Arum italicum

“Glyphosate and Tarping Treatment Trials in a Greenhouse Setting

And

Seattle Distribution in 2016”

(Boyce 1993)

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I'd like to thank

1. Introduction

1.1 Plant Invasions

Humans have been moving plant species throughout history. As humans have spread across the landscape they have brought with them crops, medicines, and ornamental plants they were familiar with in order to provide security in new regions of the world (Myers and Bazley 2003). In more modern times plants have also been moved on the landscape to provide additional services such as soil stabilization (Myers and Bazley 2003). While many of these plants are incapable of surviving outside of cultivation, a portion of them naturalize and then become problematic enough to be listed as a pest or weed by a government agency (Myers and Bazley 2003).

Species listed as pests or weeds by government agencies are commonly called noxious weeds or invasive species. The bureaucratic mechanisms for listing vary by state, but the reasons tend to be consistent. The Washington State Noxious Weed Board describes a noxious weed as "… any invasive, non-native plant that threatens agricultural crops, local ecosystems, or fish and wildlife habitat" (WSNWCB 2010). These plants cause these effects through the reduction of native plant populations and consequently can change the ecosystem services provided by that ecosystem to humans and wildlife (Leslie and Westbrooks 2011).

The impacts of non-native plants on crop species, on ecosystems, and the benefits those ecosystems provide to human communities are the primary driver for seeking ways to control them. In the United States introduced plant species account for $23.4 billion in annual crop losses (Meyers and Bazley 2003). Furthermore, the estimated costs of all invasive species in the United States is $125 billion (Meyers and Bazley 2003). Estimates of this sort are referred to as hedonistic pricing (Reichard 2014). These estimates are difficult to establish because so many of the impacts are not derived from the direct costs of management, control, or the loss of market goods (Reichard 2014).

Plant invasions cause many indirect costs that are less easy to determine. The losses of biodiversity and ecosystem function are real but have no established value in a market. Furthermore, plant invasions also can cause increased rates of illness in humans, damage to property and infrastructure, damages to water quality and quantity, and impact the severity of disturbance regimes. Hedonistic pricing can provide a cost to associate with the invasions based on property values and how they change in the presence of intact ecosystems or invaded ecosystems (Reichard 2014). Contingent valuation can also provide an estimate for these impacts based on the amount of money residents in an area are willing to pay for an intact ecosystem. Both hedonistic pricing and contingent valuation rely on people to understand an ecosystem sufficiently to place a value on it (Reichard 2014).

Furthermore, there are intrinsic values to intact native ecosystems. Many species are interdependent and the loss of one can cascade through a system. Also, the importance of a species to ecosystem function is generally not understood until it has been removed. The impacts of an invasive species also may occur in another location in the landscape downhill or downstream of the impacted site. So the values of these ecosystems also include their value to habitats that will be impacted by them (Reichard 2014).

Because plant invasions affect so many ecosystem services and the effects can be broadly distributed, government agencies generally pay the costs of mitigation. This puts the costs of plant invasions on taxpayers. Funding for noxious weed control programs is generally smaller than the scope of the problem. It is therefore important to address new invasions before they actually start (Meyers and Bazely 2003).

Invasive plants have a wide variety of traits that contribute to their ability to establish in new areas and outcompete native plant communities. The traits that help an invasive plant do these things are different depending on the plant. Grime's C-S-R model of plant succession can help to generalize how invaders come to occupy habitats and adjust the trajectory of the habitat (Myers and Bazely 2003). Grimes C-S-R model proposes that plant invasion can be described as a kind of plant succession that is dependent on plant strategies. Strategies can be grouped as those of competitors, stress tolerators, and ruderals (Grime 1979). Ruderals produce large amounts of seed and spread into disturbed habitats (Grime 1979). Competitors grow more vigorously than the other plants around them, replacing them by pushing them out of their habitats (Grime 1979). Stress tolerators move into habitats based on their greater ability to handle a stress such as salt, shade, drought, or other stressors than native species (Grime 1979). Stress tolerant invaders are fairly rare because stress tolerance is generally associated with a slower growth rate (Myers and Bazely 2003).

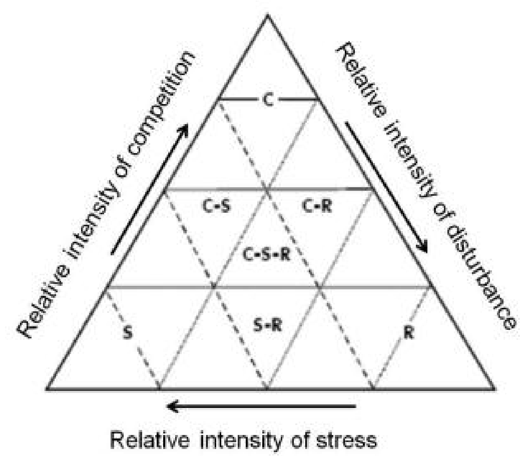


Figure 1: Grime's C-S-R Model of Succession (Grime 1979)

Because plant invasions are a form of succession, examining which category of Grime's C-S-R model a plant occupies can provide insight into possible management options. Ruderals can generally be prevented from establishing by maintaining a robust and diverse native species community or replanting following a disturbance. Competitors are more challenging to control because they can move into established habitats and tend to require more direct removal techniques. Stress tolerant invaders are rare, but can occur in situations where a new stress has been introduced (Meyers and Bazely 2003). In these cases, removal of the new stress, when possible, can help shift conditions back in favor of the native plant.

1.2 *Arum italicum*

1.2.1 Classification

Kingdom: Plantae

Subkingdom: Tracheobionta

Superdivision: Spermatophyta

Division: Magnoliophyta

Class: Liliopsida

Subclass: Arecidae

Order: Arales

Family: Araceae

Genus: *Arum*

Species: *Arum italicum* Mill.

(USDA Plants Database 2016)

1.2.2 *Arum italicum* Distribution

Arum italicum is a perennial forb native to the European subcontinent. Four subspecies are recognized and combined their native range extends from Portugal in the west to Georgia in the East, South to Morocco and Algeria in North Africa, and North to the Southern edge of England (Boyce 1993).

In these regions, *A. italicum* can be found in open woodlands, on the margins of forests, in pastures, and in hedgerows. *A. italicum* grows from sea level up to 3,600 ft of elevation (Boyce 1993)

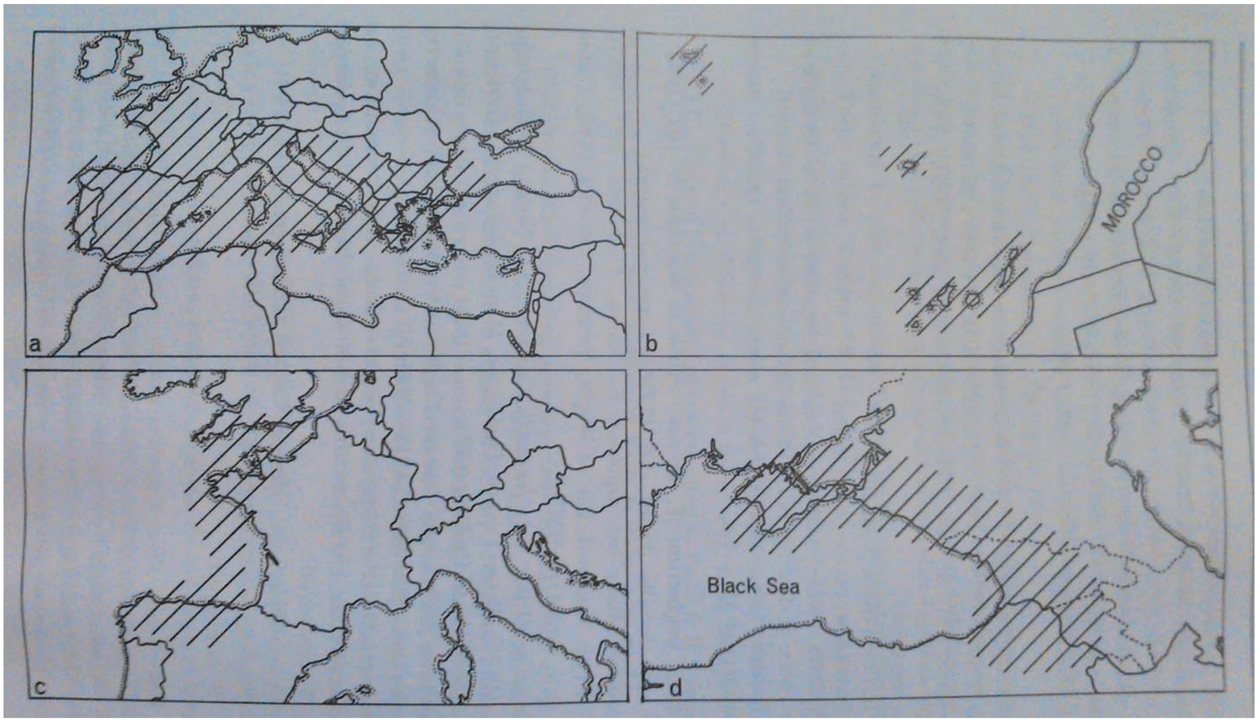


Figure 2: Arum italicum Distribution. a: subsp. *italicum*, b: subsp. *canariense*, c: subsp. *nelectum* d: subsp. *albispathum* (Boyce 1993)

1.2.3 *Arum italicum* Description

Foliar growth initiates in late autumn or early winter from the tuber. This tuber produces the new foliage and also begins the growth of a new tuber. The tuber from the previous year is consumed during this growth. The leaves are up to 16 inches long, 12 inches wide, hastate, and deep glossy green. White variegation is common, although solid green populations occur. Rarely the foliage will be marked by irregular black-purple or silver-gray blotches (Boyce 1993).

Figure 3:(Boyce 1993)

The inflorescence is composed of a spathe, a spathe tube, and a spadix. The spathe and spathe tube surround the spadix. The spathe can grow to 10 inches long. The spathe is greenish white externally and internally a very pale green to white. Both the interior and exterior of the spathe can be flushed with brownish-purple along its margins, midvein, and base. The stamen and pistils are located on the spadix within the spathe tube. The yellow stamen are located higher on the spathe and the green pistils are located near the base. Above the stamen on the spathe sterile stamen called stamenoids. Between the stamen and the pistils are sterile pistils called pistiloides. The spadix can be up to 5.5 inches in length. (Boyce 1993).

*Figure 4:*Adventitious Buds (Mallon 2016)

The roots grow from a horizontal-rhizomatous tuber up to 3 inches long and 1 inch thick. Adventitious buds along the length of the tuber grow into daughter tubers. Two types of roots grow from the tuber, contractile and feeding. The feeding roots grow horizontally and form a dense mat. The contractile roots grow down from the tuber and at the end of the growing season pull the tuber deeper into the soil (Boyce 1993).

