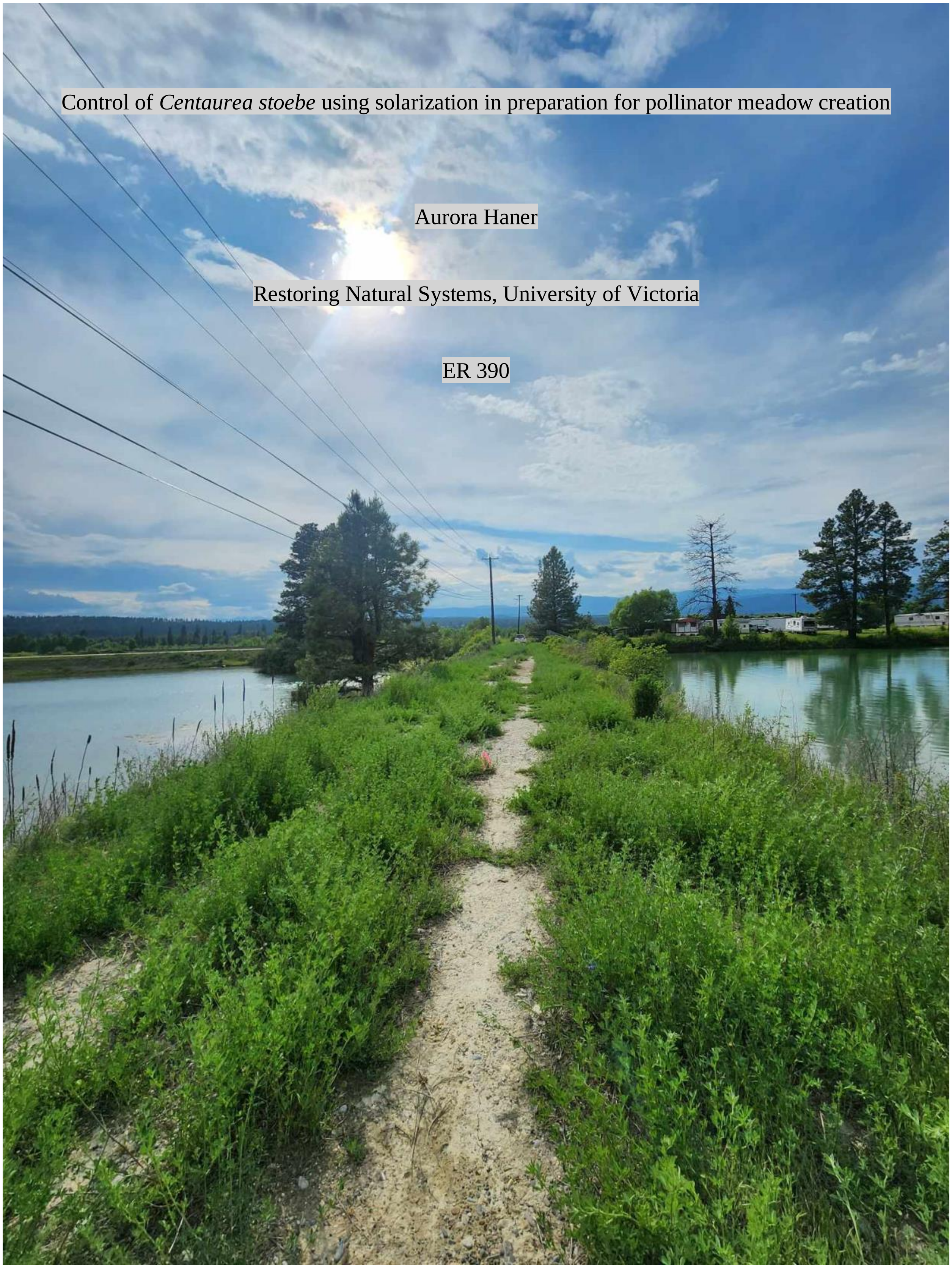

Control of *Centaurea stoebe* using solarization in preparation for pollinator meadow creation

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ER 390

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Abstract

This study Follows the first year of the Wasa Slough Dike Pollinator Meadow project. The first year's focus was to evaluate the nature and abundance of native and invasive vegetation, reduce the cover of Spotted Knapweed and Alfalfa, and examine the status of biocontrol agents previously released on site. Vegetative analysis showed that although the banks of the dikes housed 22 native species, only 13 grew on the top of the dike. 83% of the top of the dike was covered either by bare ground or invasive species, perhaps even higher if invasvie grasses were included. Solarization reduced the Spotted Knapweed and Alfalfa populations to 0% and 1% in solarized zones from 16% and 25% to 11.6% and 20% overall. Though the preliminary reduction in invasive species is hopeful, more information is needed about the effect of solarization on this seed bank to predict the long-term effects of the treatment. Evidence of Root-boring biocontrol was found in 62.7% percent of Knapweed plants, and flower-eating evidence was found in ~50-60% percent of Spotted knapweed.

