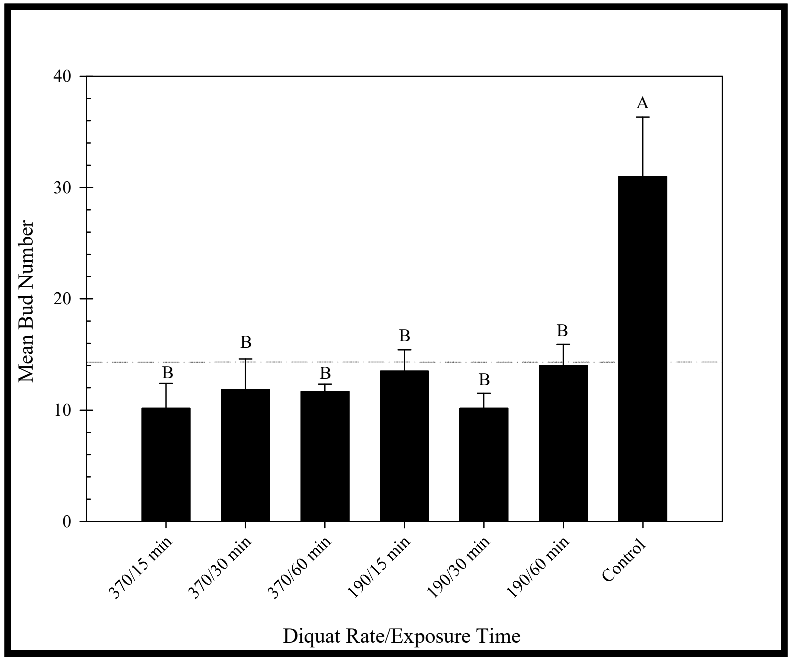
What is the minimum exposure time needed for diquat to effectively control flowering rush?

Ongoing Research: Preliminary Results

Control 14 DAT

Diquat: 190 ppb/15 minute exposure
14 DAT

Mean Number of Buds
4 Weeks After Treatment



Future Research

- Linkage of reservoir operations with water exchange evaluations
  - Low dam generation periods (early morning/night)
  - With and without bubble tubing

- Herbicide efficacy field verification studies
  - 2 year post treatment vegetation assessment
  - Expand to multiple flowering rush locations in McNary Reservoir
  - Additional Pre / Post treatment vegetation assessments

Additional information on the Bubble Curtain Evaluations

https://www.youtube.com/watch?v=fDWChNwJMIM&t=48s

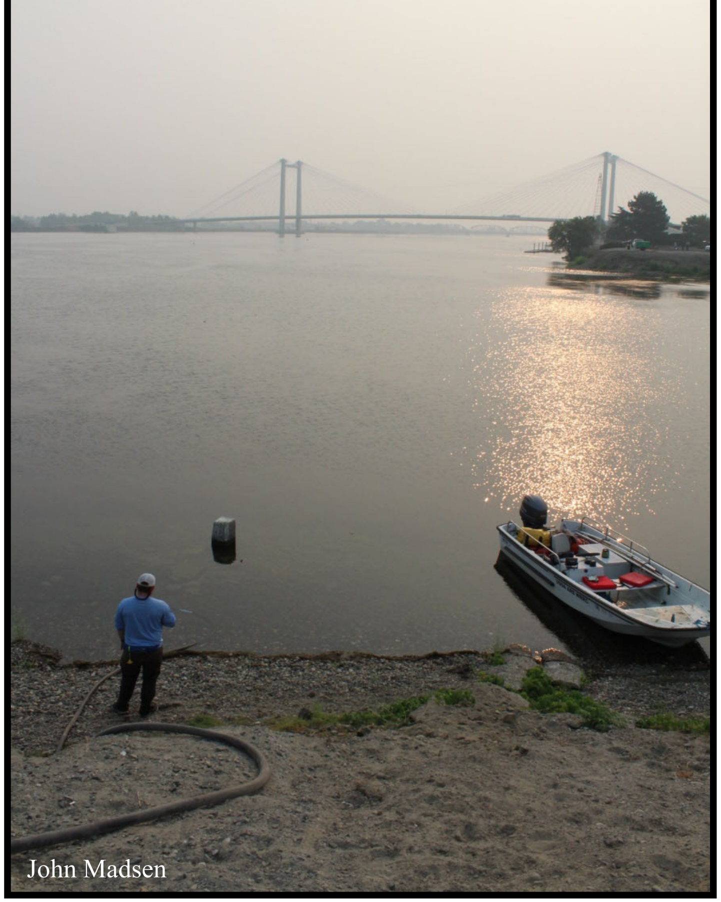
Acknowledgements

- NWW District; Pasco Office
- Coldwater Environmental LLC
- USDA-ARS Davis, CA
- North Carolina State University
- CanadianPond.ca
- AquaTechnex LLC
- NWO District, Fort Peck Office

APCRP
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Questions?

Questions?



Contact Information:

Bradley T. Sartain PhD
Research Ecologist
Environmental Laboratory ERDC
US Army Corps of Engineers
3909 Halls Ferry Rd.
Vicksburg, MS 39180
Ph: 601-634-2516
Email: Bradley.T.Sartain@usace.army.mil

Genotypic Variability and Invasive Traits of Flowering Rush

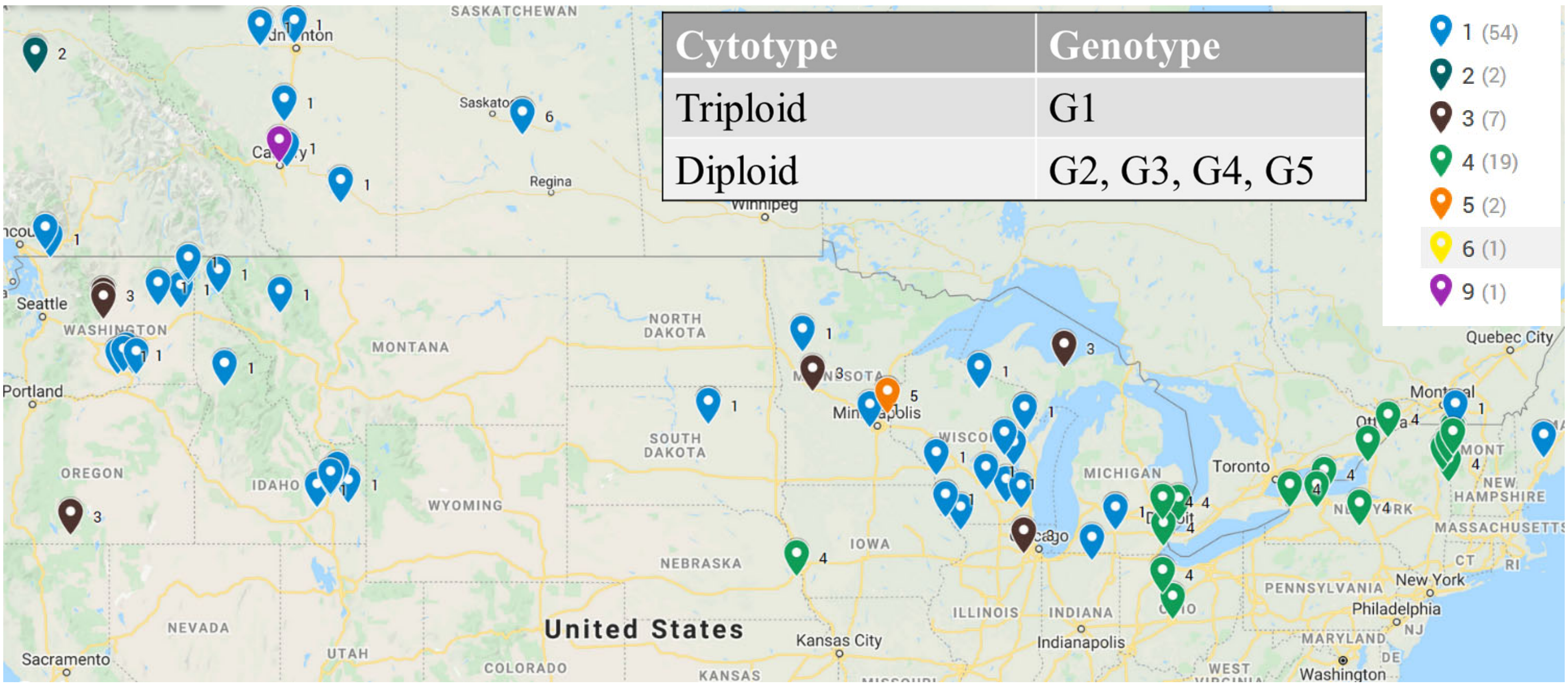
Nathan E. Harms
U.S. Army Engineer Research and Development Center, Vicksburg, MS

