APPENDIX C. COMPILATION OF TREATMENT PROTOCOLS

This Appendix summarizes the published treatment protocols gathered from our review of the peer-reviewed and gray literature, relevant webinars and conferences attended, discussion with managers, and the stakeholder meeting convened under the EPA Grant to Bourgeau-Chavez (linked from the website: **http://mtri.org/phragmiteswetlandmanagementandscience.html**).

Generally, there have been few significant innovations that are ready for implementation, beyond the many well documented and published treatment methods to date. There remains some controversy about several published and therefore theoretically acceptable practices which are highlighted in the summary below. Because most practices have been well documented already, here we provide short bulleted recaps of methods to avoid time consuming duplication of effort and draw your attention to those for which we found conflicting results or opinions. We also note methods for which there is notable uncertainty, whether it is regarding human safety, appropriate uses and specific application parameters, required expertise or specialized equipment needs, or lack of knowledge. Due to the paucity of quality data from short and long-term monitoring efforts, uncertainties are difficult to resolve. Note also, that many of these treatment methods require permits, specialized training, and detailed knowledge of herbicide formulations that can be used over water vs land, necessary and appropriate adjuvants and surfactants, and other label requirements; these are not detailed here.

The novel concept that is emerging through this project (MONDRIAN and landscape modeling) and others such as the *Phragmites* Adaptive Management Framework (PAMF) is the selection of *more specific sequencing of accepted treatment methods, based upon site-specific conditions*, including level of disturbance, *Phragmites* propagule pressure, hydrology, nitrogen levels, previous treatment regime(s) and/or *Phragmites* population "transition state". These approaches are further elaborated upon in the main body of this report. This study also substantiates the urgent need to reduce a key causal factor for *Phragmites* invasion: nitrogen loading. MONDRIAN modeling showed that nitrogen loadings above 4 g N/m^2/ year not only facilitate but drive *Phragmites* invasion at the expense of non-clonal native species which cannot compete under these levels. In addition to nitrogen inputs from agricultural run-off and other land uses, many managers are currently unable to remove dead *Phragmites* biomass from infested waters, which may further contribute to nitrogen loading and *Phragmites* establishment. Removal of biomass through burning is one option that can remove *Phragmites* biomass from the system, but opportunities for successful and safe implementation of this practice are often limited.

Exploration of the biomass issue a little further reveals considerable complexity and potential trade-offs that need to be better understood. While burning *Phragmites* eliminates that source of nitrogen, it also produces methane, contributing to greenhouse gas emissions. Some studies suggest that invasive *Phragmites* is better at sequestering carbon than native species due to its large size, deep roots, and dense growth, but critics note that permanent carbon storage only occurs when *Phragmites* decomposes to peat and stays peat. Others, particularly in the NE coastal US, assert the ecosystem service value of invasive *Phragmites* as one of few species that resists shoreline

erosion—an increasing concern in Atlantic coastal communities under climate change scenarios. While planting invasive *Phragmites* is not currently promoted, there is discussion of leaving it alone in some locations where it is firmly established. This of course allows large source infestations to contribute to propagule pressure that facilitates further invasion. Careful consideration of these factors is urgent; should we address climate change concerns using a species that we know to have devastating biodiversity impacts, or should we seek alternative solutions?

Future work should focus on resolving these concerns since reduction of the ultimate causes of invasion is pivotal to successful and cost-effective, long-term control of *Phragmites* and understanding potential interactions of treatment techniques with other biodiversity stressors such as climate change may influence best treatment decisions.

Controversy about potential human impacts from herbicides has also heightened, as well as increasing evidence and concern about herbicide resistance over time. In addition, one of the most frequently employed treatment combinations of fall herbicide application followed by mowing, crushing or mulching does not address seed production effectively. Seeds are implicated in both patch expansion and new patch establishment. In-depth study of these concerns is beyond the scope of this study.

SUMMARY OF TREATMENT PROTOCOLS

Covering with black tarp

- Potentially effective for very, small infestations, but mostly impractical.
- Goal is to stop ability of plant to conduct photosynthesis, eventually depleting the rhizome.
- Rhizomes may grow past the edges of the covered area.
- Rhizomes may grow through the tarp.
- Likely to take a long time to deplete rhizome resources.