Introduction

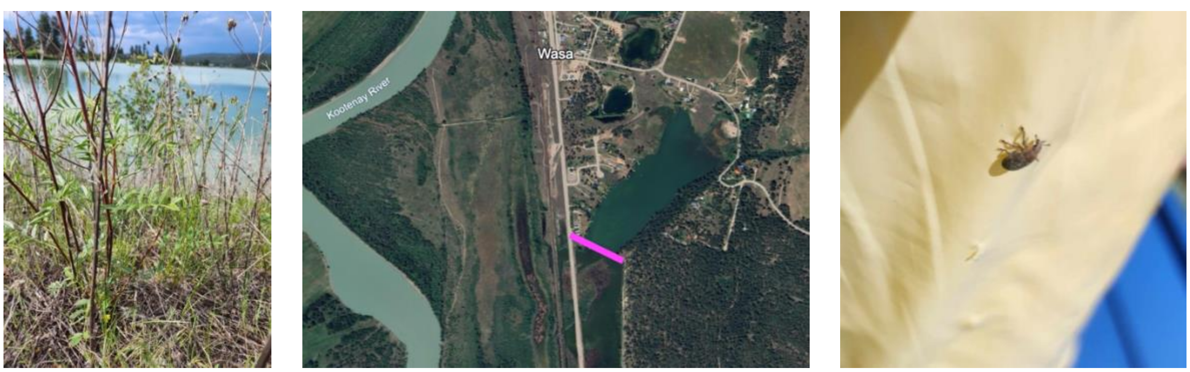

Figure 1 Left: Provincially threatened species, Wild Licorice surrounded by dense Spotted Knapweed. Middle: The location of the Wasa Slough Dike is shown as a pink line relative to Wasa, BC. Right: A Spotted knapweed biocontrol weevil, either *Cyphocleonus Achates* or ***Larinus minutus***

The interconnected declines of native species and their specialized pollinators have become a hot topic within conservation and restoration ecology. Habitat loss and displacement of rare native species are some of the most significant causes. Although visibly destructive industries such as logging, urban development, and open pit mining are undeniably major culprits of habitat loss, the insidious spread of highly adapted invasive species across natural landscapes is a source of habitat loss that is largely invisible to those who are not familiar with the problem species in their region.

As part of their land management strategy, The Nature Trust of British Columbia (NTBC) manages invasive species on their conservation properties to prevent the degradation of protected landscapes. This restoration, the Wasa Slough Dike restoration, alongside its precursor, the Bummer Flats Dike restoration, aims not only to reduce invasive species populations but to replace them with native species that will support a range of native pollinators. In 2020, a pollinator meadow creation project led by Brenda Beckwith and Valerie Huff of Kinseed Ecologies aimed to turn a weedy dike in the center of Bummers Flats Wetland into a biodiverse pollinator refuge (Beckwith & Huff, 2019). The Bummers Flats dike was deemed a vital site to restore because it supports one of the few populations of Wild Liquorice (*Glycyrrhiza lepidota)* in BC (BC Conservation Data Center, N.D)(Beckwith & Huff, 2019). Both wild licorice and its associated pollinator, the Silver Skipper butterfly (*Epargyreus clarus*), are classified as Special Concern (S3) by the BC Conservation Data Center (2001),(N, D). The restoration detailed in this report draws inspiration from the Bummers Flats restoration, as it occurs on a comparable site, houses a small population of wild licorice, and shares many of the same challenges. This project, the Wasa Slough Dike restoration, however, focuses more on invasive species management. Specifically, the eradication of Spotted Knapweed (*Centaurea stoebe*) and Alfalfa (*Medicago sativa*) using solarization on a site with ongoing biocontrol management.

Wasa Slough Dike, as seen in FIGURE 1, is located in the southern Rocky Mountain Trench on an NTBC conservation property near Wasa, BC. The property has been owned by NTBC since 1977, so although it has a myriad of anthropogenic disturbances and pressures, these pressures are not ongoing (NTBC, N.D). The property falls within the Interior Douglas Fir (IDF) BEC zone and the Kootenay Very Dry, Very Hot Interior Douglas-Fir (IDFxx2) subzone variant (MacKillop *et al.,* 2018). As is evident from the subzone name, this valley is characterized by a hot, dry climate and has historically been maintained by frequent fire (MacKillop *et al.,* 2018). The dike is 131 meters long with a 5.0-to-7.0-meter level top, likely used as a road in the past. Both historical vehicle and cattle use of the dike have compacted the soil. The origin of the sediment making up the dike is unknown. Without chemical analysis, it is difficult to predict whether the soil nutrient regime or sediment type can support local flora, which is the long-term goal of this restoration. For an in-depth theoretical soil restoration of the site, see (Haner, 2023). While the banks of the dike have been populated with diverse native species, the top is a patchwork of bare ground, *Centaurea stoebe*, and *Medicago sativa*.

Invasive species are the biggest obstacle to establishing persistent native species coverage on this plot. The invasive species present include Spotted Knapweed (*Centaurea stobe*), Mullein (*Verbascum thapsus*), dandelion (*Taraxacum officinale*), Dalmatian Toadflax (*Linaria dalmatica*), and likely invasive grasses. Although not listed as an invasive species in BC, Alfalfa (*Medicago sativa*) is a non-native species whose prevalence and persistence on this plot make it akin to an invasive species and, in this case, more problematic than all, but Spotted knapweed. Classified as a provincial noxious weed and having high ground coverage, *Centaurea stoebe* is the most prominent opponent to this restoration (Invasive Species Council of BC, 2019). A member of the family Asteracea, *Centaurea Stoebe*, has many advantages that make it highly damaging to North American landscapes. The plant is long-living, produces tens of thousands of seeds per square meter, can survive up to eight years in the soil, has allelopathic properties, and has a long taproot, which allows for survival in arid conditions (Knochel & Seastedt, 2009). In short, it is a formidable enemy to native species and land managers alike.