US Army Corps of Engineers
BUILDING STRONG®

Butomus umbellatus

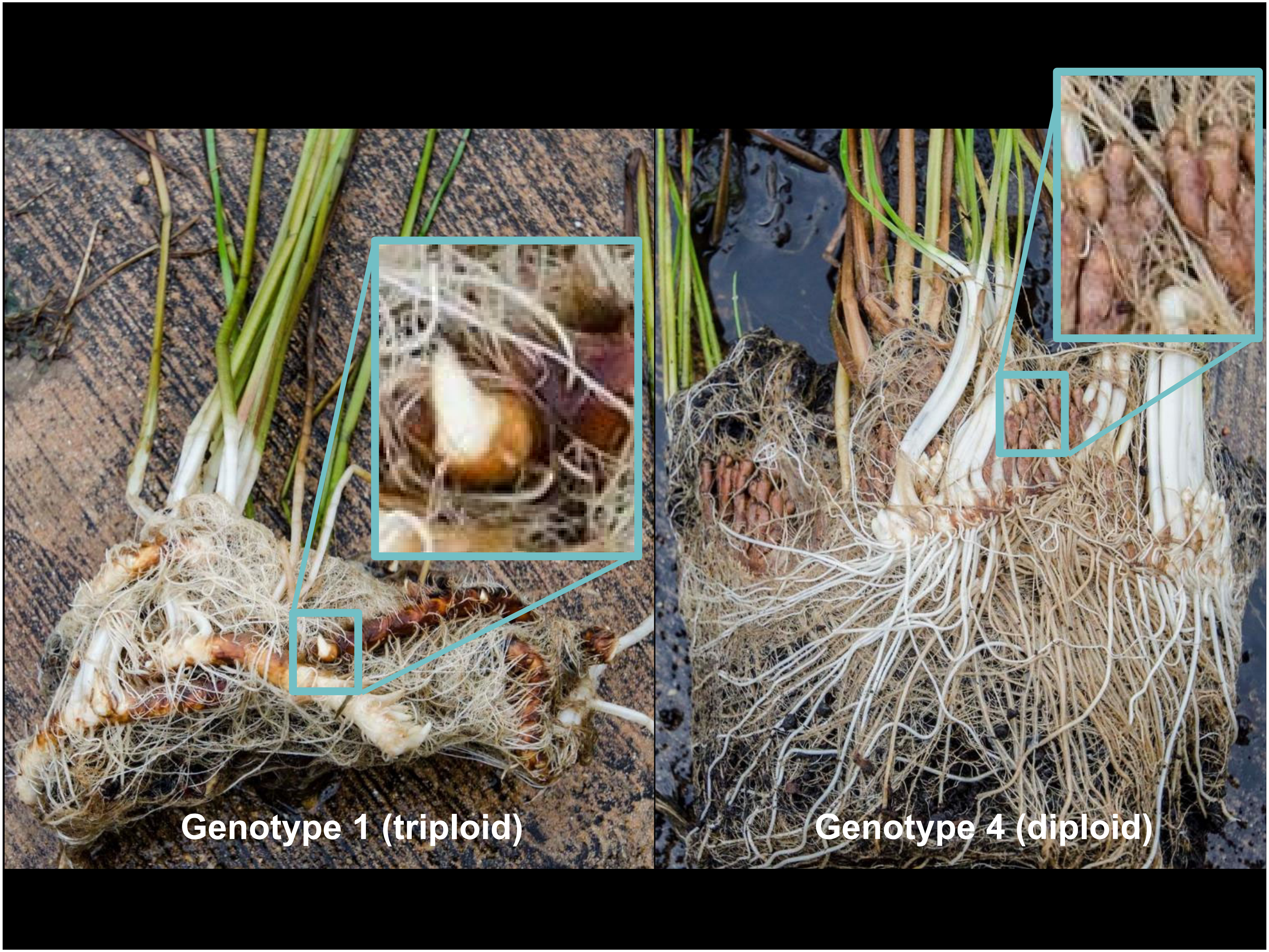
- Eurasian perennial weed
  - Rare/threatened in native range
- 2 ploidy levels in US
  - Diploid (2n=26)
  - Triploid (3n= 39)
- Multiple genotypes
  - Management implications
- Biological control development
  - CABI Switzerland

Flowering rush reproduction is largely clonal but has multiple genotypes in the US



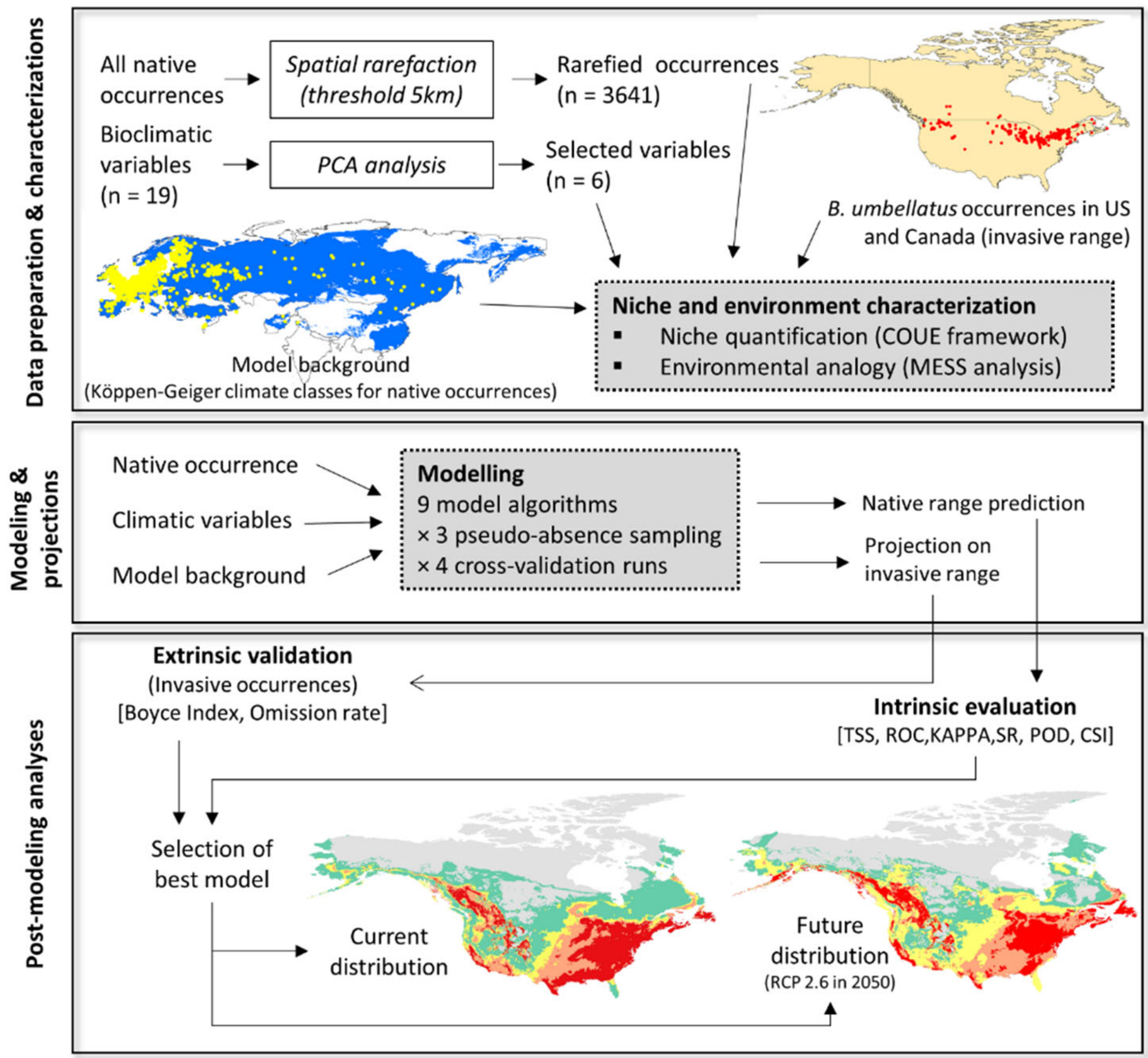
Cytotype	Genotype
Triploid	G1
Diploid	G2, G3, G4, G5

John Gaskin, unpublished data


Genotype 1 (triploid)
Genotype 4 (diploid)

Potential distribution in North America

- Areas at risk include southern locations, Alaska
- 57% of NA climatically suitable under current climate, may decrease under future climates
- A shortcoming of ENMs may be genetic variation in modelled species!



