Long-term Observations of Culm Heights of Invasive *Phragmites australis* Subjected to Three Different Control Methods in a Small Urban New England Saltmarsh

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Abstract - In the US, *Phragmites australis* ssp. *australis* (European Common Reed) generally is considered to be a harmful invasive species whose dense monoculture stands greatly reduce species diversity. I examined the effectiveness of 3 control measures in discrete stands of European Common Reed along the perimeter of a small urban New England saltmarsh. Cutting, cutting plus application of an herbicide, and increasing salinity via excavation to reduce elevation along with ditching to enhance tidal flow into the marsh, were compared. I measured culm heights as a measure of plant vigor over a period of 15 years. Three years of cutting culms, with or without treatment with the organic herbicide Burn-Out II®, was not a successful control. The only moderately successful control (2–26% reduction in height) involved increased inundation with seawater, which increased salinity by 33%. Any excavation of a European Common Reed stand should include precautions to avoid establishing a new stand in the spoils dewatering area.

Introduction

Phragmites australis (Cav.) Trin. ex Steudel (formerly *Phragmites communis* Trin.) (Common Reed) is a perennial grass found in and around saltmarshes, lakes, ponds and rivers on every continent except Antarctica and is said to have the widest distribution of any flowering plant (Tucker 1990). The native subspecies *Phragmites australis* ssp. *americanus* Saltonst., P.M. Peterson & Soreng (American Common Reed; Lindsay et al. 2023, Saltonstall et al. 2004, USDA NRCS 2024) has been present in the southwestern United States for at least 40,000 years (Hansen 1978) and along the Atlantic and Pacific coasts for several thousand years (Goman and Wells 2000, Niering et al. 1977, Orson 1999). *Phragmites* was considered to be rare or uncommon (Dame and Collins 1888, Macoun 1883, Torrey 1843, Willis 1874) until the early 1900s when its distribution and abundance increased dramatically, especially in association with Atlantic coastal saltmarshes. The rapid spread of *Phragmites* during the past century has likely been due primarily to the introduction of a non-native Eurasian lineage (haplotype M), probably from the United Kingdom (Mozdzer and Zieman 2010, Plut et al. 2011) sometime in the early 1800s along the US central Atlantic coast (Saltonstall 2002). Roads and anthropogenic modification of coastal marshes has produced conditions conducive to the establishment and expansion of invasive *Phragmites* (Bertness et al. 2002, Brisson et al. 2010, Jodoin et al. 2008, Minchinton and Bertness 2003, Roman et al. 1984). Invasive *Phragmites australis* ssp. *australis* Trin. ex Steud. (European Common

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Manuscript Editor: Thomas Trott

Reed) haplotype M has mostly replaced the native *P. australis* ssp. *americanus* haplotype F (League et al. 2006) in New England saltmarshes (Mozdzer and Zieman 2010, Saltonstall 2002), although small populations remain in each state (Lambert and Casagrande 2006; Native Plant Trust 2024; Payne and Blossey 2007; R. Rozsa, Coastal Ecologist, Ashford, CT, pers. comm.; Saltonstall 2011). Hereafter, *Phragmites* refers to the invasive subspecies *P. australis* subsp. *australis*.

In the northeastern US, *Phragmites* seeds are produced in late summer to early fall and are released from the dead but still standing culms between November and January (Marks et al. 1994). *Phragmites* can reproduce by seed, but the germination rate is very poor (~10%) and does not occur under more than 5 cm of water or in water of salinity greater than 20‰ (Haslam 1971, Marks et al. 1994, Tiner 1998). Most reproduction and expansion is through vegetative fragments and rhizomes (Bart et al. 2006). The species is especially efficient at colonizing newly disturbed areas such as created during road or other construction activities. *Phragmites* forms dense monoculture stands of culms that may reach 4 m in height in optimal conditions. A stand spreads primarily through horizontal rhizomes that live for 3–6 years and may be as deep as 2 m or more below ground, making eradication of an established population extremely difficult. Rhizomes can grow up to 10 m (30 ft) per year in nutrient-rich sites but in most cases, growth is 1–2 m (3–6 ft) annually (Tiner 1998).

In some parts of the world, particularly in Europe, *Phragmites* is considered to be a beneficial species with many economic uses, including as a stabilizer of river and canal banks, as a source of cellulose and pulp in paper and textile industries, as fuel, as cattle fodder, in the production of writing pens, sandals and musical instruments, as roof thatch, and as an additive to concrete (Brown 1981, De la Cruz 1978, Haslam 1972, Kankiliç and Metin 2020, Machaka et al. 2022, Tiner 1998). Ecologically, *Phragmites* provides habitat for some species of invertebrates, birds, mammals, and fish (Tiner 1998, van der Werff et al. 1987, Weis and Weis 2003). *Phragmites* is capable of attenuating wave action in storms (Ludwig et al. 2003, Sheng et al. 2021), although not as effectively as *Spartina alterniflora* Loisel. (Smooth Cordgrass; Coleman et al. 2023), and provides some resiliency to sea-level rise through sediment accretion (Rooth and Windham 2000), although Karstens et al. (2016) found that sediment accretion among *Phragmites* culms was insufficient to keep up with sea-level rise. The species also acts as a sink to sequester blue carbon, heavy metals, nitrogen, and various micropollutants (Kiviat 2013, Lei et al. 2022, Milke et al. 2020, Windham et al. 2003). While *Phragmites* can be beneficial under certain conditions, in the United States, most consider *Phragmites* to be a harmful invasive species whose dense monoculture stands greatly reduce species diversity (Chambers et al. 1999, Hejda et al. 2009, Marks et al. 1994, Meyerson et al. 2009). Additional detrimental considerations include potential as a fire hazard and reduction in recreational activities and views from nearby properties. The consensus is that invasive *Phragmites* is a species that should be controlled if not eradicated.