Managing Spotted Knapweed using methods such as herbicide, mowing, and controlled burning has had mixed results, reducing populations temporarily or inconsistently (Knochel & Seastedt, 2009). The most successful control methods have proven to be mechanical pulling, biocontrol, and planting of native species as competition (Knochel & Seastedt, 2009). All these methods were considered when formulating a control strategy for invasive species on the dike. Herbicide and controlled burning were quickly ruled out due to their respective risks. Herbicide application is such course, fast draining soil, so close to a wetland would not be responsible. Controlled burning is difficult to receive permission for and could put valuable native plants such as *Glycyrrhiza lepidota* at risk. NTBC has been managing this invasion site for years when resources allow. They have employed hand pulling, mowing, biocontrol, and a small patch of experimental solarization using discarded industrial conveyor belting. In 1993, FLNRORD (now LWRS) released the biocontrol *Agapeta zoegana,* a knapweed-specific, root-feeding moth on the other end of Camron Pond. In 1997 and 2016, the East Kootenay Invasive Species Council (EKISC) introduced the root-boring weevil biocontrol *Cyphocleonus Achates*, introduced carefully to North America from Europe to combat *Centaurea stoebe* (IAPP, 2023)

Considering the suboptimal results of the methods above and having the advantage of a very hot climate, larger-scale solarization using a lighter, clear plastic was chosen for the first year of treatment. The idea behind solarization is to cover the infestation with a plastic tarp to trap and amplify solar radiation and ambient heat, making the area inhospitable to vegetation (Bainbridge,1990). Though solarization is a commonly used weed control technique in agriculture, there is little literature about Solarization as a control method for *Centaurea stoebe* in a natural environment. A restoration project by Thorpe *et al.* had success controlling *Centaurea moncktonii* using a combination of solarization, mulching, and seeding, but there are no replicate studies (2009).

Methods

Figure 2 Left: Digging the shallow trench to secure the solarization tarp. Middle: Saturating the treatment area with a fire pump and hose before applying tarps. Right: Evaluating vegetation composition post solarization.

Plot setup:

Before the vegetation composition of the dike was recorded, the dike was subdivided into working vegetative zones. This was achieved by slowly walking the length of the dyke with a survey tape and placing markers at the transition between dominant species, species composition, or when the presence of native or valuable species was noted. The dyke was subdivided using this method rather than creating equal area zones both to locate the areas most in need of treatment and to ensure that valuable native species were excluded from treatment areas.

Soil sampling

Three soil samples were taken from each zone at random coordinates selected by a random number generator to test the seed bank viability before and after solarization. For zones where solarization occurred, three samples were taken from the section to be solarized, as well as the adjoining control segment. Additionally, three samples were taken from under the conveyor treatment that preceded this study. These samples were returned to a greenhouse and placed in labelled trays, spreading soil as shallow as possible. The trays were covered in several layers of paper towels to keep moisture in and were saturated daily. Successfully germinated knapweed seedlings from spring and fall samples were to be counted to determine whether seed bank viability was different before and after solarization.

Species diversity

A comprehensive list of species, both native and invasive, was taken simply by walking the length of the dyke and taking note of each species, referencing inaturalist and “Plants of southern interior British Columbia and the inland northwest”.

Vegetation composition

Vegetative composition sampling was conducted using a 1x1 meter quadrat and estimating the percentage area covered by each species in the box. The sample positions were chosen randomly using a number generator to create coordinates. The composition was measured in June prior to solarization and in early October after the solarization treatment was completed using the same coordinates. Sample locations were not marked, so although the same coordinates were used in June and September, the frame may have been placed differently. For this reason, vegetative composition changes were compared to the zone's average, not comparing samples.

Biocontrol sampling

Sampling of the root boring biocontrol *Cyphocleonus Achates* and *Agapeta zoegana* was performed In June, as previous experience on the site showed that they were not present later in the season. Knapweed plants were pulled by zone, and their taproots were examined for damage, hollowing or larva. A tally was created for plants exhibiting insect damage and those not for each section. Flower-eating weevils were sampled by the Nature Trust of BC's field crew later in the summer by observing flowers for damage and the weevils themselves.

Solarization

The two zones with the highest density knapweed infestation, few or no native species, and whose size roughly matched the size of the poly acetate sheeting were elected for solarization. In this case Zones 2 and 5 were chosen. These areas were weed-whacked as close to the ground as possible, leaving clippings on site as a source of organic matter. A two-to-three-inch trench was then dug using pickaxes and shovels around the perimeter of the treatment area, leaving room for the edges of the plastic to be buried and secured in the trench. The area ended up being approximately 98ft x 8-9ft. Next, the area was thoroughly saturated using a water pump and the adjacent pond. Immediately after soaking the area, the polyacetate was placed at tension over the area, burying the edges so they wouldn't catch wind. Large rocks were also placed on top of the tarp for additional security. The solarization material chosen was a 10ft x 100ft clear poly acetate sheeting.