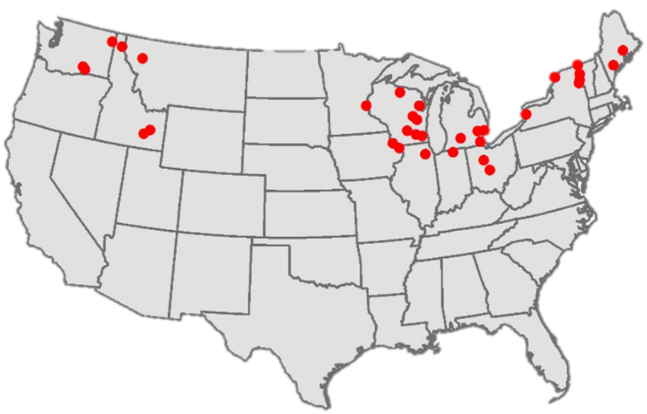
Modeling framework used by Banerjee et al. (2020)

Why is flowering rush so successful?

- Competition- invades established communities or disturbance specialist?
- Nutrient use- does flowering rush thrive in both low and elevated nutrient conditions?
- Disease- are there pathogens present that may limit fitness?
- Herbivory- are there native herbivores that feed, resist invasion?

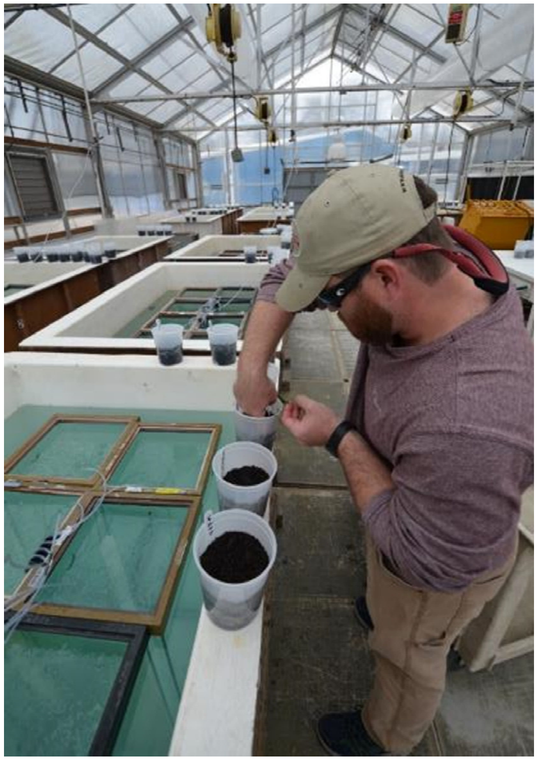
To compare characteristics of triploid and diploid flowering rush, common garden approach was used

- Allows comparison of genetic-based differences (in same environment)
- Every clone genotyped
- 10 diploid (7 G4, 1 G5, 1 G3), 19 triploid (G1)
- Propagated repeatedly to reduce maternal effects



Competition/ invasion studies

- Can indicate how likely FR is to invade established communities
- May indicate disturbance specialist
- Submersed and emergent experiments
- 10 FR populations (6 diploid, 4 triploid)
- Grown alone or in community



Submersed

- *Heteranthera dubia, Myriophyllum spicatum*
- Grown in 48 L aquaria
- Smart-Barko nutrients
- Duration 16 weeks
- Partial incomplete block design

Emergent

- *Typha latifolia*, *Schoenoplectus acutus*
- Grown in 20 L buckets
- Charcoal filtered tap water
- Duration 12 weeks
- Partial incomplete block design

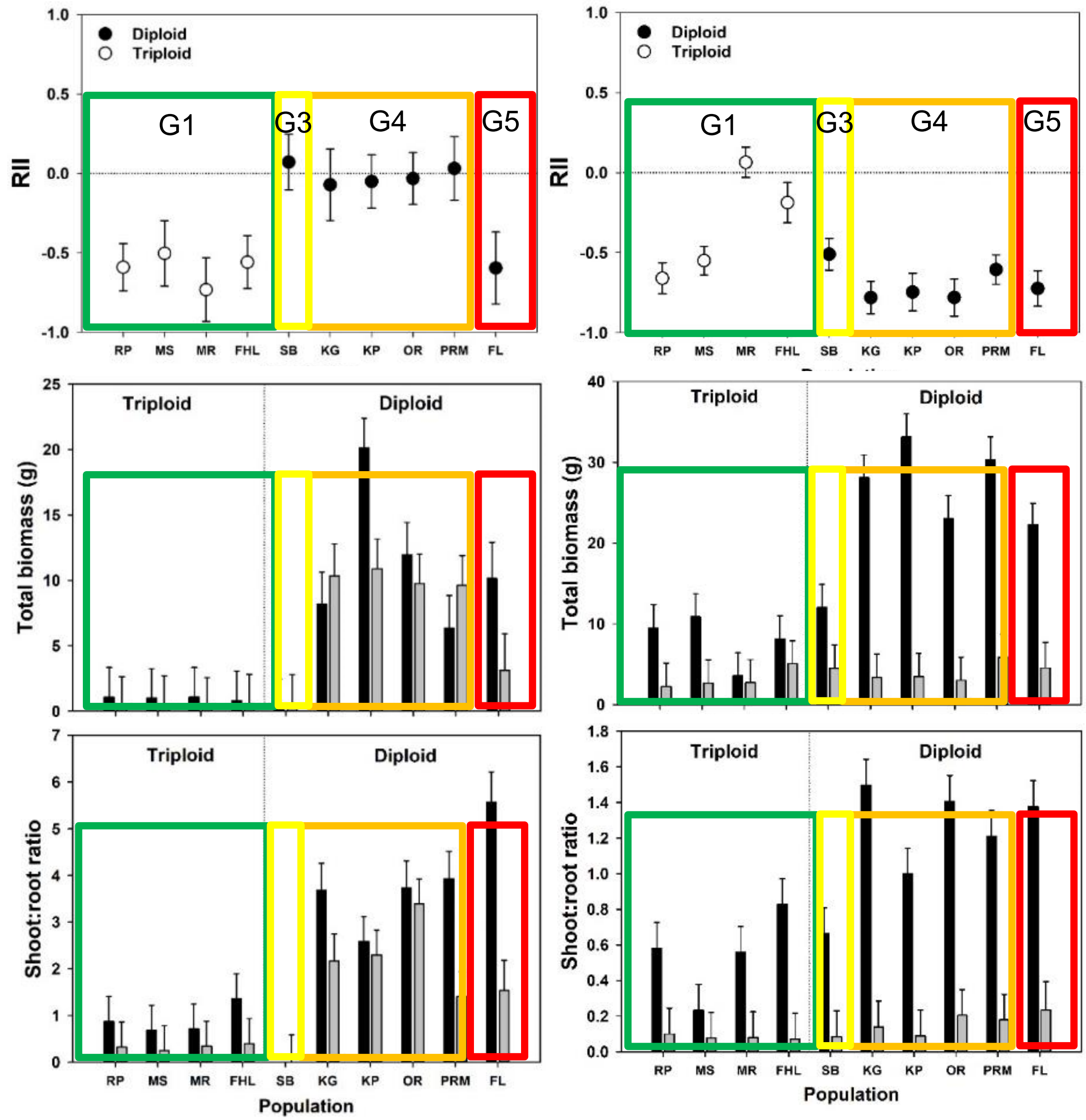
Competition study results:

Submersed

Emergent

Submersed- diploid plants less impacted by community competition (RII), diploid more successful at establishing (biomass)

Emergent- both cytotypes impacted by competition (RII), diploid more successful at establishing (biomass), BUT biomass same in competition