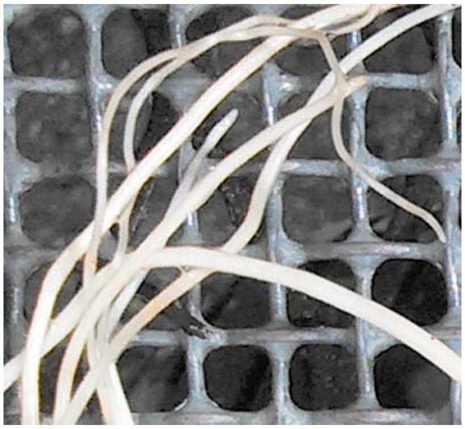


Figure 6: Contractile Roots (Mallon 2016)

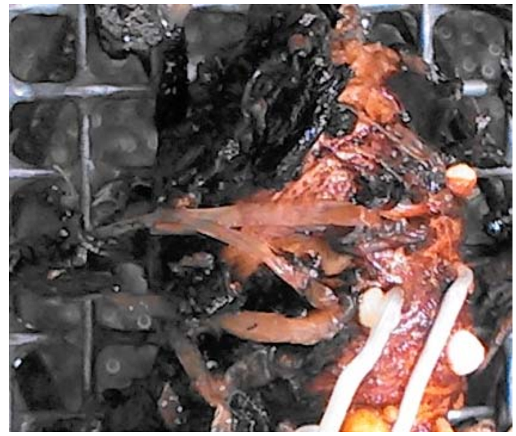
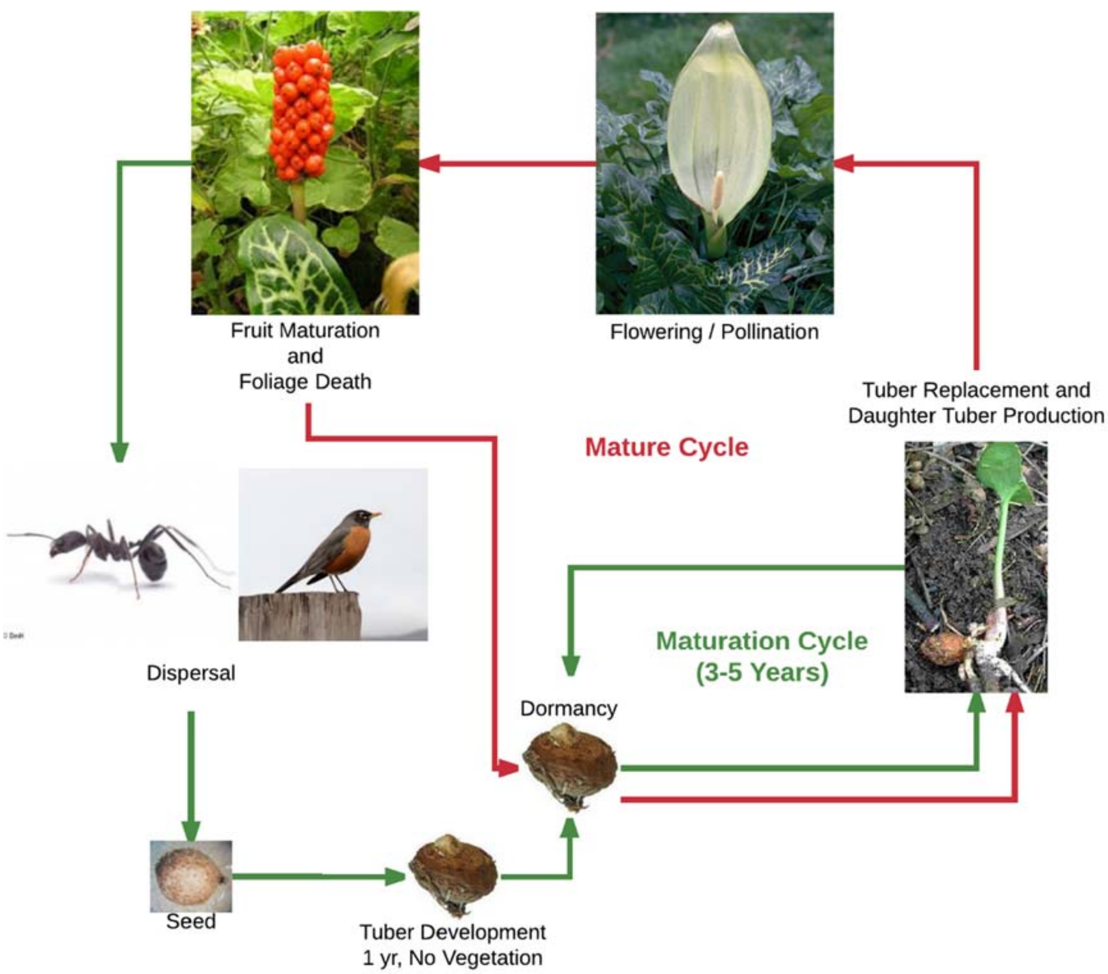


Figure 5: Feeding Roots (Mallon 2016)

1.2.4 *Arum italicum* Life History



Arum italicum seeds are distributed by birds, at least one species of ant, and by falling of the spadix by the parent plant (Baroso et al. 2013). They germinate in the following growing season. The first year is spent producing a tuber while no foliage is produced (Boyce 1993) (Prichard et al 1993).

In the second year, the normal growth cycle begins. At the beginning of this second year the main shoot develops from a terminal bud on the tuber producing the foliage. At this time contractile roots are also produced from the terminal bud growing down into the soil and anchoring the tuber. Once anchored, feeding roots develop (Boyce 1993). While the roots and foliage are forming, a new primary tuber also begins to grow, consuming and replacing the previous year's tuber (Mendez and Obeso 1993). This new primary tuber then also produces additional tubers from adventitious buds along the length of the tuber. This cycle repeats indefinitely (Boyce 1993).

The inflorescence is produced between April and June, depending on sub-species and climate, after reaching a dry tuber mass of at least 2.5 grams (Mendez and Obeso 1993). The stigmas, located near the base of the spadix in a 9-14 mm long cylindrical cluster, mature first followed by the maturation of the stamens, located higher on the spadix in cylindrical cluster 3-6 mm long (Boyce 1993). The maturation of the stigmas coincides with an increase in heat produced by the spadix that increases the volatilization of odiferous organic compounds (Boyce 1993). These provide the scent cue, akin to urine, that attracts insect pollinators. In their native range this is primarily drain flies from the genus *Psychoda*, which is a globally distributed genus (Gibernau et al 2004).

Pollinators are trapped with the mature stigmas in the spathe tube below the pistillodes, which are infertile structures derived from pistils. After the stamens have developed, the pistillodes wilt and allow the pollinators to travel up the spathe tube, through the mature stamens, and out of the spathe to pollinate the next plant (Gibernau et al 2004).

After pollination, the peduncle supporting the spathe undergoes elongation. At the same time, the seeds and fruit develop (Boyce 1993). The fruit are green while ripening, but orange when ripe. Each fruit contains between 2 to 5 seeds within a viscous pulp (Barroso et al 2013). These seeds are distributed by birds and in Spain by an ant, *Aphaenogaster senillis* (Barroso et al 2013).

Figure 7: Arum italicum Mature fruit, close up of fruit, and seeds from one berry. First two images (Ben Legler 2005), right image (WSNWCB 2014)

1.2.5 *Arum italicum* as a Noxious Weed

Outside of its native range, *A. italicum* has naturalized in several areas around the world. Distribution in the United States includes California, Oregon, Washington, Virginia, the District of Columbia, Alabama, Missouri and Illinois (WSNWCB 2014). *A. italicum* has also been listed as a weed in

Australia and New Zealand, and has naturalized in Argentina (Boyce 1993). These populations outside its native range are of ornamental origin.

Arum italicum in New Zealand forms dense cover in open sites often shading out small native plants and preventing their establishment (Weedbusters 2016). It appears to do the same in the Pacific Northwest. Although the patches are generally somewhat diffuse at first, as the density of plants

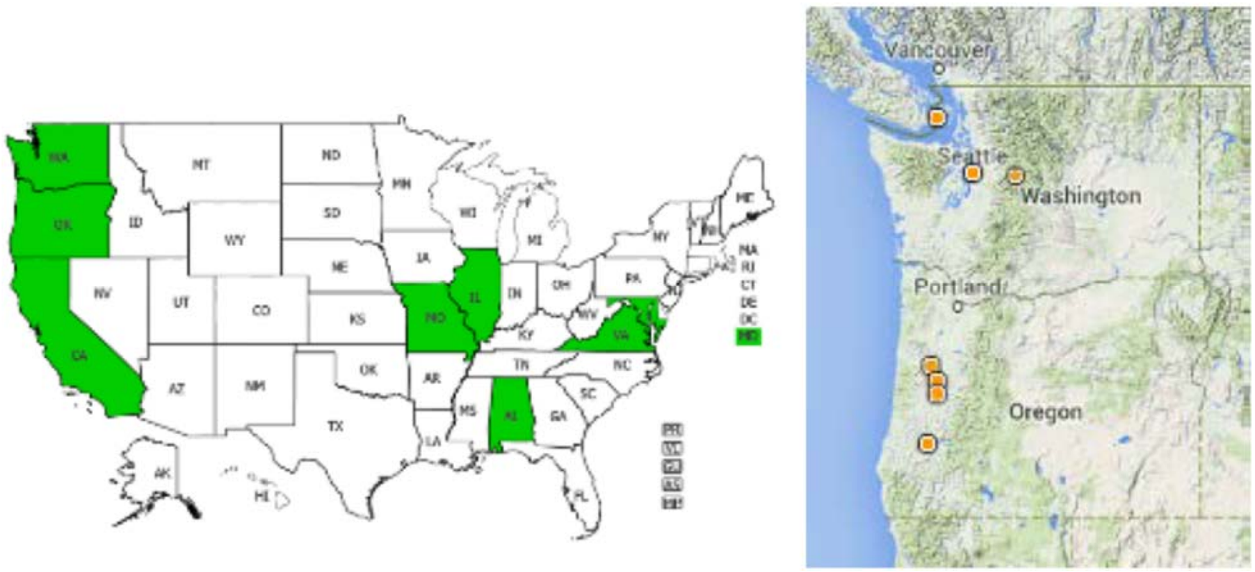


Figure 8: Arum italicum U.S. Distribution (WSNWCB 2014)

increases, no other plants can be seen germinating among them (personal observation). *Arum italicum* also is capable of growing under a wide range of light, nutrient, and moisture conditions. This allows it to grow in open fields, under forest canopies, in swamps, and along riparian areas. The establishment of *A. italicum* in riparian areas was a primary reason for its listing as a Class C noxious weed by the Washington State Noxious Weed Control Board in January of 2015 (WSNWCB 2010).

A Weed Risk Assessment (WRA) conducted by this author reveals several of the traits that make *A. italicum* a strong invader. This WRA emphasized several traits of *A. italicum*'s life history that help to make it a strong invader. One of these traits is its resistance to pests, herbivores, and diseases that that may slow its spread (Appendix A). It is avoided by herbivores due to the calcium oxalate that crystalize in its tissues (Halevy 1983). The only herbivores it does contend with are snails and slugs (Halevy 1983). It is avoided by herbivores in both its native and naturalized ranges.

These features give *A. italicum* some characteristics of a C-type plant (Competitor) by Grime's C-S-R model of succession. The invasion of established understories and subsequent replacement of established species is characteristic of how C-type plants act in succession or invasions. By invading established understories, they also capitalize on an area where other plants have a more difficult time growing. Because they are C-type plants, control methods need to focus on ways to remove it completely from invaded habitats. As a shade tolerant plant, planting shade plants is ineffective for control. Likewise, native competitors have not been capable of crowding out *A. italicum*. Consequently, more direct methods may be needed.