Various methods are employed in attempts to control *Phragmites* (see Cross and Fleming 1989, Hazelton et al. 2014, Marks et al. 1994, Tiner 1998, and van der Werff et al. 1987 for reviews of management methods). Several methods involve the removal of the aboveground vegetative culms by cutting, mowing, burning, pulling, or grazing (Carlson et al. 2009). This approach has the immediate benefit of eliminating the dense stand, thereby allowing sunlight to reach the ground, which promotes the growth of other more desirable plants. If the aerial vegetation removal continues for a sufficient number of years, the deprivation of photosynthesis reduces the stored nutrients in the rhizomes to the point when new sprouts are not possible (Marks et al. 1994). Various herbicides such as glyphosate (e.g., Rodeo®, RoundUp®), imazapyr (e.g., Habitat®), and glufosinate (e.g., Ignite®) have been used to treat *Phragmites*, often in conjunction with cutting because herbicides are more effective when applied to the cut ends of culms (El-Tokhy 2018, Lombard et al. 2012, Monteiro et al. 1999, Moreira et al. 1999, Mozder et al. 2008). Toxicity to nearby plants, as well as wildlife, including humans, presents some environmental concerns in the use of these various herbicides, and long-term efficacy (>3 years) requires reapplication (Moreira et al. 1999, Warren et al. 2001).

Another means of suppressing *Phragmites* is to increase the salinity of the groundwater. Hydrology alteration to increase salinity has been shown to decrease *Phragmites*, thereby allowing recolonization by other saltmarsh plants, and is therefore an important method for saltmarsh restoration. Populations of *Phragmites* that have become established on tidally restricted saltmarshes may not be able to remain viable with the reintroduction of tidal flow and the resulting increase in salinity (Buchsbaum et al. 2006; Karberg et al. 2015, 2018; Marks et al. 1994; Sinicrope et al. 1990; Smith et al. 2008), although Burdick and Konisky (2003) found that *Phragmites* can survive across a wide variety of flooding and salinity conditions, with culm growth reduced but not halted in a salinity regime of 30‰. Established plants with well-developed rhizomes that can access groundwater can survive surface salinities up to 45‰, while juvenile *Phragmites* usually don't survive salinity greater than 20‰ (Chambers et al. 2003, Lissner and Schierup 1997). Salinity tolerances apparently vary from population to population, but groundwater above 20‰ generally reduces plant vigor, resulting in stunted culms (Kim et al. 1985, Tiner 1998, Tucker 1990).

There is no single control measure considered to be the best in all situations. In this study, I compared the effectiveness of 3 out of many possible *Phragmites* control measures in a small urban New England saltmarsh. In isolated stands of *Phragmites* along the perimeter of the marsh, I compared cutting, cutting plus application of an herbicide, and increased seawater inundation via excavation to reduce elevation along with ditching to enhance tidal flow into the marsh. I made further observations with stands in an area where excavated spoils were dewatered before removal, in the mid-marsh area, and at a nearby reference (control) stand where no activity occurred.

Methods

Study site

In 1966, the City of Salem, MA, developed Pickman Park, a small playground and beach area on Salem Conservation land along the tidal Pickman River tributary to the Forest River that drains into Salem Harbor. The river was widened, and sand was brought in to create a small beach for swimming. A concrete retaining wall was constructed to prevent the small (~ 0.25 ha) triangular-shaped herein named Pickman Park saltmarsh (42°29'45"N, 70°53'24"W) opposite the beach from encroaching into the widened river (Fig. 1). Eventually Smooth Cordgrass colonized the area in front of the wall and the river silted in to become unsuitable for swimming (Warren 2006).

The concrete wall prevented saltwater from reaching the small saltmarsh except when it was overtopped due to extreme spring high tide or storm events. As a result, the saltmarsh vegetation was replaced by freshwater/brackish plants, including *Phragmites*. Salem attempted to restore the saltmarsh in 2003 by cutting 2 openings in the wall and digging a U-shaped ditch around the perimeter of most of the marsh area (the solid black line in Fig. 1), thereby allowing salt water to flow through the wall openings into the ditch and onto the marsh surface during normal high tides. The ditch did not completely enclose the northeast corner of the marsh because that section is privately owned and not Salem Conservation property. In addition to the ditch, a small (~25 m^2) panne was constructed within the southern half of the marsh, allowing for the retention of saltwater during low tide to provide habitat for small fish and invertebrates. The result was a marked reduction in *Phragmites* and freshwater vegetation throughout the marsh area that was surrounded by the ditch and a re-colonization by typical New England salt marsh plants. By 2005, the salt marsh