Results

Vegetative Zones

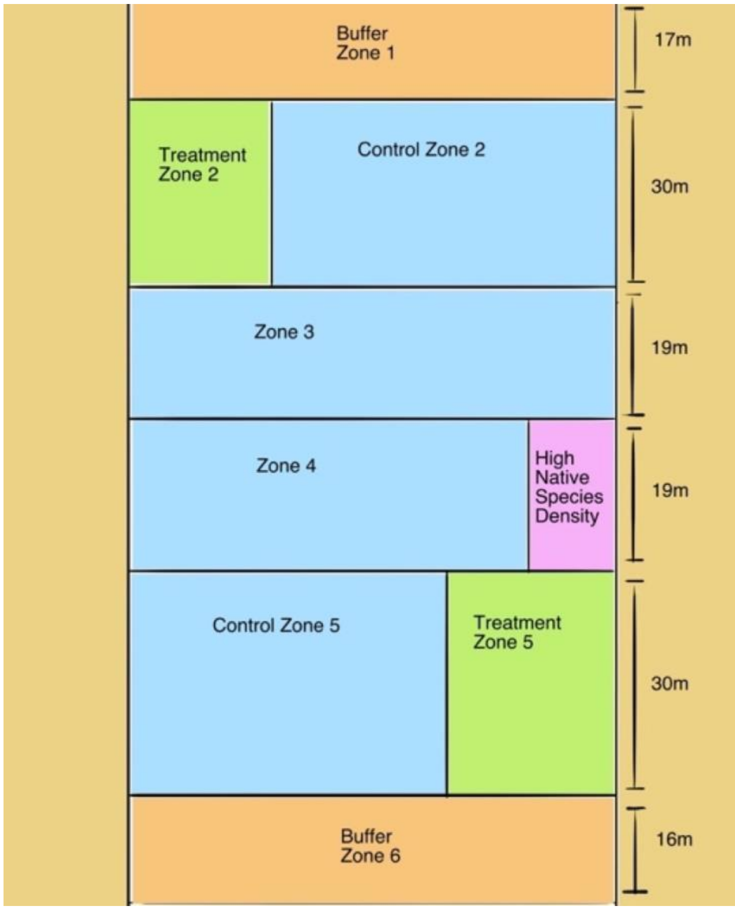

Figure 3 Map of the Wasa Slough dike and its vegetative zones decided by visual analysis.

As previously described, zones were created based on quick visual analysis of changing vegetation patterns. As seen in *Figure 2*, six natural vegetation zones emerged from visual analysis of the dike. Zones 1 and 6, measuring 17 and 16 meters long, respectively, acted as buffer zones, as they were located on the edges of the study area and were noticeably less infested than the areas directly next to them. Zone 3 was 19 meters long and contained a considerable infestation of *Medicago sativa* with Centaurea *stoebe* intermixed but was not considered for solarization. Zone 4 was divided in its composition at 19 meters in length. The south half was a sparse mix of bare ground, *Centaurea stoebe*, and *Medicago sativa*. In contrast, the north half was a mix of *Centaurea stoebe* and valuable native species, most notably *Glycyrrhiza lepidota*. Despite the high density of *Centaurea stoebe,* Solarization was not considered due to the presence of these valued species. Finally, zones 2 and 5, both 30 meters in length, were elected for solarization treatment due to very dense *Centaurea stoebe* infestations in the south half of Zone 2 and the north half of Zone 5.

Species Diversity

All species observed on the dike are recorded below in FIGURE 4. Four invasive species and nine native species were observed on the top of the compared to five invasive and sixteen native species found on the dike's banks. As is represented in the composition results below, the nine native species found on the top, were only found in a few locations each.

Veg type	**Location**	**Species**
Invasive	Top of Dike	• Spotted Knapweed (*Centaurea stoebe)* • Alfalfa (*Medicago sativa)* • Mullein (*Verbascum thapsus*) • Dandelion (*Taraxacum officinale*)
Native	Top of Dike	• Moss (*Bryophyta ssp.*) • cinquefoil (*Potentilla ssp.*) • Field Locoweed (*Oxytropis campestris*) • Summer Cypress (*Bassia scoparia)* • Snowberry (*Symphoricarpos albus*) • Prairie Rose (*Rosa arkansana*) • Yarrow (*Achillea ssp.*) • Wild Licorice (*Glycyrrhiza lepidota*)
Invasive	Banks	• Cheat Grass (*Bromus tectorum*) • Dalmatian Toadflax (*Linaria dalmatica*) • Mullein (*Verbascum thapsus*) • Spotted Knapweed (*Centaurea stoebe*) • Alfalfa (*Medicago sativa)*
Native	Banks	• Ponderosa Pine (*Pinus ponderosa)* • Saskatoon berry (*Amelanchier alnifolia*) • Star-Flowered False Solomons seal (*Mianthemum stellatum*) • Prairie Rose (*Rosa arkansana*) • Snowberry (*Symphoricarpos albus*) • Horsetails (Eq*uisetum ssp.*) • Yarrow (*Achillea ssp.*) • Silverleaf Phacelia (*Phacelia hastata*) • Red Osier Dogwood (*Cornus sericea*) • Willow(*Salix ssp.*) • Wild Licorice (*Glycyrrhiza lepidota*) • Sedges (*Carex ssp.)* • Field Locoweed (*Oxytropis campestris*)

• Field Sagewart (*Artemisia campestris*) • cinquefoil (*Potentilla ssp.*) • Moss (*Bryophyta ssp.*)

Figure 4 Species found on the dike divided by location and origin.

vegetation composition June

Pre-solarization, the average composition for the entire dike was 43.6% bare ground, 25% *Medicago sativa*, 16% *Centaurea stoebe*, 11% unidentified grasses, 1.4% Snowberry (*Symphoricarpos albus*), 0.1% Yarrow (*Achillea ssp*), 0.3% Mullin (*Verbascum thapsus*), 1.2% moss (*Bryophyta ssp*), 0.7% Wild licorice (*Glycyrrhiza lepidota*), 0.2% Field locoweed (*Oxytropis campestris*), and 0.03% cinquefoil (*Potentilla ssp*). Grasses were not identified to species, so it is unknown if they were native or invasive varieties. Most native species recorded were found along the zones' edges, close to the banks of the dike.