2. Greenhouse Trials

2.1 Introduction

The written findings of the WSNWCB discuss the variety of control methods that have been attempted with *A italicum.* As is usual when discussing control methods, they mention mechanical, cultural, biological, and chemical control methods. Presently the WSNWCB states that control attempts have "…reported little success…" with any of these attempts (2014). *A. italicum*'s vegetative reproduction makes mechanical control variably successful, but it sometimes can simply spread *A. italicum* instead (WSNWCB 2014). Landscape fabric and tarps to shade *A. italicum* are listed as cultural methods but the results of these experiments are still unknown (WSNWCB 2014). There are no biological controls known for *A. italicum* and the only species that seem to feed on them are generalists such as slugs and snails (Halevy 1983).

Attempts at control with chemicals have also been met with limited success. Several groups have attempted chemical control of *A. italicum* including the Washington State University Extension Office, King Conservation District, the Western Invasives Network, and Weed Busters in New Zealand. These trials have included both field treatments as well as greenhouse experiments. The results have been largely unsuccessful as the treated patches in field treatments and the tubers in the greenhouse experiment seem unaffected (WSNWCB 2014).

A few aspects of the chemical and cultural control methods could use closer examination. In the case of the cultural control methods with landscape fabric and tarps, previous field trials have run into confounding factors. Tarping was attempted at the Fisherman's Bay Spit Reserve in WA. In this case deer activity created holes in the tarps which compromised the efficacy of the treatment (Tim Clark, Personal Communication, 4/23/2015). A more controlled environment could answer whether or not this treatment could be effective and provide estimates in how long the treatment would require.

The chemical control methods attempted in the field also could benefit from closer examination. A glyphosate treatment on another patch at Fisherman's Bay Spit Reserve resulted in a lack of seed set (Tim Clark, Personal Communication, 11/19/2015). Another patch that had been treated with glyphosate in Frink Park, Seattle was composed of all small plants the following growing season (Personal observation). Both of these observations imply that there has been some effect. The smaller plants are associated with smaller bulbs (personal observation). Likewise, the lack of flowers or seed on the patch in Fisherman's Bay Spit Reserve also suggests that the bulbs in that patch were below the threshold size for sexual reproduction. This implies that trials in a more controlled environment could help to distinguish what is occurring.

The only previous greenhouse herbicide test this author is aware of tested a variety of herbicides (Tim Miller, Personal Communication, 4/3/2015). These tests examined glyphosate, imazapyr, metsulfuron methyl, triclopyr, clopyralid, and sulfometuron methyl from different products and in different concentrations. After the test, the tubers were examined collectively from all the treatments and many healthy tubers were found. However, the range of effectiveness ranged from 0% regrowth to 50% or more regrowth. So examining the more effective treatments and their effects on tuber size would help to determine exactly how well a specific herbicide reduced tuber growth or viability.

These trials were conducted to test a cultural and a chemical control method in a controlled environment. As a cultural control method, the tarping technique was tested to determine its effect on vegetative regrowth and tuber size. This method was chosen due to its accessibility to homeowners. As a chemical control method, glyphosate at a 2% concentration was tested to determine its effect on vegetative regrowth and tuber size. This method was chosen based on its accessibility to homeowners as well as the 0% regrowth seen in the herbicide trials conducted by Tim Miller.

2.2 Methods:

The greenhouse trials were conducted to test the effects of glyphosate and inorganic mulching by black plastic on *A. italicum* vegetative and tuber growth. It allowed for an assessment of shoot growth and a quantitative assessment of tuber growth in response to each of the treatment types. *A italicum* tubers grown in this experiment were divided into 3 treatments (control, glyphosate, black plastic mulching) in 2 groups to examine the growth differences between the treatments as well as over time. This experiment can be divided into 3 stages: tuber preparation and planting, growth and treatment, and data collection.

2.2.1 Tuber Preparation and Planting:

Tubers were harvested on April 22nd of 2015 by staff at the Washington Park Arboretum in Seattle WA. These were placed in a plastic bag and stored in a refrigerator. On May 5^{th} 2015, 225 tubers from this bag were prepared for planting. All the soil was washed off of the tubers using a wheelbarrow filled with water. The roots growing from the tubers, daughter bulbs growing from lateral buds, and any remaining shoot material were removed from the tubers.

At this point the tubers were divided into 6 separate groups. These groupings represent the two cohorts and the three treatments within each cohort (See Figure 8). The bulbs in each of these 6 groups were then weighed to determine the net mass of the bulbs in each group.

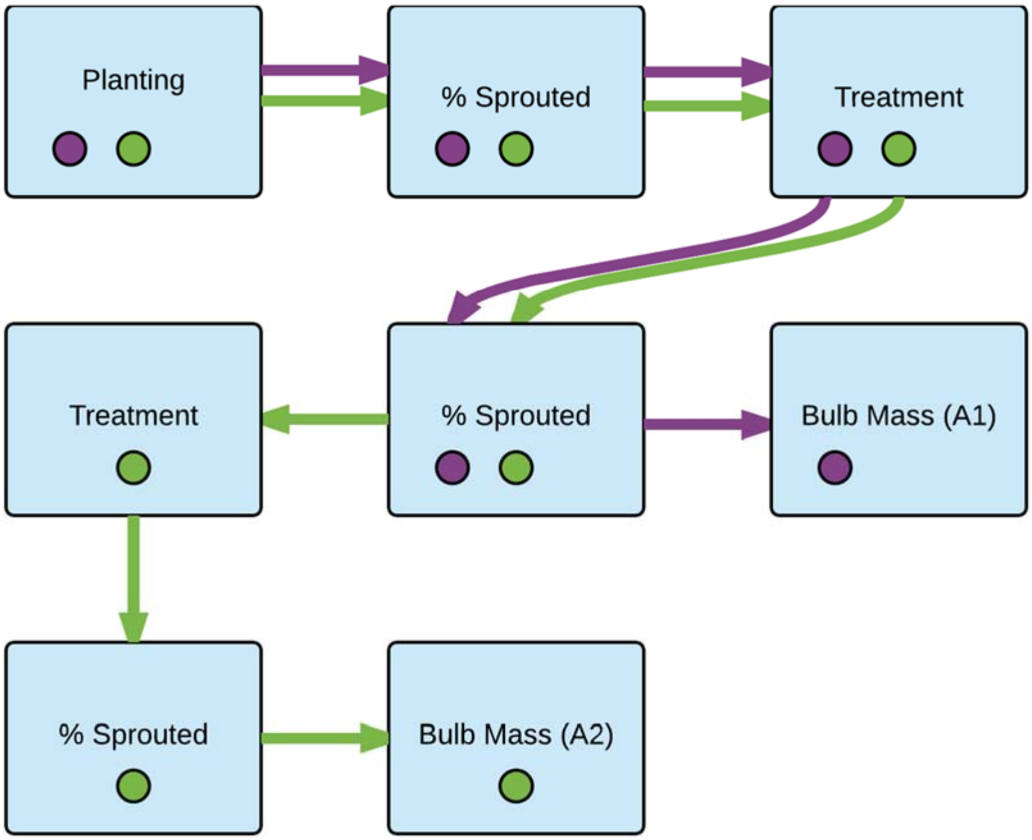


Figure 9: Work Flow

Tubers were then planted in 8” tall, 4” x 4” square pots using “Gardner and Bloom Organic Potting Soil Mix”. Each pot was color coded according to its cohort and treatment using colored duct tape. These were placed in trays with no holes, 18 to a tray. These trays were then stored in the greenhouse at the Center for Urban Horticulture in Seattle, WA.

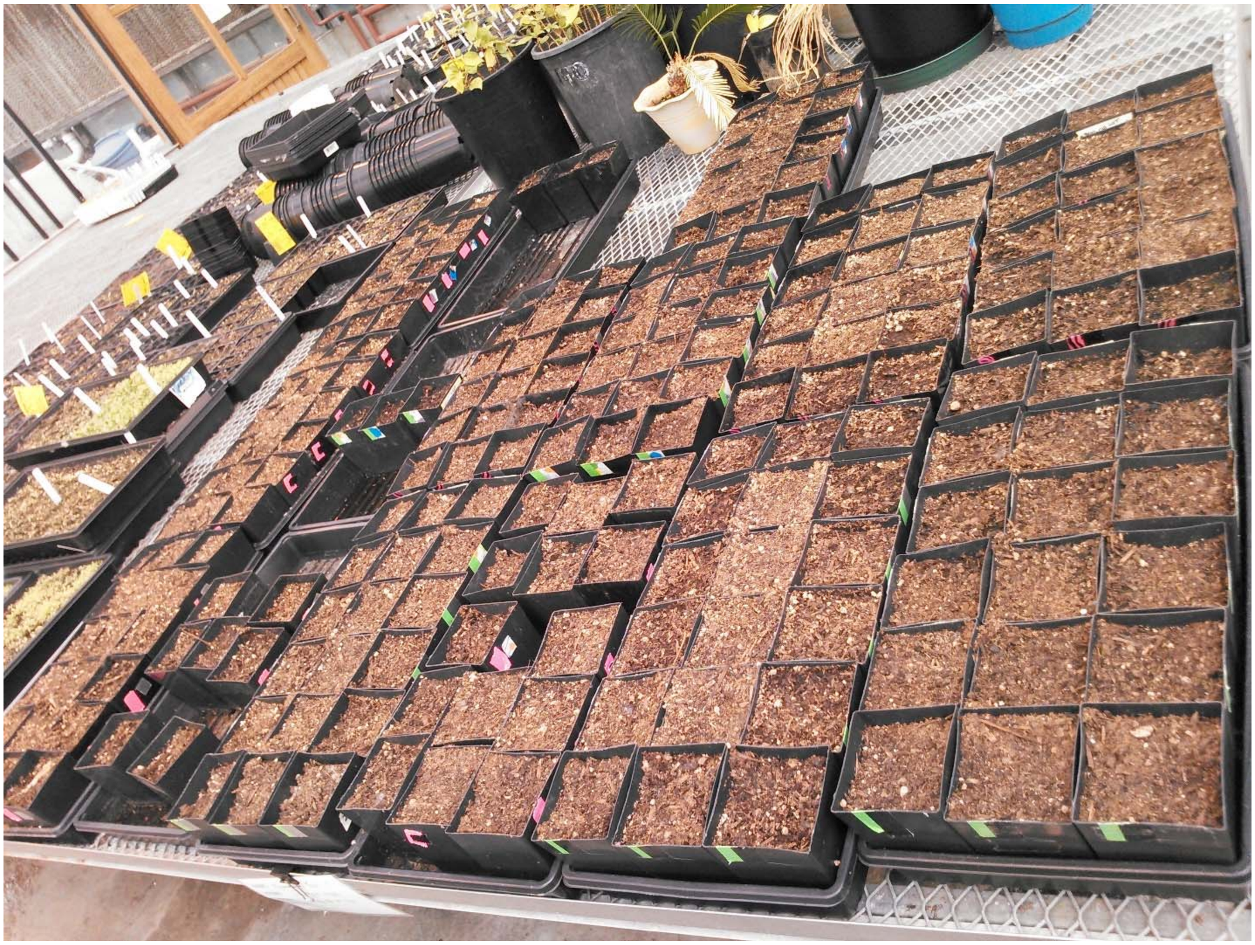


Figure 10: Experimental setup (Mallon 2015)

2.2.2 Growth and Treatment:

A italicum bulbs sprouted in October of 2015. They were grown until November 2nd, 2015 when a week had passed since the last new sprout appeared and all the plants had at least two leaves. At this point the number of plants that had sprouted were counted and treatments were applied based on their previously assigned groups. No treatment was applied to the control groups.