Hand or mechanical digging

- Suitable only for very small, preferably young infestations.
- Requires digging the entire root as fragments can regenerate.
- Monitoring required for at least several years to ensure no re-sprouts from the seed bank.
- See spading below.

Spading

- An alternative to hand digging that uses a spade to sever the root just under the surface of the ground repeatedly over time.
- Does not involve fragmenting the root system, rather it removes the photosynthetic shoots in order to deplete the underground rhizome over time.
- Intensive effort required but is currently being used effectively in Canada on sites where the use of herbicide is illegal (over water).

- Monitoring required for at least several years to ensure rhizome is depleted
- Determination of efficacy still underway.

Flooding/Drowning - General

- Video demonstrating adaptations of *Phragmites* to deep water growth is helpful; https://www.youtube.com/watch?reload=9&v=cf19duJHzck&feature=youtu.be
- Management scenarios must take consideration of native species as competitors into account in addition to *Phragmites* adaptations.
- Conflicting opinions about length of time required to kill rhizome; may be affected by size and age of stand, clarity of water, other site-specific conditions and treatment regimes.
- Natural flooding cannot be predicted with certainty or controlled in terms of when and how long it occurs; this will impact the level of control that can be achieved.
- Additional research and clarification needed.

Drowning mechanically by hand-cutting below the water Hand cutting *Phragmites* stalks as close to the sediment as possible in standing water areas.

- More effective in deeper water as there is a greater the chance of starving the belowground structures of oxygen and drowning the plant.
- Intensive effort required and subject to natural water level fluctuations.
- Further research on long-term effectiveness and practicality of use needed.

Drowning using Truxor or similar vehicle/machine that cuts *Phragmites* below the waterline

- Similar to above but using large equipment.
- Less time intensive, but expensive, machines are not widely available, and some conditions preclude its use.
- If unable to control water levels; the risk of promoting *Phragmites* may be increased: shoots must remain underwater long enough to effectively drown plants – lowering water levels provides suitable conditions for re-invasion but is required for effective competition by native plant growth.
- Subject to natural water level fluctuations.
- https://www.greatlakes*Phragmites*.net/blog/amphibious-vehicle-cutting-*Phragmites*-below-the-waterline-in-ontario/,

Drowning by water level manipulation

- Used in impoundments with water level controls to kill *Phragmites* by flooding.
- Not effective by itself; used in conjunction with pre-flood herbicide application and prescribed burning
- Timing is critical as drawdowns at the wrong time of year can promote re-invasion of *Phragmites* over establishment of native species that are needed to compete with *Phragmites*
- MDEQ recommends flooding to a minimum depth of 6 inches after late summer herbicide application, dewatering in late July of following year; implementing prescribed fire in mid-

August; and immediately re-flooding for another year. If prescribed fire is not possible, mechanical treatment of dead *Phragmites* during winter on frozen ground is recommended.
- Concern expressed in stakeholder meeting about impacts of water levels on fish movement.
- Note: *Phragmites* is adapted to deep water growth using specialized mechanisms that increases oxygen flow to the rhizomes compared to non-adapted species.

Herbicides

- It is essential to know the rules and regulations regarding herbicides in the jurisdiction you are working in. For example, in Canada, use of herbicide over water is typically not permitted.
- All label recommendations must be followed.
- In some situations, herbicides can be used effectively alone, repeatedly over time, to maintain *Phragmites* at acceptable thresholds specified by manager or landowner.
- In most cases combining herbicide application with additional control methods is much more effective
- Glyphosate, imazapyr and glyphosate/imazapyr mix are most frequently cited as acceptable herbicides.
- Glyphosate is less expensive than imazapyr, but there remains controversy over its effectiveness compared to use of imazapyr alone or imazapyr/glyphosate mix. This may have to do with site specific conditions, e.g., water vs no water, or applicator experience, but adequate monitoring data are lacking to distinguish cause and effect.
- Many managers have experienced dead zones with the use of imazapyr, but it is not clear if this is due to where and how it was applied or general use of this herbicide.
- When applied over dry land, imazapyr binds to soil and inhibits native plant regeneration, which is a necessary condition for site recovery due to native plant competition with *Phragmites*.
- The best concentration of imazapyr also remains controversial. For example, use of imazapyr in concentrations higher than recommended rates have been reported as well as more recent reports of increased efficacy and reduced non-target impacts with concentration as low as 0.5% active ingredient.
- The use of imazapyr alone without active monitoring in Green Bay was reported at the 2017 SOLM conference; this is of concern considering the conflicting viewpoints about the efficacy and potential non-target impacts of this herbicide.
- Imazapyr can be used earlier in season than glyphosate but managers expressed conflicting results on efficacy of early herbicide application over fall application.
- Early herbicide application must consider impacts to native fauna, such as nesting birds.
- It is uncertain whether imazapyr on dry land kills seeds or only inhibits germination; this has management implications, particularly regarding restorations that include planting of native species.
- More research or clarification is needed on appropriate uses and application parameters for imazapyr and for relative efficacy compared to other herbicides or herbicide combination.
- Use of imazamox is recommended by some, however, notable studies have shown significantly lower *Phragmites* kill rates.