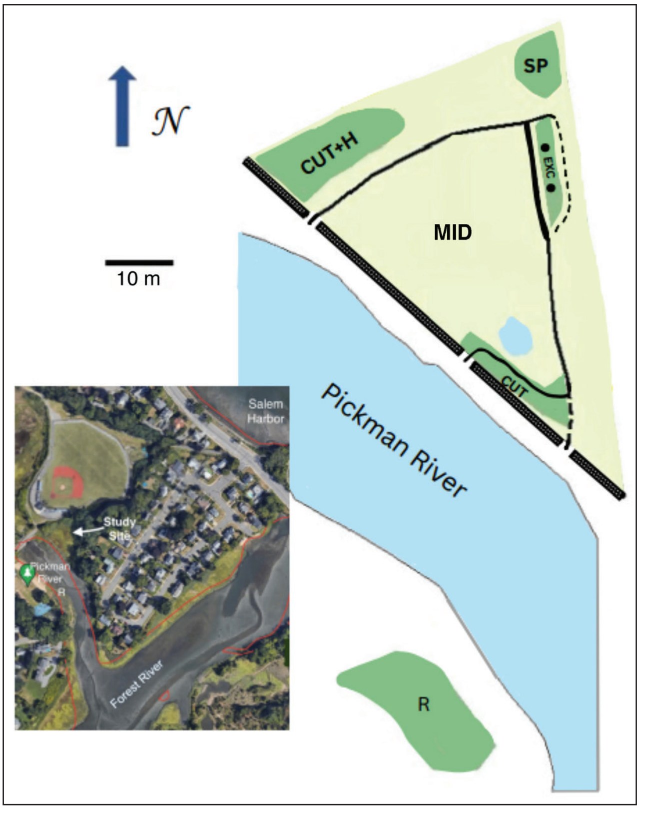

Figure 1. Sketch map of Pickman Park salt marsh study site in Salem, MA. Thick,straight black line = concrete retaining wall. Solid black line = 2003 ditch. Dashed black lines = ditch sections added in 2007. Yellow-green area = main salt marsh. Darker green patches = *Phragmites* stands; EXC = excavated area; CUT = cut only; CUT+H = cut plus herbicide; SP = former spoils dewatering area; MID = mid-marsh area; R = reference (control) stand. Black dots in EXC area are groundwater salinity wells. Blue area within salt marsh = man-made panne. Inset shows study site relationship to Pickman and Forest tidal rivers and proximity to Salem Harbor.

had been largely restored. Individual *Phragmites* culms were scattered across the mid-marsh area (henceforth referred to as MID) but were generally greatly reduced in height and did not flower and produce seeds. There remained, however, 3 dense stands of *Phragmites* near each of the 3 corners of the marsh.

Stand treatments

I compated different potential control measures in the 3 isolated *Phragmites* stands in the Pickman Park saltmarsh. Each stand was either cut, cut and sprayed with an herbicide, or excavated to increase seawater inundation.

A local non-profit environmental NGO, Salem Sound Coastwatch (SSCW), obtained funding from the Gulf of Maine Council on the Marine Environment – NOAA Habitat Restoration Partnership Habitat Restoration Grants Program to attempt further restoration of the Pickman Park marsh by eliminating or reducing the remaining stand of *Phragmites* located outside the ditch in the northeast corner of the marsh. In 2007, under the direction of SSCW, the City of Salem cut an additional opening in the south end of the concrete retaining wall to provide a more direct connection to the 2003 ditch. In addition, SSCW obtained permission from the landowners and contracted with Geoff Wilson of Northeast Wetland Restoration in Berwick, ME, to dig a new ditch around the privately owned northeast parcel out to the edge of the marsh and to connect the new concrete wall opening to the existing ditch (indicated by dashed lines in Fig. 1). The Massachusetts Department of Environmental Protection denied a request to fill in the sections of old ditch that were no longer necessary, which resulted in the creation of a small island between the original and new ditch sections in the northeast corner (area henceforth referred to as EXC). This new island area surrounded by old and new ditching was excavated to a depth of ~30 cm to provide greater saltwater inundation and retention.

Excavated spoils were deposited outside the ditch on higher ground just north of the northeast corner. After several months of dewatering, the spoils were trucked off-site for disposal. Enough rhizome material remained in the spoils dewatering site, however, to allow a new stand of *Phragmites* to become established (henceforth SP). This area rarely if ever experiences saltwater and, in fact, gets extra freshwater runoff drainage from Salem State University's artificial turf baseball field a few meters to the north (Fig. 1 inset map).

I decided to take advantage of the opportunity to explore with my students 2 different control treatments on the *Phragmites* stands located at the northwest and south corners of the marsh. Salem State University students were hired to cut the culms at ground level with a gas-powered weed-wacker. The stand at the south corner (henceforth referred to as CUT) was cut biweekly during the growing seasons between May 2007 and August 2009.