The glyphosate treatment groups were placed outside. A foliar spray of glyphosate at a 2% concentration with 1% surfactant was applied to this group. The particular product used was Roundup PROMAX®. The surfactant in this product is an ethoxylated amine surfactant. This concentration was achieved by dilution. After application, the plants were returned to the greenhouse.

6 mm black plastic was used as an inorganic mulch for the black plastic mulch group. 1 ft^2 pieces of the 6 mm black plastic were cut. These were placed over the pots, folded around the sides, and secured with rubber bands. In cases where vegetation wouldn't allow for a snug fit, leaves were folded

without breaking them and arranged so the plastic could be stretched over the top of the pot. These were then replaced in the trays.

Plants were allowed to grow after these treatments until April 30th 2016 in the greenhouse. During this time the temperature ranged between 53.31-77.41 degrees F. The average temperature in the greenhouse was 70.27 degrees F.

2.2.3 Data Collection

On March 30th 2016 the first round of trials was completed. Two types of data were collected from each of the three treatments in the first cohort. The first data type was the number of pots with live vegetation. The second type of data was the mass of the tubers.

First the number of pots with live vegetative growth were counted. To be recorded as “live” a single green leaf needed to be present in the pot. This included the very pale green growth that was present in pots that had undergone the black plastic mulch treatment.

Figure 11: Control group with vegetative growth (Mallon 2016)

name.

Figure 12: Tarped group with etoliated stems (Mallon 2016)

Figure 13: Herbicide group with dead vegetation (Mallon 2016)

Second the mass of the tubers from each treatment in the first cohort was recorded. The mass of tubers was recorded by the individual pot. To do this each pot was dumped into a ¼ inch sieve. Then the soil was washed through the sieve using a hose. The tubers were then removed from the sieve by hand. At this time the root and shoot material present was also removed. The tubers were then placed in a plastic bag, one pot to a bag, labeled treatment group. Then the tubers were weighed on a scale name.

2.2.4 Data analysis

The vegetative growth data were analyzed with a Chi Square test. For clarity, 3 chi square tests were used to test three hypotheses. These compared the control population to the herbicide treated population, the control population to the black plastic mulch treatment, and the herbicide treated population to the black plastic mulch treatment.

The bulb mass data was analyzed using t-tests assuming equal variance. In the same fashion as the Chi Square tests, tuber mass was examined through three hypotheses. These were the control population compared to the herbicide treated population, the control population compared to the black plastic mulch treatment, and the herbicide treated population compared to the black plastic mulch treatment.

2.3 Results

Significant differences were found between the control population and the herbicide treated population in both the size of *A. italicum* tubers as well as the number of pots with vegetative growth. The tarping treatment did not produce a significant change in either the size of *A. italicum* tubers or the number of pots with vegetative growth, though in both cases some reduction was observed. Significant differences were found between the tarping treatment and the herbicide population in both the size of *A. italicum* tubers and the number of pots with vegetative growth.

2.3.1 Vegetative growth

In the control group 16 of the 25 pots had vegetative growth at the time of harvest. Of the pots that had been tarped, 11 of the 25 pots had vegetative growth. None of the pots that had been sprayed with herbicide had any vegetative growth (Figure 14).

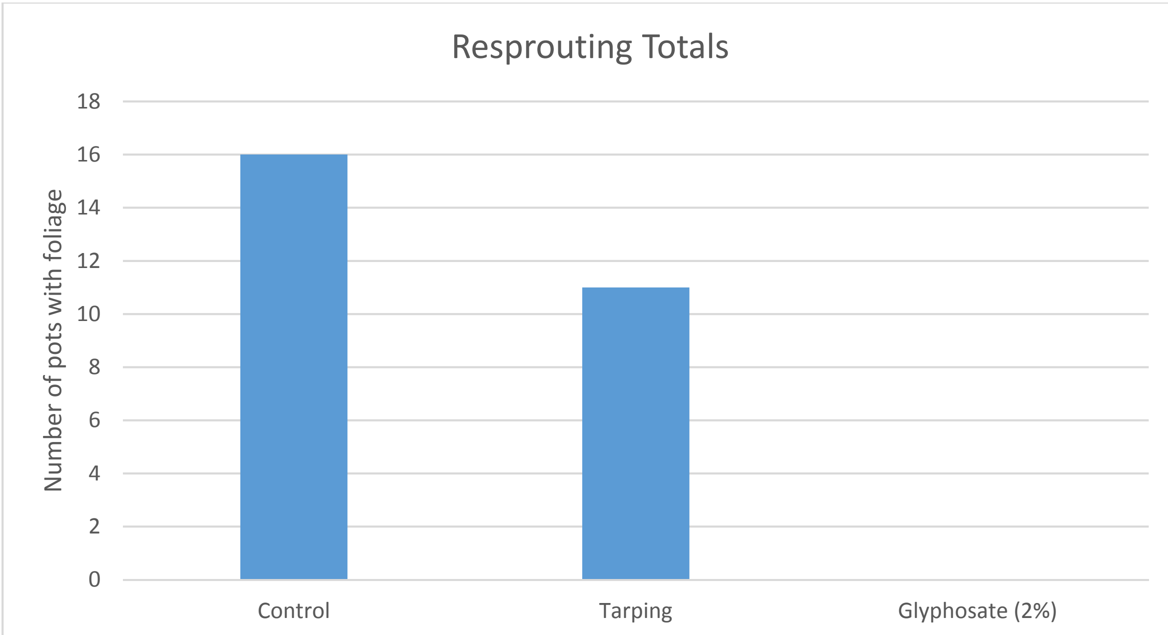


Figure 14: Vegetative growth chart

A Chi square test was performed to determine if these differences were significantly different. The results can be seen in the following tables.

Observed					Expected					
Sprouted	Control	Tarped	Total		Sprouted	Control	Tarped	Total		p
Yes	16	11	27		yes	13.5	13.5	27		0.15596874
No	9	14	23		no	11.5	11.5	23		
Total	25	25	50		Total	25	25	50		

Table 1: Control vs Tarping Chi Square Test

Observed					Expected						
Sprouted	Control	Glyphosate 2%	Total		Sprouted	Control		Glyphosate 2%	Total		p
Yes	16	0	16		yes	8		8	16		1.23019E-06
No	9	25	34		no	17		17	34		
Total	25	25	50		Total	25		25	50		

Table 2: Control vs Herbicide Chi Square Test

Observed					Expected					
Sprouted	Tarped	Glyphosate 2%	Total		Sprouted	Tarped	Glyphosate 2%	Total		p
Yes	11	0	11		yes	5.5	5.5	11		0.000173108
No	14	25	39		no	19.5	19.5	39		
Total	25	25	50		Total	25	25	50		

Table 3: Tarping vs Herbicide Chi Square Test

In both the comparison of the glyphosate 2% treatment to the control and the glyphosate 2% treatment to the tarping treatment, the results are significant. The p value for the control vs glyphosate 2% is .00000123019 which is less than .05. The p value for the tarping vs glyphosate 2% is .000173108, which is also less than .05.

There was no significant difference between the control and the tarping treatment. The p value for that comparison was 0.15596874, greater than the .05 needed for significance.

2.3.2 Tuber Mass

The tubers in the control group had a total mass at harvesting of 91.6 grams. The tubers in the tarped treatment had a total mass at harvesting of 51.9 grams. The tubers in the glyphosate 2% treatment had a total mass at harvesting of 1.9 grams. (Figure 15).

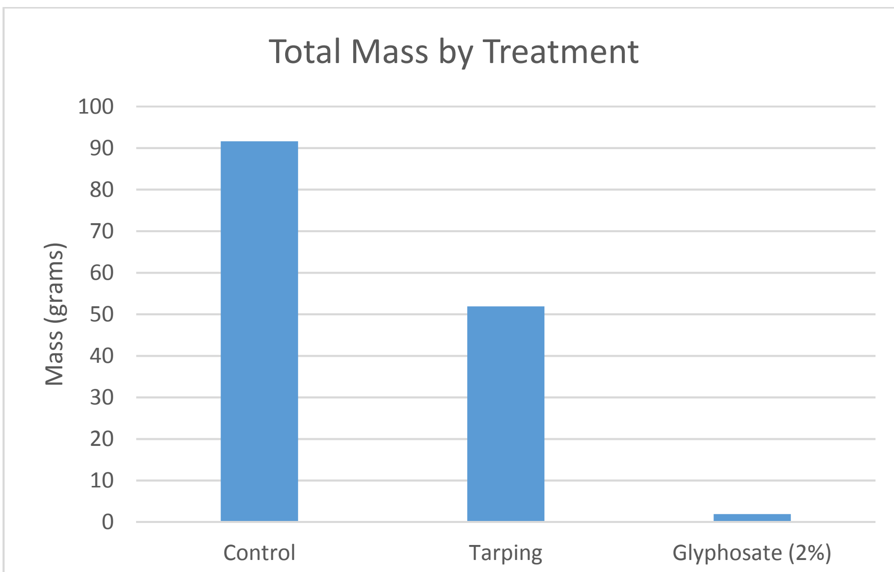


Figure 15: Tuber mass chart

By group, the tubers in each pot in each treatment had weights as follows.

Bulb Mass by pot			
	Control	Tarping	Glyphosate (2%)
	8.8	3.8	1.1
	4.7	0.4	0.8
	5.1	6.3	0
	9.7	2.1	0
	7.7	1.1	0
	0.1	2.2	0

	0.8	4.3	0
	1.6	1.3	0
	0.8	2.7	0
	1.7	7.7	0
	3.2	3.3	0
	1.3	4.1	0
	5.8	1.8	0
	8.8	1.3	0
	9.4	0.7	0
	19.4	3.3	0
	2.7	0.7	0
	0	4.8	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
total	91.6	51.9	1.9

Table 4: Bulb mass by pot

The results of the t-tests are as follows.

Control vs Tarping		
t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	3.664	2.076
Variance	22.711	4.637733333
Observations	25	25
Pooled Variance	13.674	
Hypothesized Mean Difference	0	
Df	48	
t Stat	1.5183	
P(T<=t) one-tail	0.0678	Not Significant
t Critical one-tail	1.6772	
P(T<=t) two-tail	0.1355	Not Significant
t Critical two-tail	2.0106	

Table 5: Control vs Tarping t-test

Control vs Glyphosate (2%)		

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	3.664	0.076
Variance	22.71073	0.0711
Observations	25	25
Pooled Variance	11.3909	
Hypothesized Mean Difference	0	
Df	48	
t Stat	3.75862	
P(T<=t) one-tail	0.000232	Significant
t Critical one-tail	1.677224	
P(T<=t) two-tail	0.000463	Significant
t Critical two-tail	2.010635	

Table 6: Control vs Glyphosate (2%) t-test

Tarping vs Glyphosate (2%)		
t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	2.08	0.076
Variance	4.64	0.071066667
Observations	25	25
Pooled Variance	2.35	
Hypothesized Mean Difference	0	
Df	48	
t Stat	4.61	
P(T<=t) one-tail	0	Significant
t Critical one-tail	1.68	
P(T<=t) two-tail	0	Significant
t Critical two-tail	2.01	

Table 7: Tarping vs Glyphosate (2%) t-test

In the control vs tarping comparison, the one tail p value is .0678, which is greater than .05. Therefore, the mass of the tubers in the control group are not greater than the mass of the tubers in the tarped treatment.

In the control vs glyphosate (2%) comparison, the one tail p value is .000232, which is less than .05. Therefore, the mass of the tubers in the control group are greater than the mass of the tubers in the glyphosate (2%) treatment.