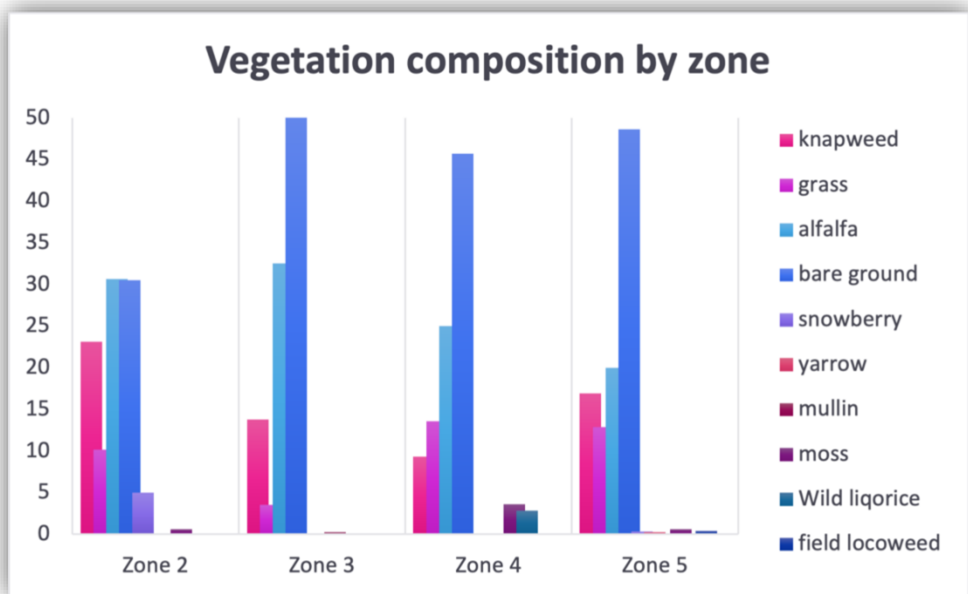

Figure 5 Vegetation composition in percent coverage broken down by zone on the Wasa Slough Dike

The species composition results by zone generally agreed with the visual analysis. Zones 2 and 5, predicted to have the densest *Centaurea stoebe* infestation, had the highest percent composition of Knapweed at 23.1% and 16.9%, respectively. Trends showed *Medicago sativa* being more common on the west end of the dike, with zones 2 and 3 having the highest Alfalfa coverage, 30.6% and 32.5%, respectively. On the other hand, the east end of the dike had the highest bare ground percentage, 45.7% and 48.6% for zones 4 and 5. As described during the visual analysis, zone 4 contained more valuable native species than any other zone, having 3.6% moss and 2.8% Wild licorice (*Glycyrrhiza lepidota*). Other native species occurred in zone 4, such as roses (Rosa arkansana), snowberries (*Symphoricarpos albus*), and Saskatoon (*Amelanchier alnifolia*). Still, these species did not happen to be captured within the random coordinates sampled.

Species composition September

Figure 6 Treatment zone 2 after weed whacking, but pre solarization (Left). Treatment zone 2 with tarps applied (Center). Treatment Zone 2 post solarization (Right)

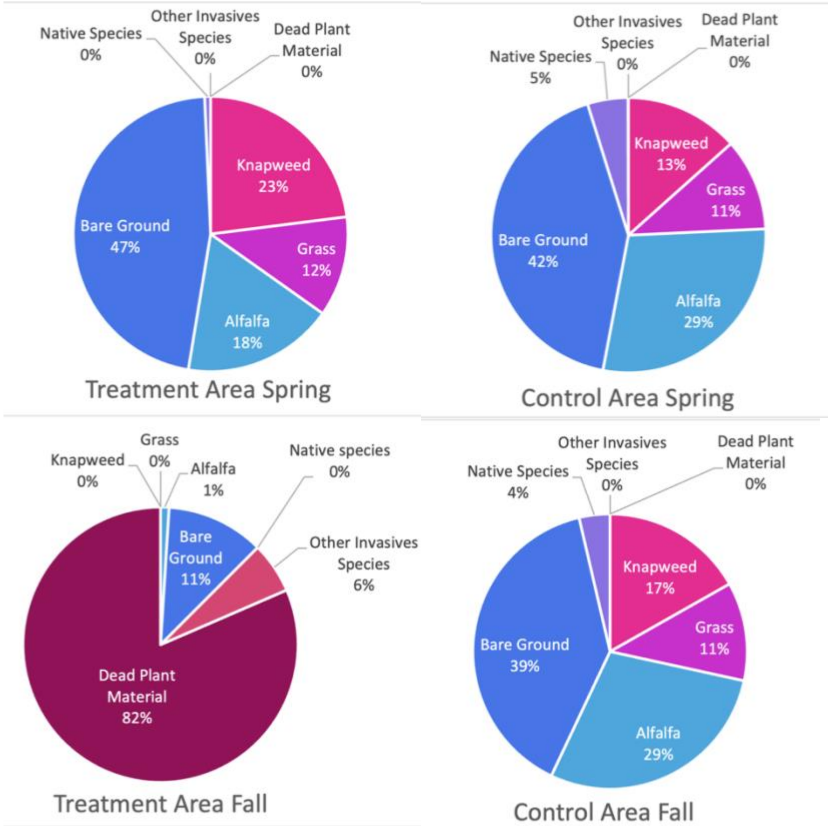

Figure 7 The average percent coverage for each species or category in the treatment and control zones pre (Spring) and post (Fall) solarization treatment.

Even before official vegetation composition analysis was performed, it was evident that the vegetation composition of the solarized zones had changed drastically. Differences between percentages in June and September are graphed in FIGURE 8. As seen in FIGURE 6, solarized plots appeared to be dead zones, with the only vegetation being weedy species such as Mullen, *Medicago sativa,* Dandelion, and *brassica*, which occurred once the weather was cool enough for conditions under the tarp to be survivable. The vegetation composition analysis reflects this observation. 93% of treated areas were bare ground or dead plant material; the aforementioned species reinfested the remaining 7%. Areas that had been solarized had an average *Centaurea stoebe* cover of 23.1% in the spring and 0% in the fall, as compared to the 13% to 16% change in the control areas (Figure 7). The statistical significance of these changes over the season was tested by performing a 2-sample t-test, comparing the percent knapweed cover in the spring versus the fall in both control and treatment samples. P-values are shown above in FIGURE 9. Comparing the calculated p-values to a significance level of 0.05, the difference in percent knapweed cover in treatment areas was deemed significant at 0.0017.