The stand at the northwest corner outside the ditch and on somewhat higher ground does not experience saltwater except for short periods of time during extreme high king tides or storm events. This stand was similarly cut biweekly from May 2007 through August 2009 but in addition the cut ends were sprayed, using an ordinary 2-gallon pump sprayer, with an organic herbicide, Burn-Out II® (active ingredients: citric acid 11%, clove oil 6.5%, and sodium laurel sulfate 3%;

inert ingredients: mineral oil, lecithin and water; St. Gabriel Organics, Orange, VA; henceforth this stand is referred to as CUT+H). Burn-Out II® is one of several safe, non-toxic herbicides widely used to kill non-selective broadleaf and grassy weeds in areas where people and animals may be present. Bi-weekly applications of Burn-Out II® alternated between full-strength "Ready-To-Use" herbicide or a 50:50 dilution with vinegar (5% acetic acid) per manufacturer's suggested use protocols. Applications only occurred under calm conditions (wind speeds under 5 mph) to avoid herbicide blowing onto other vegetation or open water.

I chose a well-established *Phragmites* stand on the opposite riverbank ~50 m downriver as a reference (control) stand (henceforth R) because it is close in distance to the study site so is subjected to the same weather conditions. This stand is situated along the bank of the Pickman River but is not associated with a saltmarsh. It extends from the high tide line upland ~20 m, and most of it does not experience saltwater except for short periods during king tides or storm surges. It is, therefore, most similar in hydrology to the SP and CUT+H stands and less similar to the EXC and CUT stands and the MID area. R is comparable in area (~100–150 m^2) to the 3 stands subjected to treatments (CUT, CUT+H, EXC) as well as to the MID area and SP stand.

Prior to excavation work I installed 2 groundwater salinity wells in the area to be excavated (indicated by black dots within EXC in Fig. 1) so changes in salinity could be measured. Wells were constructed of 2.5-cm–diameter PVC pipe with several 6-mm holes drilled in the bottom 5 cm and covered with geotextile fabric secured with duct tape. I inserted the pipes into holes 45–50 cm deep in the marsh surface created by extracting a small core of marsh sediment with an auger. I packed extracted sediment around each pipe to fill any gap between the well and the intact marsh. I placed an inverted "U" pipe on the top end of the vertical pipes to keep rainwater and surface water out. To sample for salinity, I detached the U cover, drew water from the bottom of each well weekly or biweekly throughout the summer months (May through September), and measured salinity with a refractometer (Model RF20 ATC Portable Salinity Refractometer; Extech Instruments, Nashua, NH). I took measurements in 2006 prior to excavation and in 2008–2010 following excavation. No measurements were taken during excavation in 2007 and, unfortunately, salinity readings were discontinued after 2010 due to lack of funding, vandalism, and logistic issues. I combined salinity readings for the 2 wells because they are in close proximity (~10 m) to each other. I compared combined means between 2006 (prior to excavation work and 2010 (last year of readings) and between 2008 and 2010. I used Welch's *t*-test to compare pre- and post-excavation salinity because the number of data points and variances were different among the 4 years.

Monitoring

The original grant proposal called for monitoring of results in the excavated area (EXC) for 2–3 years post-treatment to evaluate the effectiveness of the attempted *Phragmites* eradication. I continued monitoring, with the assistance of Salem State University students, culm heights in the EXC stand and in the other treated stands

(CUT and CUT+H) as well as SP, MID and R for a total of 15 years. I herein assumed that *Phragmites* culm height correlates with plant vitality and overall health and robustness of the population within a stand and use it as an indicator of overall vigor (Buchsbaum et al. 2006, Carlisle et al. 2002). I measured the height to the nearest whole centimeter from ground surface to tip of inflorescence of 20 of the tallest culms (chosen by visual identification by a person outside the stand) at the end of the growing season each year (sampling dates varied from late August to mid-October) from 2005, prior to the excavation and cutting efforts, through 2023. In MID, culms lacked inflorescence, so measurements were to the tip of the plant.

Data analysis

I used Student's *t*-test (paired, 2-tailed) to compare mean heights between 2005 and 2023 for each of the *Phragmites* stands/areas. I performed additional statistical analyses using JMP Statistical Software Version 17.1.0 (SAS Institute, Inc., http://www.jmp.com) to compare mean heights among all of the *Phragmites* stands/areas for 4 years: 2005 (prior to any management activity), 2011 (4 years after the excavation work and 2 years after the cessation of cutting), 2017 (after another 6-year interval) and 2023 (the final year of measurements after another 6-year interval). Evaluating only the data from 4 rather than 19 years reduced the number of statistical tests needed from over 250 to a more manageable 60 and is still representative of the overall results of the treatments. Initial data exploration involved descriptive statistics and visualization to assess the distribution and variability of the data. To evaluate the overall differences among stands with different treatments, I conducted a one-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference (HSD) test to identify significant differences between pairs of stands and treatments.