In the tarping vs glyphosate (2%) comparison, the one tail p value is 0, which is less than .05. The mass of the tubers in the tarping treatment are greater than the mass of the tubers in the glyphosate (2%) treatment.

2.4 Conclusions

Based on these trials, glyphosate can produce significant reductions in vegetative and tuber growth of *A. italicum.* The use of glyphosate in a foliar application at 2% concentration is also more effective at reducing vegetative growth and tuber mass than tarping. Furthermore, tarping for 7 months (November through April) of *A. italicum* does not produce a significant reduction in bulb mass or vegetative growth.

2.4.1 Control vs Herbicide

This conclusion helps to clarify a previously confused scenario. In a previous study by Tim Miller glyphosate applied at 3% also resulted in no regrowth of vegetative material one month after spraying (personal communication, 4/3/2015). However, Tim Miller also observed that healthy looking tubers remained in the pots when the tubers were dug up. Tim Miller was testing multiple herbicides and did not examine the tubers based on treatment group. This suggests several possibilities.

One possibility is that the healthy looking tubers observed were from other treatment groups and that the tubers in the glyphosate treated group had died in a similar fashion to those in this trial. When tubers were harvested in this trial from the glyphosate treated population in almost every case no tuber was found. In a few cases a viscous material was found in the soil that was all that remained of the tuber.

Another possibility is that the timing of the application was ineffective and the tubers remained healthy and viable after the herbicide application. May is toward the end of the *A. italicum* growing season and by that point the new year's tuber and daughter tubers off of it will have already formed (Boyce 1993). Furthermore, glyphosate concentrates in actively growing meristems. Consequently, minimal translocation of the glyphosate may have occurred. In this scenario the glyphosate may not have effected tuber growth which resulted in finding the healthy looking tubers.

A third possibility is that the glyphosate treatment killed the main tuber, but did not affect the daughter tubers. Because glyphosate concentrates in actively growing meristem tissues, if the daughter tubers were no longer actively growing, glyphosate translocation to those tubers may have been low. If this were the case, then the tubers seen by Tim Miller in his experiment could have been daughter tubers and not the primary one.

Examining which of these scenarios occurred would be interesting. One interesting extension of this work would be to change the timing of the herbicide application. Instead of applying Glyphosate in November as in this trial, *A italicum* plants could be allowed to grow into April or May at which point Glyphosate would be applied. Vegetative regrowth and tuber mass could be examined the following November. Similar reductions in tuber mass and vegetative regrowth would indicate that timing of the application was not the critical factor and that glyphosate application is effective in either time frame. Dissimilar results would suggest that one of the other two scenarios was occurring. If there is no reduction compared to the control group, then the second scenario where glyphosate had no effect on tubers with that timing would be likely. If there is a moderate reduction in vegetative regrowth and tuber mass and the bulbs are individually all rather small, then the third scenario with surviving daughter bulbs would be most likely. Either way, attempting to examine bulb mass after a May application of glyphosate would be useful for land managers working to control *A italicum.*

2.4.2 Control vs Tarping

Tarping did not result in significant reductions in vegetative regrowth or in bulb mass. This is not entirely surprising considering that tarping of perennial species tends to be less effective than tarping of annuals (Hutchinson and Viers 2011). Some general reduction can be observed in the tarped population, though not a significant one. The plants were stressed by the conditions though, as evidenced by the etoliation seen in the tarped population.

Though the seven-month period of tarping did not significantly reduce the vegetative growth or tuber mass, it is possible that a longer period might. A second population is continuing to be treated with the tarping treatment. It will be sampled in April of 2017 to see if a total of 19 months is sufficient.

If the longer treatment is effective, this would be very useful to land managers and homeowners. Many homeowners and land managers are averse to using herbicides. Because the only treatment for Arum that these trials can recommend currently is to use glyphosate, being able to recommend another option that demonstrates reliable results would be helpful. Because *A. italicum* is a perennial, tarps would need to stay in place longer than with an annual to produce effects (Hutchinson and Viers 2011).

2.4.3 Herbicide vs Tarping

The herbicide result was significantly more effective than the tarping treatment after 7 months for both vegetative regrowth and tuber mass. The reasons for the success of the glyphosate treatment and the limited efficacy of the tarping treatment have already been discussed. It is possible that the tarping treatment over time will produce results comparable to the herbicide treatment, but this will not be known until April of 2017 after 19 months of the tarping treatment.

3. *Arum italicum* Distribution in Seattle, WA

3.1 Introduction

Plant invasions generally follow three phases. These are introduction, colonization, and naturalization (Radosevich et al 2003). Myers and Bazely (2003) add to this sequence the phase of being listed as a noxious weed or pest. The introduction phase is the first occurrences of a plant beyond its native range. This commonly occurs through intentional human introduction or accidental transport on a vehicle. The colonization phase is defined by the establishment of reproducing and self-perpetuating populations (Radosevich et al 2003). The naturalization phase is defined by self-perpetuating populations that have spread widely through a region and have integrated as part of local ecosystems (Radosevich et al 2003). Williamson and Fitter developed a "Tens Rule" which stated that 10% of species will pass through each of these phases (Myers and Bazely 2003).

Listing by an agency as a noxious weed or pest depends on local policy, which can be variable. This action can occur between any of the above phases. It rarely occurs at the introduction stage because introductions are hard to discover (Radosevich et al 2003). Furthermore, the invasive potential of a plant may be difficult to discern even if an introduction is recognized (Morris et al. 2013). Identifying a plant in the colonizing phase is easier as it will be establishing mature self-perpetuating populations. The colonizing phase is characterized by exponential population expansion, slow at first but then rapidly increasing (Figure 16) (Radosevich et al 2003). The slow initial expansion is referred to as a lag phase (Myers and Bazely 2003). This lag phase is a critical one for land managers to identify an invader in as it represents a window in which an invader can still be eradicated (Morris et al. 2013). The rate of the exponential expansion is based on the species life history characteristics. This colonizing phase can last a short time or, in the case of some woody invaders, up to 350 years (Morris et al. 2013). If a plant is not recognized as an invader until it has reached the naturalization phase, the window of eradication opportunity may be lost. However, listing after

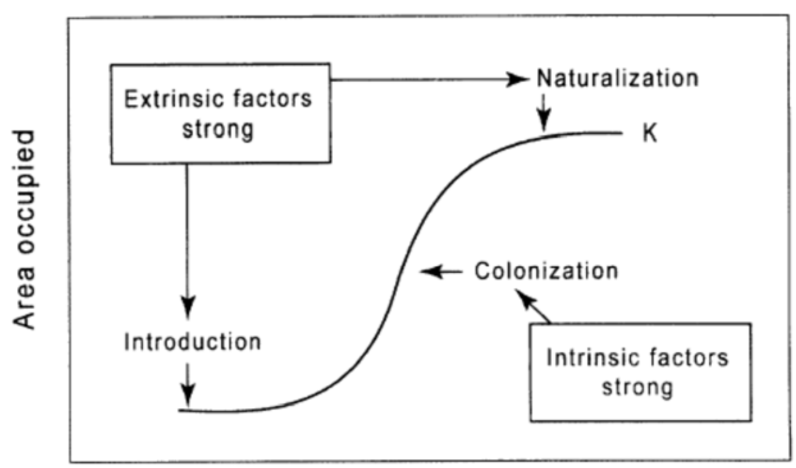


Figure 16: Phases of the invasion process (Radosevich et al 2003)

naturalization may help slow or prevent the continued expansion of an invasive plant and manage its negative impacts.

Because detection is frequently difficult with a new invader and the length of a lag time is so variable, establishing a baseline and monitoring a population are critical for managing a new invasion (Hobbie et al 2003). In this way a potential invader can be tracked in its colonizing phase and efforts can be made to eradicate or manage the population. Tracking a plants colonizing phase can also allow a land manager to implement an integrated pest management plan and respond to an invader when a critical threshold has been crossed.

Currently *A. italicum* seems to be in the colonization phase of an invasion in Washington state. It is established in San Juan, King, Clark, Skamania, Cowlitz, and Skagit County (WSNWCB 2014). However, the areas occupied range from only small patches of 5-15 plants in Cowlitz County to patches of a thousand square feet in San Juan County (WSNWCB 2014) (Tim Clark, Personal Communication, 11/16/2016). These populations are self-sustaining but the naturalization phase requires that a plant be widely distributed, self-sustaining, and incorporated into the resident fauna (Radosevich et al. 2003). Though *A. italicum* has many populations are self-sustaining, it does not seem to be incorporated widely into resident fauna or all that widely distributed.

Because *A. italicum* seems to still be in a naturalization phase, tracking its population and the expansion of that population will be critical to its control. In the city of Seattle, WA the state Noxious Weed Control Board lists populations in Frink and Leschi Natural Areas, in Lower Lions Reach and Cedar Grove Road along the Cedar River, as well as on the University of Washington, Seattle campus (WSNWCB 2014). Several other sites exist near the Union Bay Natural Area and in other parks in Seattle as well (Personal Observation). There are few resources for tracking *A. italicum* and so providing baseline data on populations, identifying new populations, and providing a mechanism for volunteer Forest Stewards with the Green Seattle Partnership to track populations in their parks is essential to long term control.

This chapter attempts to start that process. It outlines the mapping of a variety of populations both previously known and new in the city of Seattle. The mapping of *A. italicum* helps to identify habitat types it invades. Furthermore, the map of the currently known extent of *A. italicum* will be made available to Forest Stewards with the Green Seattle Partnership in a Google Maps format that will allow them to both update and track *A. italicum* in their own parks.

3.2 Methodology

Sites were identified through outreach to the Washington State Noxious Weed Control Board, King County Noxious Weed Control Board, Seattle Parks and Recreation, University of Washington Botanical Gardens, the King Conservation District, and the Washington Park Arboretum. Representatives from these groups provided guidance to known patches. These were then mapped using a Garmin GPSMAP 62 series.

A. italicum patches that were small and dense were recorded as waypoints. The size of the patch was then recorded. The largest of these patches was nine square feet. Larger patches were mapped using the calculate area function on the Garmin unit. The percent coverage of these patches was also recorded.

Both waypoints and the tracks for the larger patches were imported and converted to shapefiles using the Minnesota DNRGPS Application. This allowed the waypoints to be projected as points in ArcMap 10.3. It also converted the tracks from the larger patches into polygons projectable in ArcMap. These points and polygons were projected over a Land Use layer obtained from the Multi-Resolution Land Characteristics Consortium. A wetlands designation map was obtained from the Washington State Department of Ecology GIS Data website. Both were obtained as raster data and converted to polygons.

To determine the recorded square footage of *A. italicum* the attribute tables were edited. In the case of point data, the square footage of each patch was input for each point. In the case of polygon data, the attribute table was edited to include the percent cover that was recorded during data collection. The field calculator function was then used to populate a new “Sq_ft_Arum” field by multiplying the percent cover by the area of the polygons. Both of these attribute tables were exported as Microsoft Excel sheets. The sum of each of their square footage categories was calculated in Microsoft Excel.

To determine the habitats that *A. italicum* occupies in the city of Seattle, WA, the *A. italicum* polygons and points were used to select polygon. The *A. italicum* polygons and points were used to select by intersection from the Land Use layer obtained from the Multi-Resolution Land Characteristics Consortium. The *A.italicum* polygons and points were also used to select by intersection from the wetland designation map obtained from the Washington State Department of Ecology GIS Data website.