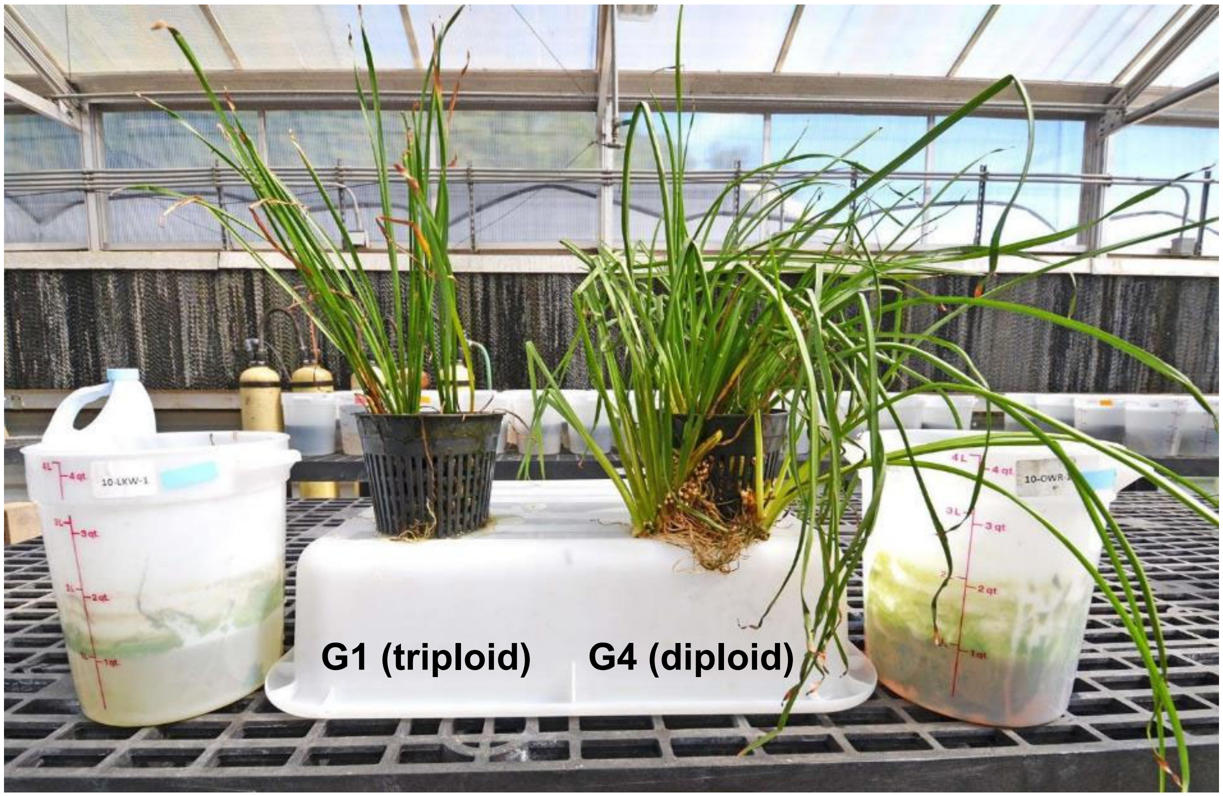
monoculture

community

Response to nutrients (N,P)

- Performance under increased (or reduced) nutrients can help identify locations at risk for impacts
- Tested FR growth under range of N and P
  - N: 4 – 400 mg/L
  - P: 0.4 – 40 mg/L
  - Other nutrients held constant
- Grown hydroponically in modified Hoagland's nutrients

Response to nutrients (N,P)



400 mg/L [N]

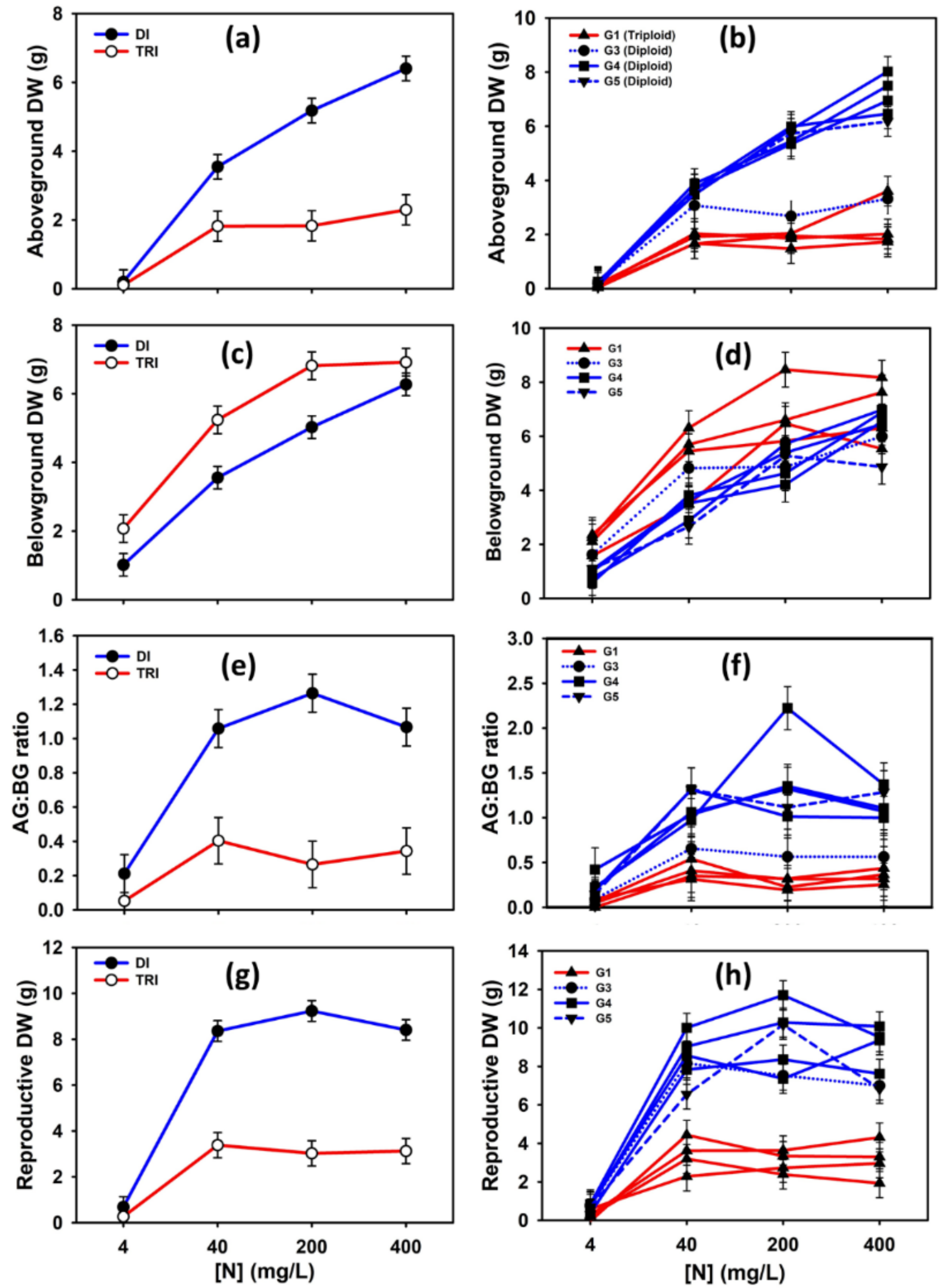
G4 (diploid)

Nutrient (N) effects were strong, as were genotype/ cytotype effects

Response to nutrients (N)

Diploid populations **increased AG biomass** with N, **both cytotypes responded in belowground biomass**