In contrast, the change was not deemed significant in control areas with a p-value of 0.4539. Other spring-to-fall composition changes that were deemed significant in treatment areas included: Grass, 11% to 0% (P=0.04033); bare ground, 46.7% to 11.5% (P=0.001103), and dead plant material, 0% to 81.5% (P=2.706 x 10^{-7}). The change in percent cover of *Medicago sativa*, 17.8% to 1%, was visually noticeable but, with a p-value of 0.0752, was not considered statistically significant. It is worth noting that the change in *Medicago sativa* is more than recorded because the plants recorded in late September appear to be new growth, and likely for a majority of the summer, the vegetative cover under the solarization tarps was 0% due to inhospitable conditions. For vegetation changes in control zones, all p-values calculated were larger than the 0.05 threshold; therefore, they were not considered statistically significant.

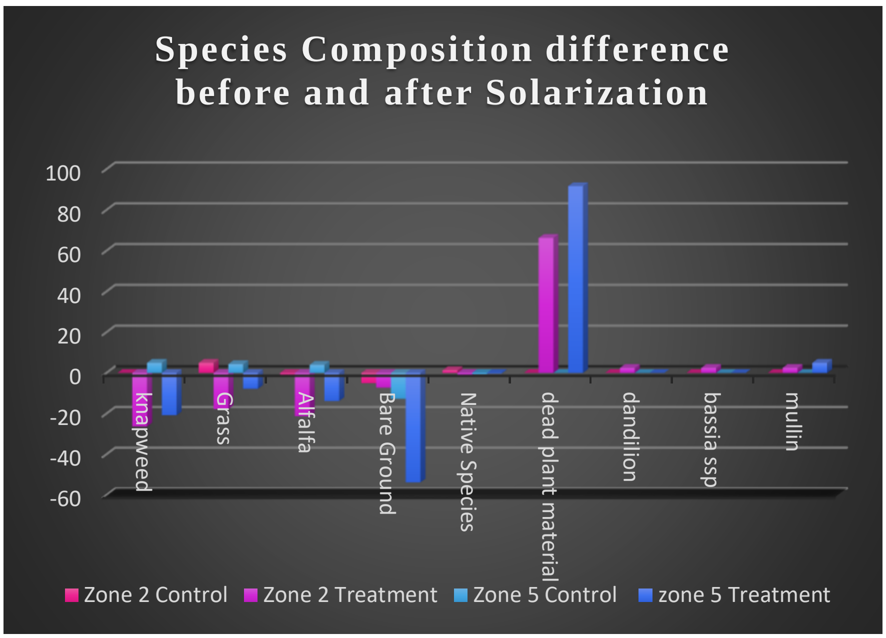

Figure 8 June percent composition of each species were subtracted from the September Value to achieve the difference. The difference is graphed above.

	Spotted Knapweed	Grass	Alfalfa	Bare Ground	Native Species	Dead Plant Material	Other Invasives
Treatment	0.0017	0.0403	0.0753	0.0011	0.1798	2.706 x 10^{-7}	0.0205
Control	0.4539	0.8430	0.9880	0.6740	0.1415	-	-

Figure 9 P-values obtained from 2-sample t-tests comparing percent composition of species In June versus September. Green values were deemed significant (<0.05) and red values were not.

Biocontrol

Figure 10 Left: Biocontrol nest inside a large Spotted knapweed tap root. Two centers: Biocontrol larva and their associated damage in Spotted Knapweed Root Systems. Right: Flower herbivory evidence in Spotted Knapweed Flower heads

In June, at the time of the biocontrol survey, we did not know that two different species of root-boring biocontrol were released onto the dike, *Cyphocleonus Achates* and *Agapeta zoegana, in* their larval form, both species hollow and inhabit the *Centaurea stoebe* root crown, so it is only possible to tell the species apart by removing the larva and identifying them. Because larval identification was not performed in this study, we will assume that root-boring could have been from either species. Of the 136 knapweed plants pulled, 61.8% exhibited taproot hollowing, obvious root herbivory, or the presence of larva inside the taproot. This presence was not highly variable by zone. The highest percent presence came from Zone 2, 78.3%, and the lowest was 53.8% in Zone 3. The standard deviation of the percent biocontrol presence between zones was 10.8. To ensure that there was an alternate source population, knapweed plants were sampled on the north bank of Cameron Pond. Knapweed populations on this property were not as dense as first thought, so only 24 samples were taken. Of these samples, 50% showed biocontrol damage or direct presence, and 50% of taproots were unaffected.

Interestingly, aboveground plants which experienced root herbivory looked just as large and healthy as their untouched counterparts, though no formal evaluation of health, height, or biomass was conducted. It is important to mention that sampling may have accidentally selected for medium-sized and medium-aged plants as it is challenging to pull young plants without breaking the root and very large plants have long, thick roots that make them difficult for any single person to pull. The NTBC field crew informally conducted a Flower-eating weevil survey because before IAPP records were retrieved, it was incorrectly assumed that one of the two biocontrol species released was a flower-eating variety. Surprisingly, the crew reported that they estimated 50-60% of knapweed flowers had “egg holes,” as seen in FIGURE 10 (M. Daniel, personal communication, September 2023). While only three insects were observed directly on knapweed, it was reported that many insects (~1000s) were observed on site (M.