3.3: Results

3.3.1: Area coverage in Seattle, WA

The total recorded cover of *A. italicum* coverage recorded in this project is 829 square feet. The total area containing *A. italicum* recorded in this project is 2,666 square feet. Recorded patches range from 1 square foot to 419 square feet. The average percent cover is 43.4% over this area. Percent cover ranges from 100% to .05%. A total of 22 polygons and 38 points were recorded in this project.

OBJECTID	facility	PerCov	Sq_ft_Arum	Shape_Area
1	Arboretum	0.4	7.784183979	19.46046029
2	Arboretum	0.15	2.730361462	18.20240998
3	Dead_Horse	0.6	45.6811142	76.13519198
4	Dead_Horse	0.8	24.38963699	30.48704644
5	Dead_Horse	0.75	157.5977478	210.1303287
6	Leschi_Park	0.1	13.0112505	130.1125073
7	Leschi_Park	0.6	199.1920319	331.9867139
8	Leschi_Park	0.8	12.22157097	15.27696366
9	Frink_Park	0.4	14.65423584	36.635589
10	Genesee_Park	0.2	11.65645981	58.28229901
11	Seward_Park	0.7	11.72324181	16.74748821
12	Sweard_Park	0.6	11.20978355	18.68297324
13	Seward_Park	0.4	27.44404602	68.61011634
14	Seward_Park	0.8	36.13622284	45.17027642
15	UW_Campus	0.05	15.02629089	300.5258208
16	UW_Campus	0.1	61.40803528	614.080342
17	UW_Campus	0.1	0.514163554	5.14163527
18	UW_Campus	0.15	1.278628945	8.524192895
19	UW_Campus	0.15	62.91083908	419.4055834
20	UW_Campus	0.1	14.45453835	144.5453803
21	Yesler_Swamp	0.8	6.002247334	7.50280893
22	Yesler_Swamp	0.8	58.38861084	72.98576299
		Total Sq Ft	795.4152419	2648.631891
		Total From Points	98	98
		Total Mapped	893.4152419	2746.631891
		Average Percent Cover		43.40909091

Table 8: Square footage of *Arum italicum* in Seattle, WA.

3.3.2: Habitat types

The land use types in Seattle, WA that *A. italicum* occurs in are developed low intensity, developed medium intensity, developed open space, deciduous forest, woody wetlands, and mixed forest.

Only two points were recorded in wetlands in this project. These were both recorded in Yesler Swamp. The wetland types are palustrine scrub/shrub wetland and palustrine forested wetland. One polygon was recorded in a wetland. This was also located in Yesler Swamp. That wetland type was potentially disturbed wetlands.

3.4: Discussion

The locations and patch sizes recorded in this project do not account for a complete inventory of the *A. italicum* in Seattle, WA. These sites are all in public areas and do not account for populations that may be on private property. Because *A. italicum* is most likely an escaped ornamental, the populations on private property may be extensive. Furthermore, this project was only able to map a portion of the sites in Seattle. Reports also suggest that other known populations exist on the Cedar River, in Ravenna Park, Madrona Park, Jackson Park, on Longfellow Creek, and on Vashon Island. Adding the populations in these sites would be valuable in making generalizations about *A. italicum*'s habitat preferences. Mapping these populations would also assist in tracking *A. italicum*'s spread and could help inform management choices.

Though only nine general locations were recorded and seven populations in Seattle are known and still unrecorded, the overall area covered by *A. italicum* is relatively low. With 893 square feet of total coverage recorded, it seems quite likely that this plant invasion has been caught in the colonization phase. As a result, continuing to track these *A. italicum* populations and management of these populations in the near future may be the most cost effective approach to management.

Adding the remaining populations to the map will make it easier to look for additional populations as well. The populations identified in this project occurred in developed low intensity, medium intensity, and open space, which suggests that disturbed areas are likely candidates for colonization. This project also identified populations in deciduous forest, mixed forest, and woody wetlands. Absent from this list is coniferous forest. This suggests that a dense enough year round cover could provide enough shade to prevent *A. italicum* from establishing. Because the growing season for *A. italicum* is in the fall/early winter and spring, it makes sense that it can grow under deciduous and mixed forest covers but would have more difficulty under a coniferous cover. If this trend holds true, it could help land managers narrow their search for populations by focusing on habitats other than coniferous forest. This determination would be based on where the currently unmapped populations occur.

Only two populations of *A. italicum* were identified in wetlands. However, wetland habitats are rare in Seattle so it is difficult to make generalizations about *A. italicum*'s habitat preferences in regards to wetlands. Furthermore, *A. italicum* is known to invade wetlands in other regions so the lack of wetland populations in Seattle is not indicative of its broader preferences (WSNWCB 2014). Continuing to monitor wetlands, particularly those listed as palustrine scrub/shrub or palustrine forested, will be important for staying ahead of any expansions into these habitats.

The shapefiles and associated metadata are available by request to this author, Zachary R Mallon, at zmallon@gmail.com. Furthermore, a Google Map version of both the shapefiles and metadata will be distributed to all the Forest Stewards and other land managers who assisted with the data collection.

Chapter 4: Recommendations

Based on the limited distribution of *A. italicum* and the control options presented in this project, *A. italicum*'s listing as a Class C noxious weed should be changed to Class A. Class A noxious weeds in Washington are "… present in only very limited amounts in Washington. Control is required for all Class A species." (WSNWCB 2010). This listing would be in line with the currently limited distribution of *A. italicum* and the potential for eradication. Class C are defined as being of "established throughout much of the state or are of special interest to the state's agricultural industry." (WSNWCB 2010). Class C required weed control is at the discretion of County level noxious weed boards. *A. italicum*'s distribution is more in line with a Class A weed than a Class C weed.

One possible reason for the Class C listing may be that no established control methods exist for *A. italicum.* This project has endeavored to guide future control methods by providing both evidence of glyphosate's effectiveness at control. This project also provides an explanation for why previous observations of *A. italicum*'s resistance to herbicide were due to *A. italicum*'s unusual life history and the persistence of the daughter tubers after herbicide application.

Before reviewing the listing of *A. italicum* as a Class A weed, field trials are recommended. This project recommends spraying *A. italicum* in October-November with Glyphosate at a 2% concentration with a surfactant. This should be followed up with another application of Glyphosate in the March-April on whatever vegetation has come back at that time. This pattern should be repeated until the entire population has been eradicated. If the applications are thorough, it seems that 2-3 years would be sufficient.

The mapping and monitoring of *A. italicum* should continue. By making the current maps available to the King County Noxious Weed Board and Green Seattle Partnership's Forest Stewards, the maps can be used to track new occurrences and the recorded sites. If the sites are resurveyed annually in the fall, changes in density and extent could help inform future management choices.

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Appendix A: *Arum Italicum* Weed Risk Assessment

Arum italicum Weed Risk Assessment for the Pacific Northwest

Weed risk assessments are used in multiple areas of the world as a mechanism to regulate the importation of plants. The Weed Risk Assessment (WRA) developed by Australia has been used in Australia, New Zealand, Hawaii, Hawaii and the Pacific Islands, the Czech Republic, the Bonin Islands, and in Florida. Averaging across all these areas the WRA system has accurately identified major invaders 90% of the time and non-invaders 70% of the time (Gordon et al 2008). To apply to areas outside of Australia, some questions in the WRA have been modified to reflect climatic and edaphic characteristics of the new area (Gordon et al 2008)

The WRA asks 49 questions; 13 about the plants history and biogeography and 36 about the plants biology and ecology (DAWR 2015). Because all the questions are directly related to the invasive potential of a plant and help to elucidate the reasons why a plant is invasive, a WRA has been conducted for *Arum italicum*. To account for differences between the Pacific Northwest and Australia, question 2.01 was modified to read “Species suited to Pacific Northwest climates, Plant hardiness Zones 7b-9b.” Question 2.04 was left alone though it refers specifically to a metric mostly relevant to identifying plants that could invade Australia (DAWR 2015). Question 8.05 was modified to read “Effective natural enemies present in the Pacific Northwest.” The results of the *Arum italicum* WRA identify it as a plant with invasive potential to harm agriculture and natural areas and had it been conducted before *A italicum*’s introduction would have resulted in its rejection for importation (See Table at end of document).

Question 1.01 asks “Is the species highly domesticated?” The DAWR’s standard for “highly domesticated” is “cultivated and subjected to substantial human selection for at least 20 generations.” (DAWR 2015). Little data exists on the first domestication of *Arum italicum* but 4 subspecies and several cultivars are recognized by Boyce (1993). It has been a common horticultural plant for centuries, having been used to starch linen in Elizabethan England (Seedaholic.com 2015). Though its history with humans is centuries old, this does not imply domestication at that time. *A italicum* occurs widely throughout much of Europe, in Turkey, and North Africa (Boyce 1993). Furthermore, the variegation seen in *A italicum* occurs naturally. As a yes answer to this question demands “substantial human selection”, this question must be answered no.

Questions 1.02 and 1.03 are only answered when the response to question 1.01 is a yes. Therefore, they are not addressed in this WRA.

Question 2.01 and 2.02 rely on using one of three climate matching programs, CLIMEX, BIOCLIM, or Climate (DAWR 2015). In lieu of computer analysis, a maximum score for these questions is assigned. These questions ask is the “Species suited to Pacific Northwest climates” and for the “Quality of climate match data”. This score, though based on a lack of approved data, seems fair. *A italicum* grows in hardiness zones 5-9 (Missouri Botanical Garden 2016). Oregon and Washington contain zones 7b-9b, all within the hardiness range of *A italicum* (Plantmaps.com 2016).

Question 2.03 asks if the plant has “Broad climate suitability” (DAWR 2015). *A italicum* in its native range grows in open woodlands, forest edges, hedgerows, open scrub, dry pasture and grassy banks (Boyce 1993). In introduced areas it is found in forest understories, riparian areas, old gardens, woodland gardens, and disturbed locations near urban development (WSNWCB 2011). It can grow from 0-1,200 m of elevation in part to full shade and can tolerate most soil types and is known to be drought resistant once established (WSNWCB 2011). This qualifies as a “Broad climate suitability.”

Question 2.04 asks if the species is “Native or naturalized in regions with extended dry periods.” (DAWR 2015). For the purposes of this question, extended dry periods are a quarter of the year with 25mm of precipitation or less. The question is included as Australian growing conditions are quite dry and any potential invader would need to contend with these conditions. This question was answered as a no.

Question 2.05 asks “Does the species have a history of repeated introductions outside its natural range?” (DAWR 2015) The answer to this question is yes. As this assessment is being done after the listing of *A italicum* in WA state, it has established there already (WSNWCB 2011). Other populations have established in Australia, New Zealand, and in Argentina (WSNWCB 2011). These populations also provide the evidence to answer question 3.01, has the species “Naturalized beyond native range”, as a yes.

Question 3.02 asks if the species is a “Garden/amenity/disturbance weed” (DAWR 2015). This is also a yes. The WA NWCB mentions that it is found in old gardens, woodland gardens, and disturbed locations near urban development (WSNWCB 2011). The New Zealand Weedbusters state that there it invades disturbed shrub land and forests, herb fields, damp areas with high light, and regenerating ex-pasture (Weedbusters 2016). In the Australian state of Victoria, it invades pasture and dry coastal vegetation (DEDJTR 2015). All these occurrences support *A italicum* as a garden and disturbance weed.