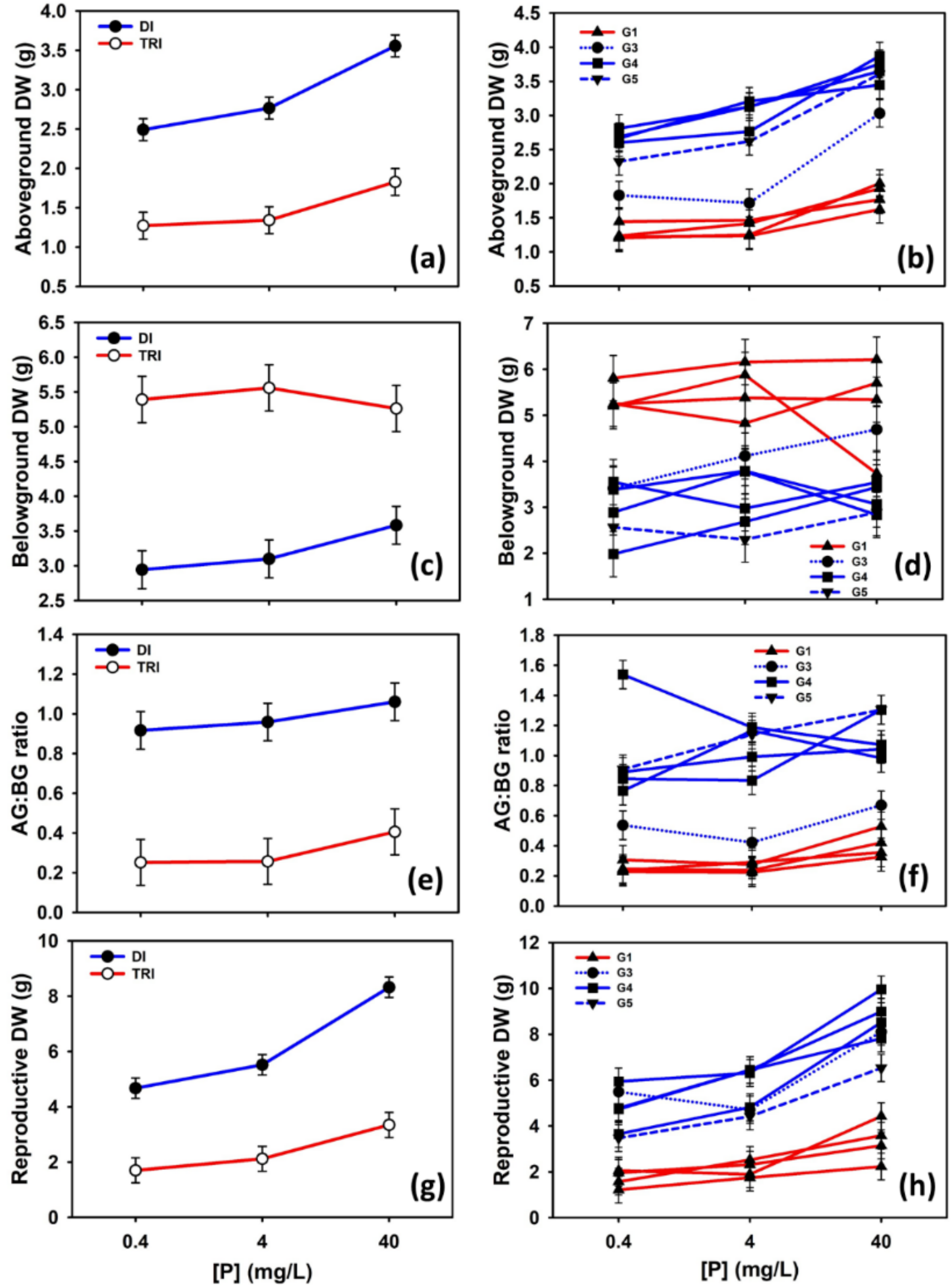
Majority of **triploid biomass in roots/ rhizomes**



Response to nutrients (P)

Both cytotypes increased AG biomass with P, **BG biomass** relatively unaffected but **nearly double in triploid** plants

Majority of **triploid biomass in roots/ rhizomes**



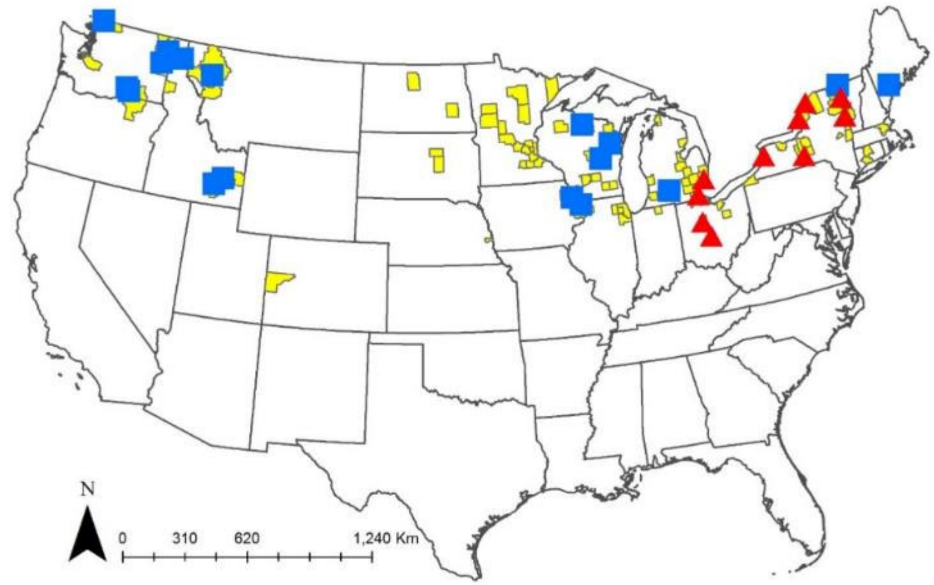
Biotic factors- disease and herbivory

Do introduced cytotypes differ in susceptibility to herbivores or disease, and what are the implications for biological control?

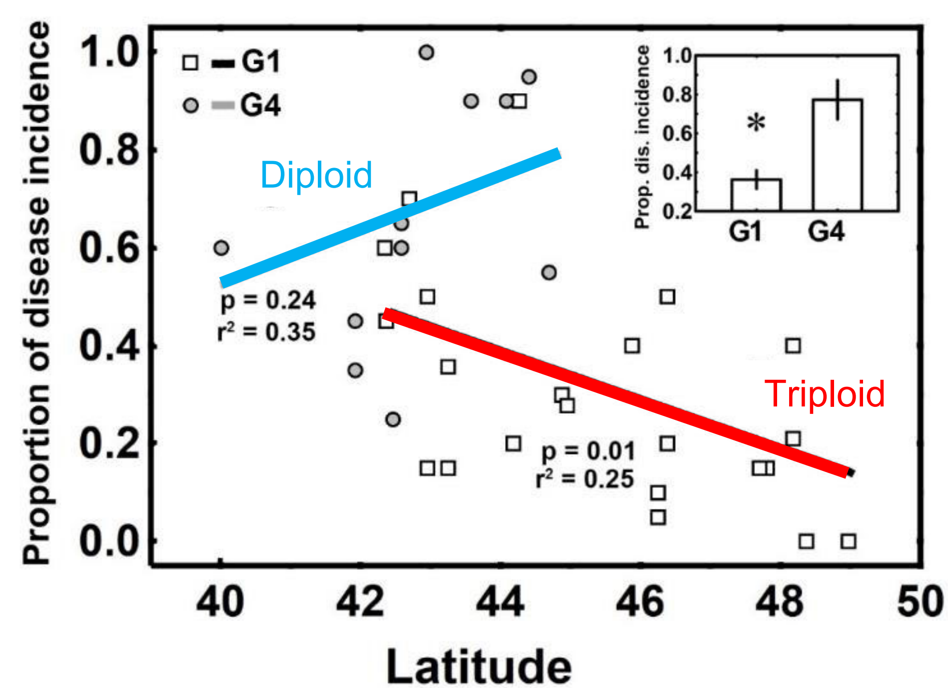
Domestic natural enemy surveys conducted during 2014-2016 with Dr. Judy Shearer (ret.)

Are there damaging native herbivores or pathogens present that could be used for control?

Will there be interactions with future biocontrol introductions?



Harms et al (2020)