- There is concern over potential resistance to commonly applied herbicides and a general consensus that minimizing the repeated use of one herbicide is a good idea; however, this does not yet appear to be a common or widespread practice.

Hand-swiping with herbicide

- With proper protective cover, absorbent gloves or towels are used to deliver herbicide directly to the leaves of phragmites shoots by swiping them.
- Effective but impractical for large infestations.
- Useful in high quality areas, especially with rare or vulnerable species, to minimize non-target impacts.
- Can be useful in mop-up work along edges of infestations.

Cut and drip or stem injection with herbicides

- Stems are cut and herbicide is injected or dripped into the stem at the cut surface.
- Highly effective, but time intensive; impractical or impossible for large infestations.
- Minimizes non-target impacts.
- Has been useful in some large treatment and monitoring effort, where stems are cut in order to create pathways through the stand for access. Foliar spray of the cut stems will not be effective on the cut stems, whereas stem injection or drip methods are.
- Safety concerns have been expressed by some, about personal use of the high herbicide concentrations required for this method.

Multiple herbicide applications in a season

- Landowners in SE Michigan have implemented multiple herbicide applications in a season in combination with pre-cutting, resulting in more effective first year treatment, which they see as critical to minimizing costs of follow-up. They found it more time-consuming to selectively spot-treat regrowth of *Phragmites* while avoiding native regrowth, if first year kill rate is not high.
- After initial treatment, they did a second herbicide application on green stems after ~ten days and one more time ~ten days later, resulting in improved efficacy (98% kill rate) over single applications and no pre-cut. This timing may not be appropriate everywhere.
- Minimum required time between treatments is 24 hours, however they recommend 10-14 days to adequately assess whether herbicide has been effective or not to avoid wasting herbicide on stems that have already yellowed from previous treatments.
- Lack of full efficacy on all *Phragmites* stems with one application is due to density of stands.
- Must ensure that maximum allowable herbicide amounts are not exceeded.
- Further study is warranted to assess if this technique is appropriate for all geographies and site conditions.

Cutting/mowing/crushing/mulching

- All of these are widely used to create better germination conditions for native plants, as follow-up after herbicide treatments, and to promote safer burning.

- Logistical constraints including water levels, available equipment and availability of staff and contractors play a significant role in determining if this step can be accomplished.
- May not be necessary for small stands,

Hand-cutting

- Suitable for small infestations where herbicides are not desired or legal and where cutting will not harm other desired plants.
- Stems should be cut prior to seed production annually until rhizome is depleted.
- Some advocate cutting more than once in a season to minimize difficulty of cutting large plants.

Removal of biomass offsite

- Goal is to get rid of nitrogen source to water ***and*** to increase germination of native species.
- There is consideration of possible use for energy production, as fuel pellets, for example.
- Expensive and not perfected in U.S. yet; trial project in process in northern Michigan.
- Biomass removal appears to be a critical stumbling block in *Phragmites* treatments to date. Techniques and equipment are not yet perfected and logistical constraints due to site conditions and weather are frequent.
- Note also the comments in the introduction of this summary.

Seeding of native species

- A majority of managers consulted during this project expressed that native seed banks are strong where they are working, and native species rebound substantially after successful treatment of *Phragmites*.
- Many expressed that when imazapyr was used alone, native regeneration was severely lacking for extended time periods favoring re-establishment of *Phragmites*; most agreed this was related to amount of water present, i.e., more water, less negative impact. Refinement of parameters for use of imazapyr is needed to avoid situations where it can bind to soil and inhibit regeneration.
- In situations where seed banks have been highly disturbed, native seeding is being implemented with some success (some Michigan restorations, Utah).