Results

Vegetation

After the concrete retaining wall was breached and the encircling ditch was dug in 2003, there was an overall decrease in the abundance of *Phragmites* and other plants that are non-native to saltmarshes within the Pickman Park saltmarsh area. The dominant species throughout the marsh now (as of 2023) are *Spartina patens* (Aiton) Muhl (Saltmeadow Cordgrass) and *Distichlis spicata* (L.) Greene (Desert Saltgrass), with large patches of *Juncus gerardii* Loisel. (Saltmeadow Rush) and small patches of *Salicornia* spp. (glassworts) within the MID area. In addition, Smooth Cordgrass is abundant within the ditch and around the panne and *Iva frutescens* L. (Jesuit's Bark) is common in both the northwest and northeast corners of the marsh and to a lesser extent in the south corner. Occasional specimens of *Atriplex cristata* Humb. & Bonpl. ex Willd. (Crested Saltbush), *Limonium carolinianum* (Walter) Britton (Carolina Sea Lavender), *Suaeda maritima* (L.) Dumort. (Herbaceous Seepweed), and *Solidago sempervirens* L. (Seaside Goldenrod) are now found along the marsh borders, either along the concrete wall or along the edge of the ditch.

As of 2023, *Phragmites* is the dominant species within all of the stands outside the central marsh area. Terrestrial grasses and bare ground occupy the remaining space among the *Phragmites* culms. *Phragmites,* which was common prior to 2003, is now absent from the central marsh area, and there are only 20–30 culms scattered about the outer edges of the MID. *Phragmites* is still common but not dense in the outermost 3–5 m in the northeast and northwest corners of the marsh, probably resulting from encroachment via rhizomes from the EXC and CUT+H stands outside the ditch. These encroaching culms were not measured or included in the MID data because they are on the marsh fringe, not in the central section.

***Phragmites* culm heights**

See Figure 2 and Appendix A for yearly means and standard deviations.

Untreated areas. From 2005 to 2023, the mean height of 20 of the tallest *Phragmites* culms in R increased 11.8%, a significant change (t = 5.4, P < 0.0001). The 19-year mean during this period was 249 cm, with the tallest culm measured in this stand being 334 cm in 2021.

The mean height of 20 *Phragmites* culms (which represents almost all of the culms present) in the MID enclosed by the original 2003 ditch decreased 17% between 2005 and 2023, which is statistically significant (t = 4.6, P < 0.001). The MID mean height is always significantly (P < 0.001) less than that of every other *Phragmites* stand during each of the 4 years evaluated with individual pairwise comparisons.

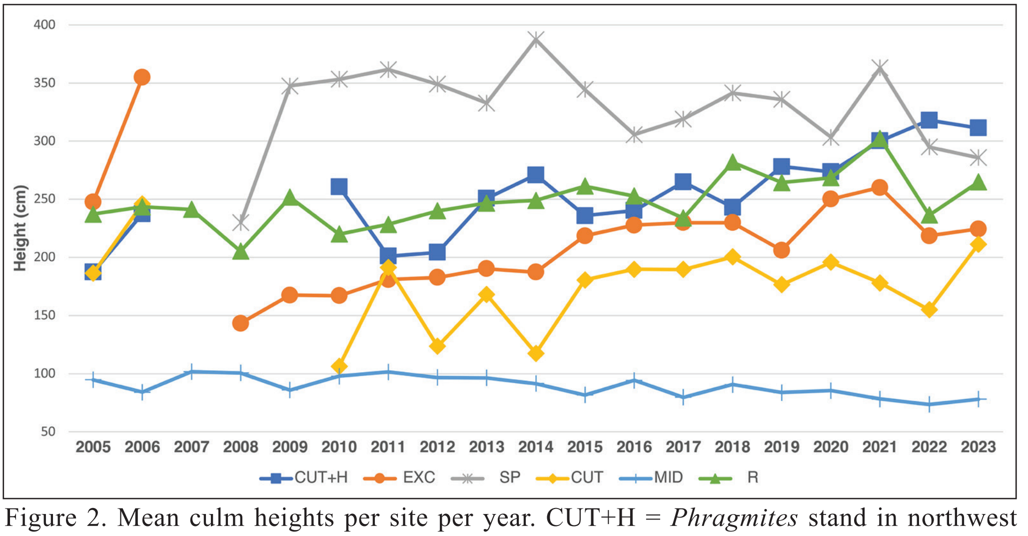

Figure 2. Mean culm heights per site per year. CUT+H = *Phragmites* stand in northwest corner cut plus herbicide application; CUT = stand in south corner cut only; EXC = northeast corner excavated in 2007 to create island with increased seawater inundation; SP = area where excavated spoils were dewatered prior to off-site disposal; MID = middle area of marsh surrounded by original perimeter ditch; R = nearby reference site where no activity occurred. No data collected in EXC in 2007 while excavation work was being performed. Culms in CUT+H and CUT stands were cut during 2007–2009. SP did not exist prior to 2008.

Areas subjected to various treatments. In 2005, prior to cutting, the average height of culms in what later becomes CUT was not significantly different from CUT+H. The mean height in CUT was lowest in 2005, increased in 2011 to where it was actually greater (but not significantly) than EXC and not significantly different from CUT+H. Since then, the mean heights in CUT have remained less than all of the other stands (except the culms in MID) until 2023 when the mean was not significantly different from EXC. Despite the increase in 2023, the mean height of CUT is still 1.4% less than in 2006 before treatment, a difference that is statistically significant ($t = 3.4$, $P < 0.01$).