Daniel, personal communication, September 2023). Again, because insects were not identified to species, it is unknown whether the observed weevils were flower-eating or root-boring varieties. The flower-eating weevils will need to be further investigated, as there is no recorded release of the insects on this plot, though they may be dispersed from elsewhere.

Seed bank sampling

Unfortunately, no valuable data was derived from the seed bank testing. The soil samples were collected, labelled, taken back to the greenhouse, placed in germination trays, and saturated regularly but did not germinate. This may have been due to unforeseen extreme heat conditions within the greenhouse. Time restraints did not allow for a second spring sampling. No soil samples were taken post-solarization because there was no pre-treatment data for comparison. It is also possible that the samples contained no seeds to germinate, but this is unlikely considering the density and recalcitrance of Spotted Knapweed seeds.

Discussion

Results showed that 85.3% of the dike's cover was composed of Centaurea stoebe, Medicago sativa, or bare ground before solarization. An additional 11.2% of the cover is grass, which has not been divided by native or invasive species, so the invasive count could be significantly higher. *Centaurea stoebe*, *Medicago sativa*, bare ground and invasive grass all pose a unique challenge to the healthy, diverse, pollinator meadow landscape land managers hope to create on this plot.

The bare ground is not as much a pressure as a symptom. In any ecosystem that supports vegetation, especially if vigorous invasive species are present, bare ground is a rare commodity that represents an opportunity to grow an individual or expand a population, so it does not last long. The fact that bare ground accounts for 43.6% of the dike suggests that the soil has significant deficiencies or issues preventing it from effectively supporting vegetation. As discussed in my soils report of this site, the major soil issues the dike is facing likely include compaction, organic matter deficiency, foreign parent material, altered soil moisture regime and soil nutrient regime (Haner, 2023).

Pre-solarization, Alfalfa accounted for 25.3% of the dike's cover. Compared to *Centaurea stoebe*, *Medicago sativa* has denser, bushier foliage, meaning there is potential to overrepresent the species in the data. This must be kept in mind when interpreting these results. Future studies may consider counting the number of plants present per m^2 in addition to the percent cover. *Medicago sativa* is often used by livestock ranchers as a forage crop, which is possibly how it was transported onto the dike through trespassing cattle's manure. This species has been bred by agriculture to be hardy and persistent, which, unfortunately, makes it susceptible to becoming feral if not invasive (Bagavathiannan & Van Acker, 2009). Many of the plant's strengths are shared characteristics with *Centaurea stoebe*, such as deep-reaching taproots, tiny recalcitrant seeds, drought and salt tolerance, and a perennial lifestyle (Bagavathiannan & Van Acker, 2009). Not shared with *Centaurea stoebe* is Alfalfa's ability to fix nitrogen by creating nodules to house symbiotic bacteria (Bagavathiannan & Van Acker, 2009). *Medicago sativa's* ability to fix nitrogen may be enabling *Centaurea stoebe* to persist on this plot despite the best efforts of biocontrol. Steinger & Müller-Schärer show that compensative growth in response to the root herbivory of *Cyphocleonus Achates* and *Agapeta zoegana* was higher in biocontrol-infested Spotted Knapweed that had access to higher concentrations of biologically available nitrogen (1992). The interactions between the two species must be tested more thoroughly to determine if this effect occurs in situ. Even if this effect exists, the competition for resources between the two species may cancel out any positive impact on Spotted Knapweed.

Despite covering less ground than Alfalfa, spotted knapweed was considered by NTBC to be the more significant threat to the ecosystem. Unlike *Medicago sativa*, *Centaurea stoebe* is managed as a noxious weed by conservation agencies in BC. After the dike's creation, the disturbed, sandy, dry and presumably infertile soil was likely inhospitable to native species who tried to colonize it. In contrast, spotted knapweed excels with little competition in poor-quality soils. During this infestation's 30 + year period, a very healthy knapweed seed bank has likely been created. When other species, native and otherwise, tried to establish themselves on the dike, they may have faced a phytochemical attack by *Centaurea stoebe.* Members of the *Centaurea* genus are known to exude the phytotoxin catechin. Still, there are varying reports on how common it is for the concentration of catechin to be high enough to affect native species. Studies such as Perry *et al.* suggest that adverse effects from catechin may not be as common as first thought (2007). In their research, only 20 of the 402 samples, taken from 11 different Spotted Knapweed invasion sites, were found to contain catechin, and all 20 samples occurred on the same date and location (Perry *et al.*, 2007). Further, on well-draining sites such as the Wasa Slough dike, years with sufficient rainfall would likely wash away most of the catechin present (Blair *et al., 2006*).

On the other hand, various studies examining the relationship between herbivory and catechin suggested that biocontrol herbivory could induce higher levels of allelopathy in *Centaurea* species (Knochel & Seastedt, 2009). If this is the case, the high rates of biocontrol presence on the dike could suggest higher-than-average catechin concentrations. Future restorations may involve testing for catechin concentrations. If concentrations of catechin in the soil are insignificant, other vegetation-limiting factors will need to be investigated.