Prescribed Fire

- It is well accepted that burning after herbiciding is one of the most effective techniques for successfully restoring *Phragmites*-infested sites. It gets rid of the nitrogen source from dead *Phragmites* and opens the site for native plant regeneration and more effective follow-up treatments.
- Burning has the added advantage of killing seeds, which are a significant propagule source for *Phragmites*.
- Winter burning or spring burning before green-up has long been recommended and is most commonly utilized.

- There are conflicting opinions and efficacy studies about early burns conducted in June; some studies conclude that it reduces flower production in the fall, reducing seed production and dispersal.
- Burning prior to mid-July must consider non-target impacts to native plants and animals, including nesting birds. Recommended herbicides are non-selective.
- Burning produces methane, which contributes to greenhouse gas emissions.
- *Phragmites* biomass has been noted to resist shoreline erosion in the Atlantic coastal zone.
- Phragmites biomass may be better at sequestering carbon than native marsh plants but note the discussion in the introduction to this summary.

Grazing

- Some studies show that regular grazing suppresses *Phragmites.*
- Grazing has been attempted with some success; however, it may be inappropriate for many site conditions; further research is warranted.

Combinations (and sequences) of treatment techniques

- There is generally widespread acceptance that combinations of treatments provide better control than any one method alone for most infestations; however, depending upon specific management goals, a single method may be enough; e.g., 20% live *Phragmites* may be acceptable at some sites and can be achieved by repeated herbicide application only.
- Water levels may influence best combinations in different vegetation zones.
- Combinations of techniques tie into the selection of optimal sequences based upon site specific conditions using MONDRIAN modeling as described in main body of this report; similarly with the transition stages in the PAMF adaptive management model.
- The most commonly cited combinations mirror those of MDEQ (2014):
  - Herbicide in mid-summer or late summer/early fall (depending upon herbicide) – cut/mow/ mulch/crush in winter – follow-up treatment with herbicide the following fall.
  - Herbicide in fall – burn in winter or spring – follow-up herbicide the following fall.
  - Herbicide late summer/early fall – immediately flood to 6 inches until late July of following year – dry down to mid-August – burn – immediately flood to 6 inches for at least 1 year – herbicide as needed in following growing season
- Less frequently cited combinations include the following variations:
  - Cut or mow 1 or more times early in the growing season but ensure that stems reach ~4 ft by late summer/early fall – herbicide late summer/early fall – cut/mow/crush/mulch in winter – follow-up herbicide in following growing season.
- Burn early in the growing season – herbicide late summer/early fall -- cut/mow/crush/mulch or burn in winter. Many more potential sequences of these techniques and selection of optimal solution based on site-specific conditions are discussed in the main body of this report and similarly included in the PAMF participant guide. https://www.greatlakesphragmites.net/pamf/

Biocontrol

- On-going research on two European stem mining noctuid moths, *Archanara geminipuncta* and *A. neurica* for potential release. Recent study showed acceptable level of specificity to invasive *Phragmites*, however a 6.5% rate of feeding on native *Phragmites.*
- Proponents consider this an acceptable condition for release, e.g., harm from invasive *Phragmites* outweighs threat to native *Phragmites* from biocontrol.

Gene silencing

- On-going and somewhat controversial research to discover ways to influence the ability of *Phragmites* to grow and reproduce, by selectively manipulating actions of appropriate genes.

Disrupting fungal and bacterial endophytes

- On-going research area supported by a "collective impact" approach.
- Goal is to manipulate endophytes that are influential in the growth and reproduction of *Phragmites*.

REFERENCES

Science Friday. 2019. The Complex Problem of the Invasive Common Reed. A segment of The State of Science. https://www.sciencefriday.com/segments/the-complex-problem-of-the-invasive-common-reed/ (accessed 1/25/19).

Great Lakes Commission, USFS, University of Georgia A. 2017. Phragmites Adaptive Management Framework Participant Guide. Draft 2. 45 pages.

Rupp, L., R. Whitesides, K. Kettenring, & E. Hazelton. 2014. Phragmites Control at the Urban/Rural Interface. Utah State University Extension. Horticulture/Weeds/2014-01pr. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1688&context=extension_curall (accessed 2-6-19)