Following treatment in 2007, 2008 and 2009, the mean height in 2010 of CUT+H was 23% greater than before treatment. The CUT+H mean decreased in 2011 and 2012 but then increased and remained relatively constant until it increased again in 2021, 2022 and 2023. Throughout that time, the mean heights averaged 216 cm and have been greater than CUT and EXC as well as MID. The means were similar to R and less than SP until 2022; they now exceed both R and SP. The mean height of CUT+H culms pre-treatment in 2005 is significantly different from the height in 2023, ($t = 16.6$, $P < 0.0001$), but the difference is an increase of 33% rather than the decrease intended from treatment.

In 2008, immediately after excavation and trenching, the average height in EXC was 52% less than pre-treatment height in 2006. In 2011, EXC was not quite significantly different from CUT+H ($P = 0.06$). There has been a 26% reduction in height from pre-treatment in 2005 compared to 2023, a difference that is statistically significant ($t = 4.6$, $P < 0.001$).

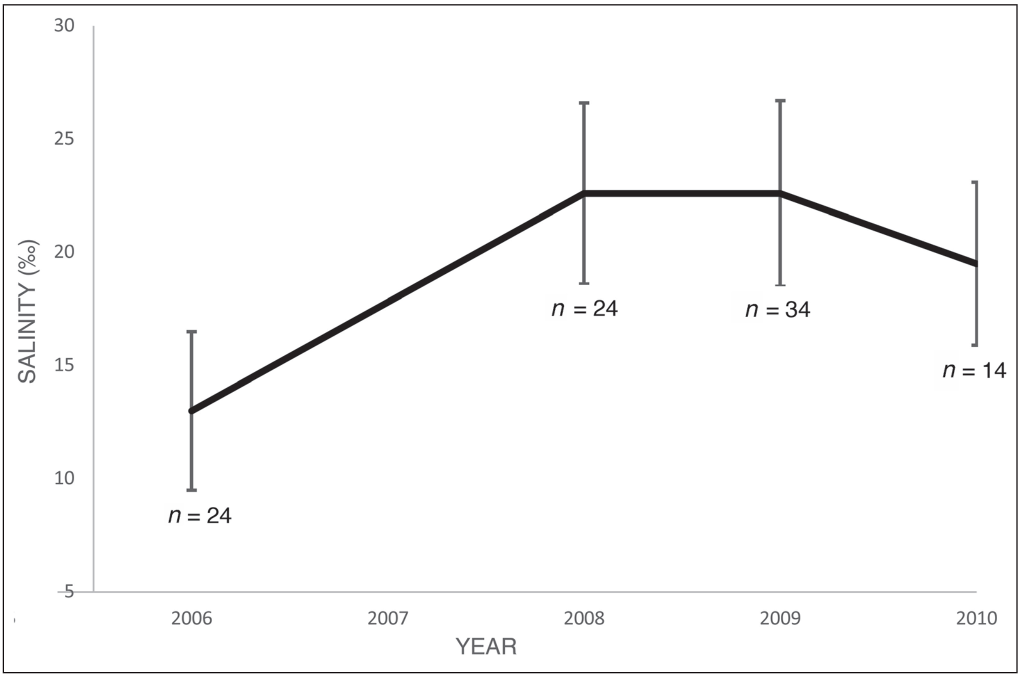

Figure 3. Salinity (‰) means with standard deviation bars per year for 2 groundwater wells combined in EXC area. No measurements were taken in 2007 during excavation.

In SP, the average height in 2008, the first year after the removal of deposited spoils, was 230 cm, then increased dramatically in the following year (2009) and has remained high ever since, with an overall average of 328 cm from 2009 through 2023. The tallest culm recorded during the entire study period was 488 cm in SP in 2014, a height considerably greater than the ~4 m generally considered to be maximum for *Phragmites* in optimal conditions. The SP mean heights are different from every other stand in all years and are the highest overall except in 2022 and 2023 when CUT+H had the greatest mean height. These two stands, CUT+H and SP, have now merged into a single large stand along the northern edge of the marsh, although culm density is greatest in the original CUT+H and SP areas.

Salinity

There was a significant increase of 74% in mean summer pore-water salinity measured in 2 wells located in EXC between 2006 (prior to the excavation work) and both 2008 and 2009 (Welch's *t*-test: $t = 4.9$, $P < 0.001$). Although there is a significant 14% decrease in salinity between 2009 and 2010 ($t = 2.64$, $P = 0.01$), the 2010 mean value is still significantly higher, by 33%, than the mean in 2006 prior to excavation ($t = 3.14$, $P = 0.003$) (Fig. 3).

Discussion

The original breaching of the concrete retaining wall and construction of a perimeter encircling ditch in 2003, resulting in inundation with seawater at every high tide rather than just during king tides and storm events, successfully controlled *Phragmites* on the open MID marsh, initially resulting in scattered short culms without seed development and ultimately in elimination of reeds altogether by 2023.