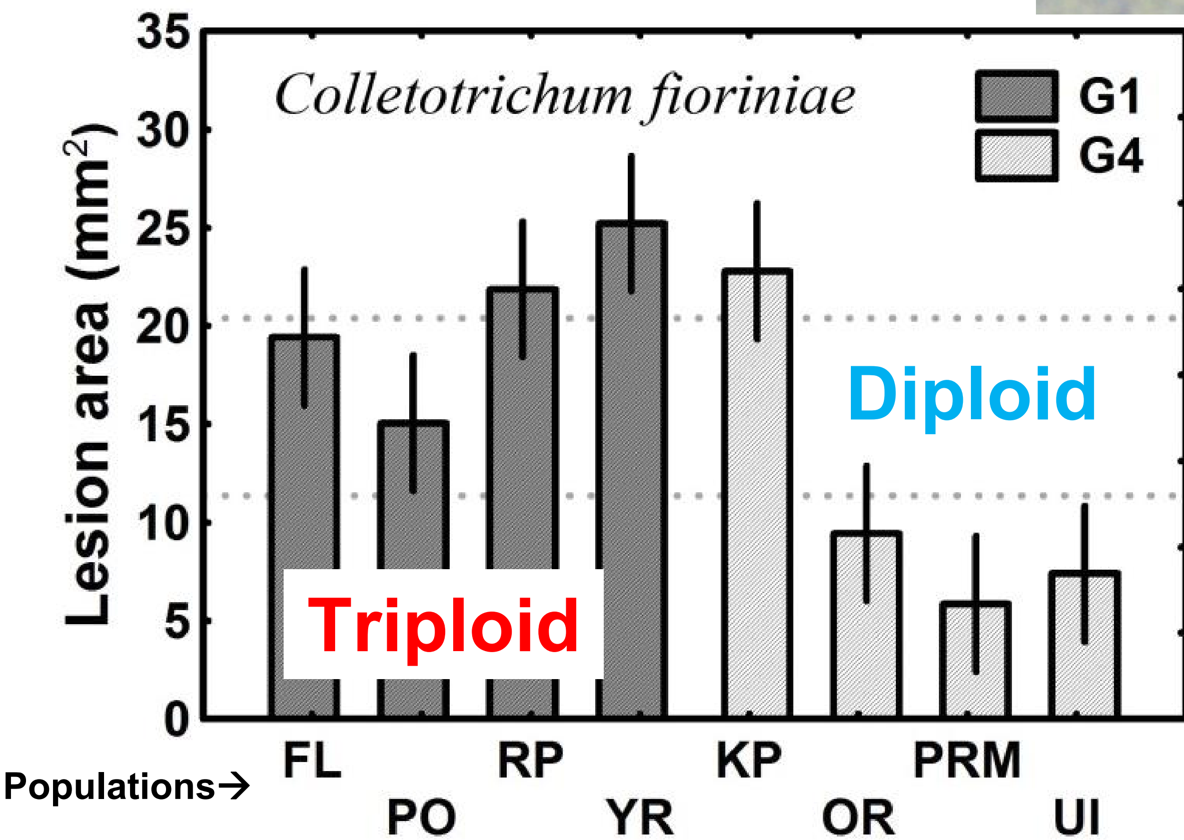


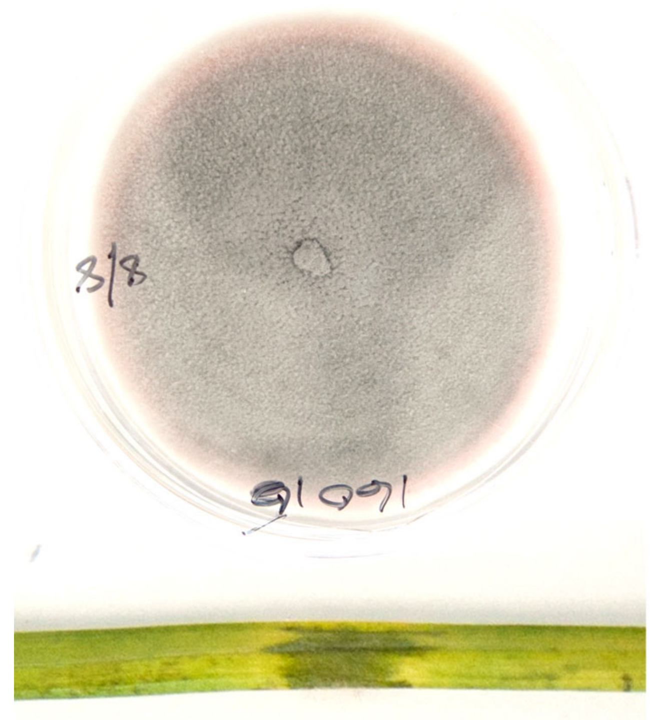
Surveys followed up by laboratory infection assays

Three pathogens isolated from US populations

Diploid plants trended towards less susceptible to infection/disease

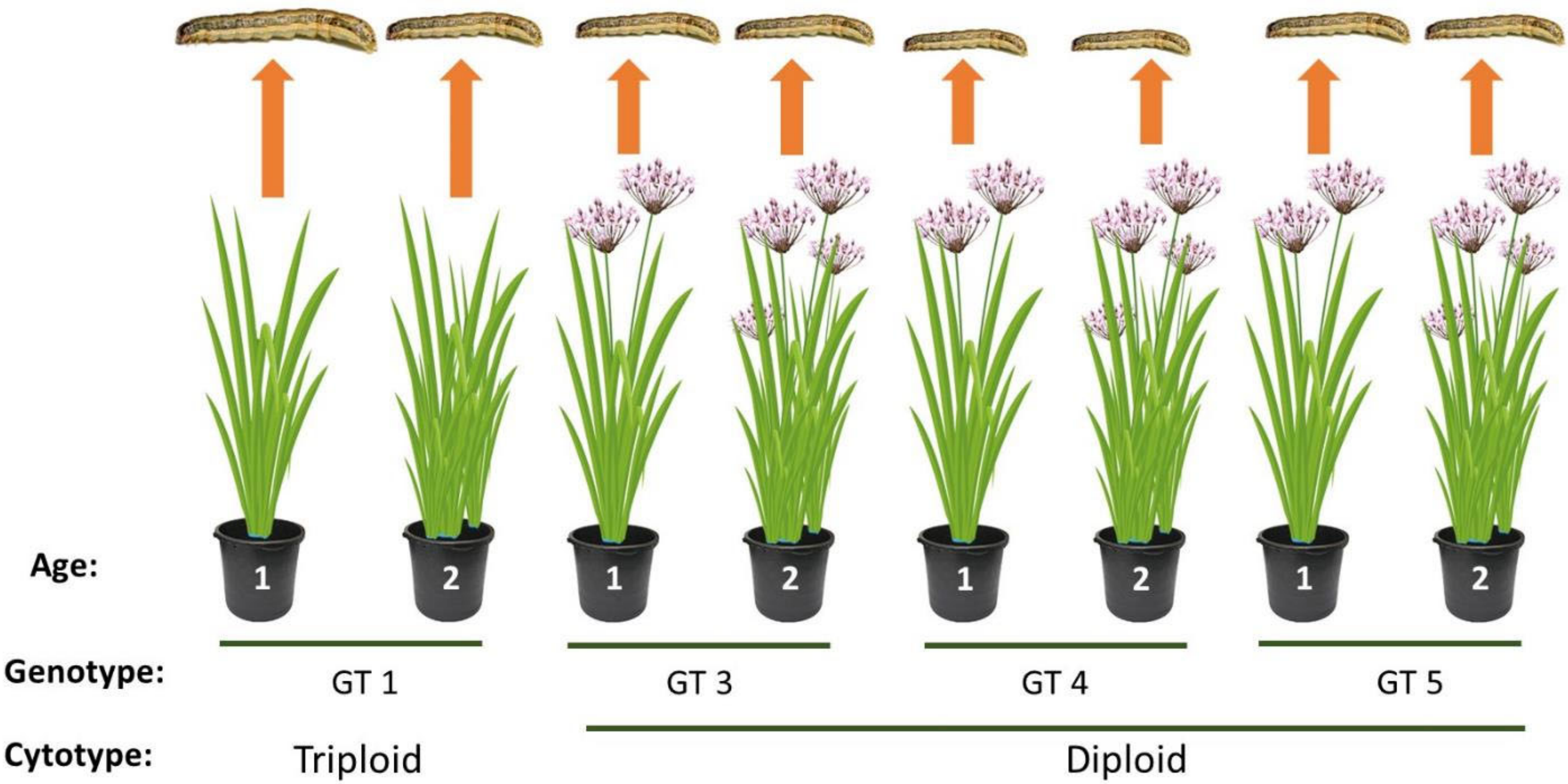
Unexpected result compared to the field- the importance of environment/climate?





Harms et al (2020)

How does genetic identity influence herbivore performance on flowering rush?



Differences between genotypes has implications for biocontrol*

Age 1 = “colonizing”
Age 2 = “established”

*whether different responses of generalist are predictive of biocontrol is not clear

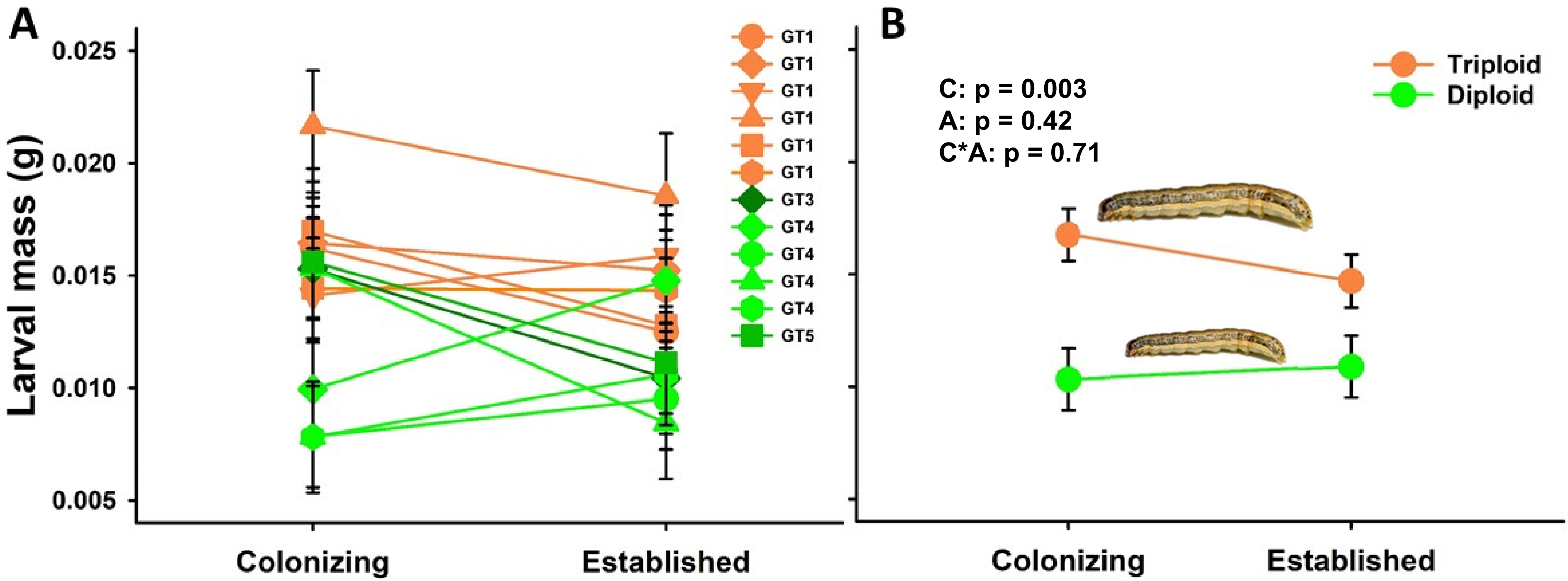
Question: How does genetic identity influence herbivore performance on flowering rush?