Question 3.03 asks if the species is a “Weed of agriculture/horticulture/forestry” (DAWR 2015). This question is answered as a no. A yes answer to this question requires that the plant causes productivity losses and/or costs due to control. Currently, this is a no, though if evidence of productivity losses can be demonstrated in the future, then this rating would change.

Question 3.04 asks if the plant is an “Environmental weed” (DAWR 2015). The parameter for this question is whether or not it alters the structure or normal activity of a natural ecosystem. *A italicum* certainly does this as it forms dense cover on the ground shading out small native plants and preventing native plants from establishing (Weedbusters 2016). In addition to crowding out the native herbaceous layer, this prevents the regeneration of both the shrub and the canopy layer in areas *A italicum* establishes.

Question 3.05 asks if there is documented evidence that similar plants within the same genus are being evaluated as weeds (DAWR 2015). There is some evidence of other species in the *Arum* genus being evaluated. The very closely related *Arum maculatum* is listed as potentially invasive by Moodley et all (2016). *A maculatum* is closely related enough to *A italicum* that they are known to hybridize in their natural range and populations of each have been misidentified as each other many times (Sowter 1949). *Arum palaestinum* is an escaped *Arum* in California that is not yet considered naturalized, though it is noted that it is highly persistent (JFP 2008). The literature evaluating other *Arum* species is relatively sparse, but exists, so this question is answered with a yes.

All the questions in section 4 relate to traits of the species in question. 4.01 through 4.03 ask if the plant produces spines, thorns, or burrs, is allelopathic, or is parasitic (DAWR 2015). *A italicum* does not produce spines, thorns, or burrs (Boyce 1993). It is not known to be allelopathic (DEDJTR 2015). It’s life history does not support the suggestion that it may be parasitic (Boyce 1993). These questions are all answered no.

Question 4.04 asks if the species is unpalatable to grazing animals (DAWR 2015). There are several compounds present in *A italicum* that would discourage this. The principle of these is calcium oxalate that crystalizes in needle shaped rhapides and causes a painful itching and burning on tender skin (Boyce 1993) (Halevy 1983). They also are reported to contain ascorbic acid and possibly an alkaloid similar to coniine found in *Conium maculatum*, hemlock (Boyce 1993). Consequently grazing animals avoid *A italicum* and herbivory on them is limited to that by snails and slugs which feed on the spathes (Halevy 1983) (Weedbusters 2016). Question 4.04 is answered as a no. Question 4.05 is related in that it asks if the species is toxic to animals, which it generally isn't because most animals avoid it.

Question 4.06 asks if the species is the host for recognized pests and pathogens (DAWR 2015). The literature does not comment on this and so it seems unlikely that it would be an issue.

Question 4.07 is asks if the species causes allergies or is otherwise toxic to humans, which based on this information presented for Question 4.04 it is (DAWR 2015). However, this question specifies that it must likely to occur under normal circumstances (DAWR 2015). As exposure to the calcium oxalate crystals in the leaves requires crushing or eating parts of the plant, the conditions for exposure are rare. Consequently, this question is answered no.

Question 4.08 asks if species creates a fire hazard in ecosystems (DAWR 2015). The literature does not comment on this and so it seems unlikely that it would be an issue.

Question 4.09 asks if the species is shade tolerant at some stage of its life cycle (DAWR 2015). *A italicum* is shade tolerant at all its growth stages (Weedbusters 2016). It grows in open woodlands, forest understories, woodland gardens, and is generally noted to grow in part to full shade (WSNWCB 2011). Seedaholic.com (2015), a website that sells *A italicum,* specifically mentions it being "Extremely useful for shady spots or woodland planting." The answer to this question is yes.

Question 4.10 asks if the species can grow in infertile soils (DAWR 2015). Weedbusters (2015) report that it tolerates most soil types. The WSNWCB notes however that it grows best in organically rich soils (2011). It is also reported to invade in dry coastal areas in Victoria, Australia (DEDJTR 2015). So, though it may grow best in organically rich soils, it seems capable of growing in a wide variety of soil types, including infertile soils.

Question 4.11 asks if the species is climbing or has a smothering growth habit (DAWR 2015). This question specifies that it is concerned with plants that are fast growing vines or those that rapidly produce large rosettes (DAWR 2015). *A italicum* does not have a climbing form. It does grow in a rosette though and one of the concerns around *A italicum* is that it crowds out the native herbaceous layers (WSNWCB 2011). So this question is answered yes.

Question 4.12 asks if the species forms dense thickets (DAWR 2015). The question further specifies that these must obstruct passage, access, or exclude other species (DAWR 2015). As *A italicum* crowds out native herbaceous layers this question must also be answered yes (WSNWCB 2011).

Question 5.01 asks if the species is aquatic (DAWR 2015). *A italicum* is not aquatic (Boyce 1993). Though it can grow in riparian areas, it prefers moist soils rather than saturated or aquatic conditions (Missouri Botanical Garden 2016). The answer to this question is no.

Question 5.02 asks if the species is a grass (DAWR 2015). This species is a dicot and not a grass (Boyce 1993).

Question 5.03 asks if the species is a nitrogen fixing woody plant (DAWR 2015). There is no evidence that *A italicum* fixes nitrogen.

Question 5.04 asks if the species is a geophyte (DAWR 2015). *A italicum* does in fact grow from a bulb (Boyce 1993). It is a perennial and is only visible seasonally, with leaves that die back in the summer and in the winters of colder climates (Missouri Botanical Garden 2016). *A italicum* is a geophyte (Mendez 1999).

Question 6.01 asks if the species shows evidence of substantial reproductive failure in its native habitat (DAWR 2015). This question focuses on whether or not predators, disease, or other factors reduce the plants native capacity in its native habitat. As previously discussed, *A italicum* experiences limited herbivory, mostly restricted to slugs and snails (Halevy 1983). Furthermore, it is not known to have any serious disease problems in its native range (RHS 2016). Its aggressive growth outside its native range is therefore unlikely to be due to enemy release.

Question 6.02 asks if the species produces viable seed (DAWR 2015). A literature review has revealed no evidence that any of the sub-species or varietals are sterile. Furthermore, several sources discuss the process of germinating and germination season of *A italicum* (RHS 2016) (seedaholic.com 2015) (DEDJTR 2015). Halevy (1989) describes the germination process as does Boyce (1993). The germination rate is highly variable, ranging from 6-100% (Halevy 1989) but *A italicum* does in fact produce viable seed.

Question 6.03 asks if the species hybridizes naturally (DAWR 2015). The home range of *A italicum* overlaps with *A maculatum* (Boyce 1993). Hybrids between the *A italicum* subsp *italicum* or subsp *neglectum* with *A maculatum* exist in this range (Boyce 1993). Also, where *A italicum* overlaps in range with *A apulum*, hybrids have been reported (Boyce 1993).

Question 6.04 asks if the species is capable of self-seeding (DAWR 2015). Species in the genus *Arum* have protogynous inflorescences, which means that the period of stigma receptivity starts and finishes before pollen liberation (Gibernau et al 2004). Consequently, *A italicum* cannot self-pollinate. This means that an isolated plant cannot spread by seed, as required by this parameter. However, as it reproduces asexually, eventually an isolated plant could pollinate its own clones. This is not sufficient for a yes answer to this question and it is answered as a no.

Question 6.05 asks if the species requires specialist pollinators (DAWR 2015). *A italicum* produces a 'cryptic' inflorescence that attracts pollinators by producing a scent resembling feces (Boyce 1993). In southern Europe it attracts a wide range of midges and gnats, with *Psychoda nervosa* and *Sciara nitidicollis* being primary amongst them (Boyce 1993). As *A italicum* attracts a wide range of midges and gnats and is capable of sexually reproducing in other areas, it does not seem reliant on specialist pollinators. This question is answered no.

Question 6.06 asks if the species can reproduce by vegetative propagation (DAWR 2015). This method of reproduction is well documented in the genus *Arum* at large (Boyce 1993). *A italicum* produces daughter tubers while it also seasonally produces a new tuber to replace the previous year's growth (Mendez 1999). Vegetative propagation is also the favored method of reproduction by horticulturalists (RHS 2016) (OABIF 2016) (Seedaholic 2015). *A italicum* reproduces very well by vegetative propagation.

Question 6.07 asks how long the minimum time is from germination to the production of viable seed or the time taken for a vegetatively reproduced plant to duplicate itself (DAWR 2015). *A italicum* produces daughter bulbs in the first year after germination (Boyce 1993). The tuber is described as horizontal-rhizomatous and as part of its usual growth cycle produces daughter tubers from adventitious buds along the length of the tuber (Boyce 1993). So the minimum time for a vegetatively reproduced plant to duplicate itself is one year.

Question 7.01 asks if the propagules are likely to be dispersed unintentionally as a result of normal human activity (DAWR 2015). As the seeds are fleshy rather than hooked and the daughter tubers are in the soil, human activity is unlikely to unintentionally spread *A italicum*. This question is answered no.

Question 7.02 asks if the propagules are dispersed intentionally by people as a result of being attractive or desirable (DAWR 2015). The seeds of *A italicum* are a showy red-orange and the foliage is popular among horticulturalists (MBG 2016). It is intentionally dispersed by people as a horticultural plant recommended for planting in shady areas of gardens (WSNWCB 2011).

Question 7.03 asks if the propagules are likely to disperse as contaminants of produce (DAWR 2015). The literature does not mention this dispersal and areas in which *A italicum* grows suggests that this is unlikely. This question was answered no.

Question 7.04 asks if the propagules are adapted to wind dispersal (DAWR 2015). The seeds of *A italicum* are fleshy and not adapted to wind dispersal (Boyce 1993). This question is answered no.

Question 7.05 asks if the propagules are buoyant and could be spread by waterways (DAWR 2015). The fruits are buoyant (personal experience) and the potential to be spread by waterways is mentioned by Weedbusters in New Zealand (2016). However, they don't cite any examples of this occurring and Weedbusters is the only source that mentions the potential to be spread by waterways. *A italicum* strongly prefers well drained soils (Seedaholic 2015) and from personal observations does not grow in saturated soils. It seems unlikely as a mechanism for dispersal. However, as Weedbusters mentions this as a mechanism, even without an example, the possibility exists and this question is answered yes.

Question 7.06 asks if the propagules are bird dispersed (DAWR 2015). Bird dispersal is considered the primary mechanism by which *A italicum* seeds are spread. The DEDJTR suggests that seeds may travel up to 1 km by bird (2015). Halevy mentions that in Seattle, *A italicum* seed is spread by quail and American robins which are active in its short range dispersal (1989). In England, the seeds are spread by members of the thrush family, starlings, pheasants, wood pigeons, sparrows, finches, and yellowhammers (Halevy 1989). In particular, based on their faster and further flight habits, pigeons may be a longer range dispersal mechanism (Halevy 1989).

Question 7.07 asks if the propagules are dispersed by other animals externally (WADR 2015). As the fruits of *A italicum* do not possess burrs or other structures to assist in this process, it seems highly unlikely that this is possible (Boyce 1993). However, Barrosso et al found that in Southern Spain the ant *Aphaenogaster senilis* harvested and transported *A italicum* seed several meters (2013). They also note, however, that other ant species seem to avoid *A italicum*, and this may be a specialized dispersal mechanism within the range of *A senilis* (Barroso et al 2013). But, as the question does not exclude specialized relationships like this, the answer to this question is yes.

Question 7.08 asks if the propagules are dispersed by other animals internally (WADR 2015). The literature offers no examples of *A italicum* dispersal by other animals internally. The answer to this question is no.