In the CUT area, *Phragmites* culm heights rebounded within 1–2 years after the cessation of cutting but have never quite reached 2006 pre-treatment values. The reduction in photosynthesis for 3 years apparently is not sufficient to completely deplete the energy reserves in the rhizomes and they were readily able to sprout new shoots after cutting ceased. The small but statistically significant reduction in height from 2010 through 2023 is more likely due to the increase in seawater attributable to the additional concrete wall opening rather than to the cutting treatment. With the more direct linkage to the ditch, seawater is able to enter the marsh in this area quicker and persist longer during high tides. This somewhat increased seawater inundation could be what is responsible for the reduction in culm heights.

Cutting plus the application of the herbicide Burn-Out II® in CUT+H had no long-term effect on height or seed production, with culms not just returning to pretreatment conditions but actually showing a significant increase in height, further evidence that cutting probably was not responsible for the height reduction observed in CUT. Herbicides such as glyphosate, imazapyr and glufosinate have been shown to effectively control *Phragmites*, although repeated applications over time usually are required (Cross and Fleming 1989, Derr 2008, El-Tokhy 2018, Kay 1995, Lombard et al. 2012, Moreira et al. 1999, Warren et al. 2001). Restrictions imposed by the local Conservation Commission prevented the use of these herbicides in this project, necessitating the use of a more environmentally friendly organic herbicide, Burn-Out II®. Burn-Out II® is promoted as a spot treatment for annual and perennial broadleaf and grassy weeds growing in patios, driveways and sidewalks and around buildings, trees and fences. Common Reed is not on the "typical weeds controlled" list offered by the manufacturer and there is no claim or indication that it would work on such a tough plant as *Phragmites*. Therefore, Burn-Out II® should not be used in an attempt to control *Phragmites*. It is entirely possible that cutting plus herbicide could be a useful control treatment if one of the known effective herbicides is used and treatment is continued over a longer period. Such an experiment would be a good topic for a future study. It is also important to note that, unlike the CUT stand, the CUT+H stand experienced no seawater inundation, further supporting the speculation that the reduction in culm heights in CUT may have been due more to increased seawater than to cutting.

The excavation of an outer ditch extension combined with a reduction in marsh surface elevation resulted in an area (EXC) that allowed for inundation with seawater at every high tide. For several years following treatment, the height of culms was reduced by 47–60%. Eight years after treatment, mean culm heights began to increase, but the heights are still 30–40% less than before excavation. The more recent increase in height may very well be due to the ditch extension becoming filled in, making the excavated area again contiguous with surrounding upland and therefore exposed to more freshwater input. The reduced elevation still allows for seawater to remain longer, however, and the culms in EXC continue to be shorter than those in the untreated SP and R stands, as well as in the CUT+H stand. Only the CUT stand and the scattered culms in the MID area are shorter. Soon after excavation, the groundwater salinity was measured to be greater than 20‰, a value commonly associated with increased stress and decreased vigor in *Phragmites* (Burdick et al. 2001, Chambers 1997, Roman et al. 1984). Presumably the increase in seawater inundation in EXC is responsible for the reduction in culm height in the EXC area.

The most prolific growth and tallest *Phragmites* culms are now found in the former spoils dewatering area (SP). *Phragmites* did not exist in this area prior to deposition and dewatering of the excavation spoils for several months. Apparently, remnant pieces of rhizomes left after removal of the spoils for disposal off-site allowed the establishment of a new and flourishing stand. SP has now merged with the CUT+H stand to create a single stand across the entire northern area outside the ditch. The culms in SP are taller, by 10–20%, than even in R where no treatment activity occurred. This former spoils dewatering area is outside the ditch and at somewhat higher elevation than the marsh and so experiences no seawater, even during extreme high tides, whereas R is at the edge of the Pickman River and so may experience seawater inundation during exceptional spring high tides and storm events. In addition to direct rainfall, SP receives drainage from the Salem State University artificial turf athletic field located a few meters north and at a higher elevation (see Fig. 1 inset).

Of the methods examined in this study, the only moderately successful controls for *Phragmites* involved increased inundation with seawater, in both the CUT and EXC stands, as well as in the MID area. The most growth occurred in the areas that were the least impacted by seawater (CUT+H, SP, R) while the least growth occurred in the areas that were the most impacted by seawater (EXC, CUT, MID), regardless of any other control measures. Three years of cutting culms with application of the organic herbicide Burn-Out II® was not a successful control.

It should be noted that there are significant limitations to the conclusions possible from this study. It was not designed as a research project. The project began as an attempt to further remediate the saltmarsh by reducing or eradicating a single stand of *Phragmites* in a corner of the marsh. I took advantage of the opportunity to examine with my students 2 additional *Phragmites* control measures in the remaining stands. This study occurred at a single site with no replicates, and each stand has different characteristics, which likely influenced the results. This limitation also pertains to R used as the control stand, which, while similar to and in close proximity, is not identical to any of the stands in the Pickman Park saltmarsh. Despite these limitations, the findings still have value. Burn-Out II® is an herbicide intended for use on broadleaf and grassy weeds and should not be used in any attempt to control *Phragmites*. The only reduction in vigor, as measured by culm height, involves an increase in seawater inundation. Any excavation of a *Phragmites* stand should allow spoils to dewater on a hard surface such as a parking lot or on a tarp to preclude the establishment of a new stand where none existed before. Once established, stands of *Phragmites* are very difficult to eradicate or even control, so the expense and time commitment of any treatment (see Martin and Blossey 2013) should be weighed against the ecological harm caused by the presence of the reeds, especially since there may even be potential benefits.