- 12 populations
- 2 age classes
- Short-term herbivore development
  - *Spodoptera frugiperda*
- Leaf traits measured:
  - %N, %C, C:N ratio, DMC, total phenolics

Population	Genotype	Cytotype	Latitude	Longitude
Oswegatchie River, NY	4	Diploid	44.69	-75.49
Kenduskeag River	4	Diploid	44.82	-68.79
Springbrook pond, IL	3	Diploid	41.73	-88.21
Point Rosa Marsh, MI	4	Diploid	42.58	-82.81
Kildeer Pond, OH	4	Diploid	40.71	-83.37
Forest Lake, MN	5	Diploid	45.27	-92.94
Missisquoi River, VT	1	Triploid	44.95	-73.16
Yakima River in Prosser	1	Triploid	46.38	-119.43
Flathead Lake, MT	1	Triploid	47.70	-114.07
Rose Pond, ID	1	Triploid	43.25	-112.32
MS River	1	Triploid	42.34	-90.41
Lake Kawaguesaga	1	Triploid	45.88	-89.73

Question: How does genetic identity influence herbivore performance on flowering rush?

Diploid genotypes generally more resistant to generalist caterpillar than triploid, age had variable effect

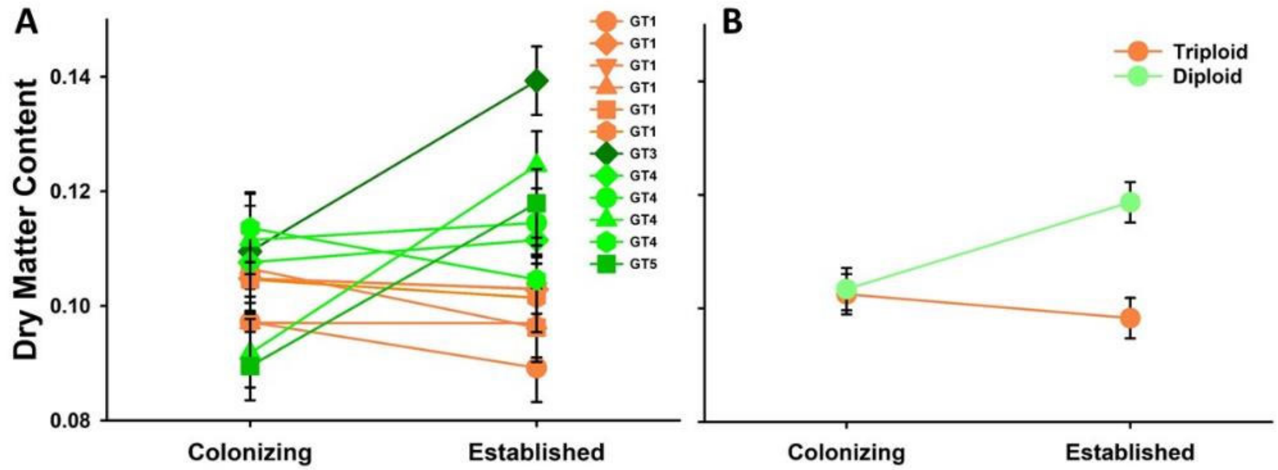


Larvae grew **36% larger** on triploid leaves

*whether different responses of generalist are predictive of biocontrol is not yet clear

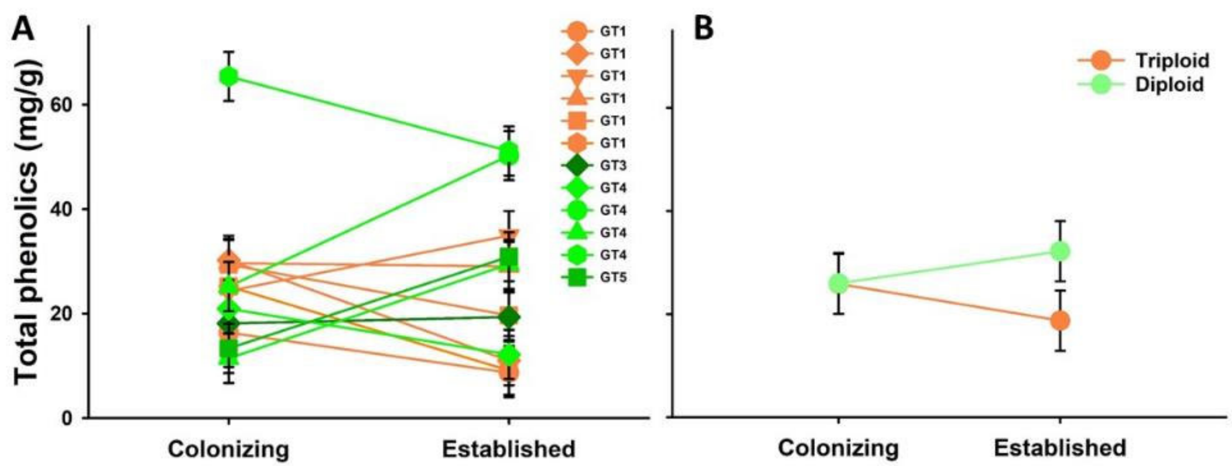
"Colonizing" = Age 1
"Established" = Age 2