Question 8.01 asks if the species is a prolific seed producer (WADR 2015). The guidelines are producing >5000-10000 / m^2 / yr for grasses and annual species or >500 / m^2 / yr for woody annuals. If the woody annual parameter is used with the average rate of seed production reported by the DEDJTR of 82.8 (2016) with a density of 3 flowering plants per m^2 (personal observation), then 248.4 seeds are produced per m^2. This is not high enough to qualify as a prolific seed producer.

Question 8.02 asks if there is evidence of a persistent propagule bank forming lasting more than 1 year (WADR 2015). There is no evidence in the literature of how long the *A italicum* seed bank persists. The answer to this question is unknown and it was left unanswered, an option in the Australian WRA (WADR 2015).

Question 8.03 asks if the species is well controlled by herbicides (WADR 2015). The New Zealand Weedbusters suggest glyphosate application and metsulfuron (2016). Tim Miller of the Washington State University Extension office also tested a variety of herbicides for their effectiveness against *A italicum*. Tim Miller's work looked at vegetative die off, but did not last long enough to examine potential regrowth and he noted that the bulbs "looked healthy" (personal communication, 4/3/2015). The results of any studies the Weedbusters have conducted on their recommendations for treatment are currently unavailable. In conclusion, it is unknown if this species is well controlled by herbicides. Conflicting reports and a lack of documentation prevent this question from being accurately answered.

Question 8.04 asks if the species tolerates or benefits from mutilation, cultivation, or fire (WADR 2015). *A italicum*'s bulbs fragment from the parent bulb readily, allowing a patch to regenerate even when subject to hand removal (personal experience). They are resistant to mutilation and cultivation. Furthermore, as the bulbs often grow quite deep (Boyce 1993), they are resistant to fires. The answer to this question is yes.

Question 8.05 asks if the species has effective natural enemies present in the Pacific Northwest (WADR 2015). The answer to this question is unknown, as specified in the parameters of this question

(WADR 2015). It seems unlikely that there are, however, as *A italicum* has been grown in the Pacific Northwest for many years and there are no reported natural enemies yet.

What the WRA tells us about *Arum italicum*

This WRA reveals several aspects of *A italicum* that make it a strong invader. This is important because defining the characteristics that make it a strong invader can help identify which opportunities may exist for developing management and control options. In particular, the WRA reveals aspects of *A italicum*'s morphology, life history and climactic adaptability that allow it to act as an invader in many regions.

A italicum exhibits the traits of a C-type, and some of an S-type, plant as defined by Grime's C-S-R model of succession (Myers and Bazely 2003). C-type plant are strong competitors and are able to establish in already established ecosystems. They exhibit traits that allow them to outcompete plants that are already present and create a niche for themselves. S-type plants tolerate stress, able to grow under some type of biotic or abiotic stress.

One aspect that makes *A italicum* a C-type plant is that it is generally subject to few diseases, herbivores, or other influences that may slow it's spread. Question 6.01 addressed whether or not the plant had substantial reproductive failure in its native range. This question was answered no and is largely due to several morphological characteristics. Herbivores generally avoid it because of the irritating compounds in its tissues, as discussed in question 4.04 and 4.05. It also is resistant to pests and diseases as described in question 4.06, which may be due to its thick cuticle. *A italicum*'s resistance means that its invasiveness is not due to release from natural enemies as described in the Enemy Release Hypothesis in a traditional sense (Myers and Bazely 2003). However, as *A italicum* doesn't have many natural enemies in general, it competes strongly with native plants that do, which is effectively the same as what the enemy release hypothesis suggests.

A italicum's has a few traits that are characteristic of S-type plants. This is its broad tolerance for a wide range of light levels. As described in question 4.09, *A italicum* is very shade tolerant. Furthermore, it also is tolerant of sun exposure, even growing in open pasture and other high light exposure areas (DEDJTR 2015) (Weedbusters 2016). Furthermore, it is also reported to grow among dry coastal vegetation, implying a degree of salt tolerance and the ability to handle nutrient poor soils (DEDJTR 2015). These traits provide *A italicum* with a broad range of possible habitats to establish in.

Another aspect that makes *A italicum* a C-type plant is it's reproductive potential. As described in questions 6.06 and 6.07, *A italicum* not only reproduces clonally, but also clones rapidly. Boyce describes *A italicum*'s tuber as a horizontal rhizomatous type (1993). This growth form is associated by Boyce with extensive, spreading colonies (1993). This growth pattern is described as a 'phalanx' growth pattern, which is beneficial in competitive environments because it resists invasion by other plants (Myers and Bazely 2003). Questions 4.11 and 4.12 refer to this type of growth by asking if the plant smothers native species or grows in dense patches.

In addition to its strong competitive ability based on clonal reproduction, *A italicum* is an effective sexual reproducer as well. Questions 6.02 and 6.05 confirm that *A italicum* can both be successfully pollinated and produces viable seeds. In fact, where *A italicum* invades wetlands, it co-occurs in the Pacific Northwest with *Lysichiton americanus* (western skunk cabbage) (personal observation). Both of these species are in the family Araceae and have a similar pollination strategy focused on attracting pollinators with strong scent cues (Brousil et al. 2015). As *A italicum* is pollinated by insects attracted to similar scents as *Lysichiton americanus*, its pollination needs can definitely be met in these habitats. One consequence of the ability of *A italicum* to sexually reproduce outside its native range is that it may become a better competitor in its new range. This is known as the Evolution of Increased Competitive Ability Hypothesis and the consequences could further complicate control in the future (Myers and Bazely 2003).

Dispersal by both animals and humans also supports the competitive ability of *A italicum*. Question 7.02 addresses the spread of *A italicum* by intentional human activity. Additionally, because humans actively spread *A italicum* as a landscaping plant, landscape plants can serve as staging areas, providing consistent propagule pressure to natural areas outside gardens (Myers and Bazely 2003). Birds are the major dispersal mechanism, with many bird species contributing to the spread of the seed as described in question 7.06. Once again, *A italicum*'s generalist needs for distribution grant it a competitive advantage over other species.

The broad climate and habitat needs of *A italicum* also make it a strong competitor. Questions 2.03 and 2.05 address both how broad a climate tolerance *A italicum* has as well as its history of establishment in several areas around the world. *A italicum*'s ability to tolerate a wide range of conditions was already established above as well.

The Lonsdale Model of Invasions, based off of these traits, further describes how well *A italicum* can establish in habitats. The Lonsdale Model states that E=IS where E is the population of Exotic species, I is the combination of accidental and intentional introductions, and S is the survival rate (Myers and Bazely 2003). S is further broken down into the survival after competition, survival after herbivory, survival after chance events, and survival after maladaptation. As we have seen, *A italicum* is intentionally introduced as well as spreading well from those to provide a population of accidental introductions. Furthermore, it has high survival through its competitive ability, high survival after herbivory, and is well adapted to a wide range of habitats. This means that the key point to addressing the establishment and spread of *A italicum* must occur through "chance events" to reduce its survivability and a reduction in intentional introductions.

The listing of *A italicum* and all its sub-species and cultivars as a class C noxious weed in Washington State in 2015 is a first step in reducing intentional introductions (WSNWCB 2010). Though this listing does not prevent the sale of *A italicum* by nurseries, it does provide a cultural pressure against the planting and sale *A italicum.* This listing also provided the impetus to find control methods for the plant.

Because waiting for "chance events" to reduce the survival of *A italicum* is unreasonable, and it has high survival through the other parameters of the Lonsdale Model of Invasions, control techniques will need to substitute for chance. Mechanical control through manual removal of the plant, tilling of soil, or mowing will be ineffective as described in question 8.04. Though they are not recommended for long term use, inorganic mulches, like plastic, have been shown to reduce weed prevalence (Chalker-Scott 2007). Furthermore, several sources recommend the use of glyphosate and/or metsulfuron-methyl as herbicide controls for *A italicum* as mentioned in question 8.03. Further exploration of these options may provide an option for "chance events" to reduce survival and control populations of *A italicum* in the Pacific Northwest.

Form C - Weed Risk Assessment scoring sheet

		a	b	c	d	e
Section		Question	Response [1]	Score	*N* score	*Y* score
A	C	1.01	no	0	0	-3
	C	1.02			-1	1
	C	1.03			-1	1
		2.01	yes	2	The response for these questions is 2 unless a climate analysis is done	
		2.02	no data	2		
	C	2.03	yes	1	0	1
	C	2.04	no	0	0	1
		2.05	yes			
	C	3.01	yes	2	Refer to lookup table	
	E	3.02	yes	2		
	A	3.03	no	0		
	E	3.04	yes	4		
	C	3.05	yes	2		
B	C	4.01	no	0	0	1
	C	4.02	no	0	0	1
	C	4.03	no	0	0	1
	A	4.04	yes	1	-1	1
	C	4.05	no	0	0	1
	C	4.06	no	0	0	1
	C	4.07	no	0	0	1
	E	4.08	no	0	0	1
	E	4.09	yes	1	0	1
	E	4.10	yes	1	0	1
	E	4.11	yes	1	0	1
	C	4.12	yes	1	0	1
C	E	5.01	no	0	0	5
	C	5.02	no	0	0	1
	E	5.03	no	0	0	1
	C	5.04	yes	1	0	1
	C	6.01	no	0	0	1
	C	6.02	yes	1	-1	1
	A	6.03	yes	1	-1	1
	C	6.04	no	-1	-1	1
	C	6.05	no	-1	0	-1
	A	6.06	yes	1	-1	1
	C	6.07	1	1		
	A	7.01	no	-1	-1	1
	C	7.02	yes	1	-1	1
	A	7.03	no	-1	-1	1
	C	7.04	no	-1	-1	1
	E	7.05	yes	1	-1	1
	E	7.06	yes	1	-1	1
	C	7.07	yes	1	-1	1
	C	7.08	no	-1	-1	1
	C	8.01	no	-1	-1	1
	C	8.02	unknown		-1	1
	A	8.03	unknown		1	-1
	A	8.04	yes	1	-1	1
	C	8.05	unknown		1	-1

Total score [3]	25
Outcome [4]	reject
Agricultural score [6]	2
Environmental [6]	10

Only score 1.02 and 1.03 if you answered yes to 1.01

Lookup table for section 3.

Locate value of inputs and lookup output for each question

										default
	Yes to questions 3.01 - 3.05									**default**
Inputs	2.01	0	0	0	1	1	1	2	2	**2**
	2.02	0	1	2	0	1	2	0	1	**2**
Results	3.01	2	1	1	2	2	1	2	2	**2**
	3.02	2	1	1	2	2	1	2	2	**2**
	3.03	3	2	1	4	3	2	4	4	**4**
	3.04	3	2	1	4	3	2	4	4	**4**
	3.05	2	1	1	2	2	1	2	2	**2**

	No to questions 3.01 - 3.05			
Input	2.05	?	N	Y
Results	3.01	-1	0	-2
	3.02-3.05	0	0	0

Procedure for scoring assessment

1. Record appropriate responses in column b.
2. Look up score in columns d & e and record result in column c.
3. Calculate total score.
4. Lookup and record recommendation.
5. Verify that minimum number of questions from each section are answered.
6. Compute Agricultural (A&C) and Environmental (E&C) scores: if either score is less than 1, the outcome pertains to the other sector.

Lookup table for 6.07

years	1	2	4
score	1	0	-1

Score	Outcome
< 1	Accept
1-6	Evaluate
> 6	Reject

Section	Minimum # questions [5]
A	2
B	2
C	6
Total	10