Biocontrol was investigated in this study for the following reasons: to describe the abundance of biocontrol on the plot, to discuss whether biocontrol has been effective against this infestation, and to predict any effects or risks solarization will have on the long-term biocontrol treatment. Considering root herbivory evidence was found in as high as 78.3% of plants in some zones and signs of flower herbivory were found in ~50-60% of plants observed, it can safely be said that biocontrol is present. The species composition of this population, however, is unknown. IAPP records tell us that *Cyphocleonus Achates* and *Agapeta zoegana* were released on the site, but to an untrained eye such as mine, the larvae of the two species and associated root damage are indistinguishable. Flower-eating weevils (*Larinus minutus*) were not released onto the dike; given that the Wasa Slough property is a part of a larger conservation complex, it is possible they were released nearby. Sitting in a valley bottom and composed of sandy soil, the dike had ideal conditions for establishing *Cyphocleonus Achates* (Sturdevant et al.,2006). Despite their confirmed presence, it is difficult to judge the efficacy of the two Spotted Knapweed-eating species in reducing the population since no data exists describing the pre-biocontrol infestation. *Cyphocleonus Achates* and *Agapeta zoegana* have been on this site for 26 and 30 years, respectively, yet the dike remains densely infested with *Centaurea stoebe*. In the absence of pre-biocontrol data, we may compare the dike's infestation to a study by Sturdevant *et al.,* which followed the establishment of *Cyphocleonus Achates* often alongside *Agapeta zoegana* on 48 different sites over eight years (2006). The study found that although *Cyphocleonus Achates* populations were successfully established on a majority of the sites and knapweed populations decreased slightly on some plots, there was no significant association between infestation decrease and either biocontrol and no matter their density (Sturdevant et al.,2006). Interestingly, a positive association was also found between the presence of the two biocontrol species despite competing for the same food source (Sturdevant et al.,2006). This data tells us that the successful establishment of a *Cyphocleonus Achates* population is not enough to have a guaranteed impact on the Knapweed population, even over a long period. Knowing this, biocontrol must be a part of a larger management strategy, not the entire plan. Solarization is likely to kill any biocontrol in the treatment area. For this reason, the 50% rate of biocontrol on the other side of Camron Pond is essential because it can be used as a source population. Knochel & Seastedt claim that allowing knapweed to persist in more disturbed, less ecologically valuable areas may help control invasions in more natural by acting as biocontrol refugia (2009).

From the before and after photos shown in FIGURE 6, it is clear that solarization had the desired short-term effect of reducing vegetative cover on the treatment plot. Overall, the composition of the treatment areas changed from 53.3% vegetation, 46.7% bare ground and 0% dead plant matter to 7% vegetation, 11.5% bare ground and 81.5% dead plant material. P-values in FIGURE 9 show that knapweed, grass, bare ground, dead plant matter, and other invasive species had significantly different percent cover before and after solarization. There did not appear to be any species that were any more or less severely affected because all species were subjected to the same intense heat that few, if any, plants could survive. Ideally, post-solarization vegetative analysis should have been performed earlier while temperatures were still too hot for seedling emergence. The emergence of *Medicago sativa*, Mullein, dandelion, and Bassia ssp may have skewed results, making the change in *Medicago sativa* appear less and other invasives appear more than reality.

For this reason, the lower P-value for Alfalfa should be taken with a grain of salt. Unfortunately, the re-emergence of young invasives on the plot in September means that a portion of the seed bank survived the treatment. Though all the soil samples meant to test seed bank viability did not germinate as hoped and provided no new insights, we extrapolate from similar studies. In Clements & Atwood, solarization was used in an attempt to reduce the *Centaurea Diffusa* seed bank near Osoyoos, BC (2012). Like this study, Clements & Atwood successfully removed the surface vegetation using solarization; however, even with high temperatures of 75°C under the tarps, Centaurea diffusa seeds in the seed bank remained viable and geminated after the tarps were removed (2012). Vegetative analysis should be done on the dike in the spring of 2024 to see if the invasion returns in full force post-solarization, as in the study above. Pending these results, the next appropriate restoration steps will be implemented.

Removing the tarps without taking further action, having the seed bank intact, and plenty of seed sources on the dike will undoubtedly result in vegetative conditions similar to pre-restoration composition. With that in mind, NTBC will have two main paths forward on this restoration project next spring. The first option is to keep the tarps in place for a second season. This would take care of the invasive species re-established on the plot in the cool weather. It would also allow for ample time to create a comprehensive revegetation plan to collect seeds and has the potential to kill the seed bank further. For this path to be most effective, the tarps may need to be removed and the plots re-saturated, as the heat shock is more effective when seeds are moistened (Clements & Atwood, 2012). Once the second solarization is complete, there may be an option to plant seasonally appropriate plants in the fall of 2024. The second option is to remove the tarps in the spring and immediately begin mulching and revegetation to keep the reinvasion of *Centaurea stoebe* and *Medicago sativa* at bay. In the first year, revegetation may focus on hardy tap-rooted species because tap roots aid in soil de-compaction (Chen & Weil, 2010). A revegetation plan will consider the native species already thriving on the dike, such as those in FIGURE 4**,** the plants that naturally occur in the IDFxx2 BEC variant, and species that are themselves endangered, like *Glycyrrhiza lepidota* or which support a critical or threatened pollinator. If after the solarization of the first plots is complete, NTBC decides that the treatment is an effective management strategy on this plot, the poly acetate tarps can be moved to the subsequent most dense infestation.

Conclusion

This project quantified the nature of vegetation on the top of the Wasa Slough Dike. It determined that it was dominated by *Medicago sativa, Centaurea stoebe*, grass, bare ground, and few native species. Evidence of the three biocontrol species, *Agapeta zoegana, Cyphocleonus Achates,* and *Larinus minutus,* were found on the site. However, their impact is called into question by the continued fitness and density of *Centaurea stoebe*. In treatment areas, solarization proved to be an effective tool for clearing ground of invasive species so space can be made for more natural assets to develop. Regrettably, these results may not be permanent, as it is unknown if the solarization treatment impacted the *Centaurea stoebe* seed bank. For this reason, great care must be taken in future steps to avoid re-infestation.

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