Diploid plants **higher DMC** overall **but varied with age**



DMC of diploid leaves **20% higher** than triploid leaves

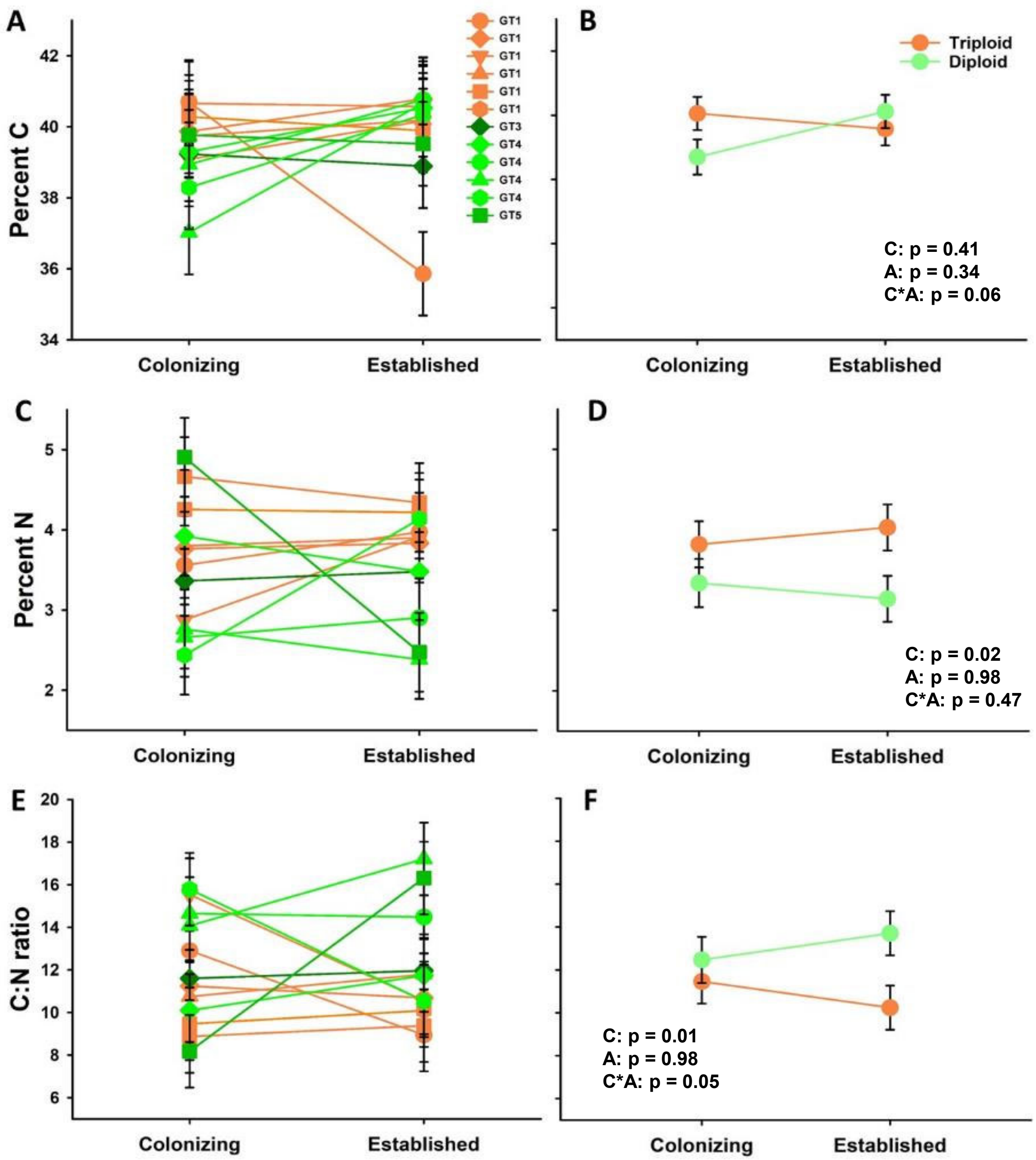
Total phenolics not different between cytotypes, high diploid variability



*whether different responses of generalist are predictive of biocontrol is not yet clear

“Colonizing” = Age 1
“Established” = Age 2

Diploid populations had **lower %N** and **higher C:N ratio** across treatments



Measured leaf traits largely **supported differences** in **larval** development

Biological control of flowering rush is under development in Europe

- CABI (Delemont, Switzerland) in collaboration with a consortium of NW federal, state and local agencies (led by Jen Andreas- Washington State)
- Two insects and one pathogen are currently under investigation
- Testing performance on US genotypes underway

www.cabi.org

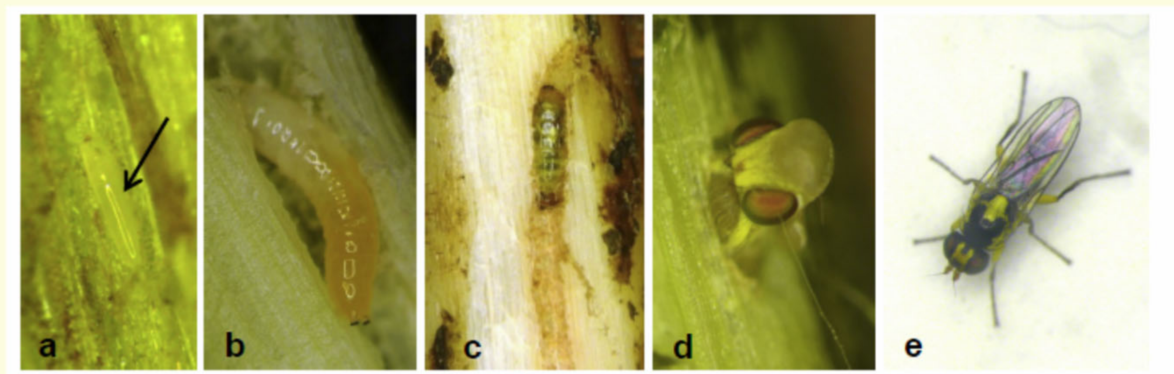
Bagous nodulosus (Col.: Curculionidae)

- Semi-aquatic weevil, most damaging herbivore during field surveys
- Larvae damage leaves and rhizomes

Photos: P. Hafliger (CABI)

Phytoliriomyza ornata (Dip.: Agromyzidae)

- Larvae mine leaves and flowering stems, cause wilting within weeks
- Host-specificity tests ongoing; 17 non-targets tested, no larval development found
- Impact experiment with 10% biomass reduction



Doassansia niesslii (white smut)

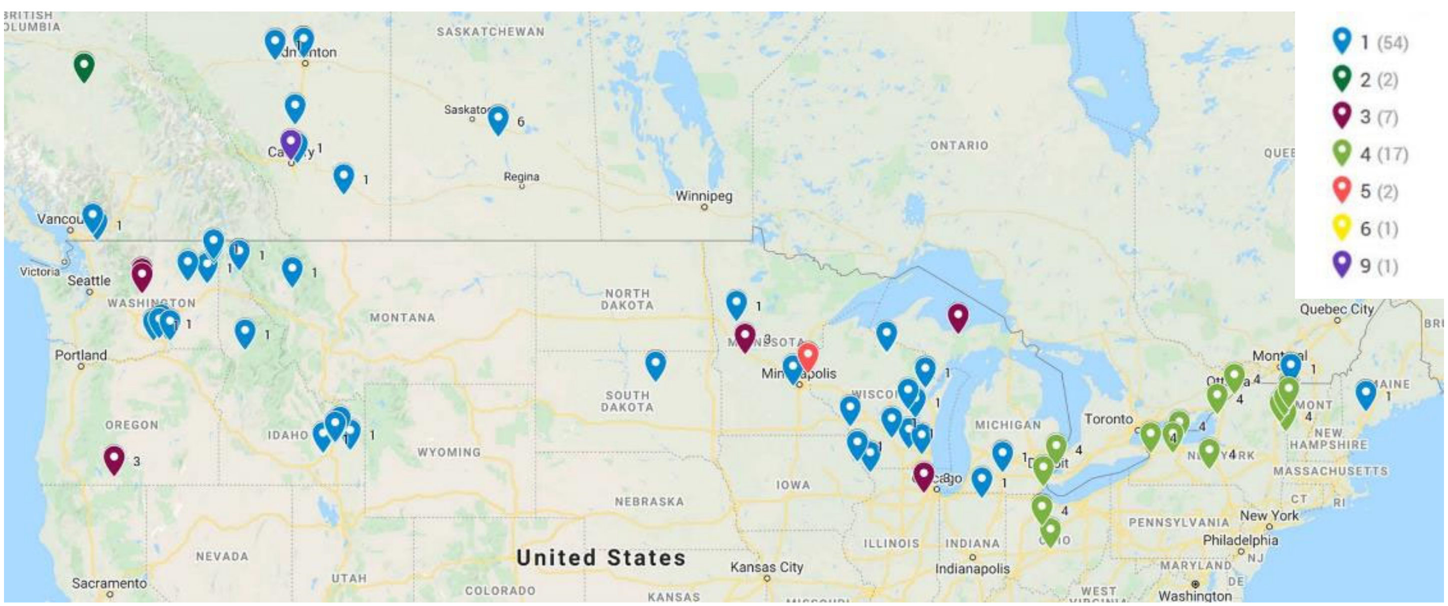
- FR genotype important!
    - Genotypes 1, 4, 5 resistant
- Preliminary host-range testing yielded promising results
- Able to infect submersed plants

Why is flowering rush so successful?

- Competition- Diploid plants more impacted by competition under emergent, but not submersed conditions. Triploid biomass allocated to roots.
- Nutrient use- Diploid plants respond strongly to increased nutrients, triploid plants allocate biomass to roots
- Disease- Many generalist pathogens, triploid plants more susceptible in lab studies, diploid plants more diseased in the field
- Herbivory- triploid plants generally less resistant to feeding, feeding in the field is low across the board
- **Resource allocation**- how does higher underground biomass allocation benefit an invader?
- **Propagule pressure-** how many propagules, and how viable are they?

Take home:

- Prioritization of management may depend on expected impacts and genetic variation in population response to management
- Genetic identity has broad implications for the ecology and biology (and thus management) of the plant
- Future plans include longer-term experiments under real-world conditions



Thanks to:

Co-presenters Drs. Sartain and Madsen

Patrick Hafliger, Hariet Hinz (CABI)

John Gaskin (USDA ARS)

Jen Andreas and Flowering Rush Consortium

Blake DeRossette, Dave Lattuca and Damian Walter (USACE)

Questions?

Email: Nathan.E.Harms@usace.army.mil