Acknowledgments

Funding for excavation work and other *Phragmites* control-treatment materials was provided by a Gulf of Maine Council on the Marine Environment -- NOAA Habitat Restoration Partnership Habitat Restoration Grants Program award (Project Award Number NA04NMF 4630224) to Salem Sound Coastwatch (Barbara Warren, Executive Director). Thanks to Paul and Margaret O'Toole for allowing work to be done on the portion of the salt marsh that is their private property. I appreciate the invaluable assistance of Salem State University students Harold Bell, Michael Costello, and James Style for cutting and applying herbicide to *Phragmites* culms during 2007, 2008 and 2009, and to Christopher Cataldo, James Courtemanche, Amanda Cutone, Ryan Gagne, Michael Rolo, Meagan St. Pierre, Rick Theberge, and my many General Ecology students who measured *Phragmites* culm heights. Thanks to Anna Sheridan of SSCW who created Figure 1, and special thanks to James Elliott who performed all of the statistical analyses. Comments and suggestions from anonymous reviewers greatly improved the manuscript.

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Appendix A. Mean ± standard deviation of *Phragmites australis* spp. *australis* culm heights (cm) per stand or area per year. CUT+H = cut plus herbicide; EXC = excavated area; SP = former spoils dewatering area; CUT = cut only; MID = mid-marsh area; R = reference stand.

Year	CUT+H	EXC	SP	CUT	MID	R
2005	187.3 ± 233.0	247.5 ± 21.3[A]	-[B]	186.3 ± 25.1	94.8 ± 16.6	237.2 ± 13.7
2006	237.6 ± 21.0	354.8 ± 23.5[A]	-[B]	246.1 ± 13.2	84.1 ± 9.0	243.4 ± 15.9
2007	-[D]	-[C]	-[B]	-[D]	101.7 ± 7.5	241.3 ± 10.2
2008	-[D]	143.4 ± 13.2	230.0 ± 37.8	-[D]	100.6 ± 9.4	205.3 ± 15.9
2009	-[D]	167.0 ± 9.0	347.5 ± 27.2	-[D]	85.9 ± 11.8	251.8 ± 13.1
2010	260.8 ± 20.7	167.1 ± 14.6	353.2 ± 24.5	106.2 ± 7.6	97.8 ± 10.6	220.0 ± 7.8
2011	201.1 ± 35.3	180.9 ± 14.6	361.6 ± 33.4	191.4 ± 16.7	101.5 ± 14.5	228.4 ± 10.8
2012	204.4 ± 20.9	182.8 ± 24.9	349.0 ± 39.6	123.5 ± 15.7	96.7 ± 13.1	240.0 ± 21.0
2013	250.8 ± 34.2	190.2 ± 14.0	332.7 ± 30.2	168.1 ± 11.5	96.3 ± 12.7	246.8 ± 15.1
2014	271.0 ± 29.5	187.3 ± 23.8	387.5 ± 37.5	117.5 ± 8.6	91.4 ± 13.8	249.0 ± 13.5
2015	235.9 ± 22.1	218.6 ± 17.4	344.4 ± 24.6	180.6 ± 12.3	81.7 ± 20.7	261.2 ± 9.8
2016	240.3 ± 14.4	227.8 ± 13.4	305.6 ± 15.1	189.8 ± 16.4	94.3 ± 14.7	252.7 ± 12.9
2017	264.9 ± 19.5	229.8 ± 18.5	319.0 ± 19.8	189.6 ± 14.9	79.7 ± 14.9	233.8 ± 9.0
2018	243.2 ± 16.4	229.9 ± 7.5	341.5 ± 30.1	200.5 ± 19.4	90.6 ± 15.4	281.9 ± 11.9
2019	278.1 ± 31.0	206.2 ± 9.7	335.9 ± 14.1	176.6 ± 221.6	83.8 ± 12.7	264.4 ± 13.0
2020	273.7 ± 21.6	250.2 ± 19.3	303.4 ± 26.5	195.8 ± 24.2	85.4 ± 14.8	268.4 ± 12.7
2021	300.3 ± 26.4	260.1 ± 6.6	363.1 ± 32.8	178.1 ± 14.6	78.2 ± 11.6	302.5 ± 13.9
2022	318.0 ± 13.6	218.5 ± 8.4	295.0 ± 15.4	155.1 ± 18.2	73.5 ± 13.8	236.4 ± 11.3
2023	311.4 ± 17.8	224.4 ± 5.1	285.8 ± 18.1	211.3 ± 30.1	78.1 ± 10.4	265.0 ± 22.0

[A]Pre-island (island created in 2007).
[B]Spoils area did not exist prior to 2008.
[C]Excavation in 2007.
[D]Culms cut 2007